Kimmo Kuismanen

CLIMATE-CONSCIOUS ARCHITECTURE
—DESIGN AND WIND TESTING METHOD FOR CLIMATES IN CHANGE
KIMMO KUISMANEN

CLIMATE-CONSCIOUS ARCHITECTURE—DESIGN AND WIND TESTING METHOD FOR CLIMATES IN CHANGE

Academic dissertation to be presented, with the assent of the Faculty of Technology of the University of Oulu, for public defence in the Apajan sali auditorium of the Department of Architecture (Aleksanterinkatu 4–6), on November 28th, 2008, at 12 noon

OULUN YLIOPISTO, OULU 2008
Kuismanen, Kimmo, Climate-conscious architecture—design and wind testing method for climates in change
Faculty of Technology, Department of Architecture, University of Oulu, P.O.Box 4100, FI-90014 University of Oulu, Finland

Abstract
The main objective of this research was to develop practical tools with which it is possible to improve the environment, micro-climate and energy economy of buildings and plans in different climate zones, and take the climate change into account.

The parts of the study are:
– State of art study into existing know-how about climate and planning.
– Study of the effects of climate change on the built environment.
– Development of simple micro-climate, nature and built environment analysis methods.
– Defining the criteria of an acceptable micro-climatic environment.
– Development of the wind test blower.
– Presenting ways to interpret test results and draw conclusions.
– Development of planning and design guidelines for different climate zones.

An important part of the research is the development of the CASE wind test instrument, different wind simulation techniques, and the methods of observing the results.

Bioclimatic planning and architectural design guidelines for different climate zones are produced. The analyse tools developed give a qualitative overall view, which can be deepened towards a quantitative analyse with wind testing measurements and roughness calculations. No mechanical rules are suggested, but complementary viewpoints and practices introduced to a normal planning process as well as improvement of consultative knowledge. The “method” is that there is no strict mechanical method, but a deeper understanding of bioclimatic matters.

Climate-conscious planning with the developed CASE method, make it possible to design a better micro-climate for new or old built-up areas. Winds can be used in to ventilate exhaust fumes and other pollutants, which improves the quality of air and the healthiness of the urban environment. The analyses and scale-model tests make it possible to shield cold windy areas and to diminish the cooling effect of wind on facades. According to studies in Scandinavian countries this will bring energy savings of 5–15 per cent.

The method can be used to:
– Evaluation of the cooling effect of wind. Areas and facades exposed to wind.
– Evaluation of the wind comfort at the pedestrian level. Windy areas, relative wind speeds.
– Enhancing wind-forced ventilation. Positive and negative pressures at the inlets and outlets.
– Analysis of the diffusion of pollutants. Ventilation of streets and areas.
– Avoiding the damages caused by wind. Planning and designing wind protective solutions.
– Characterisation of the wind loading of small and medium-size street architecture items. Designing wind resistant and protective items and plantings.
– Analysing the drifting of snow. Placing of snow fences.

Keywords: architecture, bioclimatic planning, climate change, climate-conscious architecture, design guidelines, planning, wind testing
Kuismanen, Kimmo, Ilmastotietoinen arkkitehtuuri-suunnittelu ja tuulitestaus muuttuvassa ilmastossa
Teknillinen tiedekunta, Arkkitehtuurin osasto, Oulun yliopisto, PL 4100, 90014 Oulun yliopisto
Oulu

Tiivistelmä

Tutkimuksen päätavoitteena oli kehittää käytännöllisiä suunnitteluvälineitä, joilla voidaan paranntaa ympäristöä, mikroilmastoa sekä rakennusten ja kaavojen energiataloutta eri ilmasto- ja keisissä, sekä varautua ilmaston muutokseen.

Tutkimuksen osat ovat:
– Selvitys tämän hetkistä ilmastoon ja suunnittelun liittyvää osaamisesta.
– Selvitys ilmaston muutoksen vaikutuksesta rakennetulle ympäristölle.
– Yksinkertaisten mikroilmasto-, luonto- ja rakennetun ympäristön analyysien kehittäminen. 
– Määritellä hyväksyttävän mikroilmaston kriteerit.
– Kehittää pienoismallien tuulitestauslaite.
– Kehittää metodit testitulosten analysoimiseksi ja johtopäätösten vetämiseksi.
– Laatia kaavoitus- ja rakennussuunnittelulohjeet eri ilmastovyöhykkeillä.

Tärkeä osa tutkimusta oli CASE tuulitestauslaitteen, erilaisten tuulen simulointiteknikoiden ja testausten havainnointimenetelmiä kehittäminen.


Metodia voidaan käyttää mm. seuraaviin tarkoituksiin:
– Arvioida tuulen jäähdystä vaikutuksesta. Selvittää tuullelta alitiet alueet ja julkisivut.
– Arvioida tuulen vaikutusta jalankulun mukavuuteen. Tuuliset alueet ja suhteelliset tuolennopeudet.
– Analysoida saasteiden leviämistä. Katujen ja alueiden tuuletto.
– Luonnehtia pieniin ja keskikokoisiin ulkona oleviin rakenteisiin kohdistuvia tuulikuormia. Suunnitella tuulenkestäviä ja suojaavia rakennelmaa ja istutuksia.
– Analysoida ilmen kouluissa. Lumiaitojen sijoiteltelu.

Asiasanat: arkkitehtuuri, bioklimaattinen suunnittelu, ilmastonmuutos, ilmastotietoinen arkkitehtuuri, kaavoitus, suunnittelulohjeet, tuulitestaus,
I dedicate this book to my grandsons
Eemeli, Antton and Heikki,
and to all the children of Bangladesh and other countries
who will inherit this endangered ball after us.
Preface

Already during my studies in the 1970’s I protested with some other students against the flat-roof modern way of building that was the only accepted mainstream at that time. This resulted in the “School of Oulu” architecture, a regionalist approach, which mostly concentrated to stylistic matters, but to certain degree adapted to the local circumstances as well. But I felt that building in the harsh climate of north Scandinavia need more profound approaches. The first visits to Cuba, Japan, Mexico, Morocco and Senegal convinced that there are unanswered environment problems in the building in other climate zones as well.

When I first time started to develop ideas on architecture and climate, there were only some Norwegian colleagues who shared the interest on that topic. When I at the beginning of the 1990’s proposed an article to the Finnish Architectural Review on architecture in cold climate, the answer was that the topic was not of interest to architects. Now the attitudes have matured, and there is an abundance of discussion on the climate change. But even today there is a lack of information what the effects of the climate and climate change to the built environment are, and how climate-conscious planning and architecture design could be made.

The problems are many faced and need cross discipline approaches. Therein lays the danger to be a Jack-of-all-trades. Nevertheless I have tried.

My special thanks belong to the colleagues who gave me the spark of interest to the problematic of climate and architecture:
- Prof Reima Pietilä, with whom I had long discussions about the elements of architecture, nature morphology, and typology of architecture from North Scandinavia to sand deserts.
- Dr Anne Brit Børve, who gave me the first scientific material on the subject.
- MSc (arc) Eilif Bjorge, with whom I have had immemorial sessions and made some projects in Norway and Finland.

I’m grateful to Prof Helka Liisa Hentilä for her expertise supervision and encouraging. My deepest appreciations to the reviewers of my thesis, Dr Hilkka Lehtonen and Dr Ulla Westerberg, for their critique and comments, which helped to clarify and enrich the research text.

During the years I have had very inspiring sessions with many persons on architecture, aesthetics, climate, climate change and research matters, and those talks have been the condition sine qua non for the making of this research. These people include Dr Halina Dunin-Woyseth, MSc (arc) Jürgen Eckhardt, Tech Lic
Bruno Erat, Prof Sandy Hallyday, MSc (arc) Sigurdur Hardarson, MSc (arc) Eero Juhonen, MSc (arc) John Kristoferssen, Tech Lic Pekka Lahti, MSc (arc) Olli Lehtovuori, MSc (arc) Howard Liddell, MSc (arc) Per Persson, writer Norman Pressman, MSc Timo Tuomivaara, MSc (eng) Irmeli Wahlgren and PhD Petri Vuojala. Those mentioned are only some of many who contributed help and opinions, all debts can not be acknowledged.

I wish to express my thanks to James Nimmo, who has checked the English language of the dissertation. Emma Linsuri has drawn the figures in Chapter 4.34.

I like once again express my gratitude to the persons who helped me with the making of my Tech Lic dissertation in year 2000:

- Prof Kaj Nyman, the supervisor of my Tech Lic dissertation.
- Dr Torsti Kivistö, the reviewer of my Tech Lic dissertation.
- Dr Heikki Aikivuori, the leader of the VTT building laboratories in Oulu, who helped with the measurements of the wind-test blower prototypes.
- MSc (eng) Lauri Helle, VTT wind tunnel laboratories.
- Lauri Siivola, who helped with the building of the first four wind-tester prototypes.
- Olavi Himmelroos, who helped with the building of the wind-tester prototypes numbers V and VI.
- BSc (eng) Johanna Vakkuri, who has made the measurements of the wind-test blower prototypes.

Many persons have helped with the pilot projects, among them:

- Urban renewal project at Store Lunnegårdsvann, Bergen, Norway. Dr. Anne Brit Børve, architect Arne Bjerk, architect Eilif Bjørge
- Analyses and planning of Raviradan alue (former trotting-track), Sodankylä, Finland. Municipality Director Martti Pura, Technical Director Yrjö Meltaus, researcher Irmeli Harmaajärvi (Wahlgren).
- Urban renewal project in Rajakylä, Oulu, Finland, Planning Manager Heikki Kantola, architect Sirkka Rajaviita.
- Pilot building, Tervola, Finland. Municipality Director Kalevi Virkkunen.
- Pilot building, Linnanmaa, Oulu, Finland. Man.Dir. Toivo Nurminen.
- Nature Analysis, Onnela, a Housing Fair area in Kajaani, Finland. Planning Manager Irmeli Hanka.
- Rokua LIFE. Man.Dir. Tuomas Alasalmi, architect Ritva Okkonen,
During the research questionaries have been sent to many planners, architects, administrators, property owners etc. I am grateful to everybody who assisted the work by giving their opinions.

Without the financial and material assistance of different organisations or companies the making of this research would have been impossible; thanks to them:
- Asun托hallitus (National Housing Bank).
- TEKES (National Technology Agency of Finland).
- Tervolan Metalli Oy, making of the prototypes I–IV.
- Woods Oy, axial blowers for the prototypes IV and V.
- Emil Aaltosen säättiö (culture fond).

Special thanks and a kiss belong to my girl friend and wife, Marita, who has encouraged me through the years, and sometimes helped me for instance with climate analyses and wind measurements on the field, which sometimes has been quite a wind-chilled experience. She has also drawn some of the climate analysis figures.

Oulu September 3, 2008

Kimmo Kuismanen
Glossary

Absorptivity  The fraction of the striking radiation absorbed at the surface.

Acid rain  The removal (or “washing-out”) of oxides of sulphur and nitrogen from the atmosphere by precipitation (rain, snow, hail). Such oxides are produced in the combustion of coal and petroleum-derived fuels.

Adiabatic  A process of expansion or contraction of a gas without adding or subtracting outside heat.

Anabatic flow  Upslope breeze, a wind blowing up hillsides during the day due to heating effects.

Aerodynamic roughness  The resistance of terrain or built-up areas, which modifies the wind field, and reduces the wind flow especially near the ground. See also wind profile.

Aerodynamics  The study of the way in which air or other gases travel over or through an object, and the resulting interactions that occur between the gas and the surface of the object. In Greek aero is air and dynamikos means powerful.

Air pollution  This can refer to pollution of the atmosphere on any scale from global to local. In the former case pollutants are CO₂, CFCs and other gases which cause global warming (“Greenhouse gases”), depletion of the ozone layer or both. At local level, short-lived, high concentration emissions such as NOx, carbon monoxide, and hydrocarbon particulates from road traffic are important.

Albedo  Fraction of solar radiation reflected with respect to incidence.

ASTM  American Society for Testing and Materials, an organization that promulgates standard methods of testing the performance of building materials and components.

Atmospheric boundary layer  The ABL is the lowest part of the earth’s atmosphere, and its thickness ranges from several hundred meters to approximately two kilometres.

Badgir  Wind towers used in Arabic countries to capture the wind and force the air-flow down into the building for cooling and ventilation purposes.
| **Bernoulli’s law** | For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point. A special case of the Bernoulli equation is when the height of the flow remains constant. i.e. the third term disappears from the equation. This reduced form shows that if the pressure in a fluid decreases, the flow will accelerate and vice-versa. |
| **Bioclimatic** | Describes an approach to building design which is inspired by nature and which applies a sustained logic to every aspect of a project, focused on optimising and using the environment. The logic covers conditions of setting, economy, construction, building management and individual health and well-being, in addition to building physics. |
| **Biodiversity** | The variability among living organism from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. |
| **Biomass** | The total amount of living organisms in a given area, expressed in terms of living or dry weight per unit area, but here used to describe a source of energy fuel. |
| **Boundary layer 1** | In the boundary layer the atmosphere and the earth’s surface as the base interact with each other. Above the boundary layer the features of the earth’s surface no longer affect the behaviour of the atmosphere |
| **Boundary layer 2** | In wind tunnel an irregular surface in front of the actual testing area, which imitates the usual urban environment. The boundary layer offers a steady resistance to the wind, thus making the air flow as correct interpretation of “normal wind” outdoors. |
| **Brise-soleil** | Architectural sun shading construction of a façade; often made of concrete. |
| **Building code** | A set of legal restrictions intended to assure a minimum standard of health and safety in buildings. |
| **Butterfly effect** | The butterfly effect theorises that a change in something seemingly innocuous, such as a flap of a butterfly's wings, may cause unexpected larger changes in the future, such as a tornado. The term "butterfly effect" itself is related to the work of Edward Lorenz, based in Chaos Theory. |
| **Capillary action** | The pulling of water through a small orifice or fibrous material by the adhesive force between the water and the material. |
Catabatic flow: Down-slope breeze, occurs as cooling sets in.
Cavity wall: A masonry wall that includes a continuous airspace between its outermost wythe and the remainder of the wall.
CFD: Computational fluid dynamics is in general a numerical technique in which equations describing the fluid flow are solved on a computer. In wind engineering the flow is normally the atmospheric boundary layer (ABL) flow.
Climate: Is the sum of the weather experienced at a place during a longer period of time. The average conditions of the weather elements change from year to year.
Compression: A squeezing force.
Condensate: Water formed as a result of condensation.
Condensation: The process of changing from a gaseous to a liquid state, especially as applied to water.
Conduction: Process of heat transfer from warmer to cooler molecules within a solid material.
Convection: Heat transfer by a fluid motion.
Dew point: The dew point is the temperature to which the air must be cooled in order that it will be saturated with respect to water at its existing pressure.
Ecological footprint: The area per capita needed to produce all commodities consumed by one person.
Ecology: The study of interactions of living organisms with each other and with their environment; the study of the structure and functions nature.
Ecosystem: A community of plants and animals and the environment in which they live and react with each other. In ecosystem plants and animals are linked to their environment through a series of feedback loops.
Eddy: Air or water moving fast in a circle; a swirl. Standing eddies are more or less stable swirls; in the atmosphere called as rotors.
Friction: Moving air produces friction whenever it comes in contact with other bodies. This friction has a tendency to reduce the speed of the air and alter its pattern. See also aerodynamic roughness.
Gable roof: A roof consisting of two oppositely sloping planes that intersect at a level ridge.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming</td>
<td>The surface temperature of the earth is regulated by the presence of greenhouse gases (carbon dioxide CO₂, methane CH₄, CFCs, nitrous oxide N₂O) in the atmosphere that trap long wave solar radiation reflected from the Earth’s surface. The burning of fossil fuels release CO₂, which with other greenhouse gases has caused an increase in the amount of solar radiation retained in the atmosphere.</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gas.</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>The process in which carbon dioxide and other gases build up in the atmosphere and trap more of the sun’s heat, thus leading to changes in climate.</td>
</tr>
<tr>
<td>Gust</td>
<td>Sudden, rapid and brief changes in wind speed. High points in wind speed are known as peaks and low points lulls.</td>
</tr>
<tr>
<td>Hygroscopic</td>
<td>Readily absorbing and retaining moisture.</td>
</tr>
<tr>
<td>HVAC system</td>
<td>Heating, ventilation and air-conditioning systems.</td>
</tr>
<tr>
<td>Inertia</td>
<td>Once set in motion air, just like any other moving body, has a tendency to continue in the same direction until diverted by some external body of force.</td>
</tr>
<tr>
<td>LDV</td>
<td>Laser Doppler velocimetry, also known as Laser Doppler anemometry LDA, is a technique for measuring the direction and speed of fluids like air and water.</td>
</tr>
<tr>
<td>Lorenz attractor</td>
<td>The Lorenz attractor, named for Russian researcher Edward N. Lorenz, is a 3-dimensional structure corresponding to the long-term behavior of a chaotic flow, noted for its butterfly shape.</td>
</tr>
<tr>
<td>Low-emissivity coating</td>
<td>A surface coating for glass that permits the passage of most shortwave electromagnetic radiation (light and heat), but reflects most longer-wave radiation (heat).</td>
</tr>
<tr>
<td>Lyapunov exponent</td>
<td>Named for Russian researcher Aleksandr Lyapunov, who elaborated the modern rigorous theory of the stability of a system, and the motion of a mechanical system on the basis of a finite number of parameters. The method he used for the proof is today one of the foundations of probability theory.</td>
</tr>
<tr>
<td>Mahoney tables</td>
<td>See Appendix 8.</td>
</tr>
<tr>
<td>Malgaf</td>
<td>Wind capturing building elements used in Arabic countries. Sometimes these are combined with jars filled with water to cool and humidize the air. The system can be completed with a pool, salsabil.</td>
</tr>
</tbody>
</table>
**Micro-climate**
Micro-climate is the essentially uniform local climate of a small site or habitat, and formed on the basis of the features of the earth’s surface.

**Moucharabieh**
In Arabic countries a kind of balcony or archer, which protects against solar radiation, sand storms, insects and outsiders. It is usually made of latticed wood.

**Normative**
Describes approaches that establish a norm, standard or optimum condition.

**NOx**
A term used to include nitric oxide (NO) and nitrogen dioxide (NO2).

**Ozone depletion**
The layer of ozone gas in the stratosphere protects the Earth’s inhabitants from the harmful effects of ultra-violet (uv) radiation.

**Paradigm**
The concept of paradigm derives from the Greek word “paradeigma”, meaning pattern or example. Thomas Kuhn uses this concept to describe a scientific view, a construction of theories, a conception of the world within which most scientists work.

**Permaculture (1)**
The active design of human habitats and food production systems to combine land use and community building to create integrated, sustainable living patterns. It embraces food production and resource efficiency and extends to economic and social structures such as co-housing.

**Permaculture (2)**
Or ‘Permanent Agriculture’: the concept of self-supporting system of agriculture whereby the organization of plants and animals enables continued recycling of nutrients and energy within the system, which is ultimately sustained by input of solar energy. It is possible to remove organisms from the system for human use, but this must be sustainably managed in order to prevent the system from collapsing.

**Photovoltaic**
An interconnected system of photovoltaic panels that functions as a single electricity-producing unit.

**Photovoltaic (PV) array**
The semi-conducted element within a PV module which instantaneously converts light into electrical energy (DC voltage and current).

**Photovoltaic (PV) cell**
A panel comprising an assembly of PV cells wired together and usually laminated between two rigid layers of material – the outer one usually a sheet of glass – delivering a known electrical output at ‘peak’ conditions.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIV</td>
<td>Particle image velocimetry (PIV) is an optical method used to measure velocities and related properties in fluids. The fluid is seeded with particles which, for the purposes of PIV, are generally assumed to faithfully follow the flow dynamics. It is the motion of these seeding particles that is used to calculate velocity information.</td>
</tr>
<tr>
<td>Post-modernism</td>
<td>A movement reacting against modern tendencies which began in architecture, spread into literature, then via the social sciences into human geography. It is sceptical of previous theory. Interpretations are regarded as contingent and partial, with a stress on open interpretations and plural views.</td>
</tr>
<tr>
<td>Radiation</td>
<td>Heat transfer between surfaces by electromagnetic waves across a space.</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Relative humidity is the ratio of the actual vapour pressure to the saturated vapour pressure, with respect to water at the same temperature and pressure.</td>
</tr>
<tr>
<td>Roughness</td>
<td>See aerodynamic roughness.</td>
</tr>
<tr>
<td>R-value</td>
<td>A numerical measure of resistance to the flow of heat.</td>
</tr>
<tr>
<td>Sieve mapping</td>
<td>Use of series of overlapping maps used to locate sub-areas which meet a specified set of specific requirements.</td>
</tr>
<tr>
<td>Soffit</td>
<td>The under-surface of a horizontal element of a building, especially the underside of stair or a roof overhang.</td>
</tr>
<tr>
<td>Solar chimneys</td>
<td>Flues constructed to exhaust air from a building using a combination of stack effect, external pressure differentials and the heating of the flue by the sun so that cooler is drawn in to fill the vacuum.</td>
</tr>
<tr>
<td>Solar-electric collector</td>
<td>A device for collecting solar energy in the form of electricity using a photovoltaic array.</td>
</tr>
<tr>
<td>Solar gain</td>
<td>The raising of temperature caused by the heat of the sun.</td>
</tr>
<tr>
<td>Solar-thermal collector</td>
<td>A device for collecting solar energy in the form of heat, usually by exposing a fluid to the sun’s rays.</td>
</tr>
<tr>
<td>SOx</td>
<td>Refers to oxides of sulphur, the most important of which are SO2 and SO3.</td>
</tr>
<tr>
<td>Stack effect</td>
<td>The vertical movement of air caused by convection; the phenomena by which hot air rises, pulling cooler air in to fill the vacuum. The hot air is usually expelled at high level.</td>
</tr>
<tr>
<td>Storm window</td>
<td>A sash added to the outside of a window in winter to increase its thermal resistance and decrease air infiltration.</td>
</tr>
<tr>
<td>THC</td>
<td>The Atlantic thermohaline circulation, inaccurately known as the Gulf Stream.</td>
</tr>
</tbody>
</table>
Thermal mass  The capacity of material to take up heat from the surrounding space. A material of low thermal inertia, such as stone or concrete, can be used to absorb heat during the day when temperatures are hot and release it at night when it is cooler.

Thermal resistance  The resistance of a material or assembly to the conduction of heat.

Tinted glass  Glass that is coloured with pigments, dyes, or other admixtures.

Trickle vent  A small opening, usually in a window frame, fitted with a sliding shutter which allows low levels of ventilation in winter to assist in dispersing stale air.

Trombe wall  A high thermal mass wall exposed to the sun, usually with an outer layer of glass and an inner surface of dark finish, used to absorb and store heat and release it to heat internal spaces when it is cooler.

Turbulence  Swirls, eddies or vortices in the air that are more or less random except when organized as rotors.

Vapour pressure  The vapour pressure is that part of the total atmospheric pressure that is exerted by water vapour.

Vernacular architecture  Indigenous buildings developed on pragmatic bases by the peoples of geographic region, tribe or community using materials and skills which are to hand.

Vortex  A swirl or eddy.

Weather  Is the totality of atmospheric conditions at any particular place and time. The elements of the weather are temperature, atmospheric pressure, wind, humidity, cloudiness, rain, sunshine, and visibility.

Wind load  A load on a building caused by wind pressure and/or suction.

Wind profile  The mean wind speed decreases progressively downward as a result of friction with the earth’s surface. Wind profiles describe the vertical profile of the wind, from the gradient wind level down to the ground.

Wind uplift  Upward forces on a structure caused by negative aerodynamic pressures that result from certain wind conditions.

Wind rose (1)  Icon used on old maps to show the directions from which winds blow.

Wind rose (2)  Diagram that shows the relative frequency with which winds blow from each direction. It may also show the speed and power with which those winds occur.
Wind towers  Towers constructed to direct wind into a building for cooling purposes.
Zoning ordinance  A law that specifies in detail how land may be used in a municipality.
List of figures

Fig. 1. Villa Rotonda, Palladio, uses the climate elements for warming, cooling and ventilation. ................................................................. 42
Fig. 2. Prevailing winds of the earth’s pressure zones and atmosphere. .................. 66
Fig. 3. Example of an analysis of a macroclimate, the climate of Scandinavia. .... 66
Fig. 4. Temperature difference between winters and summers are great in Scandinavia. 67
Fig. 5. World climatic regions according to the Köppen classification. ................. 67
Fig. 6. Examples of warm humid, warm dry and cold climates. ......................... 68
Fig. 7. Examples of temperate, continental and Mediterranean climates in Europe. 68
Fig. 8. Formation of the wind profile. ...................................................... 72
Fig. 9. Changing amount of animal bones at Mill Greek due to the climate change. 82
Fig. 10. Multi-model mean changes in a) precipitation, b) soil moisture content, c) runoff and d) evaporation. ........................................ 87
Fig. 11. Rising sea level, scenarios according to IPCC. ................................... 89
Fig. 12. Effect of 1 metre sea-level rise in Florida. ....................................... 90
Fig. 13. Effect of 6 metres sea-level rise in Florida. ..................................... 91
Fig. 14. Scharer’s snow study in which snow accumulation is presented quite inaccurately. 104
Fig. 15. Terrain can be divided into five landscape types. ................................ 107
Fig. 16. Ecological land use planning with the sieve map technique method. .......... 112
Fig. 17. Growth of outdoor space and building scale has increased windiness and traffic. 115
Fig. 18. Overall arrangements of a large wind tunnel. ................................... 122
Fig. 19. Pressure coefficient distribution. .................................................... 126
Fig. 20. Flow chart of e-wind. ................................................................. 128
Fig. 21. Air temperature, surface temperature, humidity, air flow speeds and natural lighting affect the micro-climate of building sites. ............... 135
Fig. 22. Too dry or humid indoor air can have harmful consequences; recommended relative humidity lies between 40–60%. ........................ 137
Fig. 23. Comfort experienced by people in winter and summer in a cold climate. 141
Fig. 24. Comfort experienced by people in winter and summer in a cold climate. 144
Fig. 25. The human range of thermal comfort indoors. ................................. 148
Fig. 26. Boundaries of acceptable conditions for still air. ............................... 148
Fig. 27. Impact of wind outside the range of thermal comfort. ......................... 149
Fig. 28. Optimal operative temperature as a function of different activities and the thermal resistance of clothing. ................................. 150
Fig. 29. Laminar flow and Bernoulli’s law. .................................................... 151
Fig. 30. Principle of a low-pressure vent. ................................................... 151
Fig. 31. Formation of the point of separation ............................................... 152
Fig. 32. Formation of the point of separation at the mouth of a sharp angled canal "vena contracta". ......................................................... 152
Fig. 33. Air flow at a plate-like obstacle ....................................................... 153
Fig. 34. The effect of shape on turbulence. .................................................. 153
Fig. 35. Wind loads directed towards a building. .......................................... 154
Fig. 36. Even laminar (at left) and turbulent (at right) flows will have different patterns when they meet a building. .................................. 155
Fig. 37. Impact of a building that is higher than its surroundings on relative windiness at a height of 2 m. ..................................................... 156
Fig. 38. Effect of different building masses on the downwind eddy. .................... 157
Fig. 39. The wind load of a polygonal hall is uneven, with both pressure and draught. 158
Fig. 40. Patterns of the air flow on a flat roof (A) and on a gable roof (B). .......... 159
Fig. 41. Gandemer’s principles, air flow patterns between buildings. ................. 161
Fig. 42. Small-scaled relatively dense pattern of building considerably reduces the power of wind. ....................................................... 163
Fig. 43. Open building way is very exposed to the winds, the direction of air-flow changes irregularly and strong turbulence occurs, which is a problem in cold climates. .............................................................. 163
Fig. 44. In narrow streets airflow is forced against the walls. ................................. 164
Fig. 45. In the upper figure the wind protection effect of row buildings with different wind directions; the darker the screen the more sheltered the area. 165
Fig. 46. Half closed block that has been shaped to protect against the wind, Rajakylä Oulu. .............................................................. 166
Fig. 47. The wind channels at ground level caused by the high buildings are seen in the model photo as distinctly bare sections. ......................... 167
Fig. 48. Carrying of snow in wind. ............................................................... 168
Fig. 49. Landscape structure analysis on a photo. ............................................. 174
Fig. 50. Division of an area into local climates. ................................................ 174
Fig. 51. Landscape structure analysis on a map. Bergen Store Lungegårdsvann. .... 176
Fig. 52. Defining problems on a map; accumulation of air pollutants. ............. 178
Fig. 53. Structure of the landscape. Bergen Store Lungegårdsvann. ................. 178
Fig. 54. Windiness around existing building stock on the basis of scale model wind testing. Oulu Rajakylä. ................................................ 179
Fig. 55. Presentation of the monthly maximum, minimum and average temperatures. 184
Fig. 56. Presentation of rain (sademäärä) in mm and snowfall in cm, Raahe .......... 184
Fig. 57. Presentation of windiness, Raahe ...................................................... 185
Fig. 58. Wind roses gathered from simultaneous measurements from the roof an apartment building in Puijonlaakso in Kuopio and the local airport at about 10 km distance. .................................................. 185
Fig. 59. Wind speeds and temperatures measured from roof A in Puijonlaakso, the yard of a shopping centre and Kuopio airport. ................. 186
Fig. 60. Relative speed of the wind around a hill group. .................................. 189
Fig. 61. Sea breeze will be created during sunny days when the terrain will warm up and the land breeze when the sea retains its heat at night. ............. 191
Fig. 62. Forming of cold air lakes at night. .................................................... 191
Fig. 63. Half closed block that has been shaped to protect against the wind, lake which is at the bottom. ................................................. 192
Fig. 64. Diurnal wind system which functions in most valleys. ......................... 193
Fig. 65. Plain. .................................................................................. 195
Fig. 66. Hilly landscape. ........................................................................ 196
Fig. 67. Valley. .................................................................................. 198
Fig. 68. Valley. .................................................................................. 199
Fig. 69. High island, mountain. ................................................................. 201
Fig. 70. Hilly landscape bordered by mountains. .......................................... 202
Fig. 71. Coast. .................................................................................. 204
Fig. 72. Axonometric drawing of landscape in which the main features of windiness during day and night are marked with arrows. ................. 206
Fig. 73. Axonometric drawing of Oslo in which both ventilation of city blocks after additional construction and air-improving water features are marked. 206
Fig. 74. Example of a micro-climate study made on a plan illustration, Kekkola, Jyväskylä. ................................................................. 207
Fig. 75. Markings used on a climate map. ..................................................... 208
Fig. 76. Drawing of observations in terrain. .................................................. 209
Fig. 77. Drawing of observations made during fieldwork. ............................... 209
Fig. 78. Observing air flows on snow is easy. Kemijärvi cemetery. ................. 210
Fig. 79. Knowledge gained from traditional building can be applied to present building methods. ......................................................... 210
Fig. 80. Overview of the sun’s influence on local climates. ............................ 213
Fig. 81. Placement of a building’s open facade, main windows or sun collector at different latitudes in order to maximise solar light. ................. 214
Fig. 82. Length of night (black) and day (white) at different places in Finland. ....... 216
Fig. 83. At small building sites the green analysis can be presented together with climatic and landscape analyses.................. 218
Fig. 84. Wind test equipment developed in this study................................................................. 239
Fig. 85. Comparison of wind tunnel tests done for a real building (at the bottom) and a scale model of a house using ground materials of different roughness (above).................... 240
Fig. 86. Observations can be illustrated with a drawing where airflows and turbulence are shown and described, Jyväskylä Kekkola.............................. 246
Fig. 87. Scale model 1:100 of Oulun Sivakka with the SIB sundial........................................... 247
Fig. 88. Cross-section of the CASE wind test equipment......................................................... 249
Fig. 89. Alternative A in Tervola................................................................................................ 251
Fig. 90. Alternative B in Tervola................................................................................................. 251
Fig. 91. Alternative C in Tervola................................................................................................. 252
Fig. 92. Details of the test house were implemented on a scale of 1:100..................................... 252
Fig. 93. Placement of the Tervola test house. 1..................................................................... 253
Fig. 94. Air flows at the Tervola test house in the scale model and around the test house........ 254
Fig. 95. Air flows at the Tervola test house in the scale model and around the test house........ 255
Fig. 96. Snow accumulation observed around the Tervola test building............................... 257
Fig. 97. Example of a “climate rose” in which the most important micro-climate factors of the site during the different seasons are shown.................................................... 262
Fig. 98. Gasoline consumption and urban densities................................................................. 273
Fig. 99. Neighbourhood developed with model wind test......................................................... 275
Fig. 100. Urbanisation of a high-rise block with a low-density urban structure, Gennevilliers................................................................. 276
Fig. 101. Multi-functioning block with shopping, parking and small-scale housing................. 278
Fig. 102. Relative wind speeds at 1.5 m height with 0%, 20%, and 50% open structures........ 283
Fig. 103. To avoid turbulence the edges of the wind protecting elements had openings........ 284
Fig. 104. Effect of height relations of façades and of protective walls on the speeds of air flows of the facade................................................................. 285
Fig. 105. Road bank in snowy terrain...................................................................................... 287
Fig. 106. Mean annual production of a 1.5 MW variable speed wind turbine in full load hours.................................................................................................................. 289
Fig. 107. Diagram of the principle of converting meteorological measurements to local conditions when planning wind energy parks.............................................................. 291
Fig. 108. Example of new rules for foundation heights in New Orleans after the floods........ 293
Fig. 109. Sloping shore. The measures are for the conditions in Finland................................. 294
Fig. 110. Quay shore................................................................................................................... 295
Fig. 111. Quay shore................................................................................................................... 296
Fig. 112. A network of green corridors suggested for the City of Bergen by CASE architects.................................................................................................................. 302
Fig. 113. Example of general plan work in Stockholm where three alternative green corridors were evaluated................................................................. 303
Fig. 114. A planted viaduct acts as a linear park in the densely built-up quarters of eastern Paris.................................................................................................................. 304
Fig. 115. The tower is tied to the ground by planted elements and also the sky courts have greenery.................................................................................................................. 305
Fig. 116. Street sections of a garden city, Santiago de Chile....................................................... 307
Fig. 117. Typical diversity of species in relation to latitude....................................................... 309
Fig. 118. Rock garden can give inspiration to the architecture.................................................. 311
Fig. 119. Wind shield plantings.................................................................................................. 312
Fig. 120. Distribution of air temperature and air flows on the sunny and shade sides of a tree........................................................................................................................ 315
Fig. 121. Zones in a building..................................................................................................... 319
Fig. 122. Protective double façade was made by gratings and garlands, kindergarten Sodankylä.................................................................................................................. 319
Fig. 123. Passive solar house principle...................................................................................... 320
Fig. 124. Directing the wind above a building group by grading construction heights............ 321
Fig. 125. A block designed and dimensioned on the terms of wind and sun............................ 321
Fig. 126. The range of interactions between a building and its environment is large.

Fig. 127. A calm air pocket can be formed also on the windward side of a building.

Fig. 128. Eaves protect the facade regardless of the type of roof.

Fig. 129. Vertical cold structures shield the facade against the wind.

Fig. 130. Presentation of the air currents around an entrance.

Fig. 131. Presentation of methods to improve the micro-climate of the entrance analysed in the Fig. 130.

Fig. 132. Façade laths that can regulate solar radiation in different seasons.

Fig. 133. The energy use of differently oriented normal walls, traditionelle Wand, and warm collecting walls, Kollektor Wand.

Fig. 134. The average ventilation amounts of some building types depending on the average wind speed of the heating season.

Fig. 135. Amount of ventilation as the function of the annual mean wind-speed.

Fig. 136. Heat balance of three different house types in regard to micro-climate in a as good as possible and bad situations.

Fig. 137. To avoid pollution concentrations the location and height of the stack must be planned correctly.

Fig. 138. Solar facade as a part of air conditioning system.

Fig. 139. Big building complex in which the ventilation of atriums is natural, Hotel du Department Marseille.

Fig. 140. Natural ventilation in a detached house in winter.

Fig. 141. Natural ventilation in a detached house in summer. Temperate climate.

Fig. 142. Energy consumption of different types of office buildings in a moderate climate.

Fig. 143. In regions with a dominant wind direction wind towers can be used to enhance the ventilation.

Fig. 144. Wind enhanced ventilation in the Strasbourg airport.

Fig. 145. Ventilation potential in direct-access building.

Fig. 146. Combination of cooling and ventilation strategies.

Fig. 147. The effect of different kinds of openings for wind force ventilation.

Fig. 148. Airspeeds in different configurations, with and without projections, at different wind directions.

Fig. 149. Activity chart for Khartoum, Sudan, hot season.

Fig. 150. Variation of the building according to climate.

Fig. 151. The best orientation of main facades and the distribution of primary mass to achieve maximum solar shading or solar gain respectively.

Fig. 152. The optimal placement of building’s vertical service cores.

Fig. 153. Examples of the accumulation of snow around buildings in arctic areas.

Fig. 154. Proposal of a new quarter in Kuwait, Pietilä.

Fig. 155. Flood and wind-resistant building types for the rebuilding of New Orleans.

Fig. 156. Relationship between gross building coverage ratio and wind velocity ratio.
### List of tables

Table 1. Examples of wind induced damage to buildings in Mio€. Above are mentioned the most important storms and on the left the countries affected.  

Table 2. CO₂ emissions per capita.  

Table 3. Development of CO₂ emissions.  

Table 4. Example for sub-classification of boundary conditions.  

Table 5. Hunts wind comfort criteria.  

Table 6. Beaufort scale related to pedestrian and pedestrian activity related effects.  

Table 7. Climate analyses.  

Table 8. Amount of solar radiation on a horizontal plate.  


Table 10. Relative wind speeds over terrain.  

Table 11. Ecosystem categories.  

Table 12. Urban analysis.  

Table 13. Roughness factor of urban environment.  

Table 14. Criteria for acceptable yearly mean wind-speeds (m/s) of the pedestrian activity categories.  

Table 15. Criteria of sun conditions in northern climates.  

Table 16. Criteria of the circumstances when wind testing is needed.  

Table 17. Life-circle of the different parts of the built environment.  

Table 18. Architecture 2030 CO₂ targets.  

Table 19. Urban typology and climate.  

Table 20. Height of wave climb on a flat-bottom shore of the Baltic Sea.  

Table 21. Green filters: percentage absorption of contaminants after 24 hours.  

Table 22. Thermal capacity of some building materials.  

Table 23. Comparison of energy use between an air-conditioned office and a naturally ventilated office.  

Table 24. Relationship of climate and nature factors to the built environment.
Contents

Abstract
Tiivistelmä
Preface
Glossary
List of figures
List of tables

Contents
1 Background ................................................................. 33
  1.1 Need for environment protection ............................................................ 33
    1.1.1 Predicted effects of climate change .............................................. 33
    1.1.2 Built environment ................................................................. 35
  1.2 Architecture and climate ................................................................. 36
    1.2.1 Architectural design methods ................................................... 36
    1.2.2 Climate and the ideal of architecture ........................................ 41
    1.2.3 Modern architecture ................................................................. 43
    1.2.4 Architecture and changing paradigms ....................................... 44
  1.3 Research problem and the objectives of the research ............................. 49
  1.4 Research methods ................................................................................ 53
    1.4.1 Outlines of the research ................................................................. 53
    1.4.2 The progress and structure of the research ................................... 54
    1.4.3 Nature and methods of the research ............................................ 55
    1.4.4 Case studies ................................................................................ 61
  1.5 Use of the results ................................................................................ 62
    1.5.1 Range of use ................................................................................ 62
    1.5.2 Significance ................................................................................ 63
2 Climatic challenges .............................................................. 65
  2.1 Climate .................................................................................................... 65
    2.1.1 Macro- and micro-climate ............................................................. 65
    2.1.2 Meteorological phenomenon ....................................................... 71
  2.2 Problems caused by the climate ........................................................... 76
    2.2.1 Climate and the built environment .............................................. 76
    2.2.2 Examples of damage ................................................................. 78
  2.3 Climate change ..................................................................................... 81
    2.3.1 Abrupt climatic changes in history .............................................. 81
2.3.2 Evidence of climatic change today ............................................... 82
2.3.3 Effects of the climate change ....................................................... 86
2.3.4 Predicted effects of the climate change in the cold and moderate climate regions .......................................................... 93
2.3.5 Predicted effects of the climate change in the warm regions ...... 96
2.4 Adaptation of building to circumstances ........................................... 97
2.4.1 Vernacular architecture ................................................................. 97
2.4.2 Designed architecture .................................................................. 99
2.4.3 Other design cultures ................................................................. 101
2.5 Present know-how and methods ...................................................... 102
2.5.1 Research on the climate and the environment ............................ 102
2.5.2 Background surveys on climatic problems ................................ 109
2.5.3 Nature analysis research .............................................................. 111
2.5.4 Urban analysis research .............................................................. 113
2.6 Present wind testing methods ......................................................... 121
2.6.1 Wind tunnel testing ................................................................. 121
2.6.2 Computational Fluid Dynamics .................................................. 125
2.6.3 E-wind ......................................................................................... 127
2.7 Need for an environmentally-conscious planning method .......... 129
2.7.1 Needs ........................................................................................... 129
2.7.2 Use of climate-conscious architecture ........................................ 132
3 Climate in built environment ............................................................. 135
3.1 Influence of climate on people ........................................................ 135
3.1.1 Components of micro-climate ..................................................... 135
3.1.2 Temperature ................................................................................ 136
3.1.3 Solar radiation ............................................................................. 136
3.1.4 Humidity .................................................................................... 137
3.1.5 Air flows ..................................................................................... 138
3.1.6 Impact of weather and climate on people’s behaviour ............... 142
3.1.7 Impact of climate on people’s comfort and health; medical climatology .......................................................... 143
3.1.8 Human adaptation to the indoor climate .................................... 146
3.1.9 Human adaptation to the outdoor climate .................................. 149
3.2 Wind in the built environment ........................................................ 150
3.2.1 Aerodynamics ............................................................................. 150
3.2.2 Air flows around buildings .......................................................... 154
3.2.3 Wind around building groups ...................................................... 159
3.2.4 Snow in the built environment ...................................................... 167

4 Case method and analyses ................................................. 169

4.1 Parts of the method ................................................................. 169

4.2 Structure of a holistic bioclimatic analysis ............................. 172

4.2.1 Holistic analyses of an area ................................................ 172
4.2.2 Planning and designing ...................................................... 175

4.3 Climate analysis ........................................................................ 179

4.3.1 Climate information needed in planning ................................ 179
4.3.2 Use of climate statistics .......................................................... 181
4.3.3 Local climates ...................................................................... 187
4.3.4 Analysing the impacts of landscape types ............................. 193
4.3.5 Working with the help of topography maps ........................... 204
4.3.6 Analysing a micro-climate on-site ........................................... 207

4.4 Sunniness analysis ................................................................. 211

4.4.1 Solar radiation ..................................................................... 211
4.4.2 Solar analyses methods ......................................................... 213

4.5 Natural environment analysis method ....................................... 216

4.5.1 Nature analyses needed in the CASE method ....................... 216
4.5.2 Analysis content ................................................................. 217
4.5.3 Wind speeds over terrain ...................................................... 219
4.5.4 Natural environment analyses at the building site ................... 219

4.6 Built environment analysis ....................................................... 224

4.6.1 Built environment analyses needed ......................................... 224
4.6.2 Analysis content ................................................................. 224
4.6.3 Impact of urban structure on the neighbouring areas ............... 227
4.6.4 Wind speeds in the urban environment ................................... 228
4.6.5 Traditional urban types and climate ...................................... 229
4.6.6 Modern urban plan types and climate .................................... 230

4.7 Use of CAD and CFD ................................................................ 233

5 Model testing ................................................................. 235

5.1 Wind tests for scale models ..................................................... 235

5.1.1 Wind simulations in wind testing .......................................... 235
5.1.2 Analysing test results ............................................................. 236
5.1.3 Possible sources of errors and false conclusions ...................... 238

5.2 Testing with the case wind test blower ...................................... 238

5.2.1 Equipment, models and instruments ...................................... 238
5.2.2 Model testing in practice ....................................................... 242
5.2.3 Requirements for a testing room................................. 243
5.2.4 Applicability of scale models scaled differently or made
    from variable materials in model testing...................... 244
5.2.5 Observation and registering techniques used in tests........ 245
5.3 Sun and shadow analyses.............................................. 247
5.4 Case wind test instrument ............................................ 248
    5.4.1 Wind testing as a part of architectural design......... 248
    5.4.2 CASE wind test blower........................................ 248
5.5 Reliability of the wind test method ................................ 249
    5.5.1 Comparison of measurements done in the field and model
          testing; Model house in Tervola............................ 249
5.6 Applicability and accuracy requirements of the equipment... 255

6 Guidelines 259
6.1 Climate-conscious planning........................................ 259
    6.1.1 Criteria of climate components of built environment, and
           the need for wind testing.................................... 259
    6.1.2 Impact of the local climate on construction............. 261
    6.1.3 Climate change and building sector....................... 263
    6.1.4 Regional and town planning................................ 267
    6.1.5 Urban typology............................................... 269
    6.1.6 Fill-in building.............................................. 275
    6.1.7 Detail planning............................................... 277
6.2 Outdoor areas.......................................................... 282
    6.2.1 Positive micro-climate....................................... 282
    6.2.2 Design of snow barriers..................................... 288
    6.2.3 Design of coastal structures............................... 291
6.3 Natural environment................................................ 297
    6.3.1 Construction and nature..................................... 297
    6.3.2 Urban parks and street greenery........................... 303
    6.3.3 Vegetation in different climates.......................... 308
    6.3.4 Wind protecting plantings................................. 311
    6.3.5 Different types of plantings as wind shelters......... 313
6.4 Buildings............................................................... 317
    6.4.1 Building design............................................... 317
    6.4.2 Impact of climate on structures........................... 322
6.5 Climate factors in building....................................... 324
    6.5.1 Wind............................................................. 324
6.5.2 Temperature ................................................................. 328
6.5.3 Solar radiation ............................................................. 329
6.5.4 Humidity ....................................................................... 331
6.6 Climate and the use of energy ............................................. 333
   6.6.1 Effect of the climate on the use of energy ..................... 333
   6.6.2 Solar energy ............................................................... 335
6.7 Ventilation ......................................................................... 337
   6.7.1 Wind and ventilation ................................................... 337
   6.7.2 Natural ventilation ...................................................... 341
   6.7.3 Cooling ...................................................................... 349
6.8 Guidelines for different climates ......................................... 354
   6.8.1 Architecture and world climate zones ......................... 354
   6.8.2 Cold and arctic climate ............................................... 358
   6.8.3 Temperate climate ...................................................... 363
   6.8.4 Warm humid climate .................................................. 371

7 Discussion ........................................................................ 377
   7.1 Objects of development ................................................ 377
      7.1.1 Development of building administration ..................... 377
      7.1.2 Development of compilation of climate statistics ......... 378
      7.1.3 Meteorological material needed because of climate change.. 378
      7.1.4 Development of construction norms ......................... 379
      7.1.5 Supplementary funding for climate-conscious construction.... 380
      7.1.6 Climate studies ......................................................... 381
      7.1.7 Education ............................................................... 381
    7.2 Further work ............................................................... 382
       7.2.1 Design criteria ....................................................... 383
       7.2.2 Development of guidelines and information ............... 384
    7.3 Use of climate-conscious architecture ............................... 384
    7.4 Finale .......................................................................... 386

Bibliography

Appendices
1 Background

"Geography or climate, that are specific for our country do not influence the character of our architectural or urban construction". (Reima Pietilä 1971)

1.1 Need for environment protection

The objectives and research methods of this study are presented in this Chapter.

1.1.1 Predicted effects of climate change

Predictions of future climate impacts show that the consequences could vary from disruptive to catastrophic.

Global warming is a contemporary challenge: complicated, involving the entire world, tangled up with difficult issues such as poverty, economic development, and population growth. Dealing with it will not be easy, but ignoring it will be worse. The industrialized countries of North America, Western Europe and Japan, are responsible for the vast bulk of greenhouse-gas emissions, and threaten the global future of mankind. Yet those to suffer most from climate change will be in the developing world; for instance 17% of Bangladesh will be flooded when the sea level rises with 1 metre. They have fewer resources for coping with storms, with floods, with droughts, with disease outbreaks, and with disruptions to food and water supplies. They are eager for economic development themselves, but may find that this already difficult process has become more difficult because of climate change. (Lee 2007: 2–3; Silfverberg 2008: 23–24)

The current warming trend is expected to cause extinctions. Numerous plant and animal species, already weakened by pollution and loss of habitat, are not expected to survive the next 100 years. Recent severe storms, floods, and droughts, for example, appear to show that computer models predicting more frequent "extreme weather events" are on target. (United 2007b: 1–3)

Human beings, while not threatened in this way, are likely to face mounting difficulties. Besides storms and other weather phenomena, new kind of security issues will arise. Floods and hunger can trigger a new epoch of great invasions, melting arctic seas open new routes to navies thus increasing military threats, increasing activities in polar areas add possibilities for major environmental accidents, the tension between industrialised and developing countries grow, and
changing circumstances compromise traditional sources of livelihood of the original people. (Heininen 2008: 5–8)

The average sea level rose by 10 to 20 cm during the 20th century, and an additional increase of 18 to 100 cm is expected by the year 2100. If the higher end of that scale is reached, the sea could overflow the heavily populated coastlines of such countries as Bangladesh, cause the disappearance of some nations entirely, such as the island state of the Maldives, foul freshwater supplies for billions of people, and spur mass migrations. In the southern USA Gulf of Mexico would creep more than 50 km inland. A rise of 1 metre would drastically affect more than 300 million people. (Hagget 2002: 606; United 2007b: 3–5)

In its Fourth Assessment Report, the IPCC states that the contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. If this contraction is sustained for centuries, that would lead to the virtually complete elimination of the Greenland ice sheet and a resulting contribution to a sea level rise of about 7m. (United 2007b: 3–6) Literally déluge après nous.

Agricultural yields are expected to drop in most tropical and sub-tropical regions, and in temperate regions, too, if the temperature increase is more than a few degrees C. Drying of continental interiors, such as central Asia, the African Sahel, and the Great Plains of the United States, is also forecast. These changes could cause, at a minimum, disruptions in land use and food supply, and the range of diseases such as malaria may expand. (United 2007b: 6; Merenpinnan 2008: 12–13)

The effects of community development on greenhouse gas emissions have already been studied for a long time, Thus far, relatively few studies have dealt with adaptation to climate change in community development. (Harmaajärvi 1996; Adaptation 2008: 3; Silfverberg 2008: 22–25)

This study will search for answers to the following questions:

– What changes in conditions will climate change cause that will require development of planning principles and impact assessment?
– What types of planning methods can take climate change into consideration and how can the consequences associated with climate change be assessed?

While no longer in a position to reverse the climate change, we can slow down its advance. The recommendations on needed research and practical measures with which climate change can be taken into consideration in community planning are
presented in Chapter 7. The results will benefit practical planning, compilation of land use guidelines, official inspections and permit procedures.

1.1.2 Built environment

Building activities globally use about 50% of the material resources, 40–45% of energy, 40% of water, 60% of fertile land and 70% of wood used by the mankind. The known oil fields will be emptied in 40 years and gas resources in 60. For these reasons construction and use of buildings are central when saving natural resources and fighting climate change. (Edwards 2005: 11, 23; United 2007a: 7)

The negative aspects of urban and suburban construction of the last decades have become largely apparent during this decade. City centres have been vacated and businesses have moved from the centres to the outskirts, where supermarkets have been constructed. This has resulted in the fragmentation of construction, disappearance of services from the city centres, and poorer services for people without a car. Many suburbs have proved to be unpleasant, and residents with the possibility have moved to more pleasant areas. The resulting available housing has either remained vacant or attracted asocial inhabitants. Especially in cold regions economic activity is subject to considerable seasonal variations. (Pienilmastont 1997: 1–3)

Although there are also many other reasons why city centres are being vacated and suburbs are unpleasant, in cold weather the windiness, draughtiness, and coldness of these areas are a significant factor. During warm weather overheating causes discomfort. It is possible to also calculate economic values for the pleasantness of outdoor areas by comparing the price of residential space in unpleasant areas with that of corresponding pleasant areas. In such areas the return on capital invested in the buildings is low. Certain regions are using the good climate as a tourism asset. Tourist sites constructed in bad weather areas are often not used to their full capacity, and in such cases the return on capital invested is very low. (Winter 1988: 15–22; Pressman 1995: 49–58; Palier 2002; Stathopoulos 2004)

Current architectural trends, through the design of large commercial centres with tall buildings, have brought new challenges to the fore. Investigations of wind effects and induced stresses on buildings and bridges, prediction of pollutant dispersion and the assessment of micro-climate in relation to pedestrian comfort have increased greatly over the last few years.
WHO confirms that the major socio-economic sectors are sensitive to climate variability and change, and that the integration of climate information into decision-making would help support the development of effective climate-related risk management. This requires multidisciplinary collaboration and partnerships. (World 2007: 22–25)

According to the United Nations Framework Convention on Climate Change (UNFCCC), approximately 30 per cent of the projected baseline emissions in the residential and commercial sectors – the highest rate amongst all sectors studied by the Intergovernmental Panel on Climate Change (IPCC) – could be reduced by 2030 with a net economic benefit. Energy consumption and embodied energy in buildings can be cut through greater use of existing technologies such as passive solar design, high-efficiency lighting and appliances, highly efficient ventilation and cooling systems, solar water heaters, insulation, highly-reflective building materials and multiple glazing. Government policies on appliance standards and building energy codes could further provide incentives and information for commercial action in this area. (United 2007b: 8, 9)

1.2 Architecture and climate

1.2.1 Architectural design methods

Climate-conscious design is no autonomous principle, but the method to be developed has to match existing design practices. Most architects have in their use a number of practical working methods and beliefs regarding architecture, which may have resulted from a method of stubbornness, authority, intuition or science. Many architects prefer the use of the word concept to theory and consider intuition to be the solving factor in the end. However, in project reports and criticism of architecture especially, there is an attempt to present things more systematically and some researchers, e.g. Tafuri, have developed justified theories of architecture. (Tafuri 1980)

The theorists of the Italian quattrocento laid a foundation for the theory and research of architecture. Alberti defined architecture-making to have a rational ground which aims at the skill of community life responding to the concepts "necessitas, commoditas, voluptas". Necessitas means dependence of construction on physical and mechanical (technical) laws as well as the environment and climate. Commoditas represents social requirements or use. Voluptas is defined as the ability of architecture to express beauty, to satisfy aesthetic needs in its own
language. According to Alberti, the quality of architecture is determined by these criteria being in harmony. The objective was harmony, in which case architecture became part of nature, cosmos and society; his philosophy is dominated by an Aristotelian aim to imitate nature. He made careful examinations of favourable conditions when planning a town based on a regular grid plan. This trilogy was reworked, re-born and stressed during the next centuries, but architects still admit that these criteria determine the essential contents of their work. In practice, different actors stress the criteria in different ways.

The analytical tools have their origins in art-historical methods, with roots in the Renaissance post-Vitruvian treatise. They were elaborated in 17th and 18th century France, transformed by 19th century German idealism and archaeology, and finally matured into the present ones. Throughout much of this time, the system with Classical Orders was being developed into a refined and coherent system, which also included climatic aspects. The modern polytechnic school saw the problems only as technical ones, in which case solving a problem usually creates a new one. (Markus 1993: 121–144; Chatelet 1998: 125–134; Théorie 2003: 22–27)

During the last 150 years, either a creative imagination or analytical technical approach has been variably stressed in urban and construction planning. The common denominator in an architect’s work and research is problem-solving but on the other hand architecture has its position somewhere between science, technology and art. Besides, economical starting points, political lines in society and many other matters state their own terms. One design problem may have several “right” answers which may alternatively emphasise pure sense, intuition, visuality or tradition. When working methods have been analysed, it has been found that architects’ approach belongs to one of the following ways of thinking: inductionistic empirism or a heuristic method.

**Inductionistic empirism**, an empiristic approach, is a successor of ”the Vienna Circle”, according to which correct problem formulation and its good analysis produce observations which result in hypotheses verifiable with empirical experiments. This way of thinking has been applied to architecture in the USA at least in the following ways (Alexander 1977; Ahlquist 1993: 81–86; Chatelet 1998: 11–12):

- Architectonic programming. Approach developed by Pena based on well-detailed conceptualisation done by a conceptor in a programming phase.
– Synthesis of form. Method identified by Alexander which decomposes a problem into "sub-problems". A combination of patterns results in a high-level entity.

– Conceptual architecture. Starts from an analysis, but stresses intuition. According to Poincaré, the solution of a problem or an invention is synthesis-based "illumination" taking place after the analysis.

*A heuristic method* is a sort of deduction, which gives grounds for suggesting solutions. According to it, there is no method of inventing. Scientific deductions cannot be purely based on an analysis and that is why “slight deduction” is needed to reason towards a solution which is tested as early as the design phase of the solution. This way of thinking stresses intuition and perception and has given material for several patterns of conceptualisation of architecture. It is partly based on Popper’s critique of the school of Vienna.

– Learning model. The concept is a result of interaction between a context and a designer’s advance idea.

– Interactive integration. The most difficult thing is to change over from an analysis to design. This requires systematic collecting of observations and associating them with a whole which forms or is updated as the solution of the problem in this process.

– Typological procedure. Realisation of architectural objects is based on intuitive understanding of symbols.

The examples above refer to similarities between architectural design and scientific working, but we must not forget the similarity between an architect’s work process and artistic creation. This all is expressly about conscious or unconscious use of references – in the comprehensive meaning of the word – as part of a future large entity. The architecture reference refers to comparison, identification and evaluation of motifs and interpretation in accordance with the task. After all, this all is about interpreting the world and giving it a visible aesthetic realisation. (Ahlquist 1993: 81–86; Chatelet 1998: 12–13)

Three different ways of activating the architectonic references can be identified:

– Transfer of dispositions.

– Repetition of a model.
– Indirect reference.

A plan is thus formed when a context analysis, outside references, criterion evaluation and diagnosing of a project interact in a complex way. This finally results in the origin of a supporting idea, but one single covering theory, method or practice for this work does not exist. (Chatelet 1998: 13) For instance Eco identifies five codes in architecture (Eco 1969):

I Based on engineering technology.

II Syntactical, based on plan forms.

III Semantic, which consists of words describing function.

IV Social utility – “ideologies of inhabitation” (which are function labels for individual spaces).

V “Sociological” typology for entire buildings.

Some researchers stress the artistic side even more. Nyman says that the qualitative is relegated to the realm of art, and architecture which is not art could be produced by a computer with the architect degenerated into a technician. Architecture should be treated as a human language, i.e. as one of the many semiotic systems in which we operate to satisfy our desire for meaning. But today a language tends to limit itself to what is clearly and distinctly expressible in terms of digital communication – the language of computers. This attitude has deep roots in western thought and it is often labelled logocentrism. But communication is mostly about analogue relations, and the main principle of communication is essentially the same in architecture as in a verbal language. Even more, as the most permanent of human creations, buildings more than any other things are manifestations of Western metaphysics. (Nyman 1989: 342–388)

According to Norberg-Schulz, after decades of abstract “scientific” theory, it is urgent for us to return to a qualitative, phenomenological understanding of architecture. When defining the spirit of place, he adds the climatic aspect. Nordic man has to enjoy the creaking sound of snow under his feet when he walks around, and he has to experience the poetical value of being immersed in fog. The Arab, instead, has to be a friend of the infinitely extended sandy desert and the burning sun. But his settlements should protect him against the natural forces. (Norberg-Schulz 1986: 13–22, 253–258)
Many others are quite sceptical about the argument that architecture is a language. An architecture theory is operating in quite a different context than linguistics, and their elements, combination rules and communication processes differ from each others. The direct use of the methods and concept systems of other sciences will weaken the quality of architecture science. Architecture semiotics is only possible, when the terms and methods are modified to match the context of architecture research. Each kind of art should have a lexicon, syntax and grammar of its own, which have socio-informative relevance. All arts, but especially urban planning and architecture, are charged with social expectations.

The making of a text, i.e. a work of architecture, is part of a communicative process, the parts of which are: the code of signs, text making rules, (aesthetic) competence, knowledge, existing text universe, social model of the reality, biographical and psychological situation, socio-economic role, historical socio-cultural status, intentions and expectations and predicted reactions. It must be remembered that we are talking about real objects that surround us every day. (Schmidt 1976: 105–116; Schneider 1976: 61–69)

For Rossi, “analogy” and “type” are the keys to architecture-making. Selected references and elements can be abstracted from the vernacular. A city is a complex urban artefact that consists of other artefacts. The kernel of making buildings is “type”, which combines technique, functions and an artistic style in a dialectic way. Monuments are primary elements, because they organize the city both physically and in time, acting as memory devices and a collective memory. But a city is as irrational as any work of art, and its secret lies in its secret and the ability for collective manifestations. (Rossi 1982)

In principle, one of architects’ working methods in use is or should be considering a built or natural environment and climate as one starting point. An environment or climate is not automatically included in the present methods, but considering these during the work depends on each designer’s personal solution and knowledge. In the literature, different climate-related designing methods (See Chapter 2.5.) have been presented, but they require extra stages, auxiliary devices and special knowledge, and that is why they usually remain unused. (Olgyay 1963; Glaumann & Westerberg 1988; Mathus 1988; Climatic 1996)

Since the process of making architecture is complicated and consists of innumerable levels and reference fields interactively entangled in each other, it is not simple to introduce new variables to the system. As far as we want the requirements of sustainable development and the solutions required by a climate to be included in urban planning and everyday practices of architectural design, we...
have to get the basic knowledge, solutions and positive images into the reference background of a large heterogeneous group of actors on different levels. When urban planning, making architecture or criticism are developed systematically, e.g. in an environment-conscious direction, instruments of research and practical project work must be developed systematically. In particular, cooperation between technical and architectural research is necessary, when suitable energy and ventilation concepts for different climates are developed.

1.2.2 Climate and the ideal of architecture

Even primitive people sought each other’s company when looking for shelter against nature or other tribes, and thus formed densely populated communities. Such opposites as warm and cold countries, inland and coast, mountains and plain produce different goods, which made the origin of trading and towns possible. Besides, one precondition for the origin of towns has been a favourable climate and other natural conditions. A climate favourable for grain-cultivating was important; we can talk about wheat, rye, corn and rice towns and the climate is also reflected at our dining table. In fact, town is a way of eliminating climatic factors and making life independent of topographic matters, but still urban culture developed differently in different climatic zones.

In antique and medieval towns, walls built for defensive reasons bordered a micro-climatic area sheltered against wind. Winding streets weakened the power of wind and archways gave shelter against rain and heat of the sun. Shelter against the open air was important, because most trading and other life took place outdoors. Life in a medieval urban house is described by poor ventilation conditions and lack of light. Since the Baroque period, broad avenues brought light, greenness and wind to towns of the new era. On the other hand, working-class quarters are described by lack of light, hygiene, fresh air and water. In general, the 19th-century town plans did not pay any attention to the directions of prevailing winds, locations of factory areas, healthfulness of soil or terrain shapes. (Meurman 1947; Mumford 1949: 56–59, 114–177)

In the history of ideal cities, there are both theories and literary portrayals of paradises on earth. From Vitruvius to the model cities of the Renaissance, architects’ city models are characterized by their geometrical array, in which nature made a part of a larger composition. Vitruvius underlined the importance of the four nature elements, and gave many practical rules how to cope with them. Palladio stated that architecture is an imitation of nature, i.e. rational, simple and
classic. In many buildings he uses the site and nature forces in a masterly way [1]. Ledoux was inspired by the ideas of Rousseau, and planned natural, humanistic, utilitarian settlements surrounded by opulent vegetation (Ledoux M. D. CCCIV; Krampen 1984: 8–10).

![Fig. 1. Villa Rotonda, Palladio, uses the climate elements for warming, cooling and ventilation. (Climatic 1996)](image)

In the ideal urban structures of the Heavenly Jerusalem portrayed in literature, gardens and nature play an important role in the ideas of philosophers of the Enlightenment. In the Utopia of Thomas Morus in the 16th century, citizens cultivate flowers, vegetables and fruits in the gardens of their blocks. The sun state Orbis Pictus, introduced one hundred years later by Tommaso Campanella, is a geometrical city model comprised of central rings that represent human culture and building on the one hand, and nature and its offerings on the other. In Nova Atlantis, described by Francis Bacon, cultivation and utilization of plants play a key role. Rob Krier’s Atlantis, with its hanging gardens, can be considered to be in the same league. At the same time, the worldview of all of these is anthropocentric; humans control nature. Indeed, the concept of the intrinsic value of nature was born as a part of ecological philosophy and biological research. (Krampen 1984: 7–10, Krier 1988; McClung 1983; Kruft 1985; Théorie 2003: 318–327)

The social aspects of climate have been studied for centuries, too. For instance, one of the most celebrated doctrines of Montesquieu is that of the political influence of climate and natural circumstances on the organization of states and organs of government. He stressed the effect of climate – primarily thinking of heat and cold – on the physical frame of the individual, and as a consequence, on the intellectual outlook of society. But he says that this influence is not inseparable, and it is the legislator’s duty to counteract it. Montesquieu took
care to insist that climate is but one of many factors and the others are of non-physical nature and their influence grows as civilization advances. (Montesquieu 1748)

Archetypes, originally connected to specific functions, have formed a basis for development in planning and design. It was the architects of the 19th century who, faced with new tasks, started to use the archetypes for new types of buildings and even mixed them. This opened the scene to modern architecture. (Ahlquist 1993: 83–86)

But did we lose the utopia at the same time?

1.2.3 Modern architecture

Drastic shifts in weather systems affect human behaviour, in both cold and warm circumstances. Climate has served as a modifying or determining force in architectural and urban design for centuries. In modern architecture climatic factors have often been ignored, resulting discomfort and even damage. The same available technologically-driven solutions are applied in spite of the circumstances. Functionalism taught us to discard the tradition in architecture, and taught that form should follow function. Unfortunately the implementation of that message proved difficult, and we got an architecture which, regardless of local culture and climate, produced a new faceless international style.

Also the content of the architects work changed as urbanization, the development of traffic, massive investment in housing as well as many other tendencies in society developed and demanded rational planning methods and procedures. In urban planning the tradition, established in many hundreds of years, to build along streets and around yards was abandoned. The rational of functionalism quickly developed into something that was so simplified that it could be coped with by almost anyone.

In 1933, CIAM (Congrès Internationaux d’Architecture Moderne) published La Charte d’Athènes, which partly consists of statements about the conditions of towns, and partly of proposals for the rectification of those conditions. Quite central was the demand to renovate the slums of the stone-cities with a new kind of planning, rigid functional zoning, with green belts between the areas reserved to the different functions. The aim was to let sunlight and refreshing wind into the open blocks, which consisted of free-standing buildings; “high, widely-spaced apartment blocks”. (Hatje 1963) Typical for the period is Finnish architect Meurman, who in his classic book about planning devotes a lot of space to the
question of sunlight, solar diagrams, the prevention of tuberculosis etc., but mentions wind only once briefly (Meurman 1947).

Some architects, like Le Corbusier, studied the effect of some climate elements, too. In their works, climatic motifs were woven into the texture of modern architecture and this became part of a common inheritance. But the language of functionalism was originally Mediterranean, and during the long exposure of Scandinavia to it, architectural ideas were adapted that do not suit the climate of Northern Europe. The same happened in other countries and climates as well. Later some modernists, like Erskine, developed solutions suitable for northern climates, but mostly they have remained as lone wolves. (Krier 1979; Kruft 1985: 504–519; Ahlquist 1993: 84–86; Pressman 1995: 45–48)

For a long time there has also been a concept that totally denies the climate by screening it outside with glass-covered structures. A classic example is the Fullers dome project, which was to cover most of central Manhattan in New York. From such origins have developed the shopping-malls and glass-covered city blocks.

But planning and construction are holistic exercises in which all aspects of human society and behaviour are included. That is why we must not reduce the problem of building and climate to any of its partial aspects, thereby losing a view of the whole. Design could derive inspiration from cultural and climatic contexts to instil a deep aesthetic and sensory meaning.

Recent urban research has emphasized the importance of functional biotopes so that cities would, even in the long term, get the air, water, food and energy they need. The current tasks of urban planning are to determine the preconditions for sustainable city development, infill development, green structures, cultural landscape, transportation networks, aesthetic qualities and the way of building. The significance of climate should be considered in all of these. (Konzept 1976: 5–7; Yeang 1999: 22–57)

1.2.4 Architecture and changing paradigms

With the changing context, which includes climate change, modern architecture is facing new challenges. Attempts to replace the old modernism with a new style or design paradigm have been made. Some of these have been more stylistic, like post-modernism, some more profound, like “green architecture”, some only commercial, like the corporate sky-scrappers or shopping-malls of urban suburbia. Many critics say that the prevailing international style of architecture is already an expression of out-of-date values and cannot face future global tasks.
But is brave new prevailing architecture possible? Old prophets like Hegel or Kuhn say “yes”. Post-modernists and the philosophers of the era of uncertainty say “no”.

The dialectic theory of Hegel claims that things are always on the move between two extremes, and sooner or later there will be a way back to the original position. Marx developed this idea further by optimistically claiming that things are developing with dialectic circles, and progress will happen during each round. His paradigm can be described as a positive spiral. (Lyotard 1979; Holmdahl 1993: 275–280; Taleb 2007b) Kuhn shows in his book how during different phases of history the established “normal science” has been overthrown by scientific revolutions, and the whole construction of theories has been demolished, to be replaced by a new paradigm.

“The transition from a paradigm in crises to a new one from which a new tradition of normal science can emerge is far from a cumulative process, or achieved by an articulation or extension of the old paradigm. Rather it is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field’s most elementary theoretical generalizations as well as many of its paradigm methods and applications. During the transition period there will be a large but newer complete overlap between the problems that can be solved by the old and by the new paradigm”. (Kuhn 1962)

Correspondingly, post-modern philosophy also says that we have moved to a period of uncertainty, in which “grand narratives” are not possible any more. In development of mathematics, the time of chaos started a hundred years earlier, at the end of the 19th century, with the Lyapunov exponent. Well-known recent examples are the dynamics of the atmosphere, butterfly effect and Lorenz attractor. During the last few years, philosophical discussions have dealt with problems of unexpected events and the fall of paradigms, and not least because of the effects of climatic phenomena. Alternatives, i.e. different possibilities, are characteristic of the future. Transitions and periods with some uncertainty make different new ways of development possible. Chaos theories also give exact mathematical possibilities to think about a non-trendy change, i.e. chaos or transition. Climate change has increased the need for the use of these theories. (Lyotard 1979; Tuuttila 2005: 164, 170–172; Taleb 2007a)

Lyotard uses the word modern to designate any science that legitimates itself with reference to a meta-discourse or grand narrative, such as dialectics of Spirit, the hermeneutics of meaning etc. Postmodern is defined as incredulity toward narratives, which is caused by the crisis of metaphysical philosophy and of the
university institution. The purpose of old institutions is no more to find truth, but to augment power. (Lyotard 1979)

But a science that has not legitimated itself is not a true science; where after the meta-narratives, can legitimacy reside? Is legitimacy to be found in consensus obtained through discussion? According to Lyotard, such consensus does violence to the heterogeneity of language games. Knowledge is no longer the subject but in the service of the subject, which leaves no legitimacy of knowledge outside the serving of the goals envisioned by the practical subject. The function of science is to supply this subject with information, which allows the subject to circumscribe the executable (Lyotard 1979). In the ears of the author the creeks of legitimacy suggested – humanism, the autonomy of the will, allowing the morality to become reality, etc. – sound also like language games; so it goes. But nevertheless, postmodern knowledge refines our sensitivity to differences and reinforces our ability to tolerate the incommensurable.

During the last few years, surprises (caused by climate, among others) have been discussed in publicity, as our ideas about the reality differ from the reality itself. Unexpected things happen, as models depicting the reality do not correspond to the reality. It is to be realized that in a world getting more intricate even models are intricate and may act unsteadily and even chaotically. That is why there have been even bigger efforts to acquire knowledge on the future, which can be acquired in four different ways (Tuuttila 2005: 167–172):

1. Chaos and evolutionary thought.
2. Structural-innovative methods.
3. Expert and time series analyses.
4. Procedures based on communicative sketching of the future.

Modelling of climate change has become possible through the increase in computer capacity, which makes it possible to consider numerous explanatory factors at the same time. Fuzzy logic and fuzzy mathematics, simulation possibilities and the chaos theory have brought new dimensions to prediction. (Tuuttila 2005: 173–175; Taleb 2007a)

In our ever-changing world researchers like Taleb try to make us learn to expect the unexpected. He calls an exceptional unpredictable event a “Black Swan”. It has the following three attributes: 1) It is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point
to its possibility. 2) It carries an extreme impact. 3) In spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable. Things are often discovered by accident, even discoveries we claim come from research are many times highly accidental. But nevertheless, the more we search, the more likely we are to find things outside the original plan. It can be called the trial-and-error method, and a range of important inventions are made in that way. It is producing doers: Black-Swan-hunting, dream-chasing entrepreneurs, with a tolerance for a certain class of risk-taking and for making plenty of small errors on the road to success or knowledge. (Taleb 2007a & 2007b)

But there is also critique against laissez-fair liberalism and free pluralism. According to Krier pluralism is by no means the sign of cultural prosperity, happiness and democracy, but instead results from the confusion of artistic means and categories. It results from the destruction of cultural traditions and ethnic identities. Culture pluralism marks the moment where idiosyncratic private interests and obsessions replace common and public culture. (Krier 1985) According to Bourdieu the Postmodern discourse is just a laissez-fair attitude, an ideology about the end of ideologies and nihilist withdrawal from science (Bourdieu 1998).

According to Aura et al. architecture theory can be approached at east from three directions (Aura & al 2001: 15–34):

1. From the methods of the principles near by. These include philosophy, history, cultural studies, nature sciences, geography, psychology sociology, semiotics and art studies. Different methodological approaches can be combined.

2. From architecture’s own theory. Target is to develop further the work started by Vitruvius, Lynch, Alexander and others, and strengthen architectural theory from its own starting points.

3. From the practice of architecture. Based on theoretical work described above, this kind of approach includes also less academic reflections, and practical design.

The latter is regarded as non-scientific by many old-school researchers, but this kind of research is gaining more space. Practical working situations are described and analysed, and developed further with different approaches mentioned in Chapter 1.4.3. The fourth variation could be that an architect uses planning or design as the research tool, and consciensly develops working processes. Planning
in this case acts as the test field for different hypotheses in a continuous series of interactive feedbacks. The author has on his mind this kind of marriage of theory and practice, and predicts a nouveau vogue of academic dissertations.

In my earlier research reports I have come to the conclusion that climate-conscious construction can be grouped into two main lines (Kuismanen 1989: 15):

1. A model based on heavy technology, excessive use of energy and capital-intensive investments.

2. A model based on eco-technology, environmental research and a more traditional method of construction.

Examples of the first model are the North American winter cities and the steel-glass skyscrapers of the international style. The modern Mediterranean white towns, new Scandinavian wooden towns or eco-villages illustrate the latter approach. In practice new languages of architecture are added to the old ones. Often architects instrumentalise the tools of thinking: for instance structuralism, deconstruction, the matrices of game theory, new systems of musical notation, graphs of phonological structures etc. are translated into visible forms or architecture concepts.

Most of the world’s population lives in conditions and on an income level which do not allow construction of expensive technology in accordance with line 1. That is why climate-conscious planning has a challenge to develop methods which support a method of construction suitable for everyone in accordance with line 2, which also helps to achieve the climate targets which have been set. But in any case, the method is also suitable for planning in accordance with heavy technology and contributes to operations of technical systems.

The future operation field of architecture will be determined by technical, economic and social factors as well as a changing climate. On the basis of consideration of the paradigms above, the author has come to the conclusion that, contrary to a post-modern axiom, the present time of transition will be followed by a period of more explicit models, which does not mean a world with one culture, no alternatives, one clear paradigm or one prevailing way of making architecture. Planning will take place in a fast-changing operating environment, in which new people and conflicting interests will get continuously involved and whose physical boundary conditions will be changed with increasing speed by advancing climate change. But the climate-conscious way of thinking will be at its best in the future
an organic part of all the working methods and phases of urban and construction planning.

1.3 Research problem and the objectives of the research

Along with development of technology and economics, there has been a worldwide increase in building construction and new areas in unfavourable conditions are taken into the sphere of construction. Building materials industry, trade and manufacturers of engineering software produce standardized average solutions which designers apply to different conditions. These standardized solutions are not always suitable for local conditions, which results in an unnecessarily big need for heating and/or cooling, structural damages and inconvenience for users. In connection with design export, we can often talk about cultural imperialism. During the last few years, the extreme weather phenomena brought along by climate change have made the problem even worse.

As a starting point I found out that there is a need to create methods and guidelines that facilitate and improve daily planning practices, but which are not expected to be “laboratory exact”. The target could be an easy-to-use and economical method which improves the design tools available to planners and architects for increasing the quality of an urban environment, improving energy economy and reducing wind-induced failures.

In broad outline, the research problems are as follows:

- There is no simple analysis or design method covering all climate areas.
- There are no design guidelines concerning climate change.
- There is no practical, cost-effective wind-testing equipment for scale models.

Climate-related problem areas can be identified in the following four categories of critical issues (Mänty 1988: 22):

1. Physical issues.
2. Social issues.
3. Economic issues.
4. Policy issues.

The main objective of this study is to provide design and town planning tools for the first category, physical issues. As a policy, the author has followed the second,
sustainable construction model mentioned in the previous Chapter (Chapter 1.2.4). In practice this means the development of methods and tools with which architects and planners can improve the environment, micro-climate and energy economy of buildings and larger areas in different climate zones. The objectives of the study are to:

- create a state of art study into the existing know-how about climate and planning
- prepare a study into the effects of climate change on the built environment
- develop simple micro-climate and environment analysis methods
- define the criteria of an acceptable climatic environment
- develop the wind test blower and the method of analysing the results
- present the ways to interpret test results and draw conclusions
- develop planning and design guidelines for different climate zones.

Because the use of a full-size boundary layer wind tunnel is very expensive and slow, it was decided at the beginning that the equipment should be cheap and easy to use, so that mid-sized planning offices and schools of architecture would be able to purchase it. The results were expected to be exact enough for ordinary planning and building design tasks.

Most countries and cities do not have approved and standardised criteria for human comfort nor micro-climate design guidelines, and decisions regarding an acceptable wind environment are left to the designers and site owners. In practice, too little attention is paid to human discomfort or energy use caused by the climate. In this study, climate-conscious design criteria for different climate zones are also discussed.

Taking climate into consideration in planning and architectural design is a complex endeavour, in which many theoretical and practical disciplines are amalgamated. As we will see in the next Chapter (2.), quite an abundance of knowledge on the subject matter has been developed in different countries, but we will also notice that most of them deal with one aspect only. The writers have defined their approaches and methods with various notions. The following definitions are used in this research.

ENVIRONMENT consists of nature environment and manmade built environment. As a concept, environment-conscious planning is a large umbrella that covers planning and building ecology, life-circle design, the use of natural materials, energy saving and so forth. Even social, economic and political “environments” should be looked at to such an extent as they affect the content of
the plan and the process of realization. A part of environment-conscious planning is a holistic environment analysis that includes large nature, landscape and built environment analyses, charting of toxins and air pollutants, and prediction of future changes.

ECOLOGICAL DESIGN. Ecology as a discipline deals with the relationships between the air, land, water, animals, plants etc. Ecological planning takes the above mentioned nature elements as its starting point, and apply this to the planning of a particular area. Ecological architecture concentrates its efforts to energy saving, the use of natural materials, healthy construction and permaculture.

According to Halliday, urban ecology is an attempt to develop strategies for living that allows us to fulfil social and community needs and aspirations and to live within the carrying capacity of the earth (Gaia 2004). It is a response to the worldwide unsustainable patterns of growth which now are the norm.

Some writers say that ecology as a term belongs to the biological sciences, and its use should be avoided in building. The use of the terms sustainable construction, design or planning are recommended. (Hänninen 2008: 20)

CLIMATE-CONSCIOUS planning stresses the awareness of climatic factors and influences. Climate-conscious planning includes meteorological studies, aerodynamics, nature and urban ecology as far as they affect micro-climate, and wind-tunnel practices. All this is applied to daily planning and architectural design. Google showed 240.000 hits for climate-conscious. (Google 2008)

CLIMATE-WISE planning is quite near the definition of climate-conscious planning, but the word is more colloquial. Google showed 1.350 hits for climate-wise, the content of which was miscellaneous. (Google 2008)

BIOCLIMATIC PLANNING is a notion that has a different content in the works of different researchers. Børve, Sterten and Jones have made narrow definitions, which are quite near the content of this research. The definitions of Olgyay or Higuera are wider, half way to environment-conscious planning. In Germany and France the placement of health spas is carried out according to the bioclimatic zones (Bioklimazonen, see Chapter 3.1.7). Today some magazines use the word to define ecological grass root architecture. In this study the word bioclimatic is used in its limited sense, almost as a synonym for climate-conscious, but with a larger nature analysis content. (Olgyay 1963; Becker 1975; Børve & Sterten 1981; Sterten & Børve 1995; Jones 1998; Sterten 2001; Higuera 2001; Bioclimatisme 2008) Google showed 39.400 hits for bioclimatic (Google 2008).

BIOPHILIC DESIGN is an approach that emphasizes the use of nature elements in the built environment. The planning process combines diverse
disciplines, aiming at an interactive relation to nature and its forces. Experiences of sunlight, weather, water, habitats etc. form the contexts for sound human maturation as well. The use of organic forms, vernacular reminiscences and natural patterns also give it a symbolic dimension. (Kellert & al. 2008: vii–ix, 4–19; Wilson 2008) Google showed 10,700 hits for biophilic design (Google 2008). The notion biophilic is quite near some kind of fundamentalist ecological or organic design. The labelling of historic buildings, like the Alhambra, as biophilic, can be questioned.

CASE METHOD. The method developed has been named the CASE method, in which C stands for climate, A for architecture, S for science and E for environment.

The CASE method consists of:

– Techniques for making micro-climatic and environmental analysis.
– Interpreting the observations.
– Wind testing of scale models.
– Guidelines for making practical solutions in urban planning and building design.

There is no direct model for this study or the method developed (See also: Chapter 1.5). The method is intended to complement the conventional planning and architectural design approaches. Environment analyses and the creation of a positive micro-climate are brought to urban planning. For architectural design it gives new tools to create buildings that use natural forces and even react interactively with the conditions, thus offering an alternative to conventional architectural design and air-conditioning practices. This will lead to a holistic sketch design practice, with joint workshops, and integrated construction and HVAC solutions. In the sketch design stage, the principal designer cannot afford to delegate any of his problems to a specialist.

Instead of a set of rules the “method” tries to give an understanding of the nature forces and air-flows of a given area, which understanding enables the creative planning and building design. The normative guidelines at the end help to solve practical problems in different climate zones.
1.4 Research methods

1.4.1 Outlines of the research

The research object is part of developing a planning theory and practice in accordance with sustainable development. This kind of design is continuously taking place in different countries. The work was confined to concern the effect of climate and climate change on the planning of entire cities and metropolitan areas, as well as individual buildings and screen plantings related to them. The research deals with all climatic zones of the world, but the focus is on the cold and temperate climates, windiness and climate change, because there is a relatively small amount of material concerning them. In particular, the effect of climate change on planning and design practices is still an almost unwritten page.

Defining the research as climate-conscious would confine the research theme to the world of weather phenomena, if interpreted narrowly. However, analyses of urban and green environments as well as design instructions are included in the research as extensively as they are related to drafting of good design instructions. In this respect, the research includes features of environment-conscious design, which consists of a wide variety of issues related to ecological architecture. The word bioclimatic includes the interaction of climate, nature and man, and is also quite near the definition of this study (See also Chapter 1.3).

In the following Chapters both the words climate-conscious (in its broadest sense) and bioclimatic (in a narrower sense) are used to denote the content of the research.

The research excludes traditional wind-tunnel working and profound entering into computational fluid dynamics (CFD) techniques, because research into them would require a lot of financing and a large group of researchers, and because research institutes and universities already do this kind of work. This research does not deal with calculations of heat demand, solar radiation, cooling demand etc. done by HVAC engineers, either, because the basic theories and calculation programmes related to them are already far advanced. The indoor climate and ventilation are only dealt with to the extent which is related to natural wind- or solar-powered ventilation or the interaction of indoor and outdoor spaces.

The research view was not confined on the basis of any scientific field, because architectural research is a multi-discipline branch. The outer context of the work is discussion and research about climate change, sustainable development and the quality of a built environment. The inner context consists of
theories and practices of community and architectural design as well as the grounds for them. In practice, this kind of sphere of activities results in the need for applying different approaches and methods of research as well as the need for intimate knowledge on the research results of different fields like architecture, town planning, flow physics, meteorology, geography, biology, mechanical engineering and information technology.

1.4.2 The progress and structure of the research

The work was started with an introductory period, which consisted of a literature survey, participation in workshops and conferences for Nordic researchers as well as discussions with some selected experts in the field.

The research work proper consisted of a literature survey, terrain work in different countries and landscape types, visits to research institutes, acquisition of wind-measuring equipment, expert interviews and questionnaire studies.

The next steps were the systematic analysis of the facts and documents, drawing of conclusions and structuring the facts and practical knowledge comprehensively. Making a holistic view from the material gathered was the critical phase of the research, because totality does not mean the sum of all facts. Totality is the reality as a structured whole, within which selected facts can be rationally comprehended.

In broad outline; the stages and structure of this research work are as follows:

- object, methods and aims of the research; formulation of the research problem
- literature survey, state of art surveys: climate, climate change, planning methods related to these
- developing of the methods of an environmental analysis
- developing of a wind-test instrument (appendice 1.), testing practice and a method of interpretation
- proving the reliability and scope of application of the developed method
- drawing up climate-conscious design instructions
- definition of the objects of further research.

As the result, methods are introduced which supplement and facilitate everyday practices of architects and urban planners:

1. Development of analysis methods and climate-conscious design criteria.
2. Development of planning and architecture design guidelines.
3. Development of wind test equipment.

1.4.3 Nature and methods of the research

In the history of sciences since antiquity, there have been two hypothesis schools. Aristotele, Bacon, Mill, Simon, Hintikka and many others think that there are certain scientific methods and if they are followed, hypotheses can be developed and we can come to reliable final results. Methods like this are induction approach, rationalisation method, induction, deduction, abduction, limited rationalism, interrogation logics etc. Poincare, Einstein, von Liebieg, Popper and Taleb, among others, think that a hypothesis is not a logical invention step, but it is based on a guess, perception or incident. According to this, the explanation only comes after an inventing act. (Olkkonen 1993: 24–26; Heikkilä 2004: 12–25; Tuuttila 2005: 161–164; Tuomivaara 2007: 5–39)

The pattern of traditional scientific research is: perception hypothesis test. However, far-advanced fields follow the pattern: hypothesis test perception. Chapter 0.24 already dealt with the world getting more complex, and different dynamic systems have been developed for modelling it. People talk about playing fields and spaces, in which the systems move (as vectors). The methods of argumentation have multiplied, and the complexity level in the process of establishing proof has risen.

There are two types of research, i.e. empirical and theoretical research. Empirical research means an empirical approach to research based on sense perceptions. The typical methods of collecting perceptions are observation, testing, interviews and questionnaires. Material for research is acquired either in the field or a laboratory. Theoretical research is based on the use of a reasoning method, even if empirical material may be included in it. Empirical and theoretical research can be descriptive or normative.

Research can also be quantitative or qualitative. Quantitative research can also be called statistical research. It is used to define dependences and changes, it requires a wide, representative sample and the material is handled with the mathematical methods of statistics. In this way, the prevailing situation can be mapped, but the reasons for the phenomena often remain unclear. Qualitative research helps to understand the research object and explain the reasons for its behaviour. It is usual to confine the research to a small amount of discretionarily collected cases, which are analysed as precisely as possible. There is an aim to understand a phenomenon on the basis of so-called soft knowledge. However,
many researchers warn not to make too strict a separation between quantitative and qualitative research. (Olkkonen 1993: 24–26; Heikkilä 2004: 15; Tuuttila 2005: 165)

According to Arbnor & Bierke, research can be approached with three different methods: analytic approach, systems approach and actors’ approach. (Arbnor 1977)

In analytic approach, research can be done in different ways (Olkkonen 1993: 24–26; Heikkilä 2004; Tuuttila 2005: 165):

- **Explorative** studies are general studies of a new theme or problem field, during which the structure, concepts and research questions of the problem field are outlined. Existing data are collected and classified.

- **Descriptive** study aims at identifying an entity of phenomena on a general conceptual and qualitative level. It is usually a question of describing, classifying or other sort of outlining of the practical problems or solutions of a question or theme area as well as finding the reasons which have resulted in different problems or solutions. The aim is to increase understanding of the phenomenon in question and create a basis for a better command of it.

- **Explanatory** study aims at finding reason-result relations between phenomena and testing them.

- **Forecasting** study means defining supposed or derived results as variables in a variable model, in which these values represent the future.

- **Normative** study develops criteria, rules, numerical expressions and parameters of how things should be done.

The systems approach aims at reproducing an objective reality and its analysis is based on techniques to be mainly modified through trial and error. The objective is to define the type of a system, represent it, define the relations as well as forecast and direct its behaviour. Researchers are not as dependent on a theory as users of analytical research, but on the other hand problem formulation through the whole research process is more extensive.

In the actors’ approach, researchers take part in joint interactive development, in which those to be researched also take part. In the work dialogue and experimental activities are used in a varying way, aiming at understanding, and based on it a diagnostic process. The actors’ approach, contrary to the two previous ones, denies the objective reality as a starting point and supposes that it is
a social structure, in which people are in a dialectical relation with the structure of the reality.

Constructive research, which is somewhat contested in the scientific world, is a method producing new constructs – idea or operation structures, solutions, objects, language or plans – and it solves problems by means of practical and theoretical knowledge. The aim is a new condition, which corrects the problem by means of the solutions developed. The work concentrates on clearly defined problems and a new construct, which is tested in practice, is produced to solve them. During and after the process, the “findings” are included in a theme-related theoretical reference frame. The researcher’s interventions and influencing are part of a constructive method and the research work is experimental. The work aims at innovations with creative, partly intuitive methods and completing the work is in most cases the achievement of a cooperative network. In practical research work, either an analytical or actors’ approach can be applied. (Arbnor 1977; Lukka 2003)

Triangulation, i.e. a combination of several research methods, often aims at verifying research results. There are four kinds of triangulation (Heikkilä 2004: 56; Lukka 2008: 5–8)

1. Multi-method: several data acquisition methods are used.
2. Multi-investigator method: several observers or coders are used.
3. Multiple data sets methods: data are collected on several occasions and in many ways.
4. Multiple theory method: a researcher uses or creates new competing theories himself.

When working as a researcher, an architect often constructs a theory on the basis of experience. We can talk about practical theorisation, which aims at deepening the understanding of a theme area and resulting in a more and more functional command of design work and construction. Research like this produces knowledge meeting practice, promotes knowing, develops methods for defining the evaluation criteria, increases understanding, develops design objectives and critically analyses design and construction practices and their current trends. An architect’s research aiming at producing knowledge meeting practice can be classified as applied, planning or qualitative research. The last-mentioned one aims at understanding the research object, not so much at measuring it. The
applied constructive way of thinking is also suitable for approach to architectural research. (Tafuri 1980; Aura 2001: 21–25; Tuomivaara 2007: 25–30)

In the author’s estimate, most of the approaches, like the systems approach, actors’ approach or case study, may not be as such applicable to architectural research like the one at hand, even if some of them suit research related to the processes, organization and decision-making of urban planning.

In architecture literature one can find other kinds of emphasising, too: should research about architecture not be artistic? Every so-called scientific discovery is originally an invention, imagination, active ordering of the world aiming at the detection of its truth. After all, architecture is essentially an issue about human values which cannot be determined without emotional involvement. Therefore it seems that a dose of honest subjectivity should increase rather than decrease the credibility of any study. According to Nyman, for this reason, the discipline of architecture is destined to be a research activity close to poetry. (Nyman 1989: 379–391) The resemblance of architecture to poetry is expressed also by others, like Bachelard (Bachelard 1957).

This research belongs to the field of applied science, because it aims at developing know-how which can be used in designing a built environment. As to its objectives, the work is both basic and applied research.

The first part of the work is based on systematically collected and classified empirical knowledge and research results, the review research method, and so we can talk about empirical research. Also the observation of nature types and climate, testing of blower prototypes, interviews and questionnaires clearly belong to the empirical world. An analytical approach was used as an operative paradigm in this work, because it was the most suitable for the research theme. The nature of the first part is explorative and descriptive. A great part of the work was focused on the analysing, understanding and explaining the problematics of climate and the built environment, and this is qualitative research. Laboratory measurements and statistical methods were used when developing the wind test instrument, and belong to quantitative research. In a multidiciplinary research study both quantitative and qualitative methods can be used.

Philosophers distinguish between deductive and inductive arguments. By deduction is meant an argument that moves from the general – i.e. generalisable laws and principles – to the individual case. What happens in each case is explained by reference to generally applicable laws. Induction entails the opposite: trying to draw generally applicable conclusions from a number of individual cases. The problem with the inductive method of reasoning is that one does not know all
the relevant cases, nor whether those cases chosen for study are really relevant. (Nordin 1988)

When forming the general conclusions of this study, the method of induction was used. The planning and design guidelines are based on these generalized principles, the method of deduction.

Normative research was made when developing the criteria of climate environment and their numerical expressions, and the design rules. This part of the results can also be described as normative guidelines. Since analysing methods, a wind-test method and design guidelines are the main results of the work, it can be said to be mainly normative research. The author has been an active and influential person in a long interactive process, in which tens of people and organizations in different roles have participated; this refers to both a constructive and actors’ approach.

According to Dunin-Woyseth research and literature on climate/environment relationship can be grouped into four main categories (Dunin–Woyseth 1991: 342):

1. **Analytical/causal.** This deals with four subjects which are, (I) historical and vernacular references, (II) meteorology, (III) the physiological limits of the human body, (IV) the effects of meteorological elements on the performance of materials. In this category climate is viewed as the cause of particular cultural patterns, or the built environment is regarded as an adaptation to specific climatic conditions in order to facilitate a particular way of life generated by the total socio-cultural situation.

2. **Prescriptive.** This covers building codes and by-laws related to the physiological limits of the human body and the effects of the meteorological elements on the performance of materials.

3. **“Remedial”**. These items deal with architectural and planning solutions concerned with different mechanical systems for achieving “normal physiological conditions”, and with the reduction of climatic stress through the proper use of architectural elements. These studies adopt a normative approach, make proposals as to how the built environment should be adapted to particular climatic conditions based on defined criteria through a process of describing the parameters, defining the criteria, and proposing methods for adaptation.
4. **Construction methods.** This work focuses on methods of construction-related to climate-conscious building.

Features of all the above-mentioned categories are included in this work. The basic studies have their focuses on categories 1 and 2. The main focus of the research results – analysis, method, design instructions – is on the last two. However, the author neither wants to strictly mark a route or final result nor to suggest any mechanical rules, but complementary viewpoints and practices introduced to a normal planning process as well as improvement of consultative knowledge in this respect are concerned. The “method” is that there is no strict mechanical method, but a deeper understanding of bioclimatic matters.

The classical dividing lines between the various fields of science are called into question: disciplines disappear and overlapping occurs. This research combines different approaches as well as collecting and analysing methods of material in order to get a comprehensive picture. In developing the method, working based on literary research sources was combined with terrain and wind laboratory working. Similarly, different ways of justifying the results achieved were combined; verification is in most cases based on both literary sources and testing in practice. Even if statistical material was utilized in the work, statistical research methods were not usually used, and in this respect we can talk about qualitative research. Triangulation was used to confirm the validity of the results; when possible, the facts have been checked from two or more sources.

Two methods were used in forecasting climate change and its effects. The future direction of climate change itself and extreme climatic phenomena is based on modelling and computer calculations done by international expert groups and large research institutions. Instead of averages, the concrete nature of extreme weather phenomena and the probability of their appearance were the objects of interest. This was continued by an expert analysis: design instructions for the different climatic zones were drawn up on the basis of literary sources and the author’s own knowledge and practice. The instructions take climate change into account by using the year 2100 as a criterion. The author chose the presented extreme values as the starting point of the design instructions, because no present research report refers to climate change coming to its end during this century. In this part, one has to bear in mind that knowledge on the future is not ”the truth”, but estimation about the future. A ”black swan” may already be waiting at the bottom of the following bay.
1.4.4 Case studies

The practical application of the method developed has been tested at various pilot projects:

– Urban renewal project at Store Lungegårdsvann, Bergen, Norway; figures 51, 52, 53 and 112.
– Analyses and planning of Raviradan alue (former trotting-track), Sodankylä, Finland; Appendice 2 and figure 88.
– Urban renewal project in Rajakylä, Oulu, Finland; figures 46, 47 and 54.
– Pilot building, Tervola, Finland; figures 89–96.
– Pilot building, Linnanmaa, Oulu, Finland; figure 87.
– Nature Analysis, Onnela, a Housing Fair area in Kajaani, Finland.
– Tourist resort planning, Rokua, Finland; appendice 3.

In the Store Lungegårdsvann region in Bergen, the operations of the parts of the CASE method were tested and its working in practice was trimmed in a real varied environment.

The monitoring made by Harmaajärvi at VTT Research Institute confirms that ecologically better planning results can be achieved with this CASE method. The Sodankylä plan was made with this method, and the area requires less energy and raw materials and causes lower emissions and wastes than an average Finnish area of small-scale housing. The study area also requires lower costs. The impacts of the area are approximately 20% less than impacts of an average area. (Harmaajärvi 1998)

In Sodankylä, Kajaani and Rajakylä, Oulu, nature analyses were made with the analysis method developed in this research. To test the reliability of the method, the same areas were also analysed by biologists. Both reports were made independently. When the results were compared, it was seen that both methods had given relatively similar final results, which speaks in favour of the use of the quick and cheap CASE method in ordinary planning. (Anttila 1996; Eskelinen 1998)

In the pilot building in Tervola and the city block of apartment buildings in Linnanmaa, Oulu, the results achieved were compared with the measuring results from real buildings by using the developed wind-test apparatus for scale models and a method of interpretation. The author and Marita Kuismanen made the measurements using portable equipment with a calculation unit. On the basis of
the comparison it was found that the method developed gave correct results.
(Kuismanen 1993; Vakkuri 1993)

The development of an ecological tourist resort in Rokua was an EU-financed
LIFE-environment project. One part was the replanning of the landuse plans using
the CASE analyses and guidelines, and the result was monitored with the
EcoBalance calculations made by VTT. According to Harmaajärvi the ecological
balance of the new land use plan is better than the ecological balance of the present
plan. Relative energy and raw material consumption, greenhouse gas emissions,
other emissions and wastes, as well as costs of the new plan are less. (Harmaajärvi
2005a)

1.5 Use of the results

1.5.1 Range of use

The main purpose of this study is to create a practical toolkit for climate-conscious
planning and architectural design. To write the guidelines and to take climate
change into consideration has been a challenge.

From an environmental point of view, it is not enough for any architect or
engineer to direct their attention to the job in hand. All professions involved in a
project need to be prepared to share knowledge and responsibility, particularly
during the important early stages of design. Everybody needs to think more
globally and consider whether more environmentally friendly alternatives could be
offered. There is a need to integrate urban planning, architecture, structure and
services strategies, and to take account of life cycle costs and environmental
impact in system selection. In many ways, an environmental approach is more a
method of solving problems and philosophy than a set of rules and hurdles.

In the past, buildings often made good use of sunshine, natural light and air.
There has been an increasing tendency to replace these natural systems with
energy-consuming services. Part of this study gives practical guidance on how to
design a building that uses natural forces for ventilation and energy-saving, and
which reacts to the climatic circumstances.

In many countries, large new towns and housing areas are continuously
constructed and in such cases it is relatively easy to use the climate-conscious
planning guidelines, and to consider the effects of climate change. But in other
countries, the major task will be to renew, replenish and develop already existing
areas. This work must be based on the totality, on detailed studies of problems and
possibilities in a broad historical, cultural, social and environmental context. Unless we are successful in doing this, a frightening future is looming with segregation, decay and social maladjustment of people. The bioclimatic planning tools developed enhance the possibilities for healthy and environmentally sound urbanism and urban renewal. The method can be used from large metropolitan developments to façade detail design.

The method developed and wind testing give us knowledge about the characteristics of the flow in the Canopy Layer, which is relevant for the following reasons:

- Evaluation of the cooling effect of wind. Areas and facades exposed to wind.
- Evaluation of the wind comfort at the pedestrian level. Windy areas, relative wind speeds.
- Enhancing wind-forced ventilation. Positive and negative pressures at the inlets and outlets.
- Analysis of the diffusion of pollutants. Ventilation of streets and areas.
- Avoiding the damage caused by wind. Planning and designing wind protective solutions.
- Characterisation of the wind loading of small and medium-size street architecture items. Designing wind resistant and protective items and plantings.
- Analysing the drifting of snow. Placing of snow fences.

Although the measurement of air-speeds around the buildings of a scale model give quantitative information, it may be correct to say that the testing mostly give qualitative information about the wind climate around the buildings. The method is not suitable for sky-scraper or bridge design, nor for the measurements of dynamic loads on structures.

The method developed is very illustrative and is therefore suitable for basic education in universities and further training of specialists in the field. Analysing of basic things in an environment gives a student a better understanding of the starting points and boundary conditions of urban and architectural planning.

1.5.2 Significance

Because there is no comprehensive scientific book regarding climate change or climate-conscious design, this research has the aim of presenting knowledge related to the field and the method developed widely enough and accompanied
with practical guidelines. The purpose is to give a compact introduction about the necessary basic knowledge needed for taking the climate into account in planning and to find a method which is simple enough to be suitable for a daily tool for practicing urban planners and architects.

It is sure some scientists will rightly find their fields of research inadequately represented. On the other hand, many architects may find this text too detailed for their daily use in design. My aim is to bridge the different disciplines involved to a creative concept of architectural design practice.

Planning ready for future changes in accordance with the climate is a demanding task, in which both specialists and students of the field have a lot to learn. The material prepared can be used as study material and a manual both in consulting firms and universities.

The research also offers material and questions for further research. (See Chapter 7)

This research does not represent a "grand narrative" or final paradigm, which would solve the problems of urban planning or architecture. However, the method developed introduces new material for design work, at its best a new inspiration, which can in future be seen as pleasant environments and new architecture. With time, environment-conscious architecture may become a new mainstream as an attitude, but not as a style.
2 Climatic challenges

"The weather is probably the most popular topic of conversation. It is non-committal because nobody can be reproached for it: The elements cannot be changed by man. Or can they…”? (Willemiene Alberts)

2.1 Climate

This chapter presents the basic facts about the climate, climate change, and the existing research into wind testing. The need to develop practical climate analysis and wind test methods is discussed.

2.1.1 Macro- and micro-climate

Climate is the general weather conditions usually found in a particular area. Climate conditions vary in different places according to the latitude, winds and the nearness of the oceans, as can be seen in Figs 3, 4, 5, 6 and 7.

Wind systems are caused by the tendency of air to seek equilibration from a higher pressure area to a lower one. In the macroclimate of the earth, air flows from warm belts to cold belts and vice versa, which brings conditions into equilibration, as in Fig. 2. Some oceanic currents, such as the Gulf Stream, work in the same way. Global winds are generated by differences in atmospheric pressure caused by uneven distribution of solar radiation and the resulting variation in temperature and air density. The flow from higher to lower pressure regions is modified by the Coriolis effect, which results from the rotation of the earth, topography and the distribution of seas and land. (Hagget 1983: 79–84)

There are four types of air masses (Pagen 1992: 15–21):

1. Continental Polar, cold and dry, originating over land.
2. Maritime Polar, cold and humid, coming from the sea.
3. Continental Tropical, warm and dry, originating over land.
4. Maritime Tropical, warm and humid, coming from the sea.
Fig. 2. Prevailing winds of the earth’s pressure zones and atmosphere. (Haggett 1983: 80)

Fig. 3. Example of an analysis of a macroclimate, the climate of Scandinavia. (drawing Kuismanen 2000)
Fig. 4. Temperature difference between winters and summers are great in Scandinavia, while in West Europe the sea evens the differences; tammikuun isotermit = January isotherms, heinäkuun isotermit = July isotherms. (Seddon 1987: 34)

Fig. 5. World climatic regions according to the Köppen classification. (FAO 1997)
Fig. 6. Examples of warm humid, warm dry and cold climates. Humidité relative = relative humidity, précipitations = precipitation. (Liebard 1996: 10)

Fig. 7. Examples of temperate, continental and Mediterranean climates in Europe. (Liebard 1996: 11)
The lowest portion of the atmosphere, which is where weather phenomena occur, is called the *troposphere*. The troposphere can be divided into two parts, the *boundary layer* and *free atmosphere*. In the boundary layer the atmosphere and the earth’s surface as the base interact with each other. Above the boundary layer the features of the earth’s surface no longer affect the behaviour of the atmosphere. The thickness of the boundary layer varies depending on the time of day and year. At its lowest, the boundary layer is about 200 m at night and in the winter. The thickness of the boundary layer can increase to 2 km in convective conditions, when the heating effect of the sun results in thermal rise and the formation of cumulus clouds. Because the properties of free atmosphere remain stable above an area that is being planned, the micro-,clime is formed on the basis of the features of the earth’s surface.

A wind field is characterized by two parameters, which are the vertical profile of the mean wind speed and turbulences. Both are modified by the roughness and profile of the terrain and urban structures. The increased resistance resulting from greater roughness reduces wind flow at the street level, and there is a sharp increase in the wind speed above the roofs. A transitional zone, the so-called *urban boundary layer*, is created between the ground and the undisturbed wind above the urban air dome. Wind speed models are presented in Fig. 8. (Pienilmaston 1997: 3–6)

The altitude affects the temperature of air. When a body of air ascends, its temperature falls 1 ° C for every 100 m of height, and when it descends visa versa (adiabatic lapse rates for heating and cooling. In practice the adiabatic cooling is partly compensated by heat absorption. In consequence, the actual cooling rate near the ground is about 0.5–0.8 ° C for each 100 m. (Izard 1993: 12; Givoni 1998: 276)

*Micro-climate, crypto-climate*

Micro-climate is the essentially uniform local climate of a small site or habitat, and is formed on the basis of the features of the earth’s surface. Thus, the factors contributing to the formation of the micro-climate are:

- distribution of land and water
- radiating properties of the earth’s surface, such as albedo, the absorption of radiation, and emission
- specific heat and moisture conditions of the earth’s surface
– profile and frictional properties of the terrain.

The components of a micro-climate are (Kossak 1994: 46; Merriam-Webster’s 2002: 733):

1. Elevation above sea level.
2. Openness to wind.
4. Topography.

For planning purposes micro-climate can be defined as the nearest area of a building or building group, about a 10–100 m circle. Crypto-climate is the smallest scale of climate, covering an area which is less than 1 m. For instance it can be a matter of temperature variations of a wall. (Børve 1987: 17)

Cities alter micro-climates in three ways (Haggett 1983: 184):

1. Production of heat, which results in the heat island effect (in calm weather).
2. Changes in the shapes of surfaces and buildings which channel air currents and change wind speeds.
3. Changes in the atmosphere resulting from air pollutants, which reduce the supply of solar radiation, increase smog effects and have a negative effect on health.

These differences are at a maximum with calm conditions. The terrain of a city lowers average wind speeds, though gusting winds in the street canyons can have high speeds. There are strong indications that cities in middle latitudes can cause sufficient local turbulence to trigger rainstorms, but there are significant variations among cities in different climatic zones. City atmospheres are polluted mainly by the emission of smoke, dust and gases, and this has three primary effects. Pollution reduces the amount of sunlight, it adds small particles to the air that serve as nuclei for condensation and hence promote fogs, and it alters the thermal properties of the atmosphere. For instance British cities are estimated to lose 25–55% of the incoming solar radiation from November to March. (Haggett 1983: 184–187)

A distinction can be made between the urban air “canopy”, the volume of air affected by the structures, and the boundary layer over the city space. The materials, geometry and surface properties of the structures modify the local ambient climate. (Givoni 1998: 241–242)
2.1.2 Meteorological phenomenon

Wind

Wind is created by pressure differences, as air tends to flow from an area of higher pressure to one of lower pressure. Wind in the free atmosphere is in the direction of the isobars (constant-pressure lines). As air flows over the base, the friction of the base retards wind speeds and turns surface wind about 30° to the left toward a lower pressure area.

From the standpoint of wind behaviour, the lower part of the atmosphere can be divided into three layers; the surface layer, the friction layer, and the free atmosphere. The surface layer extends from the earth’s surface to an altitude of a few tens of metres. The height of the friction layer is hundreds of metres. The free atmosphere begins at the upper boundary of the friction layer.

The characteristics of the air-flow at low levels in the urban environment (Canopy Layer) are quite different from, and to some extent independent of, the characteristics of the flow in the upper part of the Urban Boundary Layer. In the Canopy Layer, in fact, the flow is influenced more by the local street geometry and building height distribution, than by a homogenous energy transfer between horizontal layers. (Haggett 2001: 55; Ricciardelli 2004: D.5.1–3)

The parameters characterising the wind field are the vertical profile of the mean wind speed and the turbulence spectrum. Both are modified by the aerodynamic roughness of the terrain and the urban structure, and the increased resistance resulting from the higher roughness reduces the wind-flow (Fig. 8; urban roughness classification at 4.7; relative wind-speeds over terrain in Appendix 4). The urban wind-field is characterized by a lower average speed, but higher speed variations and turbulence. Above the roof level there is a sharp increase in the wind-speed. (Givoni 1998: 259–264)
Rain, snow, hail, fog

Rain is precipitation of water droplets which have a diameter greater than 0.1 mm, and the diameter can be as great as 4 mm. Rain and snow amounts vary greatly in different climate zones, and they are measured in millimetres per year. There are five classes of rain, which are measured in mm/h:

1. Drizzle, \( \leq 1 \).
4. Strong downpour, 80–120.
5. Tropical rain, 150–250.

With the exception of monsoon rain, the heavier the rainfall rate, the shorter is its duration. Below 0 °C, in the presence of super-cooled water droplets in clouds or rain, we obtain icing rain (droplet diameter 100 µm) or icing fog (droplet diameter 100 µm).

Snow is a precipitation of ice crystals, and it is a mixture of two or three phases, which are solid (ice), gas (water vapour saturated water) and sometimes liquid (water). There is a permanent metamorphosis, exchange between these phases. The characteristics of snow vary significantly with its temperature, humidity and density. The density of fresh snow is between 20–200 kg/m, packed
snow in snow constructions 300–600 kg/m and snow compacted with water 600–800 kg/m. (Palier 2002: 131–133; RIL 2001)

There are different kinds of snow, and in the following list are mentioned snow types, their symbols, characteristic size and forms (Palier 2002: 133–136):

1. Fresh snow + 0.1 to a few mm, forms include stars, platelets, needles and columns.
2. Recognisable particles λ 0.1–1 mm, variable forms.
3. Fine grains ● 0.1–1 mm, convex grains.
4. Deep frost ▲ 0.3 to a few mm, variable forms, hollow pyramids, columns, needles.
5. Round grains ○ 0.5 to a few mm, spheres and drift.

Hail is a precipitation in the form of balls or irregular lamps of ice, and has a diameter of 5 mm or more. Hailstones have a velocity between 10 m/s (36 km/h) to 43 m/s (150 km/h).

Fog is the result of an atmosphere over-saturated with water vapour, which condenses. With temperatures below 0°C fog becomes icing fog. The formation of fog usually is due to the presence of water or humid soil.

There are three main types of fog, classed according to their process of formation:

1. Fog of radiance is the consequence of radiated cooling of the ground which transmits itself to humid air of low layers by conduction and turbulence.
2. Fog of advection is due to the cooling of air, which moves on the ground, which is colder and colder.
3. Fog of evaporation is caused by the evaporation of a sheet of water whose temperature is higher than that of the air at the layers, the air having to be sufficiently humid.

Internationally fog is classified in five categories according to the visibility (Palier 2002: 131–133):

1. Light mist, 2–10 km.
2. Moderate mist, 1–2 km.
3. Light fog, 500–1000 m.
4. Moderate fog, 50–500 m.
5. Dense fog, 50 m.
Radiation

Solar radiation that reaches the earth is mostly short wave, visible light, while the radiation emitted by the earth’s surface is infrared or thermal radiation.

When solar radiation hits the atmosphere, part of it is reflected back into space, some of it is absorbed by gases in the atmosphere, and some is scattered by molecules in the atmosphere. Thus, solar radiation is divided into direct radiation and diffused radiation.

The amount of direct radiation depends on the angle of inclination of the surface. In other words, a surface perpendicular to the incoming radiation receives the most solar radiation. The sun’s angle of altitude varies with the time of day and the season. In addition, the amount of direct solar radiation depends on the degree of cloudiness. In practice, the amount of radiation received by different surfaces can be assessed with the help of calculated solar path diagrams.

Solar radiation is absorbed by the ground, plants, buildings, and structures. The amount of heating of the ground and building materials depends on their absorption capacity, specific heat capacity, thermal conductivity and moisture. Dark, lightweight structures warm up quickly and emit long wave thermal radiation that heats the surrounding air. Air is not warmed much by direct solar radiation; it is warmed by thermal radiation emitted by the ground and structures. Structures and materials with a large specific heat capacity are able to store a considerable amount of heat and they warm up slowly in sunlight, but they correspondingly release heat into their surroundings for a long time. Evaporation binds large amounts of heat, for which reason the evaporative effect of plants and trees, for example, retards a rise in the temperature. Correspondingly, condensation of moisture into fog, dew, or frost slows the drop in the temperature.

As solar radiation decreases with the setting of the sun, the radiation equilibrium becomes negative, because the long wave thermal radiation of the earth’s surface remains. In cloudy weather the clouds reflect nearly all the thermal radiation back to the earth’s surface, but in clear weather the long wave thermal radiation of the earth’s surface disappears into space.

Formation of temperature differences

As the thermal energy of a reflecting surface disappears into space, the temperature of the surface begins to decrease. The drop in the temperature is compensated for by heat flow from the earth, and therefore the rate of the
temperature drop depends on the thermal properties of the earth or the structures. In clear weather, the temperature of the air in the layer close to the ground drops quickly, causing a surface inversion layer, where the temperature near the surface is lower than it is in the higher layers of air. A cold layer of air is formed near the earth’s surface, where the air is denser and heavier than in the surroundings. Due to gravity, this heavy air begins to flow toward lower places in the terrain and accumulate into lakes of cold air in valleys and depressions, increasing the depth of the inversion. Thus, the difference between temperatures in valleys and on hilltops may become as great as 20 degrees. Some degree of surface inversion is formed during most nights, but in winter, especially in a high pressure situation, a surface inversion may last several weeks. The temperature differences in an inversion situation may be 0.1–0.3 degrees per metre of altitude. Thus, the temperature difference between the base and the roof of a 30-meter-high building may be 9 degrees. This fact is also significant from the standpoint of the annual mean temperature, as the annual mean temperature in a low-lying area is lower than it is higher up on a slope. (Mattson 1979: 121–129)

**Thermal island phenomenon, heat radiation, and inversion**

Measurements have indicated that the temperature in the city centre is usually higher than it is in the surrounding countryside. This temperature difference may even be over 10 degrees. This *thermal island phenomenon* is most intense in still-air nights. It generates its own airflow patterns: Warm air is rising and flows outwards, and cooler air flows toward the centre. The thermal island phenomenon already exists in small population centres, and its intensity increases with the size of the city. Changes in land use can be important for the more widely spread appearance of the thermal island phenomenon on the local-to-regional scale.

There are several reasons for the formation of the thermal island phenomenon. One mechanism that creates the phenomenon is building heating and the city’s energy consumption, which both produce heat. The city also forms a labyrinth that absorbs short wave solar radiation. This heat is released at night and raises the city’s temperature. Buildings emit long wave thermal radiation. Thermal radiation from adjacent buildings is absorbed by each other, and since the heat does not escape, it warms the city air. On clear nights, the long wave radiation of the earth’s surface disappears into space and the layer of air close to the earth’s surface cools. At night the temperature near the earth’s surface may be over ten degrees lower than the temperature at an altitude of a few tens of metres. In the city the surface
that emits heat shifts partially to the roof level of the buildings. Consequently, the temperature does not drop at ground level only, but more evenly in a thicker layer of air. This explains why the thermal island phenomenon is more intense at night. A bubble of warm air that gathers aerosols forms above the city. Long wave radiation is emitted into space from the surface of this warm air bubble. As a result, several small inversion layers are formed a few hundred metres above the city. These inversion layers also radiate long wave radiation back toward the earth’s surface, preventing the temperature from decreasing. (Givoni 1998: 243–244; Therbert 2007)

The dominant causes for urban heat islands identified include, heat trapping by urban geometry, alterations to urban thermal properties, changes in vegetation cover and man-made heat input. The presence of water and greenspace structures diminishes temperatures during warm nights and raises them during cold nights. (Emmanuel 2008)

In different climates the urban heat island has a different impact on health and comfort of the inhabitants. In warm regions it is regarded as negative, because it can disturb sleeping and cause non-sleeping and unhealthy body stress. For the higher temperatures there is a need for more air conditioning, which increases energy consumption. In cold areas in winter it is considered as positive, because it helps in energy saving. Globally the consequences for energy consumption and the environment are negative.

2.2 Problems caused by the climate

2.2.1 Climate and the built environment

Basically the reason to erect buildings is to escape the elements i.e. wind, extreme temperatures, precipitation, humidity, or get shelter against other dangers. The challenges caused by climate include storms, heavy rain, floods, coldness, overheating, forest fires, droughts, landslides and snow avalanches.

Windiness causes many problems for houses. Buildings are cooled by the wind, because heat loss increases with convection and uncontrolled ventilation increases when the air pressure changes in different parts of the building. Moisture damage will occur because wind and heavy rain force their way through the building structure. Pollution from parking areas and traffic lines pass into buildings along with air flow. Wind in sandy areas can cause sand or dust storms, where great amounts of particles are transported more than a few kilometres. The
effects of sand and dust winds are loss of fertile soil, damage to surfaces hit by sand particles, clogging of filters or ventilation ducts, appearance of dirty marks and formation of dunes. The effects of thunderstorms and lightning are electromagnetic interference and destruction by fire or collapse. Sea winds can bring air that contains sodium chloride as solid particles or minute drops of saline solutions, and these can cause corrosion in coastal areas. (Kivistö 1982: 122–131; Serra 1999: 45)

Uncontrolled air movements in the built environment are mostly experienced as negative. But the psychological effects of wind on pedestrians are difficult to assess. A combination of wind speed and temperature that might be acceptable to one person could be tolerable or unacceptable to another. The wind comfort criteria in 6.11 is based on many research reports where physiological and psychological aspects are combined.

In the history of construction we know of great collapses and crises caused by wind, like the Tacoma Narrows Bridge, the Ferrybridge cooling towers and many masts, roofs, chimneys, cranes and other structures. Several collapses of footbridges, chimneys, tubular towers, etc. due to damage accumulation have also recently pointed out the importance of wind-induced fatigue. Therefore, reliability analyses for wind loads are needed. The main effects of rain for buildings and equipment are corrosion, erosion and losses of tightness. Other impacts include decolouring, malfunction of electrical equipment and, for traffic, dangerous situations or stopping. Fog causes loss of visibility. (Palier 2002: 131–133; Solari 2002: 20) The VTT research centre in Finland predicts that breaks in the electricity distribution due to storms will be doubled till the year 2045 (Ilmastonmuutos 2008).

Air pollution in urban areas and traffic routes has serious effects on human health, mostly cardiac and bronchial ailments. Ozone depletion increases the exposure to UV-radiation, which is known to increase the incidence of certain types of skin cancer, cause cataracts and suppress the immune system. (Pressman 1995) Wind-borne sand in the streets irritates respiratory organs, and according to the Ministry of the Environment of Senegal causes ophthalmopathy and blindness (Seydon 1997: 3).

The growing cities demand more water for the inhabitants and industry, and because of the lack of rain large areas face severe water supply problems. As cities grow, water tables are being lowered, sometimes by more than a metre per year. To secure the water supply artificial bodies of water are created, which affects the nature and climate of the valleys flooded. Another related problem is the disposal
of polluted water. In many areas both low quality water for household use and polluted bodies of water result in a growing amount of diseases and impair the quality of the micro-climate nearby. (Haggett 1983: 187)

As an example, the Master Plan of Marquette, a town on the Lake Superior shore in Michigan USA, summarises the challenges of winter in the north (Marquette 2003):

- increased cost for snow management for both public and private sectors
- health costs associated with accidents
- Seasonal Affective Disorder (SAD) and psychological depression
- difficult mobility, particularly for seniors and the disabled, either as pedestrians or in automobiles
- prolonged cold, snow and icy conditions
- limited outdoor activity for many persons
- increased heating costs and energy consumption
- a visually monotonous environment dominated by grey and white.

### 2.2.2 Examples of damage

The lion’s share of all damages caused by the nature forces are induced by storms, floods, forest fires, drought, avalanches and landslides.

Windstorms are the greatest natural disaster facing mankind, in terms of economic losses see Table 1. München Re has estimated that 28% of the total economic losses due to natural hazards and 70% of the insurer’s total claim burden are traced to windstorms; the main causes in terms of fatalities are earthquakes 47%, windstorms 45% and floods 7%. For instance, a series of three windstorms in Europe during 1999 caused more than 150 casualties, 17.5 billion Euros in socio-economic losses, of which only less than 11 billion were insured, 4 million families without power supply for several weeks, public transport interrupted for several days, closed airports, and telecommunication networks badly disrupted for many days. The three biggest storms killed around 220 people in total. Comparative studies show that damage caused by windstorms has increased by a factor 1.8 to 2.0, on average, between 1990 and 1999. In Central European countries most of the damage due to wind is to tiled roofs of different sorts. (Hausmann 2002; European 2003: 3–7; Baker 2004: A.1.1, 2)
Table 1. Examples of wind induced damage to buildings in Mio€. Above are mentioned the most important storms and on the left the countries affected. (Baker 2004)

There are many storms in Japan every year. There were 23 typhoons in 2005 and 3 of them made landfall in Japan. One of them, Typhoon 0514 (NABI), according to the General Insurance Association of Japan caused damage, which amounted to at least 65.8 billion yen. Typhoon Shanshan, which formed in the east Philippine Sea and landed on Kyoshu causing damage in Nobeoka City was typical. The average wind speed before the tornado struck was 15 m/s and the gust speed 25 m/s. Suddenly, a damaging gust occurred. At that time the cumulonimbus that formed a part of the rain-band of Typhoon Shanhan arrived at the city and the tornado seemed to be caused by the typhoon. Three people died, ninety-four buildings were totally destroyed, roofs were blown off, and a train was derailed and overturned. Much damage was caused by flying objects. The damaged area was 7.5 km long and 100–150 m wide. Another example is the F3-level tornado, which struck Saroma town in Hokkaido. Nine people died and 26 were injured. Over 30 buildings were destroyed, e.g. a two storey building was blown 60–90 m. Windborne flying debris caused damage to other buildings and cars. Roof materials were found even on the sea 20 km to the north. In 2006 there were also 23 typhoons and 2 of them made landfall. (Annual 2007: 2; Matsui 2007: 4–5; Cao 2007: 5)

In USA hurricane Katrina developed into a Category 5 hurricane in the Gulf of Mexico and made landfall around the mouth of the Mississippi river as a Category 4 hurricane on 29. August 2005. Following Katrina, 36 tornadoes have occurred. It
has been estimated that the maximum 3-second wind speed in the centre of New Orleans was between 36–46 m/s. Reported damage includes 1.313 deaths, 2.5 million affected families, 527 thousand people made homeless, 71 thousand affected stores, more than 400 thousand unemployed persons, 6,644 missing people and 5 million people affected by power outage. In addition, the hurricane caused extensive damage to forests, agricultural products, stock farm products and facilities related to industry. Many houses were damaged by falling trees. On the coastal line damage was caused by flooding and storm surges combined with sea level rises due to the hurricane low pressure. Many houses disappeared without leaving any trace other than their concrete bases. The physical damage is estimated at about 200 billion USD. (Kareem 2006: 8–10; Nagao 2006: 10–14)

According to EM-DAT, floods comprised 43% of all disaster events for the period 1998–2002. During this period, Europe suffered about 100 major damaging floods, causing some 700 fatalities, the displacement of about half a million people and at least 25 billion Euros in insured economic losses. Land use changes and specifically urbanisation and infrastructure development are probably the main reason that flood damage is increasing. Urban land expanded by 20% in Europe during the period 1980 – 2000 while population increased by 6%. In part, this is because the demand for housing tends to be located away from compact urban centres and takes the form of single or semi-detached homes, requiring more land development. The altering of the natural patterns of drainage and deforestation increase the amount of flows, too. (European 2003: 2, 9)

In Europe forest fires – like drought, which can be a contributing factor – mostly affect Mediterranean and Black Sea countries but occur throughout Europe. In France, Greece, Italy, Portugal and Spain the area burnt in forest fires has varied between 200,000 and 600,000 hectares. The total number of fires reported has risen sharply from around 20,000/year to 60,000/year. (European 2003: 5–8)

In Europe, drought mostly affects the Mediterranean region but it occurs throughout most of the continent and is fairly common. Droughts can have very severe economic impacts, especially when they last a long time. They can cause a shortage of fresh water and the deterioration of water quality in rivers, lakes and reservoirs by exacerbating algal blooms that reduce the oxygen available for aquatic species. Droughts may also trigger soil erosion.

Most catastrophic landslides are associated with heavy storms and flooding, coupled with soil erosion on mountain slopes.

Alpine avalanches kill around 100 people a year. In recent history the winter of 1998/99 was especially deadly, with the heaviest snowfall in the Alpine region
for 50 years triggering numerous fatal avalanches in particular in Austria, France, Switzerland, Italy and Germany. Harsh snow storms have caused damage, accused traffic accidents and left thousands of households without electricity in the whole northern hemisphere. (European 2003: 11)

In dry regions sandstorms and dust storms are serious environmental problems because they remove valuable top soil, thus reducing the agricultural value of land, and causing other damage and loss of human lives. There are natural reasons for sandstorms, but an increasingly important factor is human activity, like overgrazing, deforestation, urban development, and improper use of agricultural and water resources. The severity of sandstorms has increased during the last half of the 20th century, and climate change will speed up this process. In some countries, like China, storms are prevented by planting large shelterbelts of trees and grass. (Newton 2003: 193–194)

2.3 Climate change

2.3.1 Abrupt climatic changes in history

In the past there have been many natural catastrophes and climate changes, which have exterminated whole animal and plant species. Also the history of mankind knows cases when flips in climatic conditions have destroyed settlements and cultures. If climates change slowly and progressively, cultures may be able to adjust, but sudden change may be too sharp for the ecological or social system to cope with.

Climate change can be difficult – you could ask the dinosaurs, if they weren't extinct. The prevailing theory is that they didn't survive when a giant asteroid struck the earth 65 million years ago, spewing so much dust into the air that sunlight was greatly reduced, temperatures plummeted, many plants didn't grow, and the food chain collapsed. What happened to the dinosaurs is a rare example of climate change more rapid than humans are now inflicting on themselves.

Three thousand years ago a great civilization, the Myceneans, was thriving on a sunny plain in southern Greece. The sudden decline of Mycenae has been conventionally ascribed to invasion from outside, but recent research suggests that environmental change may have been a critical factor, with food shortages leading to internal overthow. Bryson and Carpenter link the decline to changes in the westerlies (prevailing winds), which changed the winter storm tracks over the eastern Mediterranean, and caused a lack of rain.
About A.D. 1200 North-western Iowa was the centre of a thriving Indian culture, the Mill Creek people, who grew corn and hunted woodland species of animals. Excavations have shown that the people abandoned their villages in a short period of time and moved on. By the time Columbus was crossing the Atlantic there was nobody left. During a relatively short period of time the woodland species of animals decreased and grassland species, like bison, increased. According to Bryson, the climate, i.e. the track of the westerlies, changed so quickly that it was no longer able to support the plants and animals (wild and domestic) with which the culture was built up [9]. Today Iowa again has a precipitation of 630 mm and is a rich producing area for corn and soya beans. (Haggett 1983: 123–125)

![Graph showing changing amount of animal bones at Mill Creek due to the climate change.](image)

Research on ice cores and lake sediments shows that the climate system has suffered many abrupt fluctuations in the distant past – the climate appears to have "tipping points" that can send it into sharp lurches and rebounds. Although scientists are still analysing what happened during those earlier events, it is clear that an overstressed world with 6.3 billion people is a risky place to be carrying out uncontrolled experiments with the climate.

### 2.3.2 Evidence of climatic change today

Before one can talk about climate change, one should provide criteria for what is the normal variation in climate and what is real change? Long-term environmental swings have always happened and are going on all the time. Good examples are the prevailing western winds in the northern hemisphere, the so-called westerlies that blow over the Mediterranean and central North America. As slow environmental changes warm or cool the atmosphere, the areas covered by the westerlies contract or expand and their configurations may change. This can have
dramatic consequences for civilizations in such areas, as described in the following chapter.

There are regions of extreme climatic uncertainty, like the Great Plains in the USA and Monsoon India, which are important for food production. In these areas major annual changes are normal, and only through long middle-term environmental monitoring can possible trends be unravelled. This kind of follow-up is important for mankind, because even small constant changes can cause severe implications for people whose food supply depends on a feasible climate for agriculture. (Haggett 1983: 118–122)

Most serious research reports and important international organisations say that the climate change which is going on is outside the criteria of the normal variation of climate. The United Nations reports confirm that even the minimum predicted shifts in climate for the 21st century are likely to be significant and disruptive. Scientific understanding and computer models have improved recently and many projections can now be made with greater certainty. Global temperature has risen by half a degree Celsius in the last century. Climate models predict temperature rises from 1.5 to 4.5 degrees by 2050. Predictions of future climate impacts show that the consequences could vary from disruptive to catastrophic. (United 2007b: 5)

According to the Intergovernmental Panel on Climate Change (IPCC) it is extremely unlikely (<5%) that the global pattern of warming during the past half century can be explained without external forcing, and very unlikely that it is due to known natural external causes alone. The warming occurred in both the ocean and the atmosphere and took place at a time when natural external forcing factors would likely have produced cooling. Greenhouse gas forcing has very likely caused most of the observed global warming over the last 50 years. The IPCC's findings, because they reflect global scientific consensus and are apolitical in character, form a useful counterbalance to the often highly charged political debate. (Heggerl 2007: 7)

One of the main factors causing global warming are the greenhouse gases, like CO₂. Carbon dioxide is a gas that is naturally present in the atmosphere, but which has been increasing in concentration due mainly to the burning of fossil fuels. Another factor causing the increase in atmospheric CO₂ concentration is the extensive deforestation taking place in many parts of the world, removing trees which use CO₂ in respiration and release oxygen. Although it is not a particularly powerful greenhouse gas, carbon dioxide contributes greatly to the greenhouse effect as it is released in such great quantities. (Hegerl 2007: 7)
The CO₂ emissions of different countries per capita are (Edwards 2005: 4):

### Table 2. CO₂ emissions per capita.

<table>
<thead>
<tr>
<th>Country</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>5.85 tons</td>
</tr>
<tr>
<td>UK</td>
<td>2.92</td>
</tr>
<tr>
<td>Japan</td>
<td>2.35</td>
</tr>
<tr>
<td>European Union</td>
<td>2.31</td>
</tr>
<tr>
<td>China</td>
<td>0.65</td>
</tr>
<tr>
<td>India</td>
<td>0.23</td>
</tr>
</tbody>
</table>

The production of CO₂ has developed in different countries in different ways between 2001 and 2006; in million tons (Weltweiter 2008):

### Table 3. Development of CO₂ emissions.

<table>
<thead>
<tr>
<th>Country</th>
<th>2001</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>6.279</td>
<td>6.469</td>
</tr>
<tr>
<td>Former USSR</td>
<td>2.386</td>
<td>2.813</td>
</tr>
<tr>
<td>China</td>
<td>2.800</td>
<td>5.841</td>
</tr>
<tr>
<td>Germany</td>
<td>917</td>
<td>890</td>
</tr>
<tr>
<td>UK</td>
<td>602</td>
<td>619</td>
</tr>
<tr>
<td>France</td>
<td>432</td>
<td>437</td>
</tr>
</tbody>
</table>

The growing presence of ozone-depleting gases, such as CFS’s and halons in the atmosphere has caused destruction of this layer to such an extent that a hole in the ozone layer over Antarctica was discovered in 1984, and since then these holes have been growing. The Montreal Protocol, entitled “The agreement of substances which deplete the ozone layer”, was signed in Montreal in September 1987 by 60 Governments. It was agreed to bring to zero the consumption of CFC’s, halons and carbon tetrachloride by the year 2000. But the recovery of the ozone layer will be a long process.

Great amounts of oxides of sulphur and nitrogen in the atmosphere has caused acid rains. The presence of these compounds dissolved in precipitation causes an increase in acidity, which may prove harmful to terrestrial flora and fauna. These compounds may also be particulate, and can fall to earth in the absence of precipitation. (Nowhere 1998; Severinghaus 1998)
It fell to scientists to draw international attention to the threats posed by global warming. Evidence in the 1960’s and ’70’s that concentrations of carbon dioxide in the atmosphere were increasing first led climatologists and others to press for action. It took years before the international community responded. In 1988, an Intergovernmental Panel on Climate Change was created by the World Meteorological Organization and the United Nations Environment Programme (UNEP). This group issued a first assessment report in 1990 which reflected the views of 400 scientists. The report stated that global warming was real and urged that something be done about it. (United 2007: 1)

There are also researchers and other sceptics, who say that there is no evidence about global warming caused by mankind. According to them, what is happening sits inside the borders of normal variation in climate. The uptick in Atlantic hurricane activity is explained as an ocean-driven cycle rather than climate change. Some researchers have left the IPCC, which they regard as scientifically unsound. Also science and politics have merged; for instance the Bush administration dismisses claims that climate change has intensified hurricanes. (Mooney 2007: 67–78)

Over a decade ago, most countries joined an international treaty – United Nations Framework Convention on Climate Change (UNFCCC) – to begin to consider what can be done to reduce global warming. Recently, a number of nations have approved an addition to the treaty, the Kyoto Protocol, which has more powerful and legally binding measures. It entered into force on 16th February 2005, but unfortunately many important and polluting countries have not joined the treaty. About 180 parties have ratified the Protocol to date. Of these, 36 countries and the EEC are required to reduce greenhouse gas emissions below levels specified for each of them in the treaty. The Protocol’s first commitment period begins in 2008 and ends in 2012. A strong multilateral framework needs to be in place by 2009 to ensure that there is no gap between the end of the Kyoto Protocol’s first commitment period in 2012 and the entry into force of a future regime. (United 2007b: 2)

Major problems are expected to emerge when negotiations are initiated for the period following the Kyoto agreement, which ends in 2012. The core of the problem is that the rising standard of living and growth in production constantly increase energy consumption and emissions. It has been estimated that a sum corresponding to about 1.5% of all the world’s investments would suffice to adequately reduce emissions. This sum is around 0.5% of the world’s gross domestic product. (United 2007b: 2)
According to IPCC, 2°C warming is the limit, after which uncontrolled cumulative environment change processes will start to happen. Hence the target should be to stay under this limit. (Climate 2007)

### 2.3.3 Effects of the climate change

Effects of global warming include sea level rises and droughts, either of which could have severe consequences for the world’s food production. The greenhouse effect strengthens extreme phenomena in the climate. This means more storms and snow in some districts. The change might be even faster than evaluated. (Meehl 2007: 5–7) Strengthening the weather phenomena means the climate has to be considered at all levels of regional and town planning.

Environmental damage – such as overgrazed rangeland, deforested mountainsides, and denuded agricultural soils – means that nature will be more vulnerable than previously to changes in climate. In any case, when climate shifts occurred thousands and tens of thousands of years ago, they generally took place more gradually. Natural systems had both more space and more time to adapt. Similarly, the world’s vast human population, much of it poor, is vulnerable to climate stress. Millions live in dangerous places – on floodplains or in shantytowns on exposed hillsides around the enormous cities of the developing world. Often there is nowhere else for them to go. In the distant past, man and his ancestors migrated in response to changes in habitat. There will be much less room for migration this time around. (United 2007b: 3–5)

Agriculture is typically the most important sector in the economy of developing countries. Farmers practice subsistence agriculture and the productivity of the agricultural systems depend heavily on prevailing rainfall and temperature patterns. Climate variability, climate change and seasonal shifts in meteorological parameters strongly impact agricultural productivity, affecting the food security and even social stability of many vulnerable developing countries.

Tourism is currently one of the largest and fastest growing industries, and for a majority of nations it is one of the top sources of export or foreign exchange revenue. Climate change will not only impact tourism directly with changes in temperature, extreme weather events and other climatic factors, but it will have an indirect impact by transforming the natural environment that attracts tourists. WMO in partnership with the international meteorological community is providing relevant information to the tourism sector in order to reduce the adverse consequences of weather and climate extremes for tourism operators. At the same
the tourism sector should maximize the benefits of favourable weather conditions and changes in climate. (World 2007)

Capacities of countries to adapt and mitigate impacts of climate variability and change can be enhanced when climate policies are integrated with national development policies including economic, social and other environmental dimensions. In particular the developing countries are highly susceptible to setbacks from climate extremes.

Even more dramatic visions can be painted. In the past million years the Earth’s rotating axis has changed periodically, and this has caused Ice Ages. But this mechanism might function also in the reverse direction. It is possible that meltwater alters the Earth’s balance and tilts the rotation axis. (Ice 2008: 1–2) This would result in a unforeseen climate catastrophe.

Fig. 10. Multi-model mean changes in a) precipitation, b) soil moisture content, c) runoff and d) evaporation. To indicate consistency in the sign of change, regions are stripped where at least 80% of models agree on the sign of the mean change. Changes are annual means for the period 2080–2099 relative to 1980–1999. (Meehl 2007: 22)
Rising sea level

Average sea level has risen constantly during the 1900’s and in the IPCC report the rate of rise is estimated to be 1–2 mm per year. It has been predicted that the rate at which sea level is rising will accelerate in the future, whereupon average sea level may rise in some coastal areas. (Church 2001; Meehl 2007)

The behaviour of sea level in the future can be predicted to change as a result of changes in climate factors. It has been predicted that the earth’s climate will change in the coming decades because of the greenhouse phenomenon, amongst other reasons. The average temperature of the earth, in particular, is expected to rise. The change in the average temperature of the earth will indirectly affect sea level through several mechanisms. Thermal expansion of seawater and melting of continental glaciers and smaller mountain glaciers and land ice sheets will raise sea level. On the other hand, increased precipitation caused by the rise in temperature may also cause the Antarctic ice sheet to grow.

Fig. 11 presents IPCC’s prediction of average sea level during this century. Variation in the predictions is due to differences in the end scenarios and models. The figure shows that, according to all the scenarios, sea level will rise in 1990–2100. Larger sea-level increases of up to 1 metre by 2100 cannot be ruled out if ice sheets continue to melt as temperature rises. (Church 2001; Climate 2007) Some French scientists have predicted a rise of 1.6 metres by the end of this century. About 125,000 years ago, when the Polar Regions were significantly warmer for a more extended period than at present, melting polar ice caused the sea level to rise by 4 to 6 metres. Sea-level rise has substantial inertia and will continue for many centuries. (United 2007b; Comment 2008)
Fig. 11. Rising sea level, scenarios according to IPCC. The curves represent different end scenarios, which are examined more closely in the IPCC report. Valtameren.. = Ocean level rise m, vuosi = year. (Church 2001).

The latest tracking data on the thawing of the continental ice sheets may significantly change prior predictions (Silfverberg 2008: 24). The estimated rise in sea level in the IPCC’s predictions is primarily based on calculated thermal expansion of the oceans. Due to a lack of reliable measurement data, so far it has not been possible to predict the rise in sea level caused by thawing of the continental ice sheets. Only very recently have ice sheet researchers from different countries begun to publish tracking data on the thawing of the continental ice sheets and resulting long-term predictions.

At present it appears that tracking studies of the behaviour of the continental ice sheets give reason to worry. Satellite and aerial photo measurements and field observations of Greenland’s and Antarctica’s ice sheets and surveys of water basins and flows beneath the ice sheets indicate that the rate of thawing of the ice sheets is accelerating exponentially, their internal ice flows are speeding up and their stability is weakening in wide areas. Ice sheet researchers also feel it is possible that large masses of ice will break away and fall into the ocean. The thawing process of smaller glaciers in Europe, Asia, North America and the Andes is currently rapid, but it has only a minor impact on sea level.
In a recent article in the Journal of Geophysical Research written by Research Professor John Moore, who is the director of the climate research joint project of the Universities of Lapland, Oulu and Liverpool, estimates that the average rise in sea level during this century will be 1–2 m. (Silfverberg 2008: 24) In its Fourth Assessment Report, the IPCC states that the contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. If this contraction is sustained for centuries, that would lead to the virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m. (Climate 2007) On the other hand, if the Atlantic thermohaline circulation, known as the Gulf Stream, shuts down as the result of increasing sweet-water production, this will start new glacier forming around the North Pole regions, which can lower the sea level. This will bring colder winters to the UK, and Scandinavia will experience Siberian winters. (Cunningham & al 2007: 935–938; RAPID 2008)

Salt-water intrusion from rising sea levels will reduce the quality and quantity of freshwater supplies. This is a major concern, since billions of people already lack access to freshwater. Higher ocean levels already are contaminating underground water sources in Israel and Thailand, in various small island states in the Pacific and Indian Oceans and the Caribbean Sea, and in some of the world's most productive deltas, such as China's Yangtze Delta and Vietnam's Mekong Delta. (United 2007b)

![Fig. 12. Effect of 1 metre sea-level rise in Florida. (Weiss & Ovepeck 2008: 39)](image)
Wind and storm

A future of more severe storms and floods along the world's increasingly crowded coastlines is likely, and will be a bad combination even under the minimum scenarios forecast. Intense tropical cyclone activity has increased since about 1970. There is evidence from modelling studies that future tropical cyclones could become more severe, with greater wind speeds and more intense precipitation. Extra-tropical storm tracks are projected to move pole-wards, with consequent changes in wind, precipitation, and temperature patterns, continuing the pattern observed over the last half century. A number of modelling studies have also projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events and higher ocean waves in several regions in association with those deepened cyclones. (Meehl 2007; United 2007) Mid-latitude westerly winds have generally increased in both hemispheres (Trenberth 2007).

Rain, dryness and snow

The IPCC points to very likely increases in the amounts of precipitation in high latitudes, as well as likely precipitation decreases in most sub-tropical land
regions. Droughts have become more common, especially in the tropics and subtropics, since the 1970's.

Although regional and local effects may differ widely, a general reduction is expected in potential crop yields in most tropical and sub-tropical regions. Mid-continental areas – such as the United States' "grain belt" and vast areas of Asia – are likely to dry. Where dry-land agriculture relies solely on rain, as in sub-Saharan Africa, yields would decrease dramatically even with minimal increases in temperature. Such changes could cause disruptions in food supply in a world already afflicted with food shortages and famines.

Projections also point to continued snow cover contraction, as well as widespread increases in thaw depth over most permafrost regions. (Trenbeth 2007; United 2007b)

**Flora and fauna**

The Intergovernmental Panel states that 20–30 per cent of species are likely to face an increased risk of extinction. According to the United Nations Framework Convention on Climate Change most of the world's endangered species – some 25 per cent of mammals and 12 per cent of birds – may become extinct over the next few decades as warmer conditions alter the forests, wetlands, and rangelands they depend on, and human development blocks them from migrating elsewhere.

Wildlife and biological diversity – already threatened by habitat destruction and other human-generated stresses – will face new challenges from climate change. Many ecosystems are already responding to higher temperatures by advancing towards the poles and up mountainsides. Some species will not survive the transition, and 20–30 per cent of species are likely to face an increased risk of extinction. The most vulnerable ecosystems include coral reefs, boreal (sub-arctic) forests, mountain habitats and those dependent on a Mediterranean climate. (Intergovernmental 2007; United 2007b)

**Diseases**

Higher temperatures are expected to expand the range of some dangerous "vector-borne" diseases, such as malaria, which already kills 1 million people annually, most of them children. Climate change will increasingly alter the distribution of malarial mosquitoes and other carriers of infectious disease, affect the seasonal distribution of some allergy-causing pollen and increase the risks of heatwaves. On
the other hand there should be fewer deaths due to the cold. (Intergovernmental 2007; United 2007b)

2.3.4 Predicted effects of the climate change in the cold and moderate climate regions

The Polar Regions are of great significance in the global climate system. A major internationally coordinated, interdisciplinary, scientific research and observation in the Earth’s Polar Regions is being carried out in 2007–2008. This covers the areas of polar meteorology, oceanography, glaciology and hydrology, and will provide valuable contributions to the assessment of climate change and its impacts. (World 2007)

Snow cover in the northern hemisphere, as measured from satellites, has declined substantially in the past 30 years, particularly from early spring through summer. In some very cold places, increases in snow depth have been observed and have been linked to higher precipitation. Widespread permafrost warming and degradation appear to be the result of increased summer air temperatures and changes in the depth and duration of snow cover. (Heggerl 2007)

There is a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events and higher ocean waves. Models also project a pole-ward shift of storm tracks in both hemispheres by several degrees of latitude. (Meehl 2007)

EUROPE. Annual mean temperatures in Europe are likely to increase more than the global mean. Seasonally, the largest warming is likely to be in northern Europe in winter and in the Mediterranean area in summer. The risk of summer drought is likely to increase in central Europe and in the Mediterranean area. Glaciers and permafrost are thawing, growing seasons are lengthening and weather extremes, such as the disastrous heat wave of 2003, are more frequent. Researchers believe that Europe’s northern regions will experience warmer winters, greater precipitation, expanding forests and greater agricultural productivity. Southern regions near the Mediterranean will see hotter summers, less precipitation, more droughts, retreating forests and reduced agricultural productivity. Europe contains a great deal of low-lying coastland vulnerable to rises in sea-level, and many plants, reptiles, amphibians and other species are likely to become endangered by the end of the century.

NORTH AMERICA. The annual mean warming is likely to exceed the global mean warming in most areas. Seasonally, warming is likely to be largest in winter
in northern regions and in summer in the southwest. Annual mean precipitation is very likely to increase in Canada and the northeast USA, and likely to decrease in the southwest. Climate change will further constrain water resources, already stretched by growing demand from agriculture, industry and cities. Rising temperatures will further diminish the mountain snow pack and increase evaporation, thus altering the seasonal availability of water. Lower water levels in the Great Lakes and major river systems will affect water quality, navigation, recreation and hydropower. Wildfire and insect outbreaks will continue to intensify in a warmer world with drier soils. Over the 21st century, pressure for species to shift north and to higher elevations will fundamentally rearrange North American ecosystems.

AUSTRALIA AND NEW ZEALAND. Warming is likely to be larger than that of the surrounding oceans, but comparable to the global mean. The warming is less in the south, especially in winter, with the warming in the South Island of New Zealand likely to remain less than the global mean. There will be increasing stress on water supplies and agriculture, changing natural ecosystems, less seasonal snow cover and shrinking glaciers. Over the past few decades there have been more heatwaves, fewer frosts and more rain in north-west Australia and south-west New Zealand; less rain in southern and eastern Australia and north-eastern New Zealand; and an increase in the intensity of Australian droughts. The climate of the 21st century is virtually certain to be warmer with more frequent and intense heat waves, fires, floods, landslides, droughts and storm surges.

ANTARCTICA. This continent has proven more difficult to understand and predict. With the exception of the rapidly warming Antarctic Peninsula, both temperatures and snowfall have remained relatively constant for the continent as a whole over the past 50 years. Because this frozen continent contains almost 90 per cent of the planet's freshwater, researchers are watching carefully for any signs that its glaciers and ice sheets may be melting.

THE ARCTIC. Average temperatures in the Arctic have increased almost twice as fast as the global average over the past 100 years. The average extent of Arctic sea ice has been shrinking by 2.7 per cent per decade and large areas of the Arctic Ocean could lose year-round ice cover by the end of the 21st century if human emissions reach the higher end of current estimates. The Arctic is also particularly important because changes there have important global implications. For example, as ice and snow melts, the Earth’s albedo (reflectivity) is decreased, trapping heat that would otherwise be reflected and warming the earth’s surface even further. (Christensen 2007; Intergovernmental 2007)
Example, Helsinki

A good example of what can happen in a cold region is the City of Helsinki. Based on a simulated regional climate model, several changes will occur in Helsinki's climate during this century:

- temperatures will rise
- windiness and the number of storms will increase
- rainfall will increase
- amount of snow will decrease, but snowstorms may be violent
- sea will be frozen only a short time; waves will increase.

A prediction was compiled for a local climate change in terms of extreme phenomena and changes in average figures during the next century. According to the estimate of the year 2100, the average annual temperature will rise 4 °C, the maximum temperature will increase 4 °C, the minimum temperature will increase 16 °C, freeze-thaw cycles will decrease 40%, average annual wind speed will grow 2%, maximum wind speed will increase 15%, annual rainfall will grow 15%, the 6-hour maximum rainfall will stay the same, the 5-day maximum rainfall will increase 15%, the water content of annual snowfall will decrease 60%, the 6-hour maximum snowfall will remain unchanged, the maximum water content of the snow cover will decrease 50%, the duration of the snow cover will shorten 70 days and the duration of sea ice cover will shorten 120 days. However, changes in sea level will not necessarily result in a rise in sea level along the coasts of countries like Finland, due to the effects of land uplift. (Makkonen 2006: 1)

The rise in temperature will decrease heat consumption due to coldness, but on the other hand, increasing windiness will cool buildings more. Because the cooling effect of wind is significant, energy conservation measures cannot be diminished.

A 15 percent increase in maximum wind speeds places a stress on buildings and hinders bicycle and pedestrian traffic. Travel on docks and bridges become more difficult and at times possibly dangerous. Greater wind loads will affect roof structures, facades, canopies and balcony glass. Increased rainfall needs to be taken into consideration when designing rainwater drain systems.

The ocean remaining ice-free all year round together with increasing wind will lengthen the moist, windy period between seasons. Increasing humidity at temperatures near zero will increase slipperiness. Because the sea doesn’t freeze, strong waves will hit the shores also in winter, throwing splashes on streets near
the shore and facades of buildings along the streets; see also Appendix 5. (Wahlgren, Kuismannen & Makkonen 2007:10–15)

2.3.5 Predicted effects of the climate change in the warm regions

Droughts will become more common, especially in the tropics and subtropics. Observed marked increases in drought in the past three decades arise from more intense and longer droughts over wider areas, as the critical threshold for delineating drought is exceeded over increasingly widespread areas.

Intense tropical cyclone activity has increased since about 1970. Globally, estimates of the potential destructiveness of hurricanes show a significant upward trend, with a trend towards longer lifetimes and greater storm intensity. For many regions of the mid-latitude oceans, an increase in extreme wave height is likely to occur in a future warmer climate. (Meehl 2007; Trenberth 2007)

In Japan the most serious damage caused by winds occurs under the climates of typhoons, tornadoes and downbursts. However, in 2005 extra-tropical depressions developed in winter over the Sea of Japan and caused serious wind damage on the north-west coast of Japan. This type of wind climate had not been previously recognized. An urgent meeting was held by the Japan Association for Wind Engineering (IAWE), and it made recommendations for immediate intensive research. These recommendations stressed the necessity for an observation system network such as Doppler radar and establishment of an enhanced nowcast technique. (Wind 2006)

ASIA. Warming is likely to be well above the global mean in central Asia, the Tibetan Plateau and northern Asia, above the global mean in eastern Asia and South Asia, and similar to the global mean in Southeast Asia. Heatwaves/hot spells in summer will be of longer duration, more intense and more frequent in East Asia. More than a billion people could be affected by a decline in the availability of freshwater, particularly in large river basins, by 2050. Glacier melt in the Himalayas, which is projected to increase flooding and rock avalanches, will affect water resources in the next two to three decades. As glaciers recede, river flows will decrease. Coastal areas, especially heavily populated mega-delta regions, will be at greatest risk due to increased flooding from the sea and, in some cases, from river flooding.

AFRICA. Warming is very likely to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics. Africa is very vulnerable to climate
change and climate variability due to endemic poverty, weak institutions, and complex disasters and conflicts. Drought has spread and intensified since the 1970’s, and the Sahel and southern Africa have already become drier during the 20th century. Water supplies and agricultural production will likely be severely compromised. Yields in some countries could drop by as much as 50 per cent by 2020, and some large regions of marginal agriculture are likely to be forced out of production. Forests, grasslands and other natural ecosystems are already changing, particularly in southern Africa. By the 2080’s, the amount of arid and semi-arid land in Africa will likely increase by 5–8 per cent.

LATIN AMERICA. The annual mean warming is likely to be similar to the global mean warming in southern South America but larger than the global mean warming in the rest of the area. The tropical forests of eastern Amazonia and southern and central Mexico are expected to be gradually replaced by savannah. Parts of north-east Brazil and most of central and northern Mexico will become more arid due to a combination of climate change and human land management. By the 2050’s, 50 per cent of agricultural lands are highly likely to be experiencing desertification and salinisation.

SMALL ISLAND STATES. It is very likely that all land regions will warm in the 21st century. Particularly vulnerable to climate change, their limited size makes them more prone to natural hazards and external shocks, in particular to rises in sea-level and threats to their freshwater resources. (Christensen 2007; Intergovernmental 2007)

2.4 Adaptation of building to circumstances

2.4.1 Vernacular architecture

Man has always been forced to adapt to changing climate and environmental circumstances, which is the raison d’être of most part of the vernacular architecture. The lower the level of technology, the more adaptation has been needed. On the other hand, seemingly clear solutions have always required skilled use of natural resources. Good examples of this can be found in Rudofsky’s book called “Architecture without Architects”: planted windshields in Japan, bad-gir wind scoops in Pakistan, limonaie shelter constructions against snow and cold in Italy, architecture à pilotis in the South Sea region, semi-covered streets in Africa, arcades in Europe, warmth accumulating stone walls for vineyards in Spain etc. (Rudofsky 1964)
The relationship between vernacular construction and climate has been studied much. Some researchers have even made such far-reaching conclusions that we can talk about climate-determinism. A community’s most important task is to build a shelter. Despite this, many examples from Asia, Africa and Latin America show us that culture has been a more important factor than the environment itself, and it has had a great influence on building. Construction methods of neighbouring nations living in similar climates may differ considerably. The same construction method can also be seen in totally different climates. According to Amos Rapoport, vernacular construction aims for a balance between Nature, means of livelihood, culture and security, without letting any of these factors alone dominate.

However, the influence of climate adaptation on a traditional construction method should not be underrated. Lay builders have a great amount of know-how about choosing a building plot, the shape of a building, materials and realisation of details. This knowledge can be useful even today. Traditionally, such examples as Eskimos’ igloos, desert areas’ clay or rock houses and the reed roof houses on pillars with no walls found in tropical rainforests and islands have been highlighted in research. Another important example is peasant houses. (Rapoport 1969: 83–103)

Throughout architectural history, local builders have used great ingenuity in providing the most comfortable internal conditions within local climates. In hot areas air movement, evaporative cooling and the thermal capacity of a massive structure are used to increase human comfort. In cold regions the insulating quality of materials are exploited, and shelter against cold winds, passive solar heating and the use of natural light are arranged in many different ways.

Town construction has also adapted to scanty resources. Medieval cities are surrounded by walls, and the city inside them rises towards the castle or church situated in the middle. The streets are narrow and curved and squares are quite small. In many cities pedestrians are protected from the rain and sun by arcades. The walls and the rising city structure keep the cooling wind outside the city. The curved streets and little squares prevent wind speed from rising and the closely placed houses form a labyrinth in which the houses warm each other. The pueblos blancos of Latin culture are another example of climate-adapted vernacular urbanism.

The buildings in the Scandinavian wooden towns were low, and they usually formed closed courtyards. Residential buildings were surrounded by outbuildings and their entrances had porches which formed a protected space between the yard
and indoor rooms. A regular grid layout became more popular in the 19th century, and in the beginning the scale was micro-climatically good. Gradually the houses started to rise above the treetops and the streets and squares became wide. The amount of protective outbuildings started to decrease, as well.

Different climate regions have different architectural archetypes, like the peristyle garden, Sirocco room, loggia, the Japanese house with sliding doors and the Chinese round house which protects against not only the elements, but also marauders. There are plenty of different local small innovations like the wind towers of the Middle East, mushrabeyeh in the Arabic countries, brise-soleil, etc. (Rudofsky 1964; Chatelet 1998: 127–133)

There are lessons to be learned from vernacular architecture and old buildings, but only to certain degree, because the building volumes, functions, equipment, life-style etc. have changed so much. The low-tight traditional Scandinavian wooden towns with their relatively good micro-climate still are an example to follow in cold climates. The pueblos blancos of Latin culture still can give inspiration to modern bioclimatic architecture in Mediterranean and warm-dry climate areas. Most part of the archetypal building types and details adapted to new circumstances add much to the climate-conscious architecture of today.

2.4.2 Designed architecture

The first building instructions that take windiness into consideration are mentioned in Vitruvius’ books. Old maestros, like Palladio, were clever in using wind and other climatic phenomena as a part of their design concepts. After that windiness has been studied from both the aerodynamic and hydrodynamic sides, but also from the construction engineering side.

The majority of the great masters of architecture – Vitruvius, Alberti, Le Corbusier, Aalto, Erskine, Pietilä – have in their own way been inspired by the dialectic between nature’s forces and buildings. Many of them have implemented projects inspired by climate conditions at some point of their careers; Wright’s Usonian houses and Taliesin West, Le Corbusier’s Maison Aloles, Al Broek’s and Moore’s Sea Ranch, etc. Cristoffer Alexander’s Pattern Language has many concepts based on the exploitation of natural resources. (Alexander 1967; Climatic 1996: 15–30; Martinez 1996; Jones 1998; Théorie 2003: 22–27, 110–117)

A notable architect who applied snow research to planning and innovatively considered environmental problems is Ralph Erskine. His work methods include observation of natural phenomena and living in the natural environment and
searching for the starting point for planning from these observations. According to Erskine, the best results in avoiding snow accumulation are reached when a building’s shape facing the windy direction is quite low and narrow and the roof angle is gradual. Taking part of the roof structure all the way to the ground makes the wind flow evenly around the building. It also keeps entrances snow free, as in Borgafjell’s mountain hotel.

The authors have given different names to their theories, like climate-conscious architecture, bioclimatic design, biophilic design, environment-conscious planning or ecological architecture. According to Yeang, “bioclimatic design is the passive low-energy design approach that makes use of the ambient energies of the climate of the locality to create conditions of comfort for the users of the building. Ecological design is a much more complex endeavour.” Ecological design is multi-disciplinary and besides climate, ecological architecture includes consciousness about building material sources and outputs, local energy, etc. It has often been said that all architecture before the industrial revolution was climate-conscious and ecological. (Mänty & Pressman 1988; Sterten & Børve 1995: 16; Yeang 1999: 11; Kellert & al. 2008)

At one extreme are modern large buildings which are in no way oriented according to the cardinal points or climatic circumstances. In the worst cases these glass boxes collect the sun’s warmth and much energy is then used to cool them. In such buildings electric lights are also used during the daytime, people lack contact with the outside world, and warming and cooling are dependent on machines and the use of energy. Sixteen percent of the electricity consumed in the Unites States is used for air-conditioning. People have more and more illnesses because of this unnatural method of construction. (Serra 1999: 43–44)

The modern maestros of the functionalist style used solar radiation as one of the functions, paying less attention to the other aspects of climate. The functionalistic open urban block configuration suits Mediterranean climatic conditions pretty well, but the same lay-out in colder zones results in draughty courtyards. The famous miessian glass boxes and towers suit all climates badly. During the last century, particularly functionalism and the so-called international style have disseminated a style of construction throughout the world, which quite often did not fit the construction site and its climate.

The loss of place includes also the loss of climate.
2.4.3 Other design cultures

As an option to western rational thinking, many kinds of building cultures have developed in different parts of the world. In these cultures the relationship to the environment is considered and carried out in various ways. In many of them quality of life consists of something other than controlling the environment with machines and collecting consumer goods. The environment is not only described with magnitudes like luxes, but also with different quantities, beliefs, phenomena and meanings. Man’s most fundamental need is to experience his existence as meaningful, and architecture represents a means to give man an “existential foothold” and qualities.

Megalithic cultures, original tribes etc. have all had beliefs and visions of the placing and orientation of towns and buildings in relation to landscape, winds, sun, moon, stars and the cardinal points. There are places and periods of time when mystery and magic have been important parts of building processes. Some of the observations are based on celestial bodies others on radiation caused by minerals or water. Many cultures consider the earth as a living creature, Gaia, and in some cases the view is so holistic that even a relationship to acupuncture can be seen. (Norberg-Schulz 1986: 111–127; Serra 1999: 89–94)

We may distinguish between five basic modes of mythical understanding, which have a different weight in different cultures (Norberg-Schulz 1980: 23–32):

1. Taking forces as the point of departure, and relating them to concrete natural elements or “things”. A marriage of heaven and earth (Gaia).
2. Abstracting a systematic cosmic order. Usually based on the sun and the cardinal points, sometimes related to the local geographical structure.
3. Definition of the character of natural places and relating them to human traits.
4. Light. Sunlight understood as “thing”, knowledge, god (Christian pater luminus) and Divine Light (i.e. spirit).
5. Time as a mythopoetic idea. Experienced in the periodicity and rhythm of man’s own life as well as in the life of nature. Rituals and cosmic events (creation, death, resurrection) re-enacted.

An old teaching called Feng Shui, which was developed in China, literally wind and water, studies the relationship between human habitation and the environment. Some of the relationships are not immediately detected by the senses. Analysis of a place originates from the concepts of the harmony and latent energy of the universe. Different analogies, points that have harmonic energy and flows are
utilised in the work that is done. Some of guidelines deal with very small details in an apartment. (Serra 1999: 89–94)

Many architectural practices based on these theories have been born, which have been refined over the centuries to fit in with the environment and the community’s habits. Vernacular building is just one example of this. Even today there lie lessons to be learnt in the ways nature has been studied before building, and in the practical solutions of vernacular architecture.

2.5 Present know-how and methods

2.5.1 Research on the climate and the environment

Milestones of the research

Some useful methods for analysing the climatic factors and suggesting design guidelines of a project site have been developed. The oldest is probably the Mahoney tables, which are especially suited for simple building tasks (Climatic:75–78). A more sophisticated system is the set of bioclimatic diagrams developed by Givoni, which show with psychometric diagrams the architectural and technical means with which the inconveniences of climate can be remedied. There are different methods to study and describe windiness in urban space, like on-site measurements, wind tunnel tests, CFD modelling and on-site interviews. (Givoni 1998: 36–45; Westerberg 2004: D.2.1–10)

The first comprehensive monographs on urban climates appeared in Germany in 1937, but they were ignored by practising town planners. The introduction of many high-rise built-up areas brought more research into the wind climate. Egli’s attempt to create new basic principles for designing and building new towns in different climatic zones was published in 1951. Evans recorded in studies done in the 1950’s that a wind testing technique is needed and it has to be cheap and easy to use. The resistance of the construction was the first factor investigated. Davenport formulated in 1960 the first criteria for the construction of buildings based on wind tunnel investigations. Page attempted to bring these and other criteria to the designer’s attention. He analysed the design process in order to determine the appropriate stages at which information and investigation could be introduced into the process. The weather-resistance of the individual was first investigated by Penwarden in reaction to the severe discomfort experienced by
people in new-built areas. His criteria involved the velocity and gustiness of the wind. He assessed the weather conditions in which people can move about outdoors without hindrance or discomfort caused by wind. (Alberts 1981: 71–76; Dunin-Woyseth 1990: 341–343; Chatelet 1998:19)

Architect Olgyay suggested at the beginning of the1960’s that the micro-climate of a site can be modified when the circumstances are analysed first, and the buildings are planned according to the results of analyses (Olgyay 1963: 14–23). The Russian researcher Lebedew says that the forces of nature must be taken into consideration, and this should lead to holistic thinking of architecture. The understanding of organic processes will lead to a specific language of architecture, too. Improvement of energy systems of buildings, making better micro-climate and installing self-regulating ventilation systems are needed. By the latter he means cinematic architecture instead of technical machinery. (Lebedew 1983: 44–57)

During the 1970’s medical experts and sociologists had also become more interested in the effect of the outdoor climate on humanity, the health and comfort of which concerned them. Mol van Charante studied the health and mental aspects of the climate and dwelling in 1980. (Evans 1972: 13; Alberts 1981) Danish researcher Jan Gehl has observed that wind and coldness essentially decrease social contacts outdoors. It has been noticed in Sweden that circumstances outdoors are the most important explanation when it comes to the time spent outside. Most of the year Finland’s climatic conditions are outside of the ideal circumstances determined by several researchers. The impact of the climate and micro-climate are especially significant in non-mandatory outdoor activities. Improving the micro-climate increases outdoor activities, which has positive impacts on health and social life. (Gehl 1987: 30–45)

The impacts of snow on house construction in the Antarctic area have been studied e.g., in Canada, Russia and Japan.

The effects of snow for building have been studied in Canada, Norway, Russia and the USA. Ghiocel, Esquillan, Mateescu and Popescu, among others, have studied snow accumulation, but the results have not been reliable or applicable for planning. The aim in the so-called Scharer’s principles is to consider the building and its environment when anticipating snow accumulation, even though the theoretical result is not directly applicable to building planning (Fig. 14). Probably the most comprehensive report on the subject has been made by Anne-Brit Børve. Other important researchers who have done basic research are Eimern, Nägeli, Jensen, Watson and Sato. (Børve 1987: 41–50; Sterten & Børve 1995: 8–9)
Usually architects’ knowledge about snow accumulation on roofs is insufficient. This is usually considered meaningless – engineers can do it. The first well-known research about snow accumulation on roofs was done in Romania by Mateescu and Popescu. In these tests sawdust was used as an indicator (one grain of dust is smaller than 0.3 mm) in a scale model smaller than 1:100, with a wind speed of 3 m/s. (Børve 1987: 43–44; Glaumann & Westerberg 1988: 112)

The World Meteorological Organisation (WMO) in 1976 issued the first authoritative statement on the accumulation of carbon dioxide in the atmosphere and the potential impacts on climate. This was a key trigger that focused the attention on the potential threat of climate change and its impacts for generations to come. As a result, in 1988, WMO and UNEP jointly established the IPCC, which has been critical in providing regular assessments of climate science, potential impact of climate change and of policy options. (World 2007: 2–4)

ASTA II research, carried out by Kivistö at VTT, was a major attempt to study the effect of climate on buildings in Finland. It produced a lot of new information, and concluded that wind analysis and wind tunnel tests are needed when building in a windy area; see also Chapters 6.3 and 6.4.1. The pioneering study of climate-conscious planning by Erat concentrates mostly on solar-oriented planning of small-scale housing in the circumstances of South Finland. In Sweden Glaumann and Westerberg have published study reports on planning and wind. Professor Børve has studied (winter) landscape, Norwegian climate and the possibilities to
Climate change has brought with it many new research projects, which on the one hand try to fight that change and on the other aim to find new tools to adapt to new circumstances. Most projects are targeted on the actual local climate. There is new knowledge on urban climate change, but it is not well matched by practical applications. (Climate 2007; Emmanuel 2008: 2)

As a rule of thumb the author has identified the following climate-related research traditions in different countries:

- Natural Winter Cities, Scandinavia. Models based on eco-technology, environmental research and more traditional methods of construction.
- Ecological architecture, Germany. Architecture based on holistic development work of energy saving, solar energy and healthy building materials. Standards like *Passive House* and *Minergie* (Switzerland) are introduced into use.
- Solar architecture, France. Development of passive and active solar architecture mostly for Mediterranean and warm-dry climates.
- Bioclimatic urban development, Spain and Latin America. Research into climatic and social aspects of urbanism.
- Problems caused by hurricanes and typhoons, Japan, USA. The use of CFD in analyses and as a design tool.

**Examples of discussion**

The Winter Cities Forum was founded in the 1980’s, and it organised conferences every second year till the end of the 90’s about problems caused by winter and results obtained from research. At the work-shops Scandinavian people usually preferred a more traditional and natural approach as opposed to North America’s harsh technological style. Anyway there was a common need to develop planning methods. The author attended the conferences in Edmonton, Montreal, Winnipeg and Luleå.

A series of conferences was organised for architects in the Arctic area of the Nordic countries in Rovaniemi in 1984, Kiruna in 1986, Tromsø in 1988 and Kemi in 1992. Experience was exchanged, ideas developed, and many architects and
participants brought up the need to develop planning methods that take the climate and environment into consideration.

The planning of the Arctic Housing Fair in Tromsø in 1990 was made by a Scandinavian architect working group. New solutions to build in harsh cold climates were developed, but the attendees of the design teams expressed the need for analysis and wind test methods that are easy to use.

Working Group Education consisted of a series of Scandinavian architect’s workshops in 1991–92, which studied and developed climate-conscious / bioclimatic architecture. The workshops were arranged in Finland, Iceland, Norway and Sweden.

ECE’s Standing Committee for Urban Planning, a workshop started by the University of Oslo and Norway’s Environmental Department, was implemented in 1991–92. The aim was to find out the need for climate-aware planning and the current status of research. The need that came from the Scandinavian countries prompted the start of this research.

The author participated in the work of all the forums mentioned in this chapter.

**Examples of research and methods**

1. The European Wind Atlas shows a method which converts information obtained from over two hundred weather stations around Europe to correspond to local circumstances (Fig. 107). For the conversion, information collected from twelve wind directions, five different heights between 10 and 200 metres as well as four terrain types from open sea to dense city are used. The Atlas of Regional Wind Climate presents results which are used, e.g. when placing wind power stations. Basic meteorological facts, building sizes, the terrain’s coarseness class from the standpoint of wind, and contour lines are needed for computer-aided design. The application calculates the local wind circumstances using the information mentioned above. (Troen 1989: 15–650)

2. COST Action C14, Impact of wind and Storm on City Life and Built Environment, engaged a large and qualified majority of European leading wind-tunnel research laboratories and Institutes to discuss, exchange and disseminate the latest know-how on the effects of wind in built areas. The work focused on analyses of damage, wind-tunnel engineering and CFD techniques. The author represented Finland in these meetings.

3. Problems that wind causes to property maintenance have been examined by Jouni Ilmarinen. Small-scale interviews of the staff of property maintenance
companies were also conducted in Oulu. Some observations about the environment were also made. The results can be summarised (Ilmarinen 1996):

- snow piles up in access balconies and open stairways if they are incorrectly planned (e.g. short eaves)
- open net walls do not stop snow from entering parking houses, but make it more difficult to remove it
- gateways are windy
- rooms located on the seaward side are often cold
- snow piles up on stepped roofs
- cold draught near doors in stores.

4. To facilitate the compilation of analysis and planning guidelines, researchers have developed various classifications for terrain shapes. Børve and Sterten divide terrain into five classes, which are: A open plain, B open hilly country, C slope, D valley, E hilly terrain bordered by mountains (see Fig. 15). Each type has its own relatively constant basic features and impacts on micro-climate. Designers have planning guidelines for each type. (Børve & Sterten 1981: 21, 89)

![Fig. 15. Terrain can be divided into five landscape types. (Børve & Sterten 1981: 89)](image)

5. Glaumann and Westerberg have developed a system for evaluating windiness which helps to estimate the need for wind protection. The calculations are based on basic wind speeds, which are derived from wind statistics from some 50 Swedish meteorological stations. The data collected covers relatively flat areas only, and the method is not valid in high hilly or mountainous landscapes.

The first task is to classify the terrain according to its wind-resisting coarseness. The classes are: 0 open water, 1 open terrain containing singular
objects, 2 terrain that varies in topography and cover, and 3 covered forest or building area. In the method the surroundings of the site being planned within a radius of many kilometres are classified according to the wind forces of the terrain. The information gained from weather stations is converted to a local level using the classification mentioned above. Using a form that belongs to the method gives an estimation of windiness. The classification can also be used without forms when working with topography maps. (Glaumann & Westerberg 1988: 84–97, 144–147)

6. In different studies there are many ways to define the climatic zones of the world. Probably the most well known is the Köppen classification, Fig. 5, which is profound. Often these regions are parallel with the vegetation regions, and climate and nature analyses complement each other.

Davis Lloyd Jones and Ken Yeang use 11 types of climate (Jones 1998: 245; Yeang 1999: 203):
1. Ice Caps
2. Tundra
3. Uplands
4. Continental
5. Temperate
6. Mediterranean
7. Subtropical
8. Tropical
9. Savannah
10. Steppes

Givoni uses four regions (Givoni 1998: 331–437):
1. Hot-dry
2. Hot-humid
3. Cold

Serra’s classification consists of four different climates, which are defined by the temperature, radiation, humidity and air movement (Serra 1999: 7).
1. Warm-dry
2. Warm-humid
3. Cold
4. Temperate.

Liébard and de Herde have five grand type de climates (Liébard 1996: 10)

1. Tropical climate
2. Dry Climate
3. Temperate warm
4. Temperate cold
5. Cold.

2.5.2 Background surveys on climatic problems

To get more information about how climate conditions affect building in Finland, two interview studies were made using questionnaires. As comparison a query from the USA and another from Norway are presented.

Answers obtained from the questionnaires have been used in revising the content of this part of the research.

Finnish planners

An interview study of 75 people including community planners, architects and officers in the environmental departments was carried out. The aim was to find out the usability of different planning methods and wind testing equipment. Only 21 of the 75 responded. Ten of the respondents lived on the coast and eight inland. A summary can be seen in Appendix 9, Table A/IV. The impact of circumstances on the coast and inland on climate problems is shown in Table A/V. Only a few places were examined, so the results are only approximate.

In summary it can be stated that all the respondents had some kinds of problems with buildings and their surroundings because of the climate. Problems caused by wind are more common and difficult on the coast. Inland continental climate reflects on energy consumption and the significant amount of snow.
Property owners in North Finland

A questionnaire was sent to property owners, builders and a group of officials in Kemijärvi town in the spring of 1993. The aim was to find out the need for building regulations that pay attention to special circumstances in the North. Eight questionnaires from 27 were returned.

The respondents considered that regulations at different levels need to be drawn up. They also thought town planning and construction supervision do not pay enough attention to the special circumstances in Kemijärvi. Training related to the building regulations was also asked for. It was hoped that building regulations would pay attention, e.g. to the principles of a winter city, improvement of the micro-climate, building traditions and local culture. Good, practical examples of how to apply sustainable development in construction and energy saving and how to organise recycling were asked for. Guidelines for healthy building and milieu development would also be welcome.

Appendix 9, Table A/VI shows the themes the respondents brought up. The number tells how many of them pointed out the subject. The respondents emphasised the problems of the city image and winter. More regulations and information are needed. Based on the feedback, the city of Kemijärvi asked for building regulations from Architects’ Office Kimmo Kuismanen in 1993–94.

Felt IV, Hammerfest

Hammerfest is a town by the North Atlantic Ocean in Norway. The town is exposed to extremely strong winds from the sea and cold inland winds with heavy snowing and drifting of snow. A new climatic-consciously planned detached housing area, Fuglenesdalen Felt IV, with special guidelines for construction, was built on a windy plateau. Architect Anne Brit Børve and Professor Arne Sterten were responsible for the development of the guidelines and planning.

In 1994 the residents of the area were queried as to their opinions about the building of the Felt IV and the guidelines. Only 22% of the inhabitants expressed that they had got enough information about climatic building. The majority of the inhabitants was generally satisfied with their houses, but 81% had had problems with snow and 44% with wind. There are special wind screens in the area, and 84 % had the opinion that they contributed to the climatic quality of the area. Only 26% felt that a specially formed house did not have an effect against the wind. To the question “would you recommend climate-conscious building to others”, 51% answered yes and 12% no. (Husbanken 1994)
Inhabitants of Marquette

Marquette is a town by the Great Lakes in the North USA. In 2003 community residents were queried as to their thoughts and opinion on Marquette’s climate and the role that winter plays. 83% of the respondents indicate that winter is a positive attribute, although persons in the 65–74 age group were less likely to see winter as positive (33%). The telephone survey indicated a number of common likes and dislikes (Marquette 2003).

Common positive attributes:
- winter activities 47%
- like snow 18%
- change of seasons 13%
- tourism industry 12%
- like winter 12%.

Common negative attributes:
- dislike cold 36%
- difficult to get around 15%
- dislike snow 15%
- dislike winter 11%
- winter is too long 11%.

2.5.3 Nature analysis research

There are lots of nature analysis methods in world, but only some very simple systems are interesting for this research.

For architectural design or planning, Yeang’s six ecosystem categories are practical (Yeang 1999: 91):

1. Ecologically mature ecosystems.
2. Ecologically immature ecosystems.
3. Ecologically simplified ecosystems.
4. Mixed artificial ecosystems.
5. Monoculture ecosystems.
6. Zero culture ecosystems.
Along with climate change new research projects have arisen in many universities and institutes. The topics of interest include studies into the spatial patterning of greenery, and quantitative description of their qualities in reaction to climate change. These studies aim to clarify the vulnerability of urban greenspaces in different climate zones, and the potential to strengthen their adaptivity. (Adaptation 2008: 3)

McHarg’s sieve-map method is an easy-to-use ecological land-use planning technique (Fig. 16) that shows areas suitable for different uses. The site is analysed in terms of its physical natural features, like vegetation, soils, groundwater, natural drainage patterns, topography, hydrology, geology, etc.

![Fig. 16. Ecological land use planning with the sieve map technique method. (Takeuchi 1995: 67)](image-url)
There are many reports about the effectiveness of greenery against wind. The field study made in Denmark about the functioning of wind shield plantings in a regional scale at a 20 km distance from the sea is very interesting. According to Olesen wind speed is diminished about 50% in areas with regular wind shield plantings, but only about 20% in an area with very few trees. He also gives practical rules on how to make wind screen plantings. (Njalsson 1983)

Known examples of large regional green-structures in Scandinavia are “Det åbne lands planlægning” region-plan around Köbenhavn, “Storstockholms gröna belte” in the Stockholm area and the central park of Helsinki.

The effects of street greenery have been studied in Germany, Japan and Norway. Measurements in Norway show that a street without trees has 10,000–12,000 dust particles in one litre of air, while a similar street lined with trees has only 1,000–3,000. According to Bernatzky parks are able to filter up to 80% of the pollution from the air, and trees in avenues by up to 70%. Even without leaves in winter the plants still retain 60% of their efficiency. (Bernatzky 1979: 67; Njalsson 1983; Nyhuus 1991: 15)

2.5.4 Urban analysis research

There is an abundance of urban research and methodology development, but most of it is not relevant to the theme of this research. In the following there is a short overview about some works.

Functions in urban structure

To analyse functions is interesting for climatic urban planning because some of the functions are polluting the air, thus affecting the quality of air of the surrounding areas. Some emitting activities and traffic planning demand the arrangement of area ventilation, for which climatic analyses are needed. There are also activities which are especially sensitive to climate and, therefore, need a special placing in urban structures.

Functions are often analysed by placing them on maps from various sources of information. New geographic positioning systems enable very versatile statistical studies. However, merely stating functions does not provide a picture of the dynamics, special features, and thus the development possibilities in the development of a community. Statistical studies should in fact be supplemented with qualitative information, like the climate requirements of the activities.
Analysis of a place and its activities can also be based on a qualitative and phenomenological examination. The goal would be to describe the spirit of a place (*genius loci*) and the space-related experience of the environment as a whole, by analysing the landscape, the boundaries of areas, the identification of inhabitants, the elements peculiar to the surroundings, building structures, and historical pleasant layers. For example, the KVALITATIV STEDSANALYSE method developed by Christian Norberg-Schulz and Anne Marit Vagstein covers the milieu of both the natural and built environments, thus giving useful information for the understanding of the climate of the project area. (Norberg-Schulz 1986; Vagstein 1993)

The analysis of a functional built environment should cover four main themes:

- historical development of the urban structure
- nature and landscape
- built structure and buildings
- special local features.

The goal of historical consideration is to understand the factors and reasons contributing to the formation of city structures and functions, and thus to get an idea of the direction and dynamics of development. For example, the REALISTISK BYANALYSE developed by Ellefsen and Tvilde describes the manifestation of the elements of architecture in a city entity and the relationship between a city and society. Present structures and their activities are explained by understanding the history and development processes of a place. Often the building of historical environments have been more or less steered by the nature forces, and that is why also this kind of analysis can give valuable information for bioclimatic planning. (Ellefsen & Tvilde 1991; Stedsanalyse 1993)
Fig. 17. Growth of outdoor space and building scale has increased windiness and traffic. The figure shows the campus area of the Technical University of Copenhagen and the old city centre on the same scale. (Gehl 1987: 106)

*Townscape analyses*

Townscape analyses chart visible phenomena and aesthetic quality. Cities are examined as entities that can be described on the basis of visual “laws”. Another important point of view is how inhabitants themselves feel about the city through
the areas, boundaries, traffic lanes and landmarks being outlined. A structuralistic analysis aims at revealing the internal logical connections of an urban structure. With the development of phenomenology, the theory of the “spirit of a place” and its elements was developed. Especially the knowledge of building structures can be used when analysing the micro-climate of an area (Fig. 17).

The creators of the theories – such as Jane Jacobs, Kevin Lynch, Gordon Cullen, Aldo Rossi, Venturi & Scott Brown, Robert Krier, Christian Norberg-Schulz – have in most cases limited themselves to examining a few elements, and a balanced planning model that really functions well has not yet been successfully developed. In practice the result in city building has been a scattered practice, in which master plans are functionalistic, whereas defined entities can be planned under the inspiration of a traditional townscape or some new theory. (Ålander 1954: 458–492, Lynch 1960, Norberg-Schulz 1980, Dunin-Woyseth 1991)

Ecological environment analysis

Vitruvius and Alberti have developed urban analyses and aesthetics, and after them Sitte has been regarded as a major actor in city planning. His thesis was to learn with nature and the old masters also in matters of town planning. Geddes is regarded as the founder of urban ecology. He is widely believed to be the originator of the “triple bottom line” of sustainable development: society, economy, environment. (Gaia 2004: 8–10)

Knowledge of ecological problems has triggered the ecological architecture movement and produced a group of various schools beginning with villages of hippy-anarchists to computer-controlled energy processes. These rather divergent approaches share some common features, such as energy conservation, orientation toward the sun, protection from wind, versatile green networks, etc., which are also interesting for climate-conscious planning.

Drawing up a comprehensive ecological planning theory and practice has proved to be more difficult than anticipated. Most of the presented solutions are directed towards only some limited sector, with minor influence on ecology as a whole. Some of the presented solutions are too expensive or difficult to have extensive use or significance. Many eco-villages have been criticised for their poor total energy balance, in spite of the energy savings of buildings, because of the traffic brought about by remote locations.

A suggestive ecological review can be made on the basis of the criteria presented by Bruno Erat, for instance (Erat 1995). VTT Community Engineering
has developed several computing models and programmes to facilitate environmental planning. The three most important of these are presented next.

ECO BALANCE is an evaluation model of the ecological balance of residential areas and urban structures. In connection with town planning, it enables reduction of energy consumption, air pollutants and the build-up of waste. The ecobalance calculation can be used to estimate the direct or indirect energy consumption of a residential area or urban structure during its entire life cycle, along with the use of other natural resources, air pollutants and wastes, and costs. The model covers buildings, traffic, telecommunications and technical service networks; and different types of green areas.

The Eco Balance model is comprised of three sub-models: production, use and traffic. Ecological balance has the following dimensions:

- energy consumption (construction, use of buildings and networks, traffic)
- consumption of natural resources
- consumption of building materials
- consumption of fuels
- consumption of water
- emissions (CO₂, CO, SO₂, NOₓ, CH, particles)
- waste (building, household)
- costs (construction, use of buildings and networks, traffic).

Eco Balance analysis has been performed with two of the pilot projects, Sodankylä and Rokua.

The EMICUS model calculates the total energy consumption and air pollutants of an urban structure, predominantly of a residential area. The model is well suited for examining details of an area, and the calculation can be adjusted as work progresses by adding to the initial data, such as building types and sizes, climate data, networks, distribution of transportation, etc. Comparison calculations can be made by providing different kinds of default data for initial values.

The goal has been to make an easy-to-use tool. The target can be an entire area, a block or a single building. The model is being updated and a Windows© version is also being made.

ECOBOXX is a tool for describing and assessing the activity of a community and the effects of changes in a built environment from the point of view of economic efficiency and sustainable development.

In community planning the model can be used for area boundaries, analyses of the effects and service level of a transportation system, quantification of remote
work potential, etc. On the community economics side, it is possible to calculate the costs of construction, maintenance and transportation, determine the effects of house type and area density, and estimate start-up expenses or the economic effects of shopping centres. The model can also be used to estimate an area’s ecological balance and calculate the energy consumption of various urban structural solutions. (ECOBOXX, EMICUS)

**Climate-conscious design**

Analysis and design methods specifically suited for different climate zones of the earth have been developed. In the winter climate zone, where the average temperate is below zero degrees during the coldest month, this work has just begun.

An important milestone was Victor Olgyay’s DESIGN WITH CLIMATE – bioclimatic approach to architectural regionalism (Olgyay 1963). It deals with the age-old problem of man, the problem of controlling his environment and creating conditions favourable to his aims and activities. The main target is to show the influence of climate on building principles. The approach is global and covers many disciplines.

According to Olgyay biological know-how is needed to measure and define the requirements of comfort, meteorology to review the climatic conditions, and engineering for the attainment of rational solutions. He calls for a new principle of architecture that blends past solutions of the problem of shelter with new technologies and insights into the effects of climate on the human environment. Being a handbook, an abundance of analysis techniques, tables, useful illustrations and guidelines are presented. Climatic, solar and area evaluation techniques are presented, site selection discussed, the meaning of building forms shown and airflow patterns analysed.

Some figures about microclimatic effects are rather inexact, some examples of building types in different climate regions misleading and settlement lay-outs un-ecological. Although some of his analysis methods are impractical in everyday use, and have been outdated by CAD techniques, the greatest part of the text is still valid. Many of his drawings have been published in various books and redrawn by other researchers. Olgyay’s book is a library rarity today.

A book named DESIGN FOR NORTHERN CLIMATES by the Canadian Vladimir Matus is perhaps the most systematic result of the ways of thinking that
have emerged amongst the Winter City movement (Matus 1988). The book presents a planning method developed for residential areas and buildings.

Planning begins with an analysis of the relationships of sun, wind and water; the results are condensed into an Ecochart. The shapes of the terrain and the sunniness data of the area being planned are combined into a Slope Descriptive Synthesis document, which describes the supply of solar energy in the sections of the area. These analyses make it possible to situate and design buildings in a way that reduces the need for heating and cooling. The supply of sunlight can be further verified with the Skydome drawing developed by Matus.

The book also deals with the phenomena caused by compact city structure, such as a heat island, reflection of the sun on the street, micro-climate and air quality. No actual analysis method for this kind of environment is given, however. Instead, the author recommends including aerodynamic experts in the planning group. The value of the Ecochart method is diminished by the fact that planners in reality very seldom want to do the complicated exercises that are demanded.

The CLIMATE AND HOUSE DESIGN handbook is intended for architects of residential buildings working in different climate zones, with its main emphasis being on tropical zones. (Climate) The method developed by the London-based Department of Development and Tropical Studies of the Architectural Association is divided into three stages: drafting, development of the floor plan, and application of climate elements.

Drafting is a process aimed at the overall view and its purpose is to replace traditional thinking, which is based on separate HVAC. According to the method, planning is started by collecting monthly climate data and identifying climate problems using Mahoney tables (Appendix 8, Fig. 149). The tables provide guidelines for what kinds of basic solutions the climate requires.

The book facilitates drawing of floor plans by presenting a group of studied building types that can be used as starting points for design. The selected type is then adapted to local conditions. In addition to climate, the choice of building type is influenced by social customs, economics, building heritage, type of surrounding community, population density, etc. An activity chart of the day and night activities of family members is drawn up; this helps in interior and exterior space allotment and in details design. The need for climate protection can be concluded by comparing day and night routines and daily climate conditions.

The third stage involves detailed matching of building elements with the climate of the area. At this stage the size, direction and shielding of openings; the properties of the exterior walls; the details of the roof, etc., are specified. The
objective is good daylight, protection from excessive sunlight, functioning natural ventilation and natural cooling and heating. Another goal is to reduce the inconveniences of moisture or dust with the design of building elements.

Although the system is quite simple, only very few planners and architects have learned to use it.

**Bioclimatic planning**

The word bioclimatic has been used by some researchers, but there is no consensus about the exact content of the concept. In Scandinavia Sterten has used the term to describe his methods (Sterten 2001). Maybe the most exhausting description is the one proposed by Higueras (Higueras 2006: 26–32):

- harmonise the needs of nature environment, functions, traffic, built structure and the needs of inhabitants
- acclimatise actively and passively urban structure and buildings to local circumstances
- protect and strengthen the circular processes of nature, especially water cycles
- take pedestrian and public transport as the starting points of planning
- strengthen social community, boost safety and healthy, secure inhabitants’ participation in planning
- develop sustainable ways of using nature resources in urban infrastructure and industry; minimising the ecological footprint
- create a harmonious multi-functioning urban structure; abandoning the zoning of mono-functional areas
- create a continuous net of nature spaces
- plan areas dense enough that can maintain services, employment, local economy and public transport
- unify and harmonise the cityscape, and create a pleasant environment and a good micro-climate.

The book of Higueras is practical because it gives a good understanding of the phenomena and rules of thumb, but one does not need to learn any complicated formulae or carry out specific calculations.
2.6 Present wind testing methods

2.6.1 Wind tunnel testing

Mathematical modelling is the oldest method of studying air flows, as Newton used it in his studies already in the 1600’s. Using this method requires considerable expertise in aerodynamics. Nevertheless, the accuracy and reliability of this method are poor. (Vakkuri 1993: 28)

The first wind tunnel was built in 1871 by the English inventor Wenham. It consisted of a horizontal box about 12 feet long and 18 inches square. Wind tunnels today are classified into subsonic and supersonic ones. They can be configured as open- or closed circuit systems. Vertical wind tunnels have been built to study how smoke, toxic particles or other substances travel upward through tall buildings or urban canyons between buildings. (Newton 2003: 231–233)

Earlier most studies on the impacts of wind with big boundary layer tunnels concentrated on building construction and stability problems. For architectural purposes many tests have been conducted in small unprofessional wind tunnels or blowers with smoke or other indicators, but the results have been incomplete because they were only based on analyses of vertical sections or the air-flow field had wrong properties. Therefore, turbulence in the horizontal sections along the building’s side at ground level did not get any attention or was only mentioned as “strong winds at ground level”.

Olgyay has described a more specific, simple and illustrative method regarding flows around a building. However, the description is incomplete when it comes to wind on the lee side as well as in many details. The best and most specific report about air flowing around an object has been written by Benjamin H. Evans. Wind tunnel tests were carried out in the Texas Engineering Experiment Station already in the 1950’s. Jensen and Frank studied the size of the lee side area for a separate building from the pedestrian’s viewpoint and the impact of wind on building groups.

Beranek and Van Koten tried to improve the pedestrian’s milieu with the help of a small-scale test system using water and sand. Grooves in the sand formed by water were enough to indicate air flows near the ground. Similar equipment is also used in Canada. (Jensen 1964; Evans 1972: 1–2; Børve 1987: 41–43)

Three-dimensional flows that happen in the built environment cannot be observed with the help of sand and water, which may prevent the development of
corrective measures. In practice, the equipment is expensive and heavy, and special waterproof models are difficult to make.

Mentions of the use of sand or powder in scale models were found in many sources. Architecture schools in Oslo and Trondheim (Norway) have illustrated air flows using ordinary air-conditioning devices which have not been calibrated. These model results have been roughly compared to snow accumulation and wind around buildings. Various scale models and materials have been used in the tests. So far, no systematic series of tests has been performed. The author and Vakkuri measured the properties of the equipment used at those Norwegian schools at the VTT Oulu laboratories, and found that the performance was pretty poor; the good quality air-flow was only about 5 cm high at its best, and the flow-field narrow and irregular in form. (Børve 1987: 41–43; Vakkuri 1993; Sterten 2003)

During the past years large boundary-layer wind tunnel tests have been used more and more in planning big construction projects and high buildings and bridges everywhere in the world (Fig. 18). These tests are used to determine the effects of static and dynamic wind loads on building structures. This information is needed for special structures when standard tables cannot be used. The plans of large areas on the seacoast sometimes include studies of wind conditions with the help of scale models.

Fig. 18. Overall arrangements of a large wind tunnel. (Simiu, cit. Vakkuri 1993: 23)
Wind load affecting building structures can be measured with scale models placed inside a wind tunnel. A power scale that measures aerodynamic loads placed inside the model can be used as a measuring instrument. When investigating truss structures and especially bridges, aeroelastic models that can stimulate an object’s vibration characteristics are needed. Also the accumulation of ice on building structures can be investigated. When designing chimneys and windmills, possible turbulence caused by the structures needs to be studied, and especially how it affects structures situated nearby. All the tasks mentioned above require the use of a very precise boundary-layer wind tunnel, which can simulate the wind speed profile at different heights. (Daniels 1994: 164–175; Miquel 1997: 32)

Research centres operating in conjunction with wind tunnels have studied area-aerodynamics relatively much, but despite this the results are not often utilised with building design or town planning. (Broas 1992: 2)

Various wind tunnels are used in Finland, and VTT’s aerodynamic equipment is commonly used for planning and building design. This equipment is a closed-cycle boundary-layer wind tunnel which is 12 metres long, 1.5 metres high and 2.5 metres wide. The speed distribution and turbulence of air flow of 0.2–30 m/s is made to correspond to wind by using triangular cones at the head of the measurement area and 5–25 mm high roughing elements every 9 metres. The direction, speed and turbulence of the air flow can be measured with a hot-wire anemometer, and the results are gathered into a computer file. The Kastelli research centre in Oulu is equipped with a climatic wind tunnel, with which tests in harsh climatic conditions can be performed. (Broas 1992: 7)

The use of wind tunnel experiments to measure flow fields is a well-established technique. A model of the study area is placed in a wind tunnel in which the velocity profile and turbulence characteristics have been reproduced at the correct geometric scale. Velocity measurements are made using hot wire anemometers, Laser Doppler velocimetry (LDV) or Particle image velocimetry (PIV) systems. Quantitative measurements of surface wind speeds can be made with erosion techniques. The information obtained from boundary-layer tunnel measurements of wind conditions at the measurement points is very specific and reliable. The problem is, though, that for practical reasons the measurement points cannot be placed as close together as would be necessary to actively improve a plan or building. Improving the plan by fixing the model and arranging measurements one after another is difficult and expensive, too. Micro-climate analysis can be improved by using smoke as an indicator in the tests and video-recording the results. The readability of smoke in building and planning models is
quite weak because of blending. That is why smoke is more suitable for model work with streamlined objects like cars. The protective effect of trees is often overrated in small-scale tests, perhaps because of the small-scale technique used. (Børve 1987: 99, 129; Daniels 1994: 164–175; Oulun 1994: 12; Koss 2002: 74)

In spite of the major progress in measuring techniques, a wind tunnel test will only deliver a certain number of parameters. These are usually wind field and its fluctuating characteristics. Other parameters like air humidity or thermal stratification are extremely difficult to simulate and quite expensive. The requirements for modelling the natural wind in a wind tunnel are described in the ASCE Manual of Practice. (ASCE 1999; Koss 2002: 74; Stathopoulos 2004)

The perception of windy conditions is of subjective character and consequently difficult to parameterise. The Table 4 below gives an example how many possible comfort situations results for a given number of sub-classification for some of the boundary conditions. This illustrates the need to limit the number of variables used.

Table 4. Example for sub-classification of boundary conditions.

<table>
<thead>
<tr>
<th>Boundary condition</th>
<th>Comment/examples</th>
<th>Number of classifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male/female</td>
<td>2</td>
</tr>
<tr>
<td>Activity</td>
<td>Walking, sitting, shopping, etc.</td>
<td>5</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>Effect depends on the activity</td>
<td>4</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>Mean wind speed at pedestrian level height</td>
<td>5</td>
</tr>
<tr>
<td>Type of the Wind</td>
<td>Constant flow, turbulent flow, gustiness character</td>
<td>4</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>Average value depends on season of the year</td>
<td>4</td>
</tr>
<tr>
<td>Air Humidity</td>
<td>Depends on season of the year/weather condition</td>
<td>3</td>
</tr>
<tr>
<td>Sun Radiation</td>
<td>Depends on area of pedestrian activity</td>
<td>4</td>
</tr>
</tbody>
</table>

Number of possible combinations = 153,600 (Koss 2002)

Wind tunnels and water flumes have been used for snow accumulation studies in Finland, Canada, the USA and Russia, and with open wind test blowers in Norway. Snow deposition has been simulated with different substitute materials and also with real snow in climatic wind tunnels like C.S.T.B. in France. Snow-substitute materials used include crushed wheat grains (*mannaryymi*) and other seeds, silica sand, glass beads, sodium bicarbonate, wood sawdust and borax. The topics of research have been snow accumulation on roofs, the penetration of snow into structures and snow around buildings. Because snow can generate asymmetric or variably distributed loading which can damage roofs, wind testing of large and
complicated roofs is needed. (Børve 1987: 28–40; Kääriäinen 1989; Kuismanen 2000)

For settlement planning snow testing is also important. Often snowfalls are accompanied by winds causing local drifting on streets, railways and courtyards, and disruptions in electricity distribution.

### 2.6.2 Computational Fluid Dynamics

With the development of computer-aided design methods, the question arises as to whether computerised wind tests can be done with 3D applications. One attraction of Computational Fluid Dynamics (CFD) is its ability to calculate all types of flows. The required hardware and software costs are decreasing.

Many attempts have been made, but until now the results have been discouraging. Difficulties with the modelling of atmospheric turbulence interacting with the structure-generated turbulent flow in areas of flow separation lead to uncertain or erroneous predictions. For instance, wind tunnel data and CFD were compared for a complex development in central London. The results demonstrate that at some measuring points the computer data was up to 47% smaller or as much as 213% greater than the airspeeds measured in the wind tunnel. These and other findings illustrate the difficulty of simulating complex flow structures using CFD, but in simple isolated situations computational techniques have brought acceptable results. (Westbury 2002: 172–181; Stathopoulos 2005: 8)

Different research reports confirm that in simple cases CFD simulation can reproduce reliable results fairly well, but the calculation load is very large. In simple cases the computer simulations correlate with the wind tunnel results. The simulation is not enough, but after it expert knowledge about the interpretation of the data and defining conclusions is needed. The figure showing tests at Tokyo Polytechnic University shows a comparison of wind tunnel results and CFD modelling, and an under-prediction of wind pressure on the building edge can be seen in the Fig. 19. During another research project concentrations of pollution in urban space were modelled and the results were compared with those of wind tunnel tests. In non-steady conditions using the standard $k$- model and the LK model, the pollution concentrations on the rear surface of the building tended to be estimated to be higher than those from the wind tunnel tests. Using the RNG model that reproduced periodic vortex shedding in the boundary layer flow, the results were improved. (Jensen 2004: A.2.1–6; Wind Effects 2005: 4, 6)
Fig. 19. Pressure coefficient distribution.

According to the tests at the Tankang University the CFD procedure tends to underestimate the actual wind load by 13%, which limits its use only to the preliminary building design. But often in large urban areas CFD simulations of pollutant concentrations within roadway and building microenvironments are feasible using high performance computing. However the tools are not well evaluated for air quality modelling and best-practice methodologies have not been established. It is estimated that in future CFD simulations have the potential to yield more accurate solutions than existing regulatory air quality models, because CFD models solve the fundamental physics equations including the effects of detailed three-dimensional geometry and local environmental conditions. CFD developments are being evaluated by comparing them with both wind tunnel model and field measurements. In some cases there have been differences between modelling and wind tunnel tests results during this development work done by the National Atmospheric and Oceanic Administration of the US. Evaluation of design wind speeds is continuing (Huber 2006: 10; Chi-Ming and Jenmu 2007: 6–8; Wind 2008: 3–4).

Experiments to use CFD in the design of natural ventilation have been made. Wind-induced ventilation is a phenomenon of very complicated turbulent flow because of the interaction of internal flow with the envelope flow. The results have usually been relatively poor, and further research is needed to handle the complicated flow geometry of building interiors and the interaction of internal flow and outdoor flows. Some latest applications have given promising results.
Engineering Fluid Dynamics (EFD) is a new breed of Computational Fluid Dynamics (CFD) software that enables mechanical engineers to simulate fluid flow and heat transfer using 3D CAD models directly. (Wind 2006: 1–3; Annual 2007: 1–7; Natural 2008)

Various research centres are developing new CFD programmes. E.g. a CFD solver for predicting the wind pressure field on structures immersed in an atmospheric boundary layer is being developed. Numerical experiments of channel flow, cavity flow and flow around bluff bodies have been conducted to check the accuracy of this solver. For outdoor environment analyses CFD models are developed for predicting pollution levels in urban locations. But the CFD simulations do not take into account the gustiness of the incoming wind. (Jensen 2004: A.2.1–6; Wind 2008: 3–8)

Today the CFD approach does not have equal potential in terms of quality as properly performed wind-tunnel studies, which is important to realise when establishing static or dynamic design wind loads, as this might have severe consequences for the safety of human life. But computerized techniques provide adequate answers when modelling the wind at the pedestrian level, because mistakes here are not so dangerous.

2.6.3 E-wind

The design codes and standards for wind resistant design are usually complex and prone to misinterpretation. Often it is difficult for the average structural engineer to understand and properly utilise the building wind code, and it is not unusual to find errors in wind resistance design practice. For various reasons wind tunnel tests are not often used. Therefore, an alternative approach is needed to provide an economic yet reasonably accurate solution for the wind resistant design of tall buildings; at least at the stage of preliminary design. E-wind, which is developed by the Wind Engineering Research Centre at Tankang University is one answer to that. (Chi-Ming 2007: 6–8)

E-wind is a scheme to promote wind engineering applications. It provides wind engineering analysis, calculation and service on the Internet. It implies that wind engineering components, such as wind code, aerodynamic database, analytical models and CFD should be digitized, integrated and accessible online. The latest information and web technologies are adopted to facilitate the user-friendliness and easy accessibility. The flow chart below (Fig. 20) shows that the
wind code, aerodynamic database, the analytical wind engineering procedures and CFD are the essential parts of e-wind.

![Flow chart of e-wind. (Chii-Ming 2007: 6)](image)

The e-wind components are:

1. Aerodynamic database for isolated tall buildings. More than 60 building shapes have been studied already.
2. Aerodynamic database for building interference. The interference effects of different building shapes have been analysed and recorded.
3. Web-enabled design wind load expert system for tall buildings. A case-based expert system based on the aerodynamic database. This also incorporates analysis procedures of structural dynamics, wind load modification methods and heuristic knowledge of wind engineering.
4. Wind code based expert system for building wind resistant buildings. The user can go through a guided process to input building geometry, surroundings and structural properties step by step. The expert system finds the appropriate section of the code, calculates the necessary coefficients and parameters and works out the wind load distributions for structural designs.
5. Application of CFD to building wind resistant design. The CFD technique can be used to predict the mean wind load of an isolated building in the preliminary building design.

A simple version of e-wind is functional and can be accessed at http://windexpert.ce.tku.edu.tw/. In spite of the rapid development in both computer hardware and software, the CFD models or the e-wind cannot replace wind tunnel...
tests when designing tall buildings, groups of buildings or other complicated objects. Due to the versatility of building geometrical variations, currently the aerodynamic database should not be used at the detail design stage. (Chi-Ming and Jenmu 2007: 6–8)

There is a growing number of different databases of climate and building on the web. One example is the Japanese Aerodynamic database of low-rise buildings of the Tokyo Polytechnic University at www.wind.arch.t-kougei.ac.jp. It is based on a series of wind tunnel tests, and with this data local wind pressures, surface wind forces and even dynamic responses of a low-rise building can be calculated. (Quan 2007: 12)

2.7 Need for an environmentally-conscious planning method

2.7.1 Needs

Most nations have agreed in the Kyoto Protocol on the reduction of greenhouse gases, and the construction sector is one of the main actors in achieving the target level. Therefore, it is important to follow ecological design criteria that allow savings up to 30–50% in the amount of energy necessary for heating, cooling and lighting. To achieve this in reality means that practical planning and architectural design tools ought to be developed. Also WMO links the climate change to the need for sustainable development of energy, transport and land use, and more generally to less carbon-intensive world economic development. (World 2007: 5–28) Many researches stress that the socio-economic dimension of climate change should cut across each of the disciplines studied, and be integrated within any adaptation strategy (Adaptation 2008: 2).

The criticism of modern housing and planning has become stronger during recent years, and there is a demand for holistic approaches. Using the whole of the existing reality as a starting-point requires entirely new planning methods. According to Liddell, if we are to move forward from individual eco-houses, mini eco-villages, green expos and pilot projects towards mainstreaming ecological design as an integral part of building for the 21st century, then it is crucial that it is accessible, economic, genuinely environmentally-sound, gimmick-free and not stigmatised as a style. One should use an eco-minimalist approach instead of quick fit and bolt-on technology. (Holmdahl 1993: 275–285; Liddell 2007: 22–29)

The majority of the climatic architecture theories stress one or two factors only, and the result can be wind-oriented, heliomorphic etc., losing the holistic
approach to the question. For instance, according to the models the climate in Scandinavian countries is most of the time outside the criteria of comfort, but nevertheless the majority of inhabitants regard their four seasons as a quality of life. Until very recently, research on climate/environment relationships has been mainly directed towards problems arising in the tropical and sub-tropical world. (Matus 1988; Dunin-Woyseth 1990: 342–352)

The urban heat canopy creates discomfort, and innovative solutions to the problem of zero-energy climatisation of open spaces would be of great help to planners and architects. The acquired know-how could be used to create “guidelines” to assist municipal authorities, town planners, architects and industrialists in this matter. (Gallo 2002: 10–15)

A harsh climate causes problems especially for disabled and old people in the wintertime. Slipperiness together with wind makes walking more difficult and dangerous and is a reason why many old people become disabled every year. Slips on ice cause more than 20 deaths and cost 30–60 million Euros every year in Finland. Despite of all this, according to Reima Pietilä, modern architecture in Finland has forgotten to pay attention to the climate. We have sufficient information about our environment, but no suitable design method, which means more development work is needed. (Pietilä 1971: 554; Glaumann & Westerberg 1988: 74; Liukkaat 2005; Talvisia 2008)

Assessment of storm damage to buildings and the development of methods to avoid them are of interest to several parties, like (Munch-Andersen 2002: 32):

– code committees and building authorities in order to evaluate the performance of design rules
– insurance companies in order to assess their risk
– authors of guidelines and instructions in order to focus on general flaws in design and construction
– designers and contractors in order to avoid responsibility for failures.

As we have seen in previous chapters, there is an abundance of different climatic theories and design systems. Unfortunately most of them are quite general, and do not give tools for practising architects and planners. Some of them, like Mahoney tables, Sterten’s diagrams or Skydome, need complicated indexing and calculations, and remain therefore unused in practice. A common problem is how to describe the micro-climate and the affects of building on it. Especially the problems of high-density urban areas remain unanswered. Some authors, like Mathus, simply mention at the end of their texts “this knowledge should be
provided by experienced aerodynamics professionals collaborating with the design team”. Erat has developed a practical solar design method, but unfortunately it is valid only for solar-oriented projects which have a plot use ratio less than 0.40. Fortunately his other publications complement the picture.

Except for a few cases, neither architecture nor city planning have taken the problems caused by windiness into consideration. Wind protection of the immediate surroundings of buildings has not been studied much, and the results obtained are hard to use because the principles are presented as generalisations. For instance, some of Erskine’s models can be questioned in terms of climate-wise planning, although new information about construction methods suitable for harsh conditions has been found. Big buildings in Kiruna and Svappavaara, which Erskine planned, have problems such as windiness in uncovered yards, coldness of the north wall constructed against the wind, a large amount of snow and snow accumulation on the north side that remains long into spring. The solar studies of Le Corbusier were directed mostly to the design of building volumes and the design of sun shading motives, brise-soleils. Anne Brit Børve has developed a practical climate analysis method and design guidelines, but unfortunately her landscape classification covers only the Norwegian morphology, and the guidelines are mostly for windy coastal mountain areas in a cold climate.

There is an abundance of basic research on climate and architecture, but in most cases the link to practice is more or less weak. Present methods of town or street planning do not include an overall analysis of local climate, and especially winter conditions are not considered enough in these methods. Using snow accumulation as a starting point for house and town planning is difficult, because there is very little studied information about the matter.

An important finding during many discussions of the Winter Cities Forums and the Working Group Education sessions was, that in most cases, in connection with smaller or medium sized planning or architecture commissions, there is neither time nor economic resources for nature analyses performed by special professionals. It was concluded that there is a need for a simple nature analysis method that could be used by the planner during other field work. The pilot planning projects carried out by the author brought out that such an analysis adds much to the understanding of the micro-climate of the actual site, and gives tools to develop the wind shield vegetation.

Another observation during the discussions mentioned above was that there is a lack of built environment analysis methods, too. There are many methods for townscape and function analysis, but they do not add much to the understanding of
the micro-climate of the urban structure. There are also studies about the wind fields around buildings or building groups, but even the latter do not give tools to analyse or explain the climatic phenomena of larger urban areas.

Greenery has an impact on micro-climates, and has potential to adapt cities to climate change. Unfortunately little is known about how climate change may affect greenspace structure and function and how this, in turn, will impact back on the urban environment. (Adaptation 2008: 3)

Today it is difficult to compare the information from different countries due to different data collection techniques, and this reinforces the need for a common methodology in that field.

In spite of the rapid development of computer programmes the fact is that the use of different CFD models give different results, which often are not in harmony with reliable wind tunnel tests. The most advanced programmes are expensive, calculation loads heavy and to use them special engineering education is needed. That is why they cannot be used in “normal budget” architectural projects. It also has to be kept in mind that CFD simulations are performed for a fixed wind velocity and direction and do not take into account the gustiness of the incoming wind, except for a global turbulence level. Today the CFD modelling is not as reliable as wind-tunnel studies, and this can cause danger. But development work is going on, and the use of CFD will surely increase. Even in that case there is a need for a climate-conscious planning and design methods, because the CFD code does not draw conclusions from the analysis data.

2.7.2 Use of climate-conscious architecture

Climate data is today used to solve large-scale problems. Examples of sectors that have already benefited from the application of climate knowledge and prediction include aviation and marine transport, agriculture and food security, health, water resource development, use and conservation, energy supply and allocation, and the management and conservation of biodiversity. Climate knowledge and applications have also been used in international, national, and local planning and in response to the impacts of natural disasters associated with climate extremes. This includes reducing the impacts of floods, droughts, tropical and extra-tropical cyclones, extreme temperatures, avalanches and landslides, and human, animal and plant disease outbreaks. The importance of forecasting and early warning systems is growing along with the climate change. (World 2007: 35; Wind 2008: 4)
The impacts of different climatic parameters are analysed when placing health spas and when defining their balneologic treatments. Medical climatology examines useful climate factors, which are partly physical and partly chemical by nature, and how they function in co-operation with other treatments. (Ott 1975)

Unfortunately in planning and architecture the use of climate-conscious methods is unusual, although it brings indisputable benefits. The potential to apply the CASE method developed in this research is discussed in Chapter 7.

**Summa summarum:**

- climate change is proceeding with increasing speed
- damages caused by climate phenomena are on the rise
- in most built areas discomfort caused by wind, coldness, overheating, rain or snow is a problem
- there is a clear need to develop both a practical planning method that is climatic-conscious, as well as wind test equipment that is easy to use
- studies into the effects of climate change to built environment are needed
- guidelines on how to provide for the climate change should be developed.
3 Climate in built environment

"Die Mauern stehn / Sprachlos und kalt, im Winde / klirren die Fahne“
(Hölderlin: Halbte des Lebens)

3.1 Influence of climate on people

This chapter discusses the impacts of temperature, solar radiation, humidity and air-flows on man. The effects of wind on people, buildings and building groups are presented.

3.1.1 Components of micro-climate

Climate is comprised of temperature, humidity, rain, movement of air and solar radiation (Fig. 21). A precondition for climate-conscious planning is to specify numerically expressed target levels for those factors which can be affected by planning:

- temperature
- humidity
- movement of air
- solar radiation.

Fig. 21. Air temperature, surface temperature, humidity, air flow speeds and natural lighting affect the micro-climate of building sites. (Guyot 2007)
3.1.2 Temperature

The temperatures of an area are dominated by the macro and micro-climates, and there are only very limited possibilities to affect the outdoor temperatures of a built environment. But in a defined micro-climate area it is possible to raise or lower the temperatures. During cold seasons temperatures can be raised locally by making the micro-climate of the site better. During warm seasons or in warm regions temperatures can be lowered with shading, vegetation, evaporative cooling and air movement.

It is not possible to give any exact target levels for outdoor temperatures, the subject matter is discussed in 3.19. Indoor temperatures are discussed in 3.18, and the ventilation guidelines in Chapter 6.7.

3.1.3 Solar radiation

Solar radiation provides all the energy for the natural processes that take place on the earth. The spectrum of the sun’s radiation extends from radio wavelengths to beyond the ultra-violet. As much as 98% of the energy lies between 0.2 and 3 micrometers. Solar radiation has two types of effects on buildings. First are actinic i.e. photochemical reactions, which are modification of colours or paints and modification of polymers and natural synthetic elastomers. The second group of effects is thermal, which includes rise in external envelope temperature, deformation and modification of strength and elasticity. (Palier 2002: 129–131)

The world receives 10,000 times more solar energy than the total energy need of mankind. In southern latitudes there is enough or too much sunlight during the whole year (Liébard 1996: 13). In northern regions there is lack of sunlight during the winter months, but in spite of that there are only very few exact guidelines concerning the solar access of dwellings. In Sweden the former building code already during the 30’s demanded that a dwelling must be exposed to the sun 5 hours at the equinoxes, and children’s playgrounds to 5 hours between 9.00–17.00. Today the regulations in Sweden do no longer give such exact rules about sun hours (Solklart 1991). According to Higueras four hours of sunshine is needed in the northern latitudes (Higueras 2006: 153).

Up in the north attention should be paid to the fact that the midnight sun might be an asset to the area.

The meaning of sunlight in town building was realised again at the beginning of the 20th century, when people started to criticise big cities’ dark and close
apartment house milieus. The critique of stone cities led to functionalism. This new style answered the demands for more sun, so the open city space was adopted as an ideal style everywhere. Nowadays a growing part of the population, pensioners, spends most of the day in their residential environment, which increases the significance of the sun in housing design.

3.1.4 Humidity

The humidity of an area is affected by the climate, vegetation, soil conditions and handling of surface water. Too high humidity, which often manifests itself as fog, rain, snow and frost, can cause many troubles in everyday life and especially to traffic.

There are no possibilities to give numeric levels for the outdoor humidity conditions caused by climate, but some practical criteria are possible. It can be said that the humidity of an area can change dramatically in different seasons, especially in such climates as monsoon or Mediterranean. The figure in Chapter 1.3.3 gives a good global overview as to the affects of climate change on precipitation, soil moisture, runoff and evaporation.

For indoor air humidity there are health recommendations according to which the relative humidity of indoor air should be in the best case between 40–60%, or at least 30–70%. Higher or lower humidity can course health risks or damage structures as described in Fig. 22.

![Fig. 22. Too dry or humid indoor air can have harmful consequences; recommended relative humidity lies between 40–60%. (Indoor 2008)](image-url)
3.1.5 Air flows

Probably the first published classification of wind effects on people was published by Penwarden. A number of studies by Hunt et al, Penwarden and Murakami were subsequently carried out in the 1970’s and early 80’s to actually measure the effects of wind on people. In all of these studies wind tunnels were used to provide a controlled wind environment in which to determine the drag force on people under controlled conditions. It can be concluded that the phenomena is so complex that a complete and profound description is not possible. The large number of boundary conditions leads to an immense high number of combinations each defining a specific perception of the ambient wind. The following boundary conditions are mentioned in most sources (Blackmore 2002: 60; Koss 2002: 71–75):

- age of people
- gender (wear, hairstyle male/female etc.)
- activity
- exposure time
- mean wind speed
- type of the wind (constant flow, turbulence, gustiness character)
- air temperature
- air humidity
- sun radiation
- season of the year
- atmospheric pressure (meteoro-sensitivity)
- weather condition (what kind of weather is presumed)
- geo-social factors (acceptance level).

According to Murakami and Lawson the effect of wind on walking people can be classified in five grades (Blackmore 2002: 60; Koss 2002: 71–75):

Grade A  No effect
Grade B  Sensitive to wind (Face turns sideways to avoid gust)
Grade C  Upper-half of body bends to windward
Grade D  Whole body bends to windward, whole body swings
Grade E  Risk to be blown over causing severe injuries and risk to life

Based on their wind tunnel tests with people, Hunt and others have published wind comfort criteria, Table 5 (Hunt & al 1976). Windiness can be described by calculating the equivalence wind speed, which takes turbulence into account in addition
to the mean velocity thus giving a better view of how human beings experience the wind. The equivalent wind speed comes from the equation:

\[ V_{ekv} = V(1 + k \times Tu) \]

in which

- \( V_{ekv} \) is the equivalent wind speed
- \( k \) is a factor showing the weighting of turbulence
- \( V \) is velocity without dimension
- \( Tu \) is turbulence intensity.

According to Hunt, the factor \( k \) is 3, based on wind tunnel tests. Due to the wind chill in winter, the weighting of mean velocity is greater, and the factor \( k \) can be smaller in winter. (Hunt & al 1976)

**Table 5. Hunts wind comfort criteria.**

<table>
<thead>
<tr>
<th>Class</th>
<th>Effect</th>
<th>Max. wind speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>minor effects to comfort or actions</td>
<td>( V_{ekv} \leq 6 \text{ m/s} )</td>
</tr>
<tr>
<td>II</td>
<td>no effect to tasks</td>
<td>( V_{ekv} \leq 9 \text{ m/s} )</td>
</tr>
<tr>
<td>III</td>
<td>control of walking</td>
<td>( V_{ekv} \leq 15 \text{ m/s} )</td>
</tr>
<tr>
<td>IV</td>
<td>safety of walking</td>
<td>( V_{ekv} \leq 20 \text{ m/s} )</td>
</tr>
</tbody>
</table>

Besides these objective investigations, for the defining of wind comfort criteria it is important to analyse people’s reaction to wind during different activities and in different kinds of areas. Wind can be regarded as acceptable, if it elicits no comments about it. Tolerable are conditions, which would be described as “windy”, but which would be tolerated for the given activity. Unacceptable are unpleasant conditions for the given activity and the given user group.

A more exact classification system of pedestrian activities in association with the Beaufort scale is made by Murakami and shown in Table 6 below (Blackmore 2002: 60; Koss 2002: 71–75):
The risk of falling and getting injured is high in winter, and especially when the wind is gusty. Walking outside in gusty wind is difficult, especially if wind speed changes strongly and uncontrollably. Building corners, for example, often have a strong turbulence flow. Especially balconies and play areas need protection, because even a few units of change in wind speed causes a 5–10 degree drop in the temperature sensation. Wind pressure at a mean wind speed of 5 m/s is so high that it is impossible to sit outside and read a newspaper. If the mean wind speed is 10 m/s, it is hard to stand upright in gusts of wind, because wind speed can be more than twice the normal mean wind speed. If wind speed in gusts is higher than 20 m/s, trees may be blown down and bicycling and walking are impossible or very difficult. Wind drives snow at an average of 3–5 m/s, and also sand and dust travel with the wind. Industrial and traffic pollution is carried to housing areas by wind, but on the other hand it is also possible to ventilate them out of such places. (Børve 1987: 17–23; Glaumann & Westerberg 1988: 74–81)

The objective and general definitions mentioned above are commonly accepted in the literature, but significant differences are found in the categories of acceptable wind climate used by different research institutes in their wind-tunnel tests and climate analyses. The starting point of these categories can be either a classification of pedestrian activities or the areas where these activities take place. Quite many mixed approaches exist, too. (Koss 2004: A.2.1–6; Wind 2008: 6)
The Swedish Statens Institut för Byggforskning (SIB) researchers have examined how wind is experienced and they have proposed windiness criteria for lounging areas in a cold climate, see Appendix 9, Table A/I. The criteria apply to wind at a height of 2 m, while meteorological statistics are measured at a height of 10 m, for which reason 1/4 needs to be subtracted to obtain the correct value. In practice, the recommendations on the right side of the table are usually easier to use. SIB’s researchers gave the recommendations presented in Appendix 9, Table A/II, on the basis of wind measurements and interviews. (Glaumann & Westerberg 1988: 79–81)

It should be remembered that gustiness often makes wind in built areas more disturbing than on an open field, and the recommended mean wind-speed ratios should be adjusted in each actual situation.

<table>
<thead>
<tr>
<th>Wind m/s</th>
<th>10</th>
<th>6</th>
<th>3</th>
<th>0</th>
<th>-5</th>
<th>-10</th>
<th>-16</th>
<th>-22</th>
<th>-28</th>
<th>-35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>10</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>-5</td>
<td>-10</td>
<td>-16</td>
<td>-22</td>
<td>-28</td>
<td>-35</td>
</tr>
<tr>
<td>Freezing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncovered skin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-6</td>
<td>-11</td>
<td>-16</td>
<td>-21</td>
<td>-25</td>
<td>-30</td>
<td>-35</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>-6</td>
<td>-11</td>
<td>-16</td>
<td>-21</td>
<td>-25</td>
<td>-30</td>
<td>-35</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>-24</td>
<td>-29</td>
<td>-34</td>
<td>-39</td>
<td>-44</td>
<td>-49</td>
<td>-54</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>-24</td>
<td>-29</td>
<td>-34</td>
<td>-39</td>
<td>-44</td>
<td>-49</td>
<td>-54</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>-30</td>
<td>-35</td>
<td>-40</td>
<td>-45</td>
<td>-50</td>
<td>-55</td>
<td>-60</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>-30</td>
<td>-35</td>
<td>-40</td>
<td>-45</td>
<td>-50</td>
<td>-55</td>
<td>-60</td>
<td>4</td>
<td>9</td>
<td>13</td>
</tr>
</tbody>
</table>

Fig. 23. Effect of wind-chill. (Lehmuskallio 2000: 2)

In a cold climate the combination of wind and low temperature is experienced as wind chill. It is a qualitative measure of the relative discomfort felt on exposed skin. The body loses heat through convective heat loss faster when there is air movement. Cold wind can be even dangerous, see Fig. 23. For instance the combination of 10 m/sec wind and -10°C temperature gives a wind chill ratio of -30°C (Lehmuskallio 2000: 1–2). For this reason the City of Montreal has different limits for discomfort in summer 6 m/s and winter 4 m/s (Stathopoulos 2004: B.1.3).

Air movement increases human comfort in warm climates at air speeds of between 0.4–3 m/second. For instance air flow of 1 m/second will reduce an air temperature of 30°C to an effective temperature of 27°C. But also in warmer climates higher wind speeds are regarded as negative. According to Jackson, 60–70 percent of the people on a shopping street in New Zealand reported wind
discomfort if the hourly mean wind speed was over 5 m/s. (Glaumann & Westerberg 1988: 94; Liébard 1996: 27–33) Spanish researcher Neila gives much lower comfort rates, recommendable between 0.0–0.6 and acceptable 1.1–2.0 m/s (Neila 2000: 29).

**3.1.6 Impact of weather and climate on people’s behaviour**

The weather affects people’s behaviour in three ways:

1. People consider it very important to maintain their thermal equilibrium.
2. People avoid doing things that are hindered by the weather.
3. People react to the amount of light, which puts them in a good or bad mood.

Weather-related processes that affect behaviour are often subconscious or related to subconscious behaviour. They are not noticeable in everyday life, but on the macro-level they are reflected by the volumes of people travelling to various places and in their buying behaviour.

The process that controls people’s behaviour is the body’s thermal equilibrium with the surroundings. If this thermal equilibrium is disturbed in one direction or the other, the body reacts to this immediately. In that case people attempt to dress to achieve and seek such conditions where their thermal equilibrium with the surroundings is retained. Thus, these attempts to preserve thermal equilibrium control people’s behaviour.

The second impact of weather on behaviour is the preventive or hindering effects of weather-related factors on activities. In rainy weather people avoid getting wet and stay indoors. During a snowstorm they avoid driving, and in bad weather they prefer to go to a shopping centre with a covered parking area rather than to an ordinary store.

In a cold climate, according to Kari, Pressman and many lecturers at the Winter Cities Forums, in sunny weather people are in a good mood, they are active, and they make economic decisions. In cloudy, dark weather people are depressed and they are usually passive, although they try to compensate for their depression by eating well and granting themselves small “rewards”. (Pressman 1995: 53–58; Pienilmaston 1997: 2)

During the last few years the view of winter as a dangerous and unpleasant season has partly changed: winter is experienced also as a positive, sunny and sporty season that nowadays provides many different opportunities. Advanced
techniques have made it possible to forget the environment, but at the cost of increased energy consumption and environmental problems. (Bjørge 1992; Mänty 1988)

When broadly examined, a human’s climatic experiences are also affected by things like warm or cold colours and the noise of wind. Different factors that affect environmental experiences and the units of measuring those experiences are shown in a table in the Appendix (Appendix 9, Table A/III). The primary level of an experience is purely physical. The secondary level of the experience can be described as esthetical and experimental. This level is also strongly present when discussing experiences of the built environment or architecture. Rossi writes:” I ask myself how the seasons enter into architecture. I pause at the Milanese Galeria in the winter when the fog has entered it”. (Rossi 1985: 33)

Experiencing space is a comprehensive process in which the senses of sight and hearing transfer information. On the other hand, space is evaluated by the climate protection it offers as well as by positive climate experiences. But then again, space qualities consist of visual experiences too, like rhythm (space, time), highlights and contrasts (intensity, colour, shade, volume). These qualities depend on light and weather, so they affect differently at different times of the year and day. Noises fulfil the space experience we get from our environment, and in many cultures the noise environment is an important part of the atmosphere of a place. Esthetical experience is always bound to a person’s cultural background. In extreme cases experience is influenced by a psychological phenomenon such as claustrophobia or agoraphobia. (Serra 1999: 13–17)

### 3.1.7 Impact of climate on people’s comfort and health; medical climatology

As the temperature of the air drops below a person’s skin temperature (32° C), that person begins to lose heat to the surroundings. Heat is lost through both conduction and sweating. Metabolizing in the muscles strives to compensate for the loss of heat. At temperatures over 20° C, both temperature and relative humidity affect heat loss. Growing wind speed increases the removal of heat released by conduction and the evaporation of sweat. As the temperature decreases below 20 degrees, the significance of heat released through evaporation begins to diminish, and at temperatures below 10 degrees, relative humidity no longer has any significance. Heat loss can be prevented with clothing. At low temperatures the significance of wind speed increases, and at very low freezing temperatures wind speed has a
much more significant impact on heat loss than changes in temperature. Solar radiation also has a significant increasing impact on the sensed temperature.

A number of indices that take into consideration air temperature, relative humidity, wind speed, and solar radiation have been developed to depict people’s feeling of comfort. However, none of them can be applied to the entire range of temperatures, +/- 50°C, in which people live and function.

Fig. 24 presents a set of comfort curves that depicts comfort experienced by people in winter and summer. The shaded area indicates temperature and wind speed ranges that people experience as uncomfortable. At low temperatures, wind has a major cooling effect, and the cooling effect of wind is emphasized at freezing temperatures.

![Comfort curves for winter and summer](image)

**Fig. 24. Comfort experienced by people in winter and summer in a cold climate.** (Pienilmaston 1997: 8)

In cold climates the effects of climate upon human health are considerable. There are chronic diseases which can be affected by weather conditions, notably heart and circulatory ailments, although weather, per se, may not be a causal factor. The main population groups that are susceptible to increased psychological stress in
northern winter are the elderly, and also the young, who are prone to depression. At high latitude locations some people suffer from Seasonal Affective Disorder (SAD), which is caused by changes in photoperiodicity, the day-night cycle, during dark winters. (Pressman 1995: 54–57; Pienilmaston 1997: 9–11)

In warm climates temperate air-flows are usually regarded as positive. In arid regions winds are usually strong during the midday and afternoon hours, subsiding during the evening. Dust storms are common mainly during the afternoons and they cause health problems and inconvenience.

In hot-humid areas refreshing air-flows release the thermal stress, thus having a positive effect on people’s health. The wind conditions depend on the distance from the sea and vary during the year, depending on the annual shifting of the trade wind belt. In coastal regions sea breezes provide air movement, mitigating the heat stress, but nights are often windless. Inland calms are frequent intensifying the thermal stress. Many coastal areas are subjected to frequent hurricanes and typhoons. (Givoni 1997: 380–382)

**Medical climatology**

Although natural mineral water plays a major role in choosing the location of a spa, a special medical climatology has been developed, particularly in Germany, according to which the location of new spas is assessed and the possible content of spa treatments is specified on the basis of natural conditions – water and climate (*Balneologie, medizienische Klimatologie*). Climate has both a direct physical effect and a mental impact on persons being treated. Climate treatment is used for chronic respiratory illnesses, cardiovascular diseases, dermatological symptoms and general weakness. As a curiosity may it be mentioned that while mankind battles against CO₂ gas, carbon dioxide emanating from the ground, "healing gas" (*Heilgassen*), is used in spas as an inhalation treatment.

For thousands of years, people with the possibility to do so have moved to residential areas they consider healthy, often to the mountains in summer to escape the heat. Thanks to research, our knowledge of the impact of climate on our health has increased considerably during the past century. In some hospitals specializing in respiratory diseases, climate is actually the most important factor of treatment related to nature. To be able to speak of a curative climate, according to FITEC’s (Fédération Internationale du Thermalisme et du Climatisme) rules a hospital has to conduct an extensive climate analysis and compile a climatotherapeutic medical operating plan. Studies have indicated that Germany is divided into bioclimatic
zones according to which doctors can estimate the amount of climatic stress their patients are subjected to and if necessary, recommend a change of climate. The bioclimatic characteristics of hospitals are also listed. (Becker 1975: 71–74; Deutscher 1975: 180–187; Glaus 1975: 8–18; Ott 1995: 29–42)

The impact of climate on health is based on thermo-hydrological (heat, air movement, moisture), radiation (heat, UV) and chemical effects. In addition the amount of ions in the air, the frequency of inversion situations, air purity and elevation above sea level are also important. For example, UV radiation in the mountains and air-born NaCl aerosols along the seacoast have a direct effect on health. Plants, especially forests, also affect the quality of the local climate.

Three primary healthy climate types are identified in Central Europe: intermediate mountain climate, high mountain climate and seacoast climate. Different areas have their own particular climates with health effects. For example, tuberculosis hospitals in Finland, the most familiar being Paimio Hospital designed by Aalto, are located on pine heaths. (Ott 1995: 29–42)

3.1.8 Human adaptation to the indoor climate

People have only a limited capacity to adjust to the surrounding circumstances. The human body tries to maintain a core temperature of 37° C; in hot conditions perspiration increases to maximise heat flow through evaporative cooling of the skin, and in cold air the reverse happens. Unbalanced distribution of warmth because of wind and direct radiation can also be experienced as unpleasant. The ultraviolet rays of solar radiation affect the skin in the form of thermo-chemical reactions, like sunburns and sunstroke. Relative humidity also greatly affects the range of thermal comfort.

The range of thermal comfort is especially limited indoors. Also, the temperature difference between two surfaces situated near to each other (e.g. a wall and a window) should not be over 5–10° C. The radiation temperature difference between the roof and the floor should not be higher than 2–5° C. The vertical temperature difference indoors should not be over 3° C. The affect of the surrounding surfaces is presented in Fig. 25.

The critical value of air flow causing a person to feel a cross draught is about 0.1–0.3 m/s. Clothes, physical condition and moving have significant effects on these values. If a person has an opportunity to affect these conditions, the experienced range of thermal comfort can double. The same condition can be felt negatively or positively in different environments and also in different cultures.
(Fig. 26). A lightly dressed person can experience +30 as comfortable, but it is too high a temperature when working. Wet-bulb temperature may be used to indicate the amount of cooling possible through evaporation on the skin. Hard physical work, even in light clothing, becomes very difficult when the wet-bulb temperature rises above 29°C and impossible above 32°C. Light work is possible up to a wet-bulb temperature of 31°C in still air, or 34°C in a moderate breeze. (Palier 2002: 129; Terhaag 1994: 34–36; Serra 1999: 18)

Defining the boundaries of acceptable indoor comfort conditions has significant implications on architecture, building economy and energy consumption. It affects evaluation of the usefulness of natural ventilation and decisions concerning the need for mechanical air conditioning. Instead of mechanical cooling, higher temperatures with a higher airspeed would often be as comfortable for inhabitants. For instance, the preferred airspeeds according the Tanabe research are 1 m/s at 27°C and 1.6–2 m/s at 31°C, which is much more than most airspeed norms permit. (Givoni 1998: 4, 18)

The quality of the overall indoor environment is called IEQ, Indoor Environmental Quality. With the increasing health consciousness of residents this has attracted increasing attention. IEQ consists of indoor airflow, temperature field, humidity field, microbial contamination due to moulds and fungi, and chemical compound contamination due to volatile organic compounds (VOC). Good ventilation is necessary when ensuring a good IEQ (see Chapter 6.7). (Annual 2007: 3–5) The conclusion of 20 studies comparing natural and mechanical ventilation was that natural ventilation is healthier for human beings (Kellert & al. 2008: 123–126).
Fig. 25. The human range of thermal comfort indoors. Air temperature is on the vertical axis and the temperature of the surrounding surfaces is on the horizontal axis. Behaglich indicates the range of thermal comfort. (Terhaag 1994: 34)

Fig. 26. Boundaries of acceptable conditions for still air. (Givoni 1998: 38)
3.1.9 Human adaptation to the outdoor climate

The human body is affected outdoors by air-flow, humidity, precipitation, temperature and solar radiation.

The physiological effects of wind on people are primarily mechanical and thermal effects. The former arise from wind force acting on the body, which can unbalance people and even blow them over. Thermal effects are due to differences in temperature between the wind and the body, which can cause discomfort. Additionally, psychological effects like windborne noise affect people. Individuals can experience windiness differently. Excessive windiness when outdoors is usually considered a disadvantage in the northern climate. Mosquito areas in the North in the summertime are an exception, where moderate windiness near people and domestic animals is desirable, because it chases away mosquitoes.

The cooling effect of wind can be sensed easily already at low wind speed, as presented in Fig. 27. There are several ways for the skin to emit heat, but mainly it happens through evaporation, convection or radiation, and to some degree by conduction. Clothes form an insulating layer of air. When the wind blows, this layer is disrupted and body heat loss increases. Clothing and the category of activity are decisive to the optimal operative temperature, see Fig. 28.

![Fig. 27. Impact of wind outside the range of thermal comfort. Temperature is on the vertical axis and wind speed (m/s) is on the horizontal axis. The range of thermal comfort is darkened. (Comfort 1996: 9; redrawn Kuismanen)](image)

Even a small change in wind speed can be felt as a change in temperature. If wind speed is over 5 m/s, wind pressure starts to feel uncomfortable, especially when the wind blows in gusts. Wind forces that affect humans increase on an exponential curve. For example, when wind speed changes from 10 to 15 m/s, wind force is
five times higher than it would be if wind speed changed from 0 to 5 m/s. In gusty wind that has big changes in wind speed, wind pressure causes momentary lateral propulsive forces. (Terhaag 1994: 34–36; Serra 1999: 18)

![Fig. 28. Optimal operative temperature as a function of different activities and the thermal resistance of clothing; ISO 7730 (28) norm. (Izard 1993)](image)

3.2 Wind in the built environment

3.2.1 Aerodynamics

Aerodynamic research has mainly been done for the vehicle industry, but some of the basic information obtained can be applied to planning and building design. The most important phenomena for an architect include air pressure, continuity of motion and friction, and their impact on air flow.

1. Air moves from a high pressure area to a low pressure area, so these pressure differences cause air flows. Generally speaking, pressure differences occur because of temperature differences. Pressure differences can also be generated when air flow hits an obstacle. When air squeezes past an obstacle, a high pressure area is formed on the windy side. Air tries to keep its original motion because of the mass inertia effect, and that is why a low pressure area is formed behind the obstacle.
2. Continuity affects moving air in the same way as other moving matter. In other words, material has a certain inertial mass. Because of this quality, mass tends to maintain its motion unless some other force changes its direction or speed. The shape of terrain, forest, buildings, cars, structures and low and high pressure areas, among others, can change the direction of flowing air. Air does not flow directly from a supply air source to an exhaust air terminal, because air flows in the desired direction only as long as no structures or obstacles in the room disturb its motion.

3. There is friction at the interface of air flow and other material, which decreases the speed of the air mass and sometimes affects its pattern. Friction causes a gradual declining/diminishing of wind near the ground (see Fig. 28). (Evans 1972: 2–4; Glaumann & Westerberg 1988: 40–46)

Steady wind can be indicated with flow lines. When the lines are squeezed together, the speed of air flow increases, and vice versa. Bernoulli’s formula describes the ratio of wind speed and pressure (Fig. 29). According to the formula, an increase in flow speed is followed by low pressure, and this information is used in the wing of an airplane as well as in low-pressure vents (Fig. 30). A streamlined laminar flow usually does not change even if it hits an obstacle.
When air flow hits a perpendicularly standing wall, the flow divides into both sides at the stagnation point (Fig. 33). The kinetic energy of the flow changes into pressure energy and the speed of the flow drops to zero, just as Bernoulli’s equation indicates. The flow downwind is disrupted, and standing eddies may develop which give way to the random chaotic eddies of full-fledged turbulence. In strong winds the turbulence eddies may become very intense and smaller, and travel downstream before they break up. The force of the wind and the energy in turbulent eddies increase with the square of the velocity.

The point of separation is a section where the flow separates from the surface (Figs 31 and 32). Where the separation happens mainly depends on how laminar the flow is, the shape of the surface and the roughness of the surface structure.

Fig. 31. Formation of the point of separation. (Houghton, Carruthers, cit. Børve 1987: 20)

Fig. 32. Formation of the point of separation at the mouth of a sharp angled canal "vena contracta". (Hutcheon, Handegord, cit. Børve 1987: 20)
When examining a built environment, wind speed around a building is determined in percents compared to unlimited flow speed measured at a reference point. It is assumed that both increases and decreases in flow speeds are directly related to the unlimited flow speed. In practice, turbulence, wind speed and temperature all cause measurement errors.

Air flow causes wind forces that affect objects. How strong these forces are depends on friction and transformation resistances, so the forces are the sum of wind pressure and friction forces. Deformation resistance is the most important force when the object is not streamlined. The pressure with which wind affects a building is proportional to the square of the speed of wind flow, which means that
even a little change in flow speed causes a significant pressure change. In nature, changes in the flow speed of gusty wind are large, so wind pressure causes dynamic strain on buildings and other structures. (Børve 1987: 17–21; Glaumann & Westerberg 1988: 43–51; Pagen 1992: 113–118)

Structurally, wind turbulence affects in three ways. Stiff structures are affected by time-dependent loads, whose variations are partly caused by wind turbulence. Turbulence in air flow may also cause resonant vibration in flexible structures. Wind turbulence may also significantly affect the aerodynamic behaviour of a structure and correspondingly, the results of laboratory studies. (Simiu 1986)

3.2.2 Air flows around buildings

The wind forces which are directed towards a building are divided into three components which have effect on axes x, y and z:
- force parallel with the wind (on both sides in the walls)
- to sides directed force (on both gable walls)
- buoyant force (on the roof) (Fig. 35).

1. Effect of the wind on wall structures

The wind forces are directed at the maximum towards a wall which is located perpendicularly to the flow, particularly when the wind is a little turbulent. At the same time low pressure forces are caused on the wall. The biggest low pressure force is directed to the upper part of the gable walls and to the front corners with respect to the flow direction. At the windward facade a part of the flow is directed towards the earth. The flow which goes over a building accelerates and causes
local low pressure. A stagnation point (a rest point) – a clear division line of the flow – is created at facades at a height which is about 2/3 of the total height of the building. A similar division line is also created vertically. There will be no division line on a building, which is situated diagonally to the air flow, but the wind speed increases and on the lee of the building a large turbulent area is created.

The above-mentioned principles are simplified models of flow patterns around buildings and for example a turbulent flow brings new factors to the wholeness (Fig. 36). (Børve 1987: 22–23)

Buildings which are higher than their environment direct the wind towards the ground, which strengthens the flows near the surface of the earth. The bigger the building the bigger the pressure differences between windward and leeward sides, and the bigger the variations of wind speeds around the building, even double (Fig. 37). Also on the leeside of a building strong gusts of wind can be created even if the average speed of the wind is low. Voids between or openings through buildings cause especially big problems, because pressure differences between the windward and lee sides are at their biggest at the middle of a building. (Glaumann & Westerberg 1988: 120; Broas 1992: 22–24)

Fig. 36. Even laminar (at left) and turbulent (at right) flows will have different patterns when they meet a building. (Baines, cit. Børve 1987: 30)
Evans has performed a systematic test series of natural air-flow around buildings caused by different building forms in the wind tunnel. By the effect of wind on the lee side of a building a downwind eddy is formed, the size of which depends on the forms of the mass in the way shown in Fig. 38. The flows on the leeside of a building can be so closed in their form, that the exit of impurities in the air forms a problem. When the depth of a building increases, the depth of the counter-eddy on the lee will decrease (A, B, C). When the height increases, the counter-eddy will also be higher. At the same time the amount of air flowing over the roof remains the same, but the air flow around the corners increases significantly (C, D). When a roof becomes steeper, the size of the whirl on the leeside (E, F) will increase. A building that has been placed against an air flow at a right angle causes a larger whirl on the leeside than a building which is set obliquely (G). (Evans 1972)
At higher storey levels wind is blowing more strongly, for which reason balconies which are located high will be exposed to air flows that can be 1.5 times faster compared with those at the downstairs level. In open galleries windiness will be at its worst when the wind comes obliquely from the front. On the uppermost storey the eaves of the ridge roof adds to the speed of the air flow compared with a flat roof. (Glaumann & Westerberg 1988: 115)

2. Effect of the wind on roofs

Fringes and corners of ceilings at a width of about 0.5 m are especially subjected to the pressure effects of the wind. On flat roofs negative pressure usually domina-
tes and a different kind of turbulence appears. Wind pressure will change to over-pressure when the roof angle grows. Between 14°–21° both positive and negative loads can appear. When the angle of the ridge roof is less than 30° pressure effects will be the smallest, Fig. 38.

A pitched roof is lifted by negative pressure at angles between 0–15°. Over 15° inclination causes slight overpressure on the middle area of the roof, and at about 25° angle positive and negative powers are regularly divided. At the same time, as the pitch of the roof increases the depth of the downwind eddy increases.

Exact rules concerning roof angles cannot be presented because many factors affect the generation and division of wind powers, like the height of the building parts under the eaves and their detailing, variations of roughness of surfaces etc. (Fig. 40). An example of a dome is in Fig. 39. (Jensen 1964 & 1965; Mattson 1979: 122)

Fig. 39. The wind load of a polygonal hall is uneven, with both pressure and draught. (Jensen 1965)
Fig. 40. Patterns of the air flow on a flat roof (A) and on a gable roof (B). (Lawson, cited in Børve 1987: 32)

3.2.3 Wind around building groups

Usually surrounding buildings weaken wind speeds around individual buildings in a building group, but it is also possible that the geometry of a building group strengthens flows. When a higher building is located behind a lower one with respect to the wind direction, the vacuum caused by the lower building will strengthen turbulence between the buildings and make the front of the higher building windy. This kind of problem situation will be created, for example, in connection
with open squares in a town structure, when one wants to build a building which is higher than others in a row of buildings that lines the square. (Børve 1987: 29; CASE Kuismanen; Glaumann & Westerberg 1988: 120)

Gandemer’s principles give a simplified picture about the wind flow patterns around long rows of buildings (see Fig. 41):

1. Wall effect and turbulence behind it will be created, when a row of buildings, which is more than 25 m high, is placed at about 45° angle to the dominating wind direction. The length of the building group is more than eight times the building height.

2. Funnel will be created, when two high and long buildings are placed at a right or sharp angle with respect to each other. In the throat between a more than 15 m high and 100 m long house group the wind speed can be even 1.6 fold higher.

3. Compensation flow is created in the pass between buildings, when a pressure difference dominates between the different sides of buildings.

4. Wind channel will be formed, when the width of the pass between the buildings is smaller than two times the height of the buildings. In a street canyon, which is longer than 100–125 metres, the wind speed can increase significantly.

These Gandemer’s simplifications help the understanding of phenomena, but they should not lead to schematic solutions, in which other factors are forgotten. (Dubinski 1980: 48–55)
According to Alberts, the effects of the wind in closed blocks and the street spaces between them depend essentially on their total dimensioning, see also 3.24 (Alberts 1982):

1. A closed block structure brings special flows, which are the total result of many simultaneously affecting powers. These are the vertical wind whirl which starts from the outer corner of the block and a large whirl, which is created in the street space and which begins from the lee on a level with the eaves line of a building and continues as a big whirlwind which is directed at the facade of the opposite building. These currents are created easiest in a town structure which is located at an angle of 30–60 degrees to the dominating wind direction.

2. In the model with square court buildings of height lower than 12 m high, an air flow arising in the courtyards proceeds over the houses into the streets. In higher court buildings, no such flow arises; the moving air remains in the courtyards.
3. Streets broader than 30 m allow room for a horizontal eddy originating from the air flow around the building block. In narrower streets no such eddy occurs.

4. In a wide street, wind approaching parallel to the street’s axis will cause the highest velocity. In narrower streets an angle of approach of 45 ° results in the highest wind speeds.

5. A massive building causes more windiness in its immediate surroundings, than an equally large building mass, which is divided properly.

6. The longest uniform street canyons are also the windiest.

There are rules of thumb about the dimensioning of closed blocks. On a courtyard surrounded by no more than three storey buildings the air flow begins to have a greater effect when the distance between the buildings compared with their height is over three-fold. When the courtyard measure increases to four-fold, windiness at the ground level on the downwind side of the yard will already be extremely strong. An open square will be very windy when the length of its side exceeds 30 m. (Alberts 1982; Børve 1987: 37, 148) The dimensioning of a yard that has been protected from the winds is often in conflict with the distances required by the sun angles.

The wind speeds around small houses are usually moderate. For example a “chessboard” plan built with multi-storey dot houses is windy whereas the same configuration has a relatively good micro-climate when carried out with detached houses, see Fig. 42. An area built in an open way is exposed to the winds, and the directions of air-flows vary considerably, as shown in Fig. 43. The micro-climate around buildings can be formed with wind-protection walls, as shown in the Fig. 45 and building volumes that are formed to give shelter, see 4 6. (Kuismanen 2000)
Fig. 42. Small-scaled relatively dense pattern of building considerably reduces the power of wind. In the model the air flow goes between the houses but is considerably weakened. The highest wind-speeds are at the bare blown areas on the model. (Kuismanen 2000)

Fig. 43. Open building way is very exposed to the winds, the direction of air-flow changes irregularly and strong turbulence occurs, which is a problem in cold climates. The thread shows the airflow. (Kuismanen 2000)
Fig. 44. In narrow streets airflow is forced against the walls. Streets broader than 30 m allow room for a horizontal eddy. (Alberts 1982)
Fig. 45. In the upper figure the wind protection effect of row buildings with different wind directions; the darker the screen the more sheltered the area. In the figure below the yard is protected with a wind-protection wall that has 66% openings. (Jensen 1964)
An often-appearing problem especially on the south and west coasts of North-European countries is the blowing of cold wind from the same direction as the sun. In that case the wind can be led over the yard and to create a sheltered recess with a v-shaped building plan configuration which opens towards the wind direction or by a low sheltering construction on the windward side (a concave form). A gently sloping long roof on the leeside reduces the sheltered area and accumulation of snow. When possible, the back of a house and a building group is turned against the main wind direction. Arcades, overhangs and covered pavements protect from rain, slipperiness and sun. A building can direct air flows that cool structures or yards towards the neighbouring buildings, and cause the accumulation of snow.

The most important thing from the point of view of the pedestrian milieu is to study the behaviour of the boundary layer at the height of about two metres with scale model testing. An erosion wind test is an easy way to check the places where air-flows reach the pedestrian level (Fig. 47). This theme is discussed more in Chapters 5.2.2 and 5.2.5. (Børve 1987: 155–174; Kuismanen 1993)

![Fig. 46. Half closed block that has been shaped to protect against the wind, Rajakylä Oulu. (Kuismanen)](image)
3.2.4 Snow in the built environment

Traditionally northern communities have struggled for their existence in a harsh climate. Winter seems to have been the season which influenced the conditions of construction. Different things were developed to complement the conditions, such as sauna against the cold, sheltered yards against winds, plants which replace dead winter nature and sheltering roofs against harsh climate. The shaping of a town and buildings as protective elements made the whole construction understandable.

Snow can go with the wind by rolling, by bouncing or by flying. One can state as a summary of the separate studies that snow begins to move at about 5 m/s wind, to fly at about 10 m/s air flow and actual snowstorms begin in more than 15 m/s wind, see Fig. 48. The dropping of the wind speed from 15 m/s to 10 m/s reduces the amount of carried snow more than 85 per cent. Weather charting, in which the amount of snow and the dominating winds are shown, helps to manage the problems caused by snow in the planning stage in a harsh climate. (Stavnov, cit. Børve 1987: 24–25)
Wide variation in types of snow occurs in nature, from very dry light powdery snow to wet heavy snow. Snow is carried away from windy areas and drifts to still places. The accumulation is affected by the temperature of the ground, air humidity and wind conditions. If it is blowing when it is snowing or immediately after snowing, flakes become rounded when rolling on the surfaces, and will be packed hard. Also the wind and air humidity increase condensation. The snow that is packed is often hard because the snow crystals partly melt by frictional heat during the drifting and will freeze immediately after having settled down as a snow drift. On high places snow is often packed to become heavy crown snow loads which can injure trees and structures. Calm and cold weather causes a loose dune structure that moves easily. (Havas 1987: 14–20)

Drifting takes place in certain places year after year, usually in the same way, which must be taken into consideration in planning. On the other hand, wind cleans certain places which can be utilised to facilitate snow clearing. If on the projected building site a large part of the snow moves with the wind, drifting can be directed with active development of the micro-climate. After snowstorms the forms of snow drifts around buildings are usually exact in form which tells about permanent turbulences. (Havas 1987: 18–20; Glaumann & Westerberg 1988: 138–141)
4 Case method and analyses

"Ei ole mahdollista luoda menetelmiä jotka sopisivat täysin erilaisiin olosuhteisiin, siinä auttaa ainoastaan intuitio. ... Metodiikka ei ole taiteen vastapooli, ei sen vihollinen, vaan sen edellytys". (Alvar Aalto, cit. Schildt)

4.1 Parts of the method

In this chapter the structures and parts of bioclimatic analyses, the ways of collecting climate data, and the method of making micro-climate analyses are discussed. At the end the use of CAD and CFD techniques in connection with a planning process are presented.

Climate-conscious (bioclimatic) planning and architectural design are a complex endeavour. As we have seen in the previous chapters, much has been written on the subject matter in different countries, but we have also seen that most methods deal with one aspect only.

According to the research cited in Chapters 2 and 3, and based on the experience of the author from many town planning and architectural design projects, it can be summarized that a climate-conscious planning method should consist of following contributory factors:

- Definition of the criteria.
- Micro-climate analyses.
  - collecting meteorological data
  - nature environment analyses
  - built environment analyses
  - method for presenting micro-climate.
- Wind testing of scale models.
- Methods of interpreting the analyses.
- Planning and design guidelines.

The points described above are actually self-evident facts that traditionally belong to high-quality architecture, but which often have been forgotten in practice. On one hand the CASE method is partly based on previous knowledge and project practices, but on the other hand it introduces new things like practical micro-
climate analysis methods, effects of the climate change, model testing with the blower developed, and the planning and building design guidelines for main climate regions. The method developed can be applied globally, and it adds a deeper understanding of the environment to the standard planning processes, thus increasing the quality of planning. As a fact the method consists of some sub-methods and guidelines.

The analysis should strive to gain a total view of the quality of the climatic environment and its effects on residents’ daily routines. On one hand, the analysis should not be tied to its methodological starting points, instead it should be based on scientifically verified methods. The structure of the analysis should be uniform enough to enable comparison with other cases. It is important though, that anticipations regarding the method do not skew the planning in a certain direction, because the main idea of the town plan or building may sometimes be born only after a long period of work. Typical of good planning is usually the fact that it contains a perception that gathers many, sometimes even opposing factors, into a single entity.

An important starting point for planning is to know the residents’ habitat, values and everyday modes of behaviour. These modes of behaviour often consist of small acts, which often are sensitive to climatic conditions, and eventually define the quality of living. The behaviour of residents often varies with the different seasons and climate, depending on their hobbies, job, age, state of health, economic status, etc. That is why analyses should not consider the population as a statistical entity as is commonly done nowadays.

One of the most important fields of examination is traffic planning, because current city models cause significant traffic. Especially light traffic is sensitive to climatic conditions. The present principles of the placing of functions and dimensioning should be considered critically and alternatives should be demanded. Alternative community structures should be studied. Both in cold and hot climates the placing of functions affects the residents’ possibilities to reach different services in comfortable circumstances. The placing of main roads greatly affects the quality of air in large areas, and climate analyses reveal the potential places of air-pollutant concentrations.

Residents’ participation is an important way to gather information about climatic problems and other local circumstances, values and needs. Town planning often includes economic and other interests of both individuals and entire social groups, which is why possible conflicts may be strong. The decisions that are made are often complicated, technical and financial, where the benefits of individ-
uals and the community may be contradictory. This makes residents’ participation and self-planning difficult, and in each case this has to be arranged with care, without forgetting local circumstances. Wide-ranging conversation, which is typical in a democracy, also decreases mistakes in planning, but it may also focus attention on meaningless little details and blur the whole picture.

Be it a town model or architectural form-giving, there is no method as such that creates forms. Every designer is more or less bound to the theories, city models, inspiring examples, materials and level of technology of his time. Climate-wise planning does not require any specific design language. Nevertheless, some common factors and premises can be seen in the few projects carried out so far. In Scandinavia ideas that often came up in town planning included fairly closed, small-scale blocks, planted buffer zones and protected street spaces. Buildings have been divided into a closed side that shields against the climate and an open sunny side. Protective structures for pedestrians, solar heat collectors and garden fences and louvers complete the architecture of the area. (Børve 1987: 118–127; Glaumann & Westerberg 1988: 112–118; Sterten 1995; Hagan 1996: 11–29)

Over time new techniques and working methods have lead to the birth of new design languages in town planning as well as in building planning. That is why it can be expected that climate-wise planning will lead to research into various town models as well as development of new architectural forms. The basic ideas of environmental planning will probably be density, small-scale, mixed functions and principles of sustainable development. On the other, it is possible that the high level of know-how, research and high technology will lead the development, and this culture of know-how will get its own architectural forms. Rossi has said that in some periods architecture can be capable of synthesising the whole civil and political scope of an epoch, and then it can be seen as a style (Rossi 1985: 116). We speak, for instance, about the baroque city as a morphologic definition and we immediately have a picture of the city in our mind. Maybe in the future we can also speak of climatic or ecological cities of different climatic zones as morphologic types.

The planning process described in this study means a return to architects’ traditional skills and working habits. Observations made in the field and drawing are regarded as the basic virtues of architects. Working with models and their shaping are necessary when working with wind test equipment, and these three-dimensional work methods still give a better picture of reality than working with CAD.
4.2 Structure of a holistic bioclimatic analysis

4.2.1 Holistic analyses of an area

Before setting forth planning solutions, it is essential to have an understanding of the area: the micro-climate, i.e. temperature, sunshine, humidity, rainfall, and prevailing winds as a whole. Elements like orography, vegetation, hydrogeology and surrounding built structures affect the micro-climate, and also need to be analysed.

The emphasis in this study is on micro-climatic analyses, scale model testing and bioclimatic planning and design guidelines. Nature and urban analyses are developed to such an extent as is relevant for climate-conscious planning and architectural design.

The nature analysis method developed is valid for small and medium size planning projects. If the area to be planned is large and complicated or the natural environment is especially valuable, deeper analysis and evaluation by specialists is needed. Making a large holistic environmental analysis is a multidisciplinary task, for which a team consisting of planners, biologists, historians and other professionals is needed.

The long-list below mentions the most important topics of analysis, which are needed for bioclimatic sustainable planning, but mutatis mutandis it can be applied to large building projects, too. The items needed for each single project should be short-listed when making the work-plan for a project.

1. Climate analysis.
   - Wind.
   - Temperatures.
   - Humidity, precipitation.
   - Solar gain, shady zones.
   - Charting the climatically positive and negative places.
   - Natural hazards; the impact of climate change.

2. Natural environment analysis.
   - Topography; micro-climate borders.
   - Vegetation (flora); wind shield greenery.
   - Wildlife (fauna).
   - Ecosystems; the impact of climate change on wind shield greenery.
   - Assessing existing toxins; spreading with water and wind
– Visual features.
– Charting the buildable areas.

3. Built environment analysis.
– Built structures; their effect on local wind patterns and solar access.
– Functions; their sensitiveness to climate, guidelines of placing.
– Traffic, site access; forming and spreading of emissions.
– Energy and infrastructure systems; solar and wind energy, area drainage.
– Visual features; townscape type and its affect on climate.
– Charting the buildable areas.

These items together form the basis of bioclimatic understanding of an area, on which basis recommendations for buildable areas can be given, and bioclimatic planning guidelines made. The analyses are treated in the chapters:

1. Climate analysis 3.3, climate; 3.4 sunniness
2. Nature environment analysis 3.5
3. Built environment analysis 3.6

First of all, background information needs to be gathered. The following checklists serve as the structure of a comprehensive environmental analysis. In the left column is collected the background information needed, and the right-hand side lists the working-papers, documents and plans that needs to be made. These lists must be modified according to the needs of the actual planning or architecture project. The number in parentheses (Fig. 49) is the reference to the figure.

<table>
<thead>
<tr>
<th>1. Background information</th>
<th>Documents, plans made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information needed</td>
<td></td>
</tr>
<tr>
<td>Information about the project</td>
<td>Collect the material</td>
</tr>
<tr>
<td>Objectives</td>
<td>Defining the objectives, timetable</td>
</tr>
<tr>
<td>Special problems</td>
<td>Defining the problems</td>
</tr>
<tr>
<td>Threats</td>
<td>Defining the threats, swot analyse</td>
</tr>
<tr>
<td>Other material</td>
<td>Scale model of the project area, (3D digital landscape model), working plan, Defining necessary documents</td>
</tr>
</tbody>
</table>

173
Fig. 49. Landscape structure analysis on a photo. Landscape type, watersheds, most important structures, wind patterns, etc. are marked on the picture. (Børve & Sterten 1981: 27)

Fig. 50. Division of an area into local climates. The dashed line represents divides which limit local climates. The arrows depict the flow of cold air. (Børve & Sterten 1981: 97)
In practice the information needed can be partly obtained from written sources, but some part of the information needs field work and observation. The following long-list covers the information and measures needed for planning, and it should be short-listed for each project. The list can be adapted to major building architecture commissions as well.

<table>
<thead>
<tr>
<th>II. Gathering the information, analyses</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Information or analysis needed</td>
<td>Documents, plans</td>
</tr>
<tr>
<td>A  structure of the landscape and buildings</td>
<td>Map [51, 52]</td>
</tr>
<tr>
<td>Landscape structure</td>
<td>Axonometric presentation</td>
</tr>
<tr>
<td>Terrain type</td>
<td>Map, description</td>
</tr>
<tr>
<td>Nature of the structures</td>
<td>Description, figures [49]</td>
</tr>
<tr>
<td>Building structure; wind roughness classification</td>
<td>Map, description, roughness factor</td>
</tr>
<tr>
<td>Traffic routes</td>
<td>Map</td>
</tr>
<tr>
<td>Land use</td>
<td>Map</td>
</tr>
<tr>
<td>Development history</td>
<td>Map, diagram plans</td>
</tr>
<tr>
<td>B  Climate data and micro-climate analyses</td>
<td></td>
</tr>
<tr>
<td>Macro-climate</td>
<td>Map, diagram</td>
</tr>
<tr>
<td>Local climate districts</td>
<td>Map, drawing [50]</td>
</tr>
<tr>
<td>Micro-climates</td>
<td>Description</td>
</tr>
<tr>
<td>Temperatures, wind directions, wind speeds, rain, fog, air humidity</td>
<td>Diagram, description</td>
</tr>
<tr>
<td>Air quality</td>
<td>Description</td>
</tr>
<tr>
<td>Air pollutants</td>
<td>Map, (CFD animation) [52]</td>
</tr>
<tr>
<td>Cold air</td>
<td>Map, (CFD animation) [52]</td>
</tr>
<tr>
<td>Snowiness</td>
<td>Description</td>
</tr>
<tr>
<td>Observations, field work</td>
<td>Map, description</td>
</tr>
<tr>
<td>C  Solar analyses</td>
<td></td>
</tr>
<tr>
<td>Solar conditions</td>
<td>Map, “Solar rose”</td>
</tr>
<tr>
<td>Shadow analysis</td>
<td>Map</td>
</tr>
<tr>
<td>Warm and cool areas</td>
<td>Map</td>
</tr>
<tr>
<td>D  Natural environment analyses</td>
<td></td>
</tr>
<tr>
<td>Topography, topsoil</td>
<td>Map, description</td>
</tr>
<tr>
<td>Water systems</td>
<td>Map, description</td>
</tr>
<tr>
<td>Vegetation and animal life</td>
<td>Map, description</td>
</tr>
<tr>
<td>Green corridors</td>
<td>Map, description</td>
</tr>
<tr>
<td>Barriers</td>
<td>Map, description</td>
</tr>
<tr>
<td>Future threats (Climate change)</td>
<td>Map, description</td>
</tr>
<tr>
<td>Biotopes</td>
<td>Map, description</td>
</tr>
<tr>
<td>Wind shield vegetation</td>
<td>Map</td>
</tr>
<tr>
<td>Affect of the topography on wind</td>
<td>Map</td>
</tr>
<tr>
<td>E  Built environment analyses</td>
<td>Description, illustrations</td>
</tr>
<tr>
<td>Basic information</td>
<td>Map</td>
</tr>
<tr>
<td>Built structures</td>
<td>Map, (Axonometry) [53]</td>
</tr>
<tr>
<td>Affect of built structure on wind</td>
<td>Map, description</td>
</tr>
<tr>
<td>Bioclimatic entity</td>
<td>Map, description</td>
</tr>
</tbody>
</table>

### 4.2.2 Planning and designing

This chapter contains a checklist of documents and plans that, according to this research and the pilot projects, are needed in sustainable planning and architecture.
Naturally, the decision on what kind of material is essential is made according to the needs of the actual project. (Kuismanen 1996)

<table>
<thead>
<tr>
<th>III. Working the material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task</td>
</tr>
<tr>
<td>Defining problematic wind directions and areas</td>
</tr>
<tr>
<td>Wind tests using the scale model</td>
</tr>
<tr>
<td>Possible environmental problems that must be treated</td>
</tr>
<tr>
<td>Defining protected and buildable areas</td>
</tr>
<tr>
<td>Planning infrastructure networks</td>
</tr>
<tr>
<td>Developing the ecological quality of the plan</td>
</tr>
<tr>
<td>Outputs</td>
</tr>
<tr>
<td>Map</td>
</tr>
<tr>
<td>Map, photos, video, description</td>
</tr>
<tr>
<td>Map, description</td>
</tr>
<tr>
<td>Map</td>
</tr>
<tr>
<td>Map</td>
</tr>
<tr>
<td>Eco-balance calculations, description</td>
</tr>
</tbody>
</table>

Bioclimatic planning and architectural design processes differ slightly from the normal routine. In addition to the standard planning procedures, profound analyses about the micro-climatic properties of the nature and built structure of the project area are made, and bioclimatic planning guidelines tailored. For this reason extra economic resources and more time are needed. But the investment will be paid back as it results in a plan with lower life-cycle costs, better micro-climatic comfort, lower energy costs, lesser storm and flood damage and so forth.

Fig. 51. Landscape structure analysis on a map. Bergen Store Lungegårdsvann. (CASE 1994; drawing Børve, Bjørge & Kuismanen)
For the quality control of planning or architectural design it is often necessary that bioclimatic guidelines are set, and the controlling authorities take care of the monitoring.

But, it is as Aalto says: “not possible to create methods that completely suit different situations, only intuition helps in that. … Methodology is not the antithesis of art, not its enemy, but a prerequisite” (Schildt 1990). It is good to remember that analysis of partial factors often does not suffice to describe a climatic entity or the feel of a special place. For example, a walk in a northern African city defies numeric description; varying light filtering through openings and canvas roofs, echoing of footsteps, waves of heat and coolness, the scent of sun-heated bricks and spices. All this enhances the feel of the climate and the visual surroundings.

<table>
<thead>
<tr>
<th>IV. Conclusions, plans</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task</strong></td>
<td><strong>Outputs</strong></td>
</tr>
<tr>
<td>Planning and design tools</td>
<td>Quality control and work programmes</td>
</tr>
<tr>
<td>Tools to ensure the quality of planning</td>
<td>Planning guidelines</td>
</tr>
<tr>
<td>Improving the micro-climate, wind protection and area ventilation of air pollutants</td>
<td>Guidelines for wind protection and plantings</td>
</tr>
<tr>
<td>Using solar energy</td>
<td></td>
</tr>
<tr>
<td>Diminishing the affect of wind</td>
<td></td>
</tr>
<tr>
<td>Developing climate-wise urban structure</td>
<td>Guidelines, morphological studies</td>
</tr>
<tr>
<td>Tools to ensure the quality of architecture</td>
<td>Building regulations</td>
</tr>
<tr>
<td>Diminishing the problems caused by winter</td>
<td>Design guidelines for winter</td>
</tr>
<tr>
<td>Natural house techniques in different climate zones</td>
<td>Design guidelines</td>
</tr>
<tr>
<td>Plans</td>
<td></td>
</tr>
<tr>
<td>Making alternative plans and architectural solutions</td>
<td>Drawings, 3d-models, description</td>
</tr>
<tr>
<td>Defining protected nature and buildings</td>
<td>Map, description</td>
</tr>
<tr>
<td>Defining buildable areas</td>
<td>Map, regulations</td>
</tr>
<tr>
<td>Micro-climate design</td>
<td></td>
</tr>
<tr>
<td>Making better micro-climate, improving pedestrian wind comfort and saving energy by wind testing the alternatives</td>
<td>Map with wind arrows, Model photos with wind arrows, report, feed-back to the plans</td>
</tr>
<tr>
<td>Improving solar conditions and using solar energy</td>
<td>Map, report. feed-back to the plans</td>
</tr>
<tr>
<td>Analysing the affects on neighbouring buildings and areas</td>
<td>Map, report. feed-back to the plans</td>
</tr>
<tr>
<td>Quality control system</td>
<td></td>
</tr>
<tr>
<td>By controlling authorities</td>
<td>Guidelines, recommendations, rules</td>
</tr>
<tr>
<td>Self control</td>
<td>Quality check reports</td>
</tr>
<tr>
<td>Making the final design</td>
<td></td>
</tr>
<tr>
<td>Comparing the alternatives</td>
<td>Reports, calculations, swot analyses</td>
</tr>
<tr>
<td>Planning and designing</td>
<td>Drawings, models</td>
</tr>
</tbody>
</table>
Fig. 52. Defining problems on a map; accumulation of air pollutants. Store Lungegårdservann. (CASE 1994, drawing Børve, Bjørge & Kuismanen)

Fig. 53. Structure of the landscape, Bergen Store Lungegårdservann. (CASE 1994, drawing Bjørge)
4.3 Climate analysis

4.3.1 Climate information needed in planning

When deciding on the placement of buildings in town planning, it is usually not possible to limit construction to areas that are advantageous in terms of the micro-climate; (outdoor) functions also have to be situated in disadvantageous locations. In addition, the fact that construction in itself changes the area’s micro-climate also needs to be considered. The more disadvantageous the construction site is, the more micro-climate factors need to be taken into consideration in detail in the planning phase and the more effort needs to be placed on assessing the impact of the micro-climate on the buildings and areas in subsequent work. Building placement affects the formation of the thermal island phenomenon, the detrimental wind effects of buildings on outdoor areas or elimination of those effects, snow accumulation, moisture conditions, air pollutants etc. Thus, the pleasantness of residential areas can be improved by means of the size, shape, and relative placement of the buildings, plants, and mechanical wind barriers.
The main content of climate analysis is:

- Wind.
- Temperatures.
- Humidity, precipitation.
- Sun, shadow (Chapter 3.4).

The CASE climate analysis content consists partly of topics that belong to most climate analyses. However, there are also new items, like the methods of treating the climatic data, observation techniques, roughness classification, effects of terrain forms and landscape types, the setting of criteria, model wind testing, and the ways of drawing conclusions and presenting findings. The target is a better understanding of the climate and its effects on people and buildings. Table 7 gives the main topics of the climate analysis needed in this method.

**Table 7. Climate analyses.**

<table>
<thead>
<tr>
<th>Information or analysis needed</th>
<th>Documents, plans made</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Landscape and buildings</td>
<td></td>
</tr>
<tr>
<td>Definition of the landscape structures; watersheds, valleys, heights</td>
<td>Topographic map, [49], [51] (Axonometric presentation)</td>
</tr>
<tr>
<td>Terrain type; roughness</td>
<td></td>
</tr>
<tr>
<td>Buildings and building structure; roughness factor</td>
<td>Map, description</td>
</tr>
<tr>
<td>Traffic routes</td>
<td></td>
</tr>
<tr>
<td>Land use, functions, sources of air pollutants</td>
<td>Map</td>
</tr>
<tr>
<td>B Climate and micro-climate analyses</td>
<td></td>
</tr>
<tr>
<td>Macro-climate in different seasons</td>
<td>Description [3], [4]</td>
</tr>
<tr>
<td>Division of the area into local climate districts (often watersheds)</td>
<td>Map, drawing [50]</td>
</tr>
<tr>
<td>Winds in different (4) seasons and times of day</td>
<td>Map, description</td>
</tr>
<tr>
<td>Temperatures, wind directions, wind speeds, rain, fog, air humidity</td>
<td>Diagram, description [55–57]</td>
</tr>
<tr>
<td>Air quality</td>
<td></td>
</tr>
<tr>
<td>Air pollutants and their flow patterns</td>
<td>Description</td>
</tr>
<tr>
<td>Cold air flows and pools of cold air</td>
<td>Map</td>
</tr>
<tr>
<td>Snowiness, drifting of snow</td>
<td></td>
</tr>
<tr>
<td>Observations on the planning area</td>
<td>Diagram, map</td>
</tr>
<tr>
<td>Model wind tests</td>
<td></td>
</tr>
<tr>
<td>Prediction about the effects of the climate change</td>
<td>Scale model</td>
</tr>
<tr>
<td>C Solar analyses (Chapter 3.4)</td>
<td></td>
</tr>
<tr>
<td>Solar hours and angles in different seasons</td>
<td>Diagram</td>
</tr>
<tr>
<td>Shadow analysis</td>
<td>“Solar Rose” [83]</td>
</tr>
<tr>
<td>Warm and cool areas within the planning area</td>
<td>Map, shadows at the equinox</td>
</tr>
<tr>
<td>Night landscape</td>
<td></td>
</tr>
<tr>
<td>Conclusions</td>
<td></td>
</tr>
<tr>
<td>Micro-climates in different (4) seasons and times of day</td>
<td>Map, description [72]</td>
</tr>
<tr>
<td>Micro-climate around buildings</td>
<td>Drawings [52], [73]</td>
</tr>
</tbody>
</table>
Before a trustworthy micro-climate analysis can be done, nature and built environment analyses should be carried out as well.

The wind climate of a given site can be summarised with wind testing. Prior to wind tunnel tests and conclusions the present and projected local situations should be described in detail:

- wind profile (seasons, diurnal)
- wind shield constructions and vegetation
- surrounding urban structures, contexts.
- project site and its surroundings (also conceptual context)
- types of expected activities
- cultural and/or economic importance of the site (vulnerability to the elements)
- wind profile (seasons, diurnal)
- temperatures, possible heat island
- rain, humidity
- watercourses, watersheds (basins, micro-climate areas)
- solar radiation, shadows (slopes)
- wind shield vegetation
- surrounding urban structures, contexts.

4.3.2 Use of climate statistics

The most important factor in macro-climate is the winds. Climate statistics that are suitable for use as initial data for planners are published both country-specifically and internationally. Rural site observations are generally done according to the recommendations of the World Meteorological Organisation (WMO) at a height of 10 m in an open environment. The measurement points in a city are situated on masts placed above the roof level to avoid the wakes from neighbouring buildings.

However, observation stations are often not located near the area being planned, in which case it is necessary to calculate the average values of data from nearby climatically representative stations, as presented in Fig. 57. Sometimes the data of even one climatically representative observation point is sufficient for initial data. Special care should be taken when using statistics near coasts; the average wind speeds can be reduced 25–35% during the first 5 km inland. When mapping out climate conditions, it is sometimes possible to use research reports published by meteorological institutes, which often take into account the effect of terrain in the distribution of climate factors. WMO is linking research, data, analysis, products including climate predictions, and services, through to end users in key
socioeconomic sectors such as renewable energy, health, tourism, water resource management, agriculture and urban management. (Troen 1989: 85–92; Tilastoja 1990; World 2007: 2)

Often a review of ready wind statistics does not provide an adequate portrayal of the actual conditions. The nearby topography out to a few tens of kilometres forms the wind field greatly (Troen 1989: 5). For example, data on Finland’s west coast indicate east/south-east, north-west and north as the directions of prevailing winds. This data is insufficient in terms of planning. Detailed measurements demonstrate that the distribution is affected by a sea breeze and land breeze system in the spring and summer, which often directs the wind locally from the south-west in the daytime and from the east at night (Appendix 6). Cold north winds can blow in the area at any time. It has also been shown that the ratio of the urban mean wind speed at a height of 10 m above the roof level to the rural mean wind speed at a height of 10 m above the ground level is about 0.75. (Tilastoja 1990)

From the standpoint of a micro-climate, the most problematic thing is taking wind conditions into consideration. Winds are distributed in all directions and there is great variation in wind speeds. In addition, wind is channelled according to the shape of the terrain. Thus, the impact of wind on the heat consumption of a building and the pleasantness of a residential area must be examined comprehensively. At least the following assessment methods are necessary.

Average wind speeds are not always very successful parameters for describing the effect of wind conditions and wind in terms of planning. Instead, the distribution of moderate and strong winds during the entire year must be determined. The year should be divided into at least four periods, spring, summer, autumn and winter (Fig. 56). This indicates the direction from which the wind most often blows. Based on this distribution it is possible to specify the places in the terrain where it is most often windy and the valleys into which winds are channelled. In examining wind distribution at the target site, it is necessary to take not only the wind and terrain into consideration, but also plant distribution, the density and height of trees (nature analysis), and also the affect of the buildings in the surrounding (urban analysis).

In cold climates, from the standpoint of the heating costs and comfort of buildings, it is also necessary to know the distribution of cold winds. Cold winds should be examined on the basis of monthly distributions or at least by seasons. Distributions calculated on the basis of the cooling effect of wind can be calculated for each month using different cooling values. Thus, for example cold winds can blow from the north and east in winter, while in May and June they blow from the sea in
the west. In addition to these wind distributions, it is possible to calculate wind distributions when it is snowing or raining. It is important to know the distribution when it is snowing to be able to plan so as to avoid snow accumulation on sidewalks and driveways. In all climates it is important to know when and where it rains at an angle to be able to design wall structures that resist moisture and rain shelters for pedestrians.

In Finland, the monthly wind speed averages are greater in the winter than in the summer. The daily variation in speed is clearly greater in the summer than in the winter. During the heating period, the most common wind speeds at observation points are between 3 and 6 m/s, the average speed being in the range of 4.8 m/s. (Kivistö 1987: 14–28; Oulun 1994; Raahen)

Wind speed is comprised of three vector components: the longitudinal, transversal and vertical components of speed. However, in meteorological measurements it is more common to use vertical axle cup anemometers, which measure the resultant horizontal speed. The ratio of the gustiness of wind to average speeds has been found to be in the range of 1.3, and the dependence on wind speed is relatively small.

Besides wind, other climatic parameters that affect buildings and human comfort include temperature, humidity, rain/snow, fog, sun, and in some regions, windborne sand or dust. The combination of these parameters with wind modifies the effects of each single parameter. The most important combination from the planning point of view is wind and temperature.

The other factors of climate – precipitation, temperatures and solar conditions – are also presented in clear graphics as well (Figs 55–56). No uniform or established practice has evolved for making micro-climate assessments. The most clear-cut manner of proceeding is to sketch the distributions of different micro-climate factors on a map, each on their own map. Then, to divide the target site into small areas in terms of the micro-climate, the distributions, sketched on transparencies, can be placed one on top of the other. The assessment can be started by utilizing a topographical map and solar path diagrams. With them it is possible to differentiate sunny southern slopes and shady northern slopes. A topographical map can also be used to determine cold valley floors into which cold air flows in clear weather, and hilltops where wind speeds are above average. Geotechnical maps can be used to differentiate clay soils and peat soils, which on average are colder and moister than rocky and sandy soils, which are warm and dry.

Analyses of air quality are carried out with field measurement equipment and conclusions drawn in laboratories, and as such are not part of this research. But the
distribution of air pollutants with the winds and the charting of zones where the impure air accumulates are important parts of any micro-climate analysis. Also this information is put on the micro-climate maps.

Fig. 55. Presentation of the monthly maximum, minimum and average temperatures. Because there is no measurement station in Raahe, all of Raahe’s data are calculated as averages of the data from the three nearest stations. (Kuismanen 2000)

Fig. 56. Presentation of rain (sademäärä) in mm and snowfall (lumen syvyys) in cm, Raahe. (Kuismanen 2000)
Fig. 57. Presentation of windiness, Raahe. Calculated average wind-speeds (m/s) and the wind directions of four representative stations. (Kuismanen 2000)

Fig. 58. Wind roses gathered from simultaneous measurements from the roof an apartment building in Puijonlaakso in Kuopio and the local airport at about 10 km distance. The data correspond relatively well with each other. (Kivistö 1987: 3/47)
Fig. 59. Wind speeds and temperatures measured from roof A in Puijonlaakso, the yard of a shopping centre and Kuopio airport. The wind speeds correspond relatively well with each other, whereas there is a greater variation in temperature, depending on location, below. (Kivistö 1987: 3/48)

It is also possible to acquire more information about the site’s climate by conducting measurements in the area (Figs 58–59). Observation devices that measure temperature, moisture, and wind speed and direction can be placed in selected places in the terrain. These values can then be compared with corresponding values obtained from the reference station. Another way to obtain observation data is to travel around the area with a vehicle-mounted observation station and then compare the measured observations with the reference observations. The method mentioned first gives more reliable data, while the latter method provides observations from a broader area. Since supplementary observations are generally made during a short time period, they do not provide statistically reliable quantitative information; they provide ballpark information when they are compared with data obtained from the reference observation station. (Kivistö 1982: 15–20; Glaumann & Westerberg 1988: 54–70)

Comparisons of on-site interviews with wind-speed measurements and model tests have been carried out by Westerberg in Göteborg. As wind is directly sensed both as wind forces and wind-chill, this combination is difficult to model in a digital or physical model or describe. But humans can summarize their perceptions in few words. Wind and other climatic parameters were measured, short interviews carried out, and human activities observed. Wind tunnel tests with a 1:200 model
were produced. These studies show that both sand erosion tests, and surveys and interviews are cost-effective and flexible methods to investigate the urban wind environment. (Westerberg 2004: D.2.1, 9–10)

4.3.3 Local climates

Different types of terrain forms have certain effects on the forming of the microclimate depending on the macroclimate.

Hill

A hill strengthens the speed differences of a weak air flow. A large separation bubble becomes established on the lee side of a hill if the hill is steep enough. Behind the obstacle the wind speed declines to half in the area whose depth can be 10 times the height of the obstacle. Oblique wind against a sharp obstacle causes an increase in gusting to the windward slope. A calm area will be formed on a treeless slope on the leeward side when the inclination is greater than 1:3. A calm zone can be created on the lower part of a slope by the effect of a steep slope, and the length of the zone can be up to 30 times the height of the obstacle. Wooded brows of hills are only half as windy as bare ones, but the wind speed will increase immediately double or three-fold, if the forest is felled. A hill which is only a hundred metres high can increase rain by tens of per cent (Fig. 60). (Mattsson 1979: 76–79, 95–96; Glaumann & Westerberg 1988: 60, 88–89; Cao 2005: 16–17)

Forest

A wind that blows from an open area to a forest breaks into the depth of 300–400 metres before it deadens. In the forest the air flow is about a fifth compared to an open area. Thermal currents from the cooler shade of the tree stand towards the sunny expanse can be found on the edge of forests. On clear calm nights the temperatures in the middle of tree stands can be several degrees C higher than those in open areas. (Mattsson 1979: 105–110; Glaumann and Westerberg 1988: 56–65)
**Hollows, cold air lakes**

When thermal energy disappears from a radiating surface into space, the temperature of the surface will begin to drop. The decrease in the temperature is compensated for by the heat flux from the soil and thus the speed of the decrease in the temperature depends on the heat capacity of the soil or structures. In clear weather the temperature of air in the down-to-earth layer falls fast and ground-inversion is created in which the temperature near the surface is lower than in the higher layers of air. A cold air layer, in which the air is denser and heavier than in the surroundings, will be formed in the vicinity of the earth's surface. This heavy air begins to slide to the lower terrain sections due to gravity and accumulates as cold air lakes in valleys and hollows (Fig. 62). Thus the temperature differences may be as much as 20 degrees between valleys and brows of hills. In inversion situations the temperature differences can be 0.1–0.3 degrees per metre difference in altitude. Thus the temperature difference between the lower part of the building which is 30 m high and the roof terrace may be up to 9 degrees. This fact has significance also to the mean temperature of the year so that on a low-lying place the annual mean temperature will be lower than higher up on the slope. (Pienilmaston 1997: 7–12)

The opposite phenomenon to the cold air lakes is the forming of islands of warm air at the centres of big cities. The phenomenon is caused by the energy which is used in a city and by the long-wave heat radiation which is released from the buildings. The temperature difference is at its biggest at night when it can be as much as 10 degrees. (Mattsson 1979: 113–120; Kivistö 1982: 123)
Coasts

Due to the slow warming and cooling of the sea the coasts in spring and early summer will be cooler than the average and, correspondingly in autumn and early winter, warmer. The effect of sea on the temperatures extends to about 20 km inland.

The wind speeds are on the average double on the coast compared with inland. The wind speed decreases going inland so that the strong windy zone will extend inland from the coast about 15 km, and at a distance of 40 km inland the effect of the coast cannot be perceived. On the coast there are on average fewer clouds and the coasts get more solar radiation than inland.

When a western air flow arrives in Scotland or Norway and rises up the west slopes of the mountains, it will cool down and release moisture as rain. On the east side of the mountains air ends up in a downward motion in which case it gets warmer and drier. This föhn phenomenon extends in Scandinavia to North Sweden and even to the west coast of Finland. In Finland least rain is obtained on the coast of the Gulf of Bothnia. The flat terrain which does not cause convective rains on the west coast of Finland in addition affects the scantiness of rain. Instead in
Southern Finland the southern air-flows end up in upward motion when meeting Lohjanharju and Salpausselkä, which with the higher than average moisture contents of the air explains the abundance of rain there.

The climate of the coast will be affected during sunny days, especially in spring and early summer, by the earth-sea wind-phenomenon, the sea breeze and land breeze, as in Fig. 61. See diurnal wind systems below.

From the point of view of town planning and design in Northern Europe the facts presented above signify that the outdoor areas in the coast lane would have to be protected against the north and south-westerly winds, because energy saving protection towards the north and east is necessary. To help the ventilation of exhaust gases the main traffic lines should be opened to south-western and northern flows. In Scandinavia when it snows with the south-westerly winds, the air flow has often a relatively high speed which affects drifting.

Continental areas

In continental areas the diurnal variation of temperatures is large because of the absence of the balancing effect of the seas. In some seasons the difference between day and night can be more than 20° C. In addition rapid changes can occur in short periods of time because of a change of wind or by heavy showers or thunderstorms.

Diurnal wind systems in valleys and on coasts

Temperature differences cause thermal flows, which in some conditions can form diurnal wind systems which deviate from the macroclimate.

Valleys canalise flows. When the wind blows obliquely or directly into a valley the flow rate increases 10–20%. A valley slows down cross direction flow by 20–30%, landslide valleys even 40%. In the bottom of valleys or of even smaller dents cold air lakes are easily created, because the layers of air near the earth's surface cool down, especially on clear and calm nights more than the higher layers of air (Fig. 62). As heavier cold air begins to slide downwards and at the same time gathers behind obstacles to make pockets of cold air and cold air lakes in the valleys. Thus in Finland, the higher the terrain the building is located on, the warmer the place, but on high mountains this can be vice versa. Figs 63 and 64 show the wind system of valleys, up valley and down valley winds.
The coasts of seas and of big lakes affect the land breeze and sea breeze phenomenon. In spring air above cold water is cool. When the sun warms the continent near-by, air will begin to rise upwards and the partial vacuum which has been created in this way will be filled by the cold wind which blows from the sea, and a local circular motion is created. The effect of this climate system, which lowers the temperatures in the spring near the northern seas, extends about 20 km inland. At night the cooled air of the continent will flow back towards the warmer sea, but the phenomenon is considerably weaker than daytime. Fig. 61 describes the sea- and land-wind systems. (Venho 1971; Børve & Sterten 1981: 27–29; Pienilmaston: 10–12)

Fig. 61. Sea breeze will be created during sunny days when the terrain will warm up and the land breeze when the sea retains its heat at night. (Venho 1971: 55)

Fig. 62. Forming of cold air lakes at night. (Mattsson 1979: 86)

Large-scale local winds

In Europe the most famous wind is probably the mistral which blows from the northern Alps south toward the Mediterranean. It brings cold strong conditions to southeast France. An adjacent system to the mistral is the tramontagne which means “cross mountain”. This blows parallel to the Pyrenees from west and across the spine of Italy from the Balkans.
In North America most special winds occur in the west for high mountains, originating from the Great Basin uplands. The Chinook blows on the eastern slopes of the Rocky Mountains, while the mono and Santa Ana blow towards the Pacific coast. Often a strong sea breeze may return these winds which have had only a short trajectory over the ocean and it is drier than normal marine air.

Fig. 63. Wind speeds in a valley, where a valley wind dominates, and a cold air lake which is at the bottom. (Børve & Sterten 1981: 74)

In most mountain areas there are föhn winds, a drying down-slope wind. Down-slope gravity winds that originate at high elevations over permanently cold areas are known as a bora, and they flow over the terrain much like mist to the lowest available place. The Alps and Himalaya, as many other areas, possess weather
altered by almost all the conditions mentioned in this chapter; lake breeze, heat fronts, slope and valley winds, anabatic and catabatic flows, convergences etc. (Pagen 1992: 109–110, 155)

4.3.4 Analysing the impacts of landscape types

To facilitate the compilation of an analysis and planning guidelines, a classification for terrain and landscape shapes has been developed during this research. The range of landscape types covers the whole world, and is partly based on the classifications of Børve and Sterten, Hagget, and Troen, all of them being insufficient, as such, to cover different cases. (Børve & Sterten 1981: 89; Troen 1989: 16–23; Hagget 2001) It consists of seven landscape types which can be found on all continents, and shows examples of how a micro-climate can be considered in different types. All drawings are made by the author. The guidelines are based on the meteorological and fluid dynamics literature cited in Chapters 3.2 and 4.33.

The proposed landscape types are:

1. Plain
2. Hilly landscape
3. Slope
4. Valley
5. Mountain or a high island
6. Hilly landscape bordered with mountains
7. Coast

The seven terrain types are described below. Comments on considering a microclimate during the planning phase are made according to these types. In the figures, it is assumed that the landscapes are viewed from the south.

1. Plain

Terrain type 1 (Fig. 65) describes wide, relatively flat areas. The land can be a low-lying or high plateau. The terrain is open to winds blowing from different directions. In northern latitudes, snowstorms occur because of strong winds and a flat terrain, which causes snow to accumulate behind wind fences. In dry climates, airborne sand affects people and structures, and erosion can be a threat to agriculture.

Plants planned to be used as shelters against wind should be planted 5–10 years before construction work starts. All the buildings in the area should be low except in hot climates, where the height differences of buildings enhance ventilation. If a constructed area is wide, the building height can gradually rise towards the centre. Building placement should be considered carefully, and in windy regions, the placement and shapes of buildings should be tested by using wind tunnel tests. Residential buildings should be constructed so that they form courtyards, and separate buildings can be connected to each other by semi-permeable wind fences. Long streets in one direction should be avoided; neither should they open directly towards the edges of the area. Snow deposit areas should be examined carefully during the planning phase.

In forest terrain, micro-climatic problems should not appear in cold climates, if buildings are lower than the forest. High trees should be saved and construction of long, straight roads that channel the wind should be avoided. It is important, however, that the forest does not shade the buildings or yards).
2. Hilly landscape

The Fig. 66 describes a relatively wide hilly landscape or inland islands. Because the forested hills cover less than one half of the surface area, wind speeds are relatively high. In this case, the wind circles the hills and a so-called point effect occurs on the edges of the hills. This causes wind speed to grow. The highest wind speed is achieved at the tops of the hills and in the valleys between them, especially if there is no forest. The amount of solar radiation varies greatly in different terrain situations.

There is a village in the low terrain, and even small differences in height cause air to flow down. The village road running from the west to the east channels winds and increases the (cooling) effect of wind. Buildings placed in the village
are so large themselves that they cause turbulence and create winds in their surroundings. However, the buildings are located so far away from each other that a heat island phenomenon does not occur in the centre.

**Cold and moderate climates.** Spending time in the village centre is unpleasant for most of the year, because neither plants nor buildings give any shelter against wind or rain. Making a shadow analysis is recommended, but usually the best places for buildings are on the south slopes. However, the buildings should not be placed above the forest on the hill. If the buildings are placed on the plain between the hills, the building density should be high enough so that heat can be contained among the buildings. When building placement is planned, wind channelling and strengthening near the hills should be considered. By making the structures of the village centre denser and providing it with plants and sheltered pedestrian streets and seats, the cosiness of the area can be improved. Existing vegetation should be preserved.

**Warm climates.** The best sites for a residential area are the wind-exposed slopes and valleys. To create shadow, the streets should be directed at a 45-degree angle in respect of the cardinal points.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Prevailing wind</td>
</tr>
<tr>
<td>II</td>
<td>Cold air flow</td>
</tr>
<tr>
<td>III</td>
<td>Cold air lake</td>
</tr>
</tbody>
</table>

---

Fig. 66. Hilly landscape. (Kuismanen)
3. **Slope**

The character of a slope is determined by its orientation in respect of the cardinal points and prevailing winds. In the northern hemisphere, terrain facing southwards gets more solar radiation. Vegetation and the soil usually consist of relatively homogenous horizontal belts. A mountainside which is on the windward side increases rain.

Slopes strengthen the speed differences of weak air flows, and especially the upper zones have a heavy wind stress. A calm area will be formed on a treeless slope on the leeward side when the inclination is greater than 1:3. Oblique wind against obstacles increases gusts on the windward slope. If wind meets a slope at an angle less than 45°, the wind will blow parallel to the slope, while a convergence angle more than 45° forces the air flow to cross the high land. In foothill regions distinct and persistent flow systems occur, such a Föhn and Bora.

Heavier cold air tends to slide downwards and gather behind obstacles to make pockets of cold air. On the sunny side, there can be a weak air flow upwards on clear days. The temperature differences may be big between the lower and upper zones of a sloping terrain.

When buildings are planned on mountainsides, special attention should be paid to avoiding erosion, landslides and avalanches.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Heavy wind loads</td>
</tr>
<tr>
<td>II</td>
<td>Cold air flow</td>
</tr>
<tr>
<td>III</td>
<td>Rising air flow during sunny days</td>
</tr>
<tr>
<td>IV</td>
<td>Oblique wind, 45 °</td>
</tr>
<tr>
<td>V</td>
<td>Oblique wind, 45 °</td>
</tr>
<tr>
<td>VI</td>
<td>Cold air pocket</td>
</tr>
<tr>
<td>VII</td>
<td>Shelter plantings against cold air flows</td>
</tr>
</tbody>
</table>
4. Valley

A valley is an axial V- or U-shaped terrain formation and there is usually a waterway at its bottom. Watersheds mark the limits of valley systems and also define micro-climatic areas.

Valleys usually have a special wind system. In daytime, there is often a moderate wind upwards. At night cold air flows from slopes into the valley, where a cold air stream and cold air lakes are formed and the valley breeze becomes channelled into the bottom. Thus, valley floors are often micro-climatically disadvantageous places for building. South hillsides are especially good areas for construction because of the large amount of sunlight and only minor disadvantages due to wind. In Central Europe, these zones are sometimes called “beech belts”. Diurnal variations of temperature are relatively big. On the topmost parts of high mountainsides rain often falls as snow.

When there is an intention to build in mountain areas, a careful study of the micro-climate should be made before construction is started. Wind shelters and protection against landslides and avalanches are often needed. Micro-climatic
problems may arise, if buildings much higher than the forests are constructed. Long building masses that are oriented in the direction of elevation contours should not be built, because in that case cold air flowing from the slopes piles up behind the structures. The potentials for area ventilation are limited, and that is why air pollutants easily concentrate on valley floors.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>System of valley wind / mountain wind</td>
</tr>
<tr>
<td>II</td>
<td>Cold air lake, fog</td>
</tr>
<tr>
<td>III</td>
<td>Watershed</td>
</tr>
<tr>
<td>IV</td>
<td>Relatively warm and calm zone</td>
</tr>
<tr>
<td>V</td>
<td>Relatively chilly and calm zone</td>
</tr>
<tr>
<td>VI</td>
<td>Wind screen plantings; avoid creating cold air pockets</td>
</tr>
<tr>
<td>VII</td>
<td>Shelter zone / tree stand against avalanches and land slides</td>
</tr>
</tbody>
</table>

Fig. 68. Valley. (Kuismanen)
5. **Mountain or a high island**

A high sea island or a mountain on a plain is usually located in a climate in which the main wind direction can be determined. On the different sides of a mountain, wind and light conditions vary strongly. The most sheltered areas are on the windward and leeward sides of a hill, while on both edges the wind speed is high. On the windward slope, precipitation is the highest.

Many islands (and some mountains) are little weather systems unto themselves. When the land heats up in the day it forms a local heat low that sucks in air from all sides that converges and rises over the island forming a cap cloud, causing afternoon rains. Often the sea breeze is combined with large-scale wind movement.

The latitude of the project has effect on instructions for planning. In a cold climate, building should be concentrated in sunny places sheltered from the wind and in addition, shelters against the wind should be made or planted. In a hot climate, a windier, shady construction place may be recommended, if there is no need to have shelter against wind, for instance, because of sandstorms. On an island, the location of buildings is also influenced by finding a sheltered boat harbour (Fig. 69).

---

<table>
<thead>
<tr>
<th>I</th>
<th>Prevailing direction of wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>Wind arrows on the ground</td>
</tr>
<tr>
<td>III</td>
<td>Turbulences</td>
</tr>
<tr>
<td>IV</td>
<td>Construction area with little wind; recommended in a cold climate</td>
</tr>
<tr>
<td>V</td>
<td>Necessary wind shelters in a cold climate</td>
</tr>
<tr>
<td>VI</td>
<td>Windy construction area; recommended in a damp / hot climate</td>
</tr>
</tbody>
</table>
6. Hilly landscape bordered by mountains

This type of landscape is characterized by high mountain chains, which border a varied hilly landscape, “Mittelgebirgs-relief”. The mountains border a macro-climatic area, in which several varied micro-climates and a system of waterways are included. The winds at the peaks may be representative of free atmospheric values. Inside the area, the wind, light, snow, fog and thermal conditions vary a lot and so do vegetation and the soil. Mountain valley winds dominate often, and winds can turn into storms locally. In the details of the terrain, there are characteristics and problems described in landscape types 3, 4 and 5.

Due to the conditions, wind, sunniness and soil mapping must be carried out and risks of floods and landslides must be assessed before town planning and construction. Due to varied wind directions, shelters and shelter plantings easily get
the basic shape surrounding the object. The most recommendable way of building is a dense form with a uniform height, but even then sufficient shelter tree zones must be preserved in the places shown by the micro-climate and nature analysis. Locally, there can also be places which gather air pollutants, and industrial plants or traffic routes should not be placed there.

Fig. 70. Hilly landscape bordered by mountains. (Kuismanen)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Main direction of the wind on uplands</td>
</tr>
<tr>
<td>II</td>
<td>Main direction of the wind on downlands</td>
</tr>
<tr>
<td>III</td>
<td>Varied complicated wind conditions in a hilly landscape</td>
</tr>
<tr>
<td>IV</td>
<td>Wind shelter plantings and structures breaking wind corridors are needed</td>
</tr>
<tr>
<td>V</td>
<td>Watershed</td>
</tr>
</tbody>
</table>

Fig. 70. Hilly landscape bordered by mountains. (Kuismanen)
7. Coast

In addition to a macro-climate, the climate on the coasts of a sea and big lakes is dominated by a diurnal system of sea and land wind, which usually prevails in springs and summers when water is colder than land. On a coast, the wind usually blows from the sea on sunny days, which can be experienced to be unpleasant in a cold climate but pleasant in warmer zones. At night, a weak air flow blows from the land to the sea (Fig. 71).

The planning instructions for coastal areas are different in different climates. In a cold climate, exterior spaces and buildings should be sheltered against wind, and long streets in the direction of the sea wind should be avoided. In warm zones, cooling sea wind should get into streets, which requires long streets beginning from the coast in the direction of the wind. Interior spaces of buildings should be ventilated by leading air flows into them. (See: Design guidelines 6.82 and 6.85).

I Sea wind; may cause turbulences in a street
II Sea wind; a flow gets stronger in an open structure of apartment buildings (suitable for a hot climate)
III Closed yards are sheltered against wind (suitable for a cold climate)
IV In a low-dense structure the flow rate of air is low
4.3.5 Working with the help of topography maps

Information obtained from weather stations can be made usable for local circumstances by evaluating how a micro-climate takes shape in the topography with the help of maps. A sufficiently large area outside the planning area should be analysed as well, so that all possible forces that may have effect will be taken into account. The work can be improved in the built environment on a more specific scale by using the plan illustration as a base.

1. Climate map. Usually watersheds and ridges outline local climate areas, and that is why climate map making begins by marking watersheds and local climates on a cartogram. With the help of climate analysis, residents’
interviews and observations, wind channels, cold air flows, cold air lakes and areas on the slopes where cold air stands by a fence can be evaluated. The amount of sun and shade in different spots in the terrain can be determined using a sunniness analysis and by construing shadows near large building masses and hilly terrain. Special observations such as erosion, watercourses, damp areas, wind protected zones and local wind systems are also marked on the map. Appendix 7 contains an example of a Norwegian climate map and the signs used in it. (Halvorsen 1995: 30–33, Sterten Nordisk 1991: 36)

2. Illustration. For clarity it is often wise to draw an axonometric or bird’s eye view drawing of the planning area, where the most important climatic occurrences and main points of the built and natural environment as well as different zones are marked. It is necessary to mark the main wind directions, and phenomena like sea and land breeze, other diurnal winds, etc. (Figs 72–73).

3. Shadow analysis. One part of a study of the suitability for construction in hilly terrain and large valleys is a shadow analysis, where the amount of sun at the construction sites during the summer equinox is checked. Today CAD is in most cases used. One useful method can be found in the publication by Børve and Sterten called Arbeitsrapport 26. (Børve & Sterten 1981: 15–17)

4. Built environment. If a scale model of the planning site is not made, the forthcoming micro-climate can be evaluated by placing the flow models obtained from other site’s wind tunnel measurements into the illustration of the target in question, using a scale of 1:1000–1:500 (Figs 74–75). The result is not even nearly as exact and reliable as when using small-scale tests.

5. Geological map. Soil quality affects the temperatures above. Subsoil information can be used to locate clay and peat soil, which are usually colder and damper than sandy soil and bedrock.
Fig. 72. Axonometric drawing of landscape in which the main features of windiness during day and night are marked with arrows. (Sterten 1995: 79, drawing Gunnarsdottir & Hardarson)

Fig. 73. Axonometric drawing of Oslo in which both ventilation of city blocks after additional construction and air-improving water features are marked. (Sterten 1995: 39, drawing Børve)
4.3.6 Analysing a micro-climate on-site

Subsoil and climate circumstances are essential for life on earth, and studying them is also a starting point for bioclimatic planning. Information gained from books and maps is inadequate; observations made at the building site are also needed. Depending on the needs of the planning objective, the goals of the fieldwork have to be defined. The mission may be, e.g. to find out the watersheds and flows of surface water, to define small climate areas and biotopes, etc. The observations are registered by drawing different kinds of information on maps and then combining the maps at the end of the study.

When analysing windiness, the statistics of weather stations usually cannot be used as such, but it is necessary to map out an area’s windiness with observations on-site. Sometimes it is necessary to specify the information of some key areas by using local measurements. Wind speeds around buildings and vegetation can be measured using portable equipment or a stationary measurement station.

Fig. 74. Example of a micro-climate study made on a plan illustration, Kekkola, Jyväskylä. Main wind channels are marked with piles, catabatic flows with fat piles, air pollutant accumulations with a fat pile trapped in a square, warm places with +, and cold areas with −. (Kuismanen 1992)
Since the gustiness of wind is random, one measurement result does not play a significant role, as wind speeds are evaluated by statistical methods. When comparing the mean values of wind speeds, the same mean value period which is usually ten minutes, has to be used. When making a wind map of a place, many measurement points are needed, as well as a measurement period of several weeks. According to international practice, the constant speed of wind is measured 10 metres above ground level in an open area. The WAP PC Wind Atlas Analysis and Application Programme can be used in processing the information. (Troen 1989; Tilastoja 1991; Halvorsen 1995: 30)

Windiness at the building site can be estimated using natural signs (Figs 76–78). Annual wind directions and speeds are reflected by vegetation forms and snow accumulation. Trees bend and their crowns are shaped according to the prevailing direction of the wind. In very windy conditions the strained side will have thick, aerodynamically formed protective plant growth, while branches grow more freely on the protected side. By examining the shapes of trees and bushes in windy spots the correct roof angles and building and terrace’s forms and orientation can be concluded, as shown in Fig. 77. (Mattsson 1979: 86–87; Børve 1987: 65–71)

Luxuriant vegetation indicates a warm sheltered place where the subsoil is also favourable. Low plants such as heather (*Calluna vulgaris*) and moss (*Bryophyta*) are good wind indicators, because they usually grow on the protected side of rocks. Branches of bushes and trees which grow on the windy side may die in the wintertime because of excess evaporation (drying). Vegetation is more luxuriant in areas protected from the wind. In a windy place even the soil becomes coarser, as the fine topsoil is blown away by the wind.
Fieldwork in the wintertime is very productive, because natural forces can be seen easily, if the ground is covered with snow (Fig. 78). By studying snow accumulation, wind directions, windy spots and calm areas can be localised. In a very windy spot the land is often bare and has only a little snow or the snow is densely packed. In an area protected from the wind, the snow is loose. It is good to keep in mind, though, that wind observations made in the wintertime cannot be used in the summertime, as such.

In many areas cold and damp places can be mapped out with visual perceptions. This happens by observing the landscape on bright mornings at the end of summer or the beginning of autumn. Low-lying terrain and valleys where cold air accumulates will have radiation fog, which reveals the cold areas. A picture of the
distribution of cold and moist areas can be simply obtained by means of visual observations. By mapping the foggy areas it is easy to chart cold areas.

The principles according to which old buildings have been placed and shielded usually tell about local climate conditions and how those conditions have been considered. Investigating damage in buildings gives hints of climatic stresses and helps the architect avoid repeating the same mistakes (Fig. 79). Damage caused by heavy wind and rain can be seen especially at the bottom parts of windows and facades. Frost damage in bricks indicates either heavy rain or missing eaves. (Sterten & Børve 1981: 63; Bjørge 1992)

Fig. 78. Observing air flows on snow is easy. Kemijärvi cemetery. (photo Kuismanen)

Fig. 79. Knowledge gained from traditional building can be applied to present building methods. (Sterten & Børve 1981: 64; drawing Bjørge)
4.4 Sunniness analysis

4.4.1 Solar radiation

Solar radiation reaching the earth is mainly shortwave visible light, while radiation emitted by the earth is infrared radiation (thermal radiation). Only a small part of this radiation is visible to the human eye.

When solar radiation hits the atmosphere, about 43% of the radiation is reflected back into space, some is absorbed by gases in the atmosphere (heating the air only 0.5° C per day) and some is scattered by molecules. Thus, radiation coming from the sun can be divided into solar radiation and diffused radiation. The distribution of diffused radiation on divergent surfaces has not been studied much. It has been found out, however, that diverging banks and wall faces receive almost as much diffused radiation regardless of whether the weather is sunny or cloudy. The solar radiation that different surfaces receive consists of both direct and diffused radiation. For example, in the wintertime a wall located on a south bank receives a significant amount of diffused radiation from the horizontal snow surface located in front of the bank. Elomaa has examined the distribution of radiation on different surfaces. (Elomaa 1980: 61–81)

Solar radiation can be absorbed into the subsoil and vegetation, as well as into buildings and building structures. How easily the subsoil and building materials warm up depends on their ability to absorb, their specific heat capacity and their humidity. For instance dark surfaces reflect only 10–15% of the incident radiation. Dark, lightweight structures warm up quickly and radiate long-wave thermal radiation, which heats up the surrounding air. The air is not actually warmed by solar radiation, but through thermal radiation from the subsoil and (building) structures. Structures and materials that have a large specific heat capacity can bind a considerable amount of heat and warm up slowly, but on the other hand they also release heat to the surrounding environment quite slowly. Evaporation binds a great deal of heat, for which reason the evaporative effect of plants and trees slows warming. Correspondingly, when dampness condenses into fog, dew or hoarfrost, it slows temperature falling. (Elomaa 1980: 61–81; Pagen 1992: 5–10)

Solar angles of a given place and time of year can be calculated, but in most countries there are ready-made tables and figures or CAD-programmes available, where this information can be found. Based on this information a “solar-rose” or other descriptive material can be drawn (Figs 80 and 83).
The amount of solar radiation is interesting when planning the use of either passive or active energy in connection to urban planning or building design, Table 8. But besides the bare annual amount of solar radiation, its seasonal division affects the possibilities of the use of solar energy. For example at the time of the equinox the east-facing slope receives the same heat at 8 AM as the horizontal surface at noon and the west-facing slope at 4 PM. (Pagen 1992: 8–9; Erat 1995: 22).

Table 8. Amount of solar radiation on a horizontal plate.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>kWh/ma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archangel</td>
<td>64 ° 35' N</td>
<td>819</td>
</tr>
<tr>
<td>Helsinki</td>
<td>60 ° 12' N</td>
<td>938</td>
</tr>
<tr>
<td>Bergen</td>
<td>60 ° 24' N</td>
<td>908</td>
</tr>
<tr>
<td>Hamburg</td>
<td>53 ° 38' N</td>
<td>938</td>
</tr>
<tr>
<td>Paris</td>
<td>48 ° 49' N</td>
<td>1032</td>
</tr>
<tr>
<td>Wien</td>
<td>48 ° 15' N</td>
<td>1070</td>
</tr>
<tr>
<td>Rome</td>
<td>41 ° 48' N</td>
<td>1435</td>
</tr>
<tr>
<td>Nairobi</td>
<td>1 ° 18' S</td>
<td>1855</td>
</tr>
<tr>
<td>Edmonton</td>
<td>53 ° 33' N</td>
<td>1354</td>
</tr>
<tr>
<td>New York</td>
<td>40 ° 47' N</td>
<td>1405</td>
</tr>
<tr>
<td>El Paso</td>
<td>31 ° 48' N</td>
<td>2309</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>34 ° 35' S</td>
<td>1622</td>
</tr>
<tr>
<td>Sapporo</td>
<td>43 ° 3' N</td>
<td>1189</td>
</tr>
<tr>
<td>New Delhi</td>
<td>28 ° 35' N</td>
<td>1987</td>
</tr>
<tr>
<td>Aden</td>
<td>12 ° 24' N</td>
<td>2708</td>
</tr>
<tr>
<td>Melbourne</td>
<td>37 ° 49' S</td>
<td>1588</td>
</tr>
</tbody>
</table>

It must be pointed out that the amount of solar radiation alone does not tell much about the climatic conditions. For instance Helsinki and Bergen have the same amount of solar radiation, but the latter has almost four-fold more precipitation and milder winters, and thus a quite different climate.

When the amount of solar radiation decreases, the radiation balance becomes negative because only the long-wave radiation emitted by the earth remains. During cloudy weather the clouds reflect almost all thermal radiation back to the earth, but in sunny weather the long-wave thermal radiation is radiated into space. (Haggett 1983: 70–75)
4.4.2 Solar analyses methods

The quality of sunlight is better for the human eye and human functions than artificial light, and that is why natural light should be favoured indoors in the daytime. The best light is even, non-glaring and adequate. Depending on the latitude and seasons, sunlight hits buildings at different angles (Figs 80–81). Designers have to know the boundary values of the angles and the amount of sun hours to be able to specify the size and direction of windows, the need for shade elements and places for reflective surfaces or the angles of solar collectors (Fig. 82). (Serra 1999: 29–32)

The Fig. 80 below gives an overview of the sun’s influence in different climates. The shading requirements depend upon the sun’s path in each season.

![Fig. 80. Overview of the sun’s influence on local climates. (Yeang 1999: 222)](image-url)

Solar paths; The hatched sections indicate the sunpath as observed in each climate zone. Sunshade analyses; Diagram indicates the optimum location of vertical sun shading needed in the morning and evening (Solid line), and of horizontal sun shading needed in the midday (Broken line). Insolation; Represents the shape of the sunpath. Sun requirement; in higher latitudes the need for solar heating increases.

A sun analysis reveals the amount of sun indoors or in the yards, but it also indicates how sunniness conditions change in a built environment during the day. A summary of the analysis should be appended to either the draft plan or the site plan or description of the building project.
As a starting point for a sun analysis it is necessary to examine when natural light is needed. In northern climates the spring and afternoon sun are considered the most pleasant, and in summer it is necessary to protect against excess sunlight. From the standpoint of energy economy, free radiation energy is an important part of the ecological entity, and especially from autumn to spring. The modifiability of facade zones according to solar radiation is an important design goal.

Town and detail planning are the most important phases when creating sunny conditions for housing estates. The amount of sunlight needed in various activities is presented in the research report of Børve and Sterten (1981: 35–39). Plans should be tested with a sun analysis before realising them.

When doing 3D CAD designing, it is possible to use various computer applications to examine how buildings create shade (e.g., 3D STUDIO/AUTODESK, ARCHICAD/GRAFISOFT, SOLARCAD, etc.).

When working with a scale model, as in the method employed in this research, making a sun analysis is easy using a sundial. The latitude of the site is specified on the sundial. Then the sundial is placed in the scale model and a lamp or a floodlight is directed towards it. The scale on the sundial tells the day and the time when it is as light as in the scale model at the time. The desired date can be found by changing the model or moving the floodlight. (Statens)

In Finland shading can be drawn by using approximate shadow lengths which are given in the RT-card RT 055.33. A good impression of the circumstances in the yard is obtained when the shadows at 10 am, 12 am and 2 pm are presented in the same figure. (RT)

The importance of solar analyses and natural daylight design can be understood when we remember that artificial lighting can account for up to 50 percent of
the overall electricity costs in a modern office skyscraper. This together with
uncontrolled solar gain can lead to high energy expenditure for air conditioning.
(Yeang 1999: 214)

The great differences in lighting in northern areas at latitudes of 60 to 70
degrees have an impact on outdoor activities, the need for lighting and people’s
frame of mind. Because of the low sun angle and changing cloudiness, the grade of
light is usually soft, perhaps even romantic or picturesque (Fig. 82). This also has
an impact on the architecture of the place. The sun shining low gives the environ-
ment a reddish tinge, which has to be considered when making colour designs.
(Wikberg 1963)

According to the measurements, adequate sunlight in Finland can be obtained
by obeying the following rules regarding distances between buildings (Solklart
1991):

– Southern Finland: the width of free space between buildings should be at least
four times the building height.
– Northern Finland: the width of free space should be at least five times the
building height.

If we consider wind conditions, such long distances between buildings are not
desirable. In the courtyards wind comes down from the roof level, and in the wide
streets there is room for a horizontal eddy (Fig. 38).

Originally the only lights visible in the night were the moon, stars and north-
ern lights, and their observation was dependent only on the weather. The invention
of fire-based lighting and later electric lighting changed the scene. The possibili-
ties to observe the night sky in urban areas are scarce. During the blackout of New
York, caused by an electric dropout, some children were horrified for the strange
phenomena in the sky, the stars.

People are interested in watching the moon and stars or phenomenon like illu-
minated night clouds, shooting stars, comets and northern lights, but the ever-
spreading lighting pollution makes it difficult. A “darkness charting” could add
interesting aspects to an area use plan. For example for the Rokua resort the author
did an illumination and darkness plan to ensure the possibilities to enjoy the cele-
tstial bodies in the dead of night.
Fig. 82. Length of night (black) and day (white) at different places in Finland. In the middle is the so-called bourgeois twilight, when the sun is 0 to 6 degrees below the horizon. (Havas 1987: 11)

4.5 Natural environment analysis method

4.5.1 Nature analyses needed in the CASE method

As described above, natural environment and built environment analysis are essential parts of a micro-climate analysis, and needed before town and detail planning is started.

This chapter deals with analysis of the natural environment (item number 2), its flora, different biotopes and their dynamics, etc. In all ecosystems the climate has the predominant influence, even though other biotic factors like flora, fauna and soils also affect the system. In urban situations the climate is sometimes the only natural thing remaining. Although fauna, per se, is an important factor when gathering background information for town planning, it is out of the scope of this study; nevertheless, it is recommended to record all observations made during field work or information from the inhabitants. Guidelines for preserving and restoring the existing natural environment and wind screen vegetation of the building site are given in Chapter 6.3. The main content of green analysis is:

- Topography; micro-climate borders.
- Vegetation (flora); wind shield greenery.
Environment-conscious design is a complex endeavour, and the basic requirement is a good understanding of the ecosystem of the project site. In “normal” architectural projects a relatively simple analysis is enough, and this can be made after some practice by planners and architects using the methods described here. The method consists of different parts, whose reliability has been proved by Anttila, Børve, Kuismen and Yeang. (Børve 1987: 90–97; Anttila 1996; Kuismen 1996; Yeang 1999)

The nature analyses method was developed by the author in connection with two planning projects in Finland; a plan for a residential area in Sodankylä and a renewal plan for the Rajakylä suburb in Oulu. Natural environment analyses were made by the author at both places using this method, and independent biological analyses were made to check the reliability of the results. The results of these two analyses were quite similar, thus ensuring the reliability of the method developed.

The method can be used in most small and medium sized planning and architectural design projects. If the nature of the project area is vulnerable or contains special nature values, it should be analysed as an ecosystem by specialists, and in that case the method proposed in this study is not adequate.

**4.5.2 Analysis content**

When doing nature analyses, in addition to the vegetation, elements like orography, vegetation and hydrogeology also need to be analysed. Sometimes a SWOT analysis can be useful at the beginning.

In practice the information needed can partly be obtained from written sources, but some part of the information needs field work and observation. The following list gives the main topics of the nature analysis needed in this method.

The developed analysis content party contains topics that belong to every nature analysis. However, there are also new items, like the roughness factor, the proposed field work practices, elaboration of wind shield vegetation, analysing the effects on wind patterns, and the ways of actively improving the micro-climate.
with greenery. The target is a better understanding of the bioclimatic entity. Table 9 gives the main topics of the nature analysis needed in this method.


<table>
<thead>
<tr>
<th>Information or analysis needed</th>
<th>Documents, plans made</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure of the landscape</strong></td>
<td></td>
</tr>
<tr>
<td>Definition of the landscape structure</td>
<td>Map, axonometric presentation [49], [51]</td>
</tr>
<tr>
<td>Terrain type</td>
<td>Map, description</td>
</tr>
<tr>
<td>Nature of the green structures, special features</td>
<td>Description [112], [114]</td>
</tr>
<tr>
<td><strong>Natural environment analyses</strong></td>
<td></td>
</tr>
<tr>
<td>Topography, topsoil, erosion, groundwater</td>
<td>Map, description</td>
</tr>
<tr>
<td>Water systems, wetlands, surface water</td>
<td>Map</td>
</tr>
<tr>
<td>Vegetation (and animal life)</td>
<td>Map, description [Ax 2.]</td>
</tr>
<tr>
<td>Green corridors</td>
<td>Map, description [113]</td>
</tr>
<tr>
<td>Barriers dividing the natural environment</td>
<td>Map, [16]</td>
</tr>
<tr>
<td>Future threats against the site’s</td>
<td>Map, description</td>
</tr>
<tr>
<td>Natural environment</td>
<td>Description [16]</td>
</tr>
<tr>
<td>Definition of the biotopes</td>
<td>Map, description</td>
</tr>
<tr>
<td>Wind shield vegetation</td>
<td>Map, description</td>
</tr>
<tr>
<td>Affect of the vegetation on wind patterns and speeds</td>
<td>Map, roughness factor</td>
</tr>
<tr>
<td>Affect of the vegetation on temperatures, humidity, noise and air quality</td>
<td>Map, description</td>
</tr>
<tr>
<td>Prediction about the effects of the climate change</td>
<td>Description, map</td>
</tr>
<tr>
<td><strong>Conclusions</strong></td>
<td></td>
</tr>
<tr>
<td>Proposals for wind shield plantings</td>
<td>Map, description [116], [119]</td>
</tr>
<tr>
<td>Proposals for placing of green areas</td>
<td>Map</td>
</tr>
<tr>
<td>Proposals for green corridors</td>
<td>Map, flow chart [112]</td>
</tr>
<tr>
<td>Bioclimatic entity</td>
<td>Map, description [16]</td>
</tr>
<tr>
<td>Eventual planning guidelines</td>
<td>Illustrations, description</td>
</tr>
</tbody>
</table>

Fig. 83. At small building sites the green analysis can be presented together with climatic and landscape analyses. (Chatelet 1998: 27)
4.5.3 Wind speeds over terrain

Wind speeds over terrain can be estimated using the table of this chapter, which is based on the wind pattern studies and measurements of Børve, Givoni, Glaumann and Westerberg, and Troen. (Børve 1987: 65–73; Glaumann & Westerberg 1988: 46–109; Troen 1989: 16–23; Givoni 1998: 261–263)

The roughness of a particular surface is determined by the size and distribution of the roughness elements it contains, like vegetation, built-up areas and the soil surface. The proposed relative wind speeds (roughness factor) describe the airflows over terrain in comparison with the wind speed over open sea. The relative wind speeds run from 1, wind speed over open sea, to 0.4, a dense forest, Table 10.

Table 10. Relative wind speeds over terrain.

<table>
<thead>
<tr>
<th>Terrain type</th>
<th>Relative wind speed (roughness factor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water surface, more than 1 km</td>
<td>1.0</td>
</tr>
<tr>
<td>Open flat country, sparse trees, single houses</td>
<td>0.7</td>
</tr>
<tr>
<td>Hilly country, trees and fields, single houses</td>
<td>0.5</td>
</tr>
<tr>
<td>Hilly country, dense forest</td>
<td>0.4</td>
</tr>
</tbody>
</table>

When the wind speeds of a given site are calculated, the starting points are the gradient wind speeds from the nearest meteorological stations, which give the airflow speed at 10 m height. Often the gradient wind is a combination calculated from the data from the two or more nearest stations. When calculating the airflow near the ground, the gradient wind-speed should first be reduced by a factor of 0.75, i.e. 75% will be left (Glaumann & Westerberg 1988: 46–109). Then the wind speed is reduced with the factor presented in Table 10. The effect of different terrain shapes on wind-speeds at 2 m height can also be estimated with the help of Appendix 4.

These values are an indicative tool for micro-climate and wind shield planting analyses. One restriction is that the airflow estimation method presented above is not valid in mountain areas, if the height differences are greater than 100 m.

4.5.4 Natural environment analyses at the building site

Before the basic characteristics of a plan or the placing of buildings are defined, the build-ability of the site should be charted. The first information will come from topographic maps or special maps (Appendix 7). The work made for the climate analysis gives already the basic facts of the project site:
– different micro-climate zones of the building/planning site (wind, temperature, rain, snow, humidity)
– topography
– watersheds, cold air pools
– sun and shadow (cool and warm places).

In addition to the above information, the following charting should be made in order to understand the nature and the potential of uses of the site:

– Topography, topsoil, erosion, groundwater. Ocular visual estimate of topsoil and erosion on a topographic map is sufficient, but for the groundwater charting special maps are needed.
– Water surfaces, wetlands, surface water. The circulation patterns of water should be charted. Wet biotopes are especially valuable.
– Wind screen vegetation. Information about the vegetation on a topographic map, with roughness factor classification. Planting type categorization, as described in Chapter 6.35.
– Other vegetation (possibly information on the animal life). As previous paragraph.
– Green corridors. Existing corridors and proposition of needed new ones, as described in Chapter 6.32.
– Barriers and wind channels dividing the natural environment. These can be rivers, traffic arteries etc.
– Existing toxins. These can be buried in the earth. Especially air-borne impurities and polluted water systems can affect large areas.
– Future threats to the site’s natural environment and wind screen vegetation. These consist of urban plans, developments, accumulating affects of pollutants, effects of the climate change etc.
– Potential to improve the wind screen vegetation. Charting of needs and areas, where wind-screen vegetation can be developed.
– Value classification. Define the value of the vegetation of different sub areas (ecosystems) according to the classification in the Table 11.
– Build-ability definition. Buildable and protected areas, and existing and needed wind shield vegetation zones are demarcated.

Field work is the key of the method. In summer it is easiest to identify the flora, but for the best results the analyses should include observations at various times of the year. Pilot projects carried out during this research (Kuismanen and Anttila at
Sodankylä and Rajakylä, and Kuismanen and Eskelinen in Kajaani) show that in normal cases the information mentioned above is enough to understand the natural environment and its dynamics at a planning or building site. When there is an understanding of the bioclimate of the area, it is possible to design the interaction between the projected building or settlement and its climatic and green surroundings. (Anttila 1996; Kuismanen 1996; Eskelinen 1998)

The basis for understanding the natural environment, as well as the climate, of an area is to analyse the circulation of water. Water comes down as rain or snow, which is partly absorbed into the soil as groundwater, partly runs over the ground and partly evaporates back into the air. Water, solar radiation and soil form the pre-requisites for all life. The first step is to make a topographic map, on which water, soil and solar conditions are marked, and this is usually done with the micro-climate analysis. The quality of water in lakes and rivers greatly affects their potential for recreational use and the biotopes that live in them. The groundwater level is usually studied during planning and at the latest before building design. An estimation of the impact of climate change on the hydrology of the site is a valuable tool for planning.

When collecting information about vegetation, it is not necessary to make a complete list. It usually suffices that the key species are mentioned and the area is divided into different zones, like evergreen forests, deciduous forests, meadows, shrubs, hedges, orchards, lawns and flower beds. In many countries there are simple classifications of common environment types. For instance, in Finland forests are divided into five categories, which are herb-rich forests, moist sandy pine forests, dry sandy pine forests, wilderness forests and pine bogs. Each of these can be further defined according to the most common ground cover plant, like blueberry (Myrtillus), heather (Calluna), lingonberry (Vaccinium), etc. For green analysis purposes it is possible to define the whole forest biotope by naming the forest category and the dominating ground cover plant. Besides the type of natural environment it is necessary to mention the age, size and condition of the vegetation. (Lehto 1964: 15–78; Anttila 1996; Sterten 2001)

For planning the animal life of an area is a useful piece of information, but it can be difficult to chart during some relatively short visits, and usually it is not needed for climate-conscious planning. The vegetation classification mentioned above tells what kind of fauna will probably live there. More information can be obtained from local inhabitants or, for instance, nature preservation associations. Often rare, threatened and endangered animals are already charted, but often, espe-
cially in developing countries, such information is not readily available. Defining the biotopes and food chains is even more difficult, and needs special education.

Green corridors are a matter that requires maps and observations from a much larger area than the building site itself. It is important to understand possible connections with large nature areas, because with that information it is possible to judge if the local biotope has realistic possibilities to maintain its biodiversity and the wind screening properties. On the other hand, man-made or natural barriers can prevent genetic flow between biotopes, thus accelerating the loss of species, especially in small green areas. Often the wind screening vegetation offers a hide-away for animal life.

Future threats can be caused by natural forces, a lack of green corridors, planned roads or other barriers, construction projects or the actual project itself. It is also necessary to evaluate if the building site can maintain its original greenery in the long run after the project is finished. (Storstokholms 1991: 35–40; Kuismanen 1996)

The effects of the climate change vary in different areas, and new predictions are published yearly by the United Nations, WMO and research institutes. The effects can be very local, and such information is not publicly available; it has been produced only by some climate projects and mostly for internal use. For instance the average wind-speeds will grow in Finland some 5 to 10%, but on some west-coast areas they will diminish by 10% whereas in some inland regions they will increase by even 15%. (United 2007; Wahlgren, Kuismanen, Makkonen 2008)

All the observations made during field work are collected on a map. The information needed includes the built areas, surface materials, vegetation, topsoil quality, water surfaces, sun and shadow, wetlands, observations about erosion, environmental problems, etc.

When the analysis material is collected, the ecological and micro-climatic value of the vegetation of the area can be defined. For architectural design or planning, Yeang’s six ecosystem categories are practical, Table 11.
Table 11. Ecosystem categories.

<table>
<thead>
<tr>
<th>Value classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ecologically mature ecosystems. These have very high biodiversity, and they include forests, deserts, wetlands and rain forests. These should be preserved.</td>
</tr>
<tr>
<td>2</td>
<td>Ecologically immature ecosystems. These are still natural, but recovering from damage or in the process of succession or regeneration. To be mostly preserved.</td>
</tr>
<tr>
<td>3</td>
<td>Ecologically simplified ecosystems. These have been savaged by grazing or burning, and biotic components have been removed. Increase biodiversity and develop in low-impact areas.</td>
</tr>
<tr>
<td>4</td>
<td>Mixed artificial ecosystems. These are maintained by man through crop rotation, agro-forestry, parks and gardens. Increase biodiversity and develop in low-impact areas.</td>
</tr>
<tr>
<td>5</td>
<td>Monoculture ecosystems. Artificial monoculture areas. Increase biodiversity and rehabilitate. Develop in areas of non-productive potential.</td>
</tr>
<tr>
<td>6</td>
<td>Zero culture ecosystems. Totally artificial urban sites, open-cut mines, etc. Increase organic mass and rehabilitate the ecosystem.</td>
</tr>
</tbody>
</table>

For site planning it is necessary to try to understand the essential functions and interrelationships of the individual site factors. After that an evaluation of the impacts of the actual project on the natural environment should be done. It is necessary to consider how the natural elements will adapt to change. After this, recommendations about protected areas, building sites and recommendations about restoring the natural environment can be made. (Yeang 1991: 91)

In practice, a visual presentation of the project site map is needed. The developed method is an easy-to-use ecological land-use planning technique that shows areas suitable for different uses; see Appendix 2. The site is analysed in terms of its physical natural features, like vegetation, soils, groundwater, natural drainage patterns, topography, hydrology, geology, etc.

The overall architectural solution of the projected building, its shape and floor area determine its footprint on the site and also the possibilities for saving the natural environment. The height of the building determines the length of shadows and also the air movement of the surrounding areas. Areas that have already been developed are usually types of land that can be intensively used. In zero culture sites new structures and landscaping may bring new flora and fauna, which in the best cases are compatible with those which have been there before, and over the years make an effective wind barrier, too.
4.6 Built environment analysis

4.6.1 Built environment analyses needed

This chapter deals with analysis of the built environment (item number 3) to the extent needed for the definition of micro-climate and climate-conscious planning process. To make a town plan is a complex endeavour, and the basic requirement is a good understanding of the project site and its climatic prerequisites. In “normal” architectural projects this can be made after some practice by planners using the methods described here.

In most climates urbanization, due to its increased thermal capacity, lack of water for evapotranspiration, and the canyon effect, tends to aggravate the negative effects of climate. Climate change will worsen the circumstances especially in warm and hot regions. Urban climatic environment is affected both by the conditions prevailing in the surrounding rural areas and the city structures. If we know the characteristics of an urban climate it is possible to modify the urban micro-climate through planning and architectural design.

The main objectives of development of urban micro-climate are energy consumption, ventilation of buildings, dispersion of air pollutants, and human safety and comfort. Within urban areas there is often a need for wind induced street-level ventilation to minimise the frequent occurrence of high levels of pollutants. Understanding the micro-climate of different settlement configurations and urban canyons is important for an understanding of the whole urban climate in densely built central areas. The basic space unit in cities is the street canyon, and their geometry/architecture, materials and facade design greatly influence the urban climate.

But bioclimatic urban planning is not a mere sum of best-practice planning techniques. A new kind of interaction is needed. The objective is towards closed material and energy circles, to minimize the ecological footprint, and diminish emissions to the air, water and soil. The prerequisite is a profound investigation of the actual environment and local climate.

4.6.2 Analysis content

When making urban analyses, both the built structures of the project site and its surrounding areas, and their affect on the climatic conditions, are of interest.
In practice the information needed can mostly be obtained from written or digital sources, but some part of the information needs field work and sometimes field measurements. The first information will come from topographic maps or sometimes available 3D-models. The main topics of the built environment analysis are:

- Built structures; their effect on local wind patterns, solar access and surface water circulation.
- Functions; their sensitiveness to climate and production of air pollutants; guidelines of placing.
- Traffic, site access; emissions.
- Energy and infrastructure systems; solar and wind energy, area drainage.
- Visual features; townscape type.

Before the built environment analysis of an area can be done, the micro-climate characterization of the area must have been done. The maps made for the climate analysis already give the basic facts of the project site:

- different micro-climate zones and wind directions of the area
- topography
- watersheds, cold air pools
- sun and shadow (cold and warm places).

The proposed analysis content partly contains topics that belong to every urban analysis concept. However, there are also new items, like urban structure roughness classification, sensitiveness classification of functions, wind pattern analysis, proposals for windshield means, area ventilation and the ways of concluding them. The target is a better understanding of the bioclimatic entity. Table 12 gives the main topics of the urban analysis needed in this method.
Table 12. Urban analysis.

<table>
<thead>
<tr>
<th>Information or analysis needed</th>
<th>Documents, plans made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure and functions of the built environment</td>
<td></td>
</tr>
<tr>
<td>Charting the urban structure</td>
<td>Map, classification</td>
</tr>
<tr>
<td>Heights, structure roughness</td>
<td>Map, classification</td>
</tr>
<tr>
<td>Functions, their sensitiveness to climate</td>
<td>Map, classification</td>
</tr>
<tr>
<td>Special features</td>
<td>Description</td>
</tr>
<tr>
<td>Traffic routes, emissions</td>
<td>Map</td>
</tr>
<tr>
<td>Other sources of air pollutants</td>
<td>Map, spreading patterns</td>
</tr>
<tr>
<td>Development history</td>
<td>Map, diagram plans</td>
</tr>
<tr>
<td>Future plans</td>
<td>Map, description</td>
</tr>
<tr>
<td>E. Built environment analyses</td>
<td></td>
</tr>
<tr>
<td>Built structure type</td>
<td>Map, description</td>
</tr>
<tr>
<td>Affect of the built structure on wind patterns and speeds (existing and future developments)</td>
<td>Map [73]</td>
</tr>
<tr>
<td>Affect of the built structure on solar access (existing and future developments)</td>
<td>Map</td>
</tr>
<tr>
<td>Affect of the built structure on humidity and surface water (existing and future developments)</td>
<td>Map</td>
</tr>
<tr>
<td>Basic information on the characteristics, history, monuments, vernacular buildings, life style, sources of livelihood, etc.,</td>
<td>Description, illustrations</td>
</tr>
<tr>
<td>Defining the effects of the surrounding urban structures on the actual project area</td>
<td>Map, description</td>
</tr>
<tr>
<td>Conclusions</td>
<td></td>
</tr>
<tr>
<td>Bioclimatic entity</td>
<td>Map, description</td>
</tr>
<tr>
<td>Proposals for wind shield constructions</td>
<td>Map, description</td>
</tr>
<tr>
<td>Proposals for placing of functions</td>
<td>Map</td>
</tr>
<tr>
<td>Proposals for area ventilation</td>
<td>Map, flow chart</td>
</tr>
<tr>
<td>Eventual planning guidelines</td>
<td>Illustrations, description</td>
</tr>
</tbody>
</table>

The long-list above should be short-listed for each project. The analysis items mentioned above can in practice consist, for instance, of the following measures:

- division of the urban structure of an area into different urban types according to the classification in Chapters 4.65 and 4.66
- definition of the urban roughness of the sub-areas; this will give the approximate wind profile and air-flow speeds near the ground (feedback to climate analyses and wind testing)
- architectural features (building volumes) and façade details of buildings; these affect the flow patterns both in street canyons and around free-standing buildings
- wind screen constructions, their affect on the wind patterns and air-flow speeds
- wind corridors, their affects on wind chill and ventilation
- functions; climate sensitive functions, like schoolyards, sports grounds, marinas, allotment gardens etc.
– air polluting functions and areas of pollutant concentrations (feedback to climate analysis for pollution distribution modelling)
– treatment of surface water in built areas
– future threats; these can be technical, economic, social, unsuitable developments, aging of infrastructure or climate change
– potential to develop urban structure, infill building, wind screen constructions, urban ventilation, humidity control etc.

Field work is a part of the whole CASE method, and it is highly recommended that climate, nature and urban analyses are carried out simultaneously.

4.6.3 **Impact of urban structure on the neighbouring areas**

Urban structure context is a matter that requires understanding from a much larger area than the detail plan or building project site itself. All observations are marked on a map or town plan.

An estimation of the impact of climate change – rain, drought, storm winds, floods – on the structures of the site is a valuable tool for planning. For bioclimatic planning it is necessary to understand the essential processes and interrelationships of the individual site factors. An evaluation of the impacts of the actual project on the whole neighbourhood, and vice versa, should be done. These impacts are treated in this chapter.

Neighbouring urban structures can channel winds, cause turbulence or redirect cast winds towards the actual project area, and naturally the project can do the same to its neighbours. Especially high buildings, pressure differences, openings in buildings and funnels can increase airspeeds at the ground level; see Chapter 3.2. Wind channels can bring snow or sand that can pile up in drifts or dunes in calm zones.

Building structures can form a barrier that prevents winds. In winter it can be regarded as positive, but such barriers have negative consequences on the potential for ventilation, cooling of outdoor areas and carrying away air pollutants. It is important to chart those neighbouring functions and traffic arteries that produce air pollutants, and the existing accumulations of impure air. Wind barriers can also contribute to the forming of the urban heat island phenomena.

The higher and denser the built structure is, the more shading results, which has both negative and positive consequences. Shading can preclude the exploitation of solar energy, cause dark dwellings and playgrounds, and prevent evapora-
tion thus increasing humidity. In warm climates mutual shading established with low distances between buildings or vegetation is an essential part of natural cooling concepts of buildings and outdoor places.

New developments can hamper the leading away of storm water by closing runoff routes or diminishing absorption surfaces. They can cause changes in water tables, wet biotopes or the availability of ground water, which can lead to changes in vegetation or local temperatures.

4.6.4 Wind speeds in the urban environment

Wind speeds in built-up areas can be estimated using the roughness categories and wind environment approximations of the following chapters, which are based on the wind pattern studies of Alberts, Børve, Evans, Givoni, Glaumann and Westerberg. The proposed roughness factor describes the relative wind speeds over terrain and built-up areas in comparison with the wind speed over open sea. Roughness factors run from 1, wind speed over open sea, to 0.4, a well protected city centre, Table 13. (Evans 1972; Alberts 1981; Børve 1987: 118–127; Glaumann & Westerberg 1988: 46–109; Børve & Jonassen 1994; Givoni 1998: 256–265)

Table 13. Roughness factor of urban environment.

<table>
<thead>
<tr>
<th>Area type</th>
<th>Roughness factor (relative wind speed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water surface, more than 1 KM</td>
<td>1.0</td>
</tr>
<tr>
<td>Open suburbs</td>
<td>0.7</td>
</tr>
<tr>
<td>Small towns, suburbs</td>
<td>0.6</td>
</tr>
<tr>
<td>Medium size towns, medium density areas</td>
<td>0.5</td>
</tr>
<tr>
<td>City centres, high density areas</td>
<td>0.4</td>
</tr>
</tbody>
</table>

When calculating the wind speeds of a given site, the starting points are the gradient wind speeds from the nearest meteorological stations, which give the airflow speed at 10 m height. When the airflow near the ground is calculated, the gradient wind-speed should first be reduced by a factor of 0.75. Then the wind speed is reduced by the factor presented in Table 13.

The roughness factor treats the built-up areas as one entity. The effect of single free-standing buildings, or buildings much higher than the ones in the near surrounding, on air-flows is discussed in Chapters 3.2.2 and 3.2.3.
The relative wind speeds vary during several periods of the day; the greatest lowering effect usually occurs in the afternoons, while during the night hours, with weak winds, the urban wind can even be stronger than the flows at the fringes of cities. This is because of the urban heat island phenomenon. (Givoni 1998: 256–265)

These values are rough rules of thumb, and for instance Givoni says that the possibility of defining a representative “urban wind speed” with a simple general model is questionable. Another restriction is that the air-flow estimation method presented above is not valid in hilly country where the height differences are larger than 100 m. (Børve 1987: 118–127; Glaumann & Westerberg 1988: 46–109; Givoni 1998: 264–266)

The roughness factors can be used when evaluating the protecting potential of the surrounding built structure and its affect on the relative wind speeds. It also gives the first rough estimation of the micro-climatical quality of a new planned area.

### 4.6.5 Traditional urban types and climate

Throughout the history of urban settlements there have always been two principal modes of town plans, organic and geometric (Guidoni 1981; Kroll 1995; Espil 2006). The majority of settlements up to the beginning of the last century evolved in a manner responsive to climate and was effectively formed. Traditionally towns in a cold climate avoided hill tops or cold valleys, and vice versa in warm climates. Micro-climate was considered and streets perpendicular to rivers encouraged the catabatic flow of air-borne pollutants into river valleys (Gaia 2004). At the end of each type is mentioned the roughness factor, which can be used with air-speed approximations.

**Organic town**

Organic towns are irregular in their form, though there usually is a logic in the seeming chaos. These are born at favourable geographical locations, and were built step by step in harmony with the context. Examples include different kinds of settlements, like medieval towns and Islamic Kasbahs, but also some planned settlements, like l’Art Nouveau quarters. They all have similarities in their wind environment.
The street pattern of organic towns is winding and small-scale, which diminishes the air speeds at the pedestrian level. Only in open places near towers there can occur heavy gusty winds and turbulence. Eventual walls around the settlements further add to the wind screening, and at the same time prevent area ventilation. The wind-still alleys encourage the forming of air-borne snow or sand drifts.

Roughness factor 0.4–0.5.

**Geometric town**

Geometric towns are also called rational or abstract. They are built according to a town plan, often for military, religious or administrative purposes. Leitmotivs include an orthogonal plan, cross plan (Roman *cardo et décumanus*), radiant plan, and hierarchic arrangement of lots.

The street lay-outs are based on a geometric pattern, which on flat land is easy to carry through, but in a hilly landscape may entail a lot of landscaping. In most cases the hierarchy of traffic routes starts from narrow bystreets and ends with wide avenues and ceremonial squares (Guidoni 1981). The windiness of the small streets depends on their orientation with respect to the prevailing winds. The open places and wide avenues parallel to the wind have high air-speeds, and when at an angle with respect to wind a horizontal eddy will be formed. Narrower, less than 30 m, streets do not offer sufficient horizontal scope for this kind of large eddy.

Roughness factor 0.45–0.55; notable wind channels.

**4.6.6 Modern urban plan types and climate**

**Functionalistic town**

The Modern Movement introduced a new kind of urban structure: segregation of functions and traffic means, dematerialisation of urban block and street space, discontinuing urban structure with the building of vast quarters, large building-scale in one style, and vast open outdoor spaces. (Espil 2006: 48–50)

All this resulted in a windy micro-climate, which is experienced as positive or negative according to the local climate. Free-standing buildings have relatively good possibilities for long-wave radiation to the sky, thus cooling the area during clear nights, which is comfortable during warm periods, but increases the need for warming in the cold seasons. In still-air conditions radiation is the main source of heat loss, while during windy nights convective heat loss may be more important.
Tall buildings create, sometimes dangerous, strong air currents to the surrounding areas also at the ground level. Most of the down-flow can be eliminated with a setback of the tower, with respect to its base, starting about 6–10 m above street level. Such a design solution still maintains the potential for wind enhanced ventilation and the mixing of the street-level polluted air with the clearer air above. (Givoni 1998: 266–270, 297)

The building mass configuration in open plans may vary considerably – towers, clusters, row buildings – and the wind resistance of urban structure respectively. Roughness factor 0.5–0.6, even 0.7; notable wind channels and cast winds can occur.

Court block town

The reincarnation of the stone city in Continental Europe, or wooden town in Finland, happened after the crisis of the Modern Movement. The new concepts emphasized on the one hand the traditional urban elements – street space, closed block, nodes, dominants, mixed functions and traffic, urban tissue – and on the other hand developed a new language of urbanism that includes contextual thinking, development of urban typology, phenomenological studies etc. Alas, often in practice the brave new towns, as such progressive, are but urban isles in an ocean of suburbia, a fact that diminishes their positive effect on the total eco-balance of the region. Maybe the most fruitful ground for this new urbanism has been the restoring and infill building of existing cities, and the transforming of abandoned industrial areas for new uses.

These kinds of plans consist of court buildings, a closed rectangle of connected houses around a courtyard, and defined street spaces. Understanding the micro-climate of urban canyons is important in understanding the whole urban climate in densely built central areas, especially in European cities.

Heights, densities and types of buildings may vary considerably. In a densely built urban space a significant part of the incoming solar radiation impinges on roofs and walls. The taller the buildings and the smaller the distances between them, the less solar radiation hits the ground level. The radiation falling on the vertical walls is partly reflected, mostly towards other walls, and this begins the process of radiation bouncing back and forth. Only a small part of the radiation is reflected upward to the sky, while most of it is absorbed in the surfaces, to be released back into the urban dome in the evening and night hours. The higher and denser the built-up area is, the slower the rate of night-time cooling thus causing
the urban heat island. This kind of urban structure suits cold and moderate climates well.

The major cooling factor is the long-wave radiant heat loss, but in the court block urban structure most of the sky dome is blocked by other buildings, which results in only a little cooling effect near the ground. In this case wind is important for cooling, but when the wind subsides at night, natural convection along the walls become the major component of the heat loss from walls of high buildings in areas where the sky view is restricted. (Givoni 1998, 266–270; Espil 2006, 49–52)

Roughness factor 0.4–0.5.

**Garden town, suburbia**

Some industrialists, the Arts & Crafts Movement and Howard started an urban development approach which was to develop into the Garden City Movement of the early 20th century. The attempt was to create communities blending the advantages of both the town and the country, resulting in a cluster of Garden Cities around a Central City. The principles of a garden city have been adopted to construct blocks and areas that are close to nature, suitable for families with children, and appreciated by their inhabitants. (Gaia 2004: 6–10)

The urban structure of a garden town consists of spatially relatively well defined streets, small-scale individual or clustered buildings, relatively high density, greenery and separation of functions. There is also often a touch of the spirit of the Enlightenment. The best-known example of a garden city in Finland is Tapioila, but suburban construction in Finland as a whole has been directed toward some degree of forest city. With a climate-conscious design of houses and the right kind of flora a garden town can climatically suit cold, moderate and warm-humid climates. Dense vegetation gives shelter against winds and levels out temperature differences, while tropical trees give shadow but let the refreshing winds blow.

The influence of modernism and catalogue houses has changed the nature of the garden suburbia of today. In the worst cases the urban tissue is opened up, borders are lost, and the coherence of space damaged; suburbia can be an endless chessboard of windy roads. In many neighbourhoods space and also winds are freely flowing between slab-like buildings that take into consideration neither the climate nor the cardinal points. The sense of scale and shelter is lost at the main roads and streets. (Norberg-Schulz 1980: 189–194; Dunin-Woyseth 1991; Théorie 2003: 668–673)
In sparsely constructed areas the natural landscape governs building. These areas are often home to a traditional way of building and living. Increasingly efficient transportation brings pressure to build farther and farther from city cores, adding to the need for planning.

Roughness factor varies greatly, normally between 0.5–0.6, even 0.45–0.65; in modern suburbia there can exist notable wind channels.

4.7 Use of CAD and CFD

Nowadays often a 3-D CAD model of the urban area or building is made, and this can be used for computerized micro-climate analyses with the Computational Fluid Dynamics (CFD) technique. The nearest buildings should be modelled as well, but the level of detail depends on the application. If surface pressures on the roof of a particular building are of interest, the details of the roof should be presented, while general massing of the buildings of the area is enough, if the pedestrian-level wind speeds are required. The need to represent local landscaping and plantings depends on the application of results, but there appears to be no documentation on the effect of modelled vegetation in relation to real vegetation. Available information from nearby meteorological station or the profiles of the wind tunnel simulations are used in determining the wind speed at the reference height. (Franke 2004: C.1.1–2)

In many ways the CFD and wind-tunnel approaches are similar and analogous. The process can be broken into the following steps:

1. Planning, usually with CAD.
2. Transforming drawings into a model, either on a CFD grid or a physical scale model.
3. Performing flow calculations in a CFD programme or perform measurements in the wind tunnel/CASE blower.
4. Analysing and presenting the results.

With modern techniques the boundaries between the two approaches have started to vanish in step number 2. Both CFD and wind-tunnel models are “built” in highly efficient 3-dimensional CAD software. In the case of a CFD model some automated grid generator will be applied. Either a hand-made scale model or Rapid Prototyping can be used to manufacture the physical wind-tunnel and
presentation model. The latter is an efficient production method, a kind of a 3-D copy machine that makes a physical scale model directly from the CAD model.

For air-flow analysis, step 3., both methods can be used. In larger complicated tasks this step can be carried out with both CFD and wind-tunnel testing. Systematic variations can be made with CFD, and after the alterations in the design the final confirmation verified by a wind-tunnel/CASE blower study. Often the process is the other way round. With a physical model it is easy and rapid to analyse the critical wind directions, and the model is easily modified on the spot. At this stage it might be beneficial to continue with a CFD model to obtain a full account of all the flow parameters.

With regard to step number 4., analysis and presentation of the CWE results are easier than wind-tunnel results, as all data are already in the computer and available for further analyses.

The technical disciplines that need to be mastered with regard to CFD techniques and domain knowledge are multidisciplinary, and an efficient use of CFD requires a group of specialists. The CFD specialist needs a qualified expert for exchange of information and problem solving. The infrastructure needed for execution of CFD studies include the CFD code, suitable hardware platform, advanced CAD tools to produce the input to specialized grid generating tools and post-processing tools. Modifications to the code and automation of batch runs may require knowledge of programming tools such as PERL. (Jensen 2004; Franke 2004: C.1.2–9; Stathopoulos 2005: 8–10)

When a CAD model of the project is made, it is enclosed by the computational domain. Several wind directions are usually analysed, at least the prevailing winds. The size of the entire computational domain must be large enough. The inlet, lateral and top boundary should be 5H away from the building, and the outlet boundary at least 15H, where H is the building height. These measures can be applied for urban areas with many buildings, where H is the height of the tallest building. (Franke 2004: C.1.5)

**Summa summarum:**

- CASE method consists of micro-climate analyses and wind testing
- micro-climate analyses consist of collecting the climate data, nature analysis and urban analysis.
5 Model testing

"Sneen liker ikke for mye träkk og trafikk. Da blir den skitten og smelter. Sneen ønsker stillhet og ro". (Christian Norberg-Schulz)

5.1 Wind tests for scale models

This chapter discusses different wind simulation alternatives in wind tunnels, and the methods of observing the results. The case wind test instrument, its reliability and applicability are presented.

5.1.1 Wind simulations in wind testing

There are four basic methods of investigation of the wind field and pollutant dispersion around buildings and in urban areas (Baker 2002: 49):

1. Full-scale measurements.
2. Wind tunnel experiments.
3. CFD calculations.
4. Analytical models.

To get an overall picture of wind flows in nature and in a wind tunnel, the flows should be dynamically, terminally and cinematically similar. In practice this ideal similarity has to be compromised, because simulating all these factors at the same time is relatively difficult. Also, simulating an inversion (warm air lying on cold air, preventing vertical flows) in a wind tunnel is basically impossible. (Pirinen 1987: 5/12; Daniels 1994: 165–166; Baker 2002: 49)

The starting point for scale model wind testing is to analyse the local climate (see Chapter 4.2). Based on this micro-climate analysis it is possible to know which wind directions have to be examined.

The vertical profile of the wind field is modified by the roughness and profile of the terrain and urban structures, and the wind-tunnel air-flow should have a similar profile during the test. When making a wind analysis for architectural work, a result efficient enough for planning can be obtained by treating the wind profile with the help of a terrain model which precedes the area in question. Exact simulations of turbulence are not needed when measuring average speeds. If pressure measurements are done, e.g. during structural planning, the quantities that depict turbulence have to be simulated more exactly. (Pirinen 1987: 5/12–5/15;
Broas 1992: 4–6) The assessment of pedestrian wind comfort and safety can be made with scour (sand erosion) technique, which indicate gusts (Desző-weidinger 2004: B.4.5–B.4.)

When studying windiness around and close to buildings, relative wind speed can be used. This is the relationship between the speed measured in front of the model and the reference speed of the examined point. Relative wind speed tells us whether the wind speed at the examined point is higher or lower than at the reference point. Thus, relative wind speed describes changes inside the area and, for example, the impact of urban planning and building volumes and placement on the wind around the buildings.

The reference speed can be determined by measuring the speed of air flow at the model’s front edge 10 metres above the ground. Local wind speeds near the houses differ from the reference speed in a particular direction because of the topography, urban plans and the size of the buildings. The direction of the flow may also differ from the direction of the main flow. (Pirinen 1987: 5/18; Broas 1992: 7–8)

Air flow characteristically keeps going straight ahead unless it meets an obstacle. That is why the flow area stays relatively well together, which can be confirmed by measurements. This makes it possible to wind test scale models by using a blower which is set in an open space. The flow area of the blower has to have the right speed, turbulence and profile. (Børve 1987: 18; Glaumann & Westerberg 1988: 41–43; Kuismanen 1993)

5.1.2 Analysing test results

Scale model wind testing which is done in an open space allows observation of the model and phenomena during the test, an example of this is in Fig. 84. By using this method it is possible to determine:

1. Formation of flows in a built environment
   – windy and calm areas
   – formation and force of turbulences
   – impacts on buildings nearby.
2. Observe high and low pressures around buildings.
3. Facade areas that are exposed to weather.
The results of the micro-climate analysis should be used to find out the biggest problems in the target area and in construction and which issues have to be determined by means of wind testing. For example, winds that increase energy consumption often have different directions than the winds that hamper outdoor activities. Wind may be uncomfortable on the streets, but on the other hand it clears the air of traffic pollution. Closing off the wind channel with building mass may also obstruct sunlight. A sea wind in July is considered warm and pleasant, while the same wind in October is very uncomfortable and cold. This means that the issues have to be prioritised.

The most important factor in planning wind conditions is pedestrian height, which is usually 1 to 2 metres above the ground. Windiness on the ground is easy to observe when using indicator material during testing, the so-called erosion test. The areas where air flow has removed all the indicator material are the windiest. The force and characteristics of the flow can be determined by examining the size and shape of bare areas. An even flow leaves a long, bare mark, while vertical turbulence leaves a round mark. Accumulation of indicator material indicates that a place is well shielded against the wind.

The characteristics and directions of flow can be found by observing the trajectories of the indicator material. To measure flow speeds, a small rotor-equipped measuring device is needed that measures the mean speed during a couple of seconds, usually three seconds mean air flow speed is measured. The meter gives the highest value directly against the air flow, so by changing the position of the meter, the direction of the flow can be determined. For more specific measurements, anemometers and calculations are needed. (Børve 1987: 129–131; Kuismanen 1993; Westerberg 2004: D.2.4–10)

Formation of the entire flow area in the model can be observed by examining the positions of thread streamers placed in the model. Turbulences and areas where the flow can separate from the terrain model can also be observed with the help of these thread streamers. Strongly vibrating streamers also warn of turbulences and flow separation from the model’s curved surface. (Pirinen 1987: 5/15–5/17)

Wind speed in an open space two metres above the ground is about 75% of the reference wind ten metres above the ground. In a protected built environment wind speed on the ground is sometimes only 25% of the reference wind speed. Wind on the ground around the buildings has a lot more turbulence than at a height of 10 metres, which has to be remembered when assessing how people experience different wind-speeds. (Glaumann & Westerberg 1988: 46–48; Oulun 1994: 5–7)
5.1.3 Possible sources of errors and false conclusions

The flow area in a wind tunnel is limited by the roof and walls, which cause a blocking effect. The average speed of flow in a model increases when the flow surface area decreases. This kind of error does not occur in an open space. Other limitations are presented in Chapter 5.1.1.

Errors will occur in the results if round shapes are tested with too glossy a model. This happens because the flow separates from the curved surface. A slippery model causes the indicator material to detach too easily, and therefore distorts the results. If testing is carried out on metallic, glass or Plexiglas plate, the electrostatic charges on the plate have strong influence on the distribution of the particles (Deszö-Weidinger & al 2004: B.4.5).

When modelling snow accumulations in model tests, the results are never exactly similar to reality, because real snow is always compressed. Almost the correct overall shape can be achieved by using semolina. (Børve 1987: 22; Pirinen 1987: 5/23–5/24)

On average the erosion and measurements follow each other quite well, with some exceptions. The mismatch between the measured and erosion test velocities is largest near the walls of the windward facades, the erosion model showing too high velocities. Comparative research has proved that erosion models correspond to the level of gust wind speed rather than to the level of mean wind speed. This means that that the patterns of erosion would correspond to the gust wind speed that people perceive or may assess in terms of comfort. (Westerberg 2004: D.2.9)

5.2 Testing with the case wind test blower

5.2.1 Equipment, models and instruments

The equipment and method developed during this study can be considered as an open space wind tunnel. It is based on the calibrated CASE blower which is described in Appendix 1, and Fig. 84.
The buildings and environment in the model need to be of the right scale. The best scale for the indicator material is 1:100–1:500, but even 1:50 and 1:1000 are possible. The model should not be too big compared to the cross-section of the tunnel and flow area.

The wind profile and turbulences have to correspond to the circumstances in the target area. The wind profile can be modified in the area between the model and the blower with the help of wind cones or some other roughening element. The studies of Jensen and Frank show differences in the wind test results when using model-ground made of materials of different roughness (Fig. 85). Experience from the author’s wind tests show that a sufficiently correct wind profile is achieved by making the side of model, where the studied winds are located, at least 20–30 cm bigger than the studied area itself. This is because the model alters the wind profile in its area. It is necessary to use a coarse spacer between the model and the blower. It could be, for example, a foam rubber carpet taped to the front edge of the model.
Fig. 85. Comparison of wind tunnel tests done for a real building (at the bottom) and a scale model of a house using ground materials of different roughness (above). The comparison was made to study how different ground materials affect the analysis results. (Jensen 1964)

If air flows are studied only at ground level for pedestrian comfort, the wind profile does not need to be modified, and the blower can be used to remove evenly sprinkled indicator material from the model surface, the so-called erosion study or scour technique (compare with 5.12). This method indicates the zones of relative windiness, and the turbulence present in the flow promotes an earlier particle motion. The surface of the model should not be too slippery in these experiments. (Børve 1987: 130–131; Kuismanen 1993; Daniels 1994: 165–166; Oulun 1994: 3; Dezsa-Weidinger 2004: B.4.2–6; Westerberg 2004: D.2.9–10)

The most important factors affecting the flow areas are presented in the scale models. These factors include the basic forms of terrain and vegetation as well as the buildings and various building groups and their locations in the terrain.
Especially in single-family house areas where the diversity of the houses is high, the external dimensions have to be simplified into rectangles. Solid forests are represented in terrain models by Landscape rubber carpeting, which consists of 20 mm high spines, or pipe cleaners, etc. Exact imitation of vegetation is needed only when planning wind baffle planting.

To avoid turbulence the steps between contour lines are filled with mass. This is not needed if the contour lines are low, about 0.5 to 1 mm. (Børve 1987: 130–131; Pirinen 1987 5/7–5/8; Oulun 1994: 4–6)

According to Pirinen, every planning area has many small-scale details, such as utility buildings, fences and local unevenness of the terrain. The impact of these factors on the overall picture are of minor importance and do not need to be considered in the models. On the other hand, according to Glaumann, and the experience gained from the test project in Sodankylä, the above-mentioned details can essentially change the results of wind tests near the ground level. (Pirinen 1987: 5/8; Glaumann & Westerberg 1988: 115; Kuismanen 1996)

If round or curved objects are studied, the forces affecting the model have to be similar both in the model and in nature. This is possible by using matt-surfaced material in the model, such as wood or cardboard, or by painting the surface with matt paint. Also, the terrain should not consist of slippery material, so that the indicator material is not removed too easily.

The only instrument necessary is a fine strainer or an oblong frame with a net to sprinkle the indicator material. The best result is obtained if the following equipment is used:

- testing room in which at least one side wall is matt black and the lightning is movable for photographing and shadow analysis
- portable wind measuring equipment and various sizes of sensors for field and model work
- sundial (for instance the SIB model).

It is important to choose the most appropriate indicating material for wind tests of scale models. Many alternatives are presented in the research literature. For instance, Nozawa et al. have tried to use activated clay and crushed wheat as an indicating material when modelling snow drifts. Activated clay was more airborne, while crushed wheat accumulated easier. Sand is often used with erosion tests. (Nozawa 2000: 355; Westerberg 2004: D.2.4)

In the author’s and Børve’s studies many materials like sand, crushed acrylic material, flour and crushed seeds were used, and their flying characteristics and
accumulation patterns were compared. Different flours are dusty, difficult to use and air flows were difficult to see. Crushed plastic is easily charged and it accumulates incorrectly in the model. Sand is too heavy to be airborne, and therefore it is only suitable for erosion tests. Semolina appeared to be the best indicator material, because it flies at moderate air speeds, it is big enough for visibility and easy recording, it is not dusty and is not charged with static electricity. Semolina can be used more than ten times before its edges are rounded too much. Smoke was unclear in complex models because it became mixed on the wake side of any obstacle, thus making observation of air flows difficult. (Børve 1987: 129–131, 136, 139, 148; Kuismanen 1993)

5.2.2 Model testing in practice

The model is placed about 60 to 100 cm away from the blower. The location depends on which is the desired wind direction. To avoid turbulence there should be no threshold at the edge of the model base. If necessary, pieces imitating earlier terrain or other suitable shapes can be used.

The model has to be fastened tightly to its base to prevent test material from going under the model. To facilitate photographing, there should be an adequate colour difference between the model and the test material. Cameras need to be protected from dust or dustproof equipment should be used. A dark matt-surfaced environment makes photographing easier.

Different kinds of tests can be done with the wind test instrument:

1. Erosion test.
2. Air flow simulation with an indicating material.
3. Air flow simulation with smoke.
4. Air flow visualising with threads.

1. An erosion test is done with indicator material. Before blowing, a uniform layer of the indicator material is sieved onto the model from directly above without air movement. The blower is started and the wind speed is then gradually increased until saltation of the particles begins. This speed is then maintained for a few minutes, the blower is stopped and the resulting indicator distribution patterns recorded.
Taking successive images of sand erosion contours, when changing wind velocity, gives the possibility to observe and evaluate the evolution of turbulence and thus the zones of discomfort.

2. Air flow simulation with indicating material is recommended when studies of wind patterns around houses are needed. First a thin layer of the indicator is sieved onto the model. The blower is started and the indicating material is introduced into the air flow from the upstream side of the model. This can be done with a sieve system or a simple kitchen strainer. Air flow patterns and turbulence can be observed and recorded as long as the material is fed into the air flow.

3. Air flow simulation with smoke is recommended when studies of wind patterns inside houses or ventilation air flows are needed. The blower is started and smoke is introduced into the air flow from the upstream side of the model. Air flow patterns and turbulence can be observed and recorded as long as smoke is fed into the air flow.

4. To visualize main flows, a thread streamer method can alternatively be used. The studied terrain model can be covered by needles that have thread streamers attached to them. The cotton/silk threads in the streamers, which are very mobile, will become oriented according to the flow direction. The thread streamers are placed evenly on a grid pattern. How high the threads are from the model surface depends on the scale of the model.

The results can be presented as average speed curves of measurements done outside or indicated with an arrow that shows the flow direction and whose length corresponds to the speed (Figs 96 and 97). (Børve 1987: 130–131; Pirinen 1987: 5/6–5/12; Kuismanen 1993; Oulun 1994: 12).

5.2.3 Requirements for a testing room

The planned wind testing equipment can be moved by two persons and used either on the floor or on a table. A separate testing room or wind tunnel is not necessarily needed. However, a black painted background wall facilitates photography when done from the side.

If terrain curves are not used to build the base, a good base for the blower and scale model is a matt black-painted table surface. The table size should be at least 100 x 200 cm. To avoid turbulence, there should be no staggering between the test equipment and the model. If the lower edge of the blower hole cannot be placed at table level, a thin foam plastic or matt-surfaced panel has to be stretched between the blower air outlet and the table.
The testing room has to be large enough so that the side walls do not cause flow field aberrations when the object is located too close to the wall. Air returning to the blower should have an unhampered path near the roof and floor. (Børve 1987: 130; Kuismanen 1993)

5.2.4 Applicability of scale models scaled differently or made from variable materials in model testing

The applicability of different kinds of scale models for wind testing has to be known so that the method can be used. To find out the needed information, a series of tests were carried out. The purpose of these tests was to:

– compare the times required to make models consisting of various materials
– compare how different materials affected the test results
– compare the test results of separate models that were scaled differently.

It was already noticed at the beginning of the study that, because of the indicator that was used, the scale of 1:1000 is usually too small. Whirls of indicator material are not visible enough and the model clogs too easily. Only areas with big buildings can be studied on this scale. Since the maximum size of the test area is about 80 x 80 cm, the consequence of this is that in town planning large projects cannot be tested with the CASE blower. In building design the height limit is about 30–40 cm, which on a scale of 1:200 means about 20 stories.

To compare various materials, models from the test block of Tervola were made on a scale of 1:500. The materials used were balsa and Plastilin mass. The balsa model is better in terms of appearance and endurance. On the other hand, modifying the balsa model later on is slow and hard to do when doing wind testing at the same time. The mass model is faster and cheaper to make and modifications can easily be done while wind testing is going on. Both models gave similar test results.

In conclusion it can be said that, at least in the beginning when basic principles are being studied with a 1:500 model, it is better to use Plastilin or some other easily moulded material. If the model is used for presentation purposes later on, it is also possible to use a model which is made of hard material. A model made from cardboard on a scale of 1:200 or 1:100 is economical and relatively easy to modify during testing.

The influences of different scales on the test results were studied by using models of a Tervola test house. Scale models of the block’s first phase were made
on a scale of 1:500 (balsa), 1:200 (cardboard) and 1:100 (cardboard). All of these
models were tested in both north and south winds.

All three scales gave similar results. The whirls, flows, etc. looked basically
the same, but they had different sizes. There were some occurrences though, that
could be seen only on larger scales. They included vertical flows near walls and
whirls around eaves.

A comparison of the models indicated that making observations with a 1:500
scale model is difficult, and photographing single detailed events using such a
small-scale is basically impossible. But is possible to study how building volumes,
wind fences and plantings affect wind flows when using a scale of 1:500. Studying
how different roof pitches, eaves, wind fences, separate trees, etc. affected the
micro-climate was relatively easy when using scales larger than 1:500. Registering
the results is also easier with larger scales.

In conclusion it can be said that the results obtained with all the experimented
scales are reliable. For the planning phase a scale of 1:500 is suitable, but during
building design it is better to use a scale of 1:200 or 1:100. Models from various
materials made by the author are presented in Figs 90 and 91. The use of different
materials did not change the wind test results.

5.2.5 Observation and registering techniques used in tests

Observations during wind testing can be divided into two main parts:

1. Flows, whirls, suctions, etc. during testing. Since for practical reasons one
testing period is relatively short, about 30–60 seconds, when using an
indicator material, the observer has to be fast and experienced so that all the
results will be written down. Without an indicator material the testing period
can be long, and in that case observation is done by examining a wind thread
or a wind meter set on top of a rod.

2. With erosion tests observation of indicator material that has not moved during
blowing. Analysis and recording of such data can be done without any rush.

Phenomena that occurred during testing were observed and registered using the
following methods:

- Visual observation. This is a very exact and reliable method. Even small flows
  and movements of indicator material can be noticed. It is essential, however,
to train people who use this method to analyse quickly and exactly.
– Wind meter. A small wind meter reliably indicates the strength and direction of air flow. By studying these strengths an air flow map can be drawn and conclusions be drawn about which parts of the plan need re-thinking.

– Photography. Movements and flows of the indicator material can be photographed using time exposure. Photographing streamers in a large model gives an illustrative picture of how flows behave.

– Taping. Taping is a method which has been experimented with by using various types of equipment and lighting.

The flow figure that thread streamers form is photographed from above using a time exposure of a few seconds. Because of the long exposure time, the “time history” of the thread streamers can be seen. It shows turbulence in the flow and wake vortexes that are formed when the flow has passed a building. (Børve 1987: 130–131; Pirinen 1987: 5/15–5/17; Kuismanen 1993; Daniels 1994: 166–170; Westerberg 2004: D.2.4–5)

Indicator material that has not moved during testing can be registered:

– Visually, as long as the indicator material is not removed from the model.
– By photographing it. After testing the model is easy to photograph to make an exact document of the matter.

When the method is used for design purposes, each wind test should be recorded to avoid any unnecessary repetition. A good recording lets the test be analysed afterwards, but it also allows the results to be presented to users. Usually drawings are the best way to show the results (Fig. 86).

Fig. 86. Observations can be illustrated with a drawing where airflows and turbulence are shown and described, Jyväskylä Kekkola. (drawing Kuismanen)
5.3 Sun and shadow analyses

It is recommended that solar access is checked simultaneously when doing wind testing with a scale model. A number of methods can be used to make sun and shadow analyses.

1. Sundial, Fig. 87. The sundial used is made in Sweden by Statens Institut för Byggnadsforskning (SIB). The position of the sundial depends on the site’s degree of latitude. The sundial is placed towards north in the scale model and a lamp or a floodlight is directed at it. The sundial then shows the date and time of the present lightning condition. The amount of sunlight at a desired time can be determined by moving the model or the floodlight/lamp. Shadows can be drawn on a paper placed in the model or registered by photographing. The number of hours of sunlight in a certain place can be determined by moving the floodlight along a path indicated by the sundial and writing the information down, e.g. once an hour. (Statens)

Fig. 87. Scale model 1:100 of Oulun Sivakka with the SIB sundial. (Kuismanen)

2. Sun machine. A movable model table whose scale shows the angle of the sun. With advanced models the degree of latitude and the desired point in time can be entered into a calculator that adjusts the model’s degree of slope. However, examination of large models using this method is basically impossible. (Lütkenmeyer 1994: 157–163)

3. Sun simulators. Some large building laboratories have special so-called “sun rooms” where programmable and movable floodlights can be used to simulate the amount of sunlight in different circumstances. However, because of
their expense and scheduling, these rooms are used only in special cases. (Lütkemeyer 1994: 157–163)

4. 3-D modelling. Today the most common way to make a solar access checking is to produce a 3-D model of the town plan massing or building, and simulate the solar radiation on that model.

5.4 Case wind test instrument

5.4.1 Wind testing as a part of architectural design

Scale model wind test methods can be divided into two groups according to their objectives:

1. Methods that show flows mainly at ground level.
2. Methods that show the whole flow area around buildings.

The target was to develop an instrument that can be used for both purposes mentioned above, and did not need a special room or tunnel structures. Equipment that can be used on the floor or table at the same time as design work is going on, would replenish design processes and improve quality without causing much prolongation to design schedules or extra costs.

5.4.2 CASE wind test blower

The purpose of the wind test equipment developed during this study is to find out the whole flow area near buildings. Prototypes I–III had a flow area about 60–200 mm high. Prototypes IV–V were developed later to produce a higher flow-field, about 500 mm, which would make it possible to test, e.g., 10-storey buildings with a 1:100 scale model. The final VI prototype has a flow area which is over 400 mm high, and the width is about 800 mm (Fig. 88). Information about the phases of the development work is presented in Appendix 1.

The properties of the prototypes were tested at the laboratories of VTT Research Centre in Oulu by Johanna Vakkuri (Appendix 1). The airflow was even, but turbulent. Wind in nature is also turbulent, and it was concluded that the measured amount of turbulence is acceptable for an open air-field wind tester. When carrying out aeroelastic wind testing, the air-field must be free from turbulence and the CASE blower can not be used. (Børve 1987: 129–175; Vakkuri 1993)
During the experiment various construction techniques for scale models were tested and a comparison of how the models with different scales behaved during testing was made. The results were registered by photographing. The reliability of the method was verified by comparing the air flow speeds obtained from the scale models to wind circumstances around a model house built in Tervola.

Fig. 88. Cross-section of the CASE wind test equipment. On the right side are two horizontal flow blowers placed one above the other and on the left side is a cell that evens out turbulence. (Vakkuri 1993: 30)

5.5 Reliability of the wind test method

5.5.1 Comparison of measurements done in the field and model testing; Model house in Tervola

Professor Anne Brit Børve from the University of Oslo has done research on the reliability of scale model testing done in an open space by comparing snow accumulation in models and in nature, as well as by comparing her own results with Evan’s results, for example. The reliability of an open wind test tunnel has also been studied by architects Eilif Bjørge and Ulla Westerberg. According to sources, the results obtained with scale models correspond to winds and snow accumulation around real buildings. The patterns of indicator material erosion correspond to the gust wind speed that people perceive or may assess in terms of comfort. (Børve 1987: 74–128, 151, 175; Glaumann & Westerberg 1988: 112; Westerberg 2004: D.2.9–10)

To determine the reliability of scale model wind tests done in an open space wind tunnel, the results obtained from the scale model and the test building were compared. A housing building for elderly people in the village of Tervola
functioned as the test site. Although construction of the block is done in stages, the
design of the entire block was completed at once, which was actually necessary for
micro-climate planning. Field measurements done during the first construction
phase were finished in 1992.

The climate analysis indicated that northerly and southerly winds were the
most problematic, and therefore during both design and model testing attention
was paid to minimising the disadvantages of these winds. Three alternative drafts
of the block were made. The models were on a scale of 1:500 and tests were made.
A Alternative A is an open U-block open towards the north and based on a plan
illustration presented by Oulun Ympäristökehitys Oy, Fig. 89.
B Alternative B was based on row house-like building masses perpendicular to
the wind direction, Fig. 90.
C Alternative C, was based on a neighbourhood of several relatively closed
courtyards bordered by residential buildings, Fig. 91.

First 1:500 scale models were used to test the whole block. The micro-climate of
the U-model in alternative A was considered bad because of the windy yard. The
air flow could also easily cool the buildings in this plan. The micro-climates of
alternatives B and C were good. Alternative C was chosen as the basis for subse-
quent work because it follows the building tradition of the area and is suitable for
construction in phases.

Later work was done on a scale of 1:200 and 1:100 and included only the first
building phase of alternative C. During the work the impact of masses, roof
shapes, façade details, protective fences and plantings on air flow was examined,
Fig. 92.

During the work the qualities of various scales and materials were also
compared.

The test house is a housing and collective building for elderly people. Some of
the apartments open directly to a common space, some under a protective canopy
that circles the inside courtyard. The common space has a baking oven and panels
in the roof that reflect the low winter sun. Residents who need a wheelchair have
their own glassed porches that allow them to enjoy outdoor life and at same time
protect them from insects and cold winds. One apartment is flexible and enables
even major modification and is therefore suitable for many generations. Most of
the materials used in the test house are natural materials and materials that are also
easy to recycle.
The reliability of the wind test method was tested by comparing the wind speed results measured around the test house with those of the scale models. In both measurements a meter with a propeller was used (AIRFLOW DVA 30 VT anemometer). One unit shows a mean speed of three seconds. To eliminate the impact of wind changes and turbulence, two measurements series were made. During the measurement 20 readings were taken at every measurement point and their mean value was used in the comparison; this means altogether 40 readings from each point.

Fig. 89. Alternative A in Tervola. Bare areas are windy. (Kuismanen 1993)

Fig. 90. Alternative B in Tervola. Only some corners are windy. (Kuismanen 1993)
Fig. 91. Alternative C in Tervola. Note the wind screen fences which improve the microclimate. (Kuismanen 1993)

Fig. 92. Details of the test house were implemented on a scale of 1:100.

Since southerly and northerly winds in Tervola are the most problematic, the measurements at the site were made when there was wind from these directions. Comparative scale model tests that were done after the field measurements used
exactly the same wind directions. The measurements were carried out at the same points both in the field and in the model.

The result was that the air flow speeds measured in nature and in the model are very close to each other. Differences that mainly occurred in the inside courtyard may be caused by sensors that could not be placed in exactly the same places in the model and at the test house. Flows observed in the inside courtyard, at the eaves and around corners were about the same in the model and in reality. The results are presented more accurately in Figs 93, 94 and 95.

The micro-climate of the planned inside courtyard is good, and even during heavy winds the flow speeds are quite low, usually 0.5–1.8 m/s. The front faces of the single-pitch roofs directed air flows downwards, and this together with low pressure on the protected side of the building masses caused turbulence in the yard. The protective canopy which circles the yard protects the walkways from these flows. Protective plants were placed in some problematic places noticed in the scale model. However, the plants need to grow first, which will take several years.

The suitability of using a scale model to examine snow accumulation was tested by comparing snow accumulation in the scale model and in the field. Field work was done around the Tervola test house on the 23rd of October 1993 after a flurry of snow and heavy southwest wind. Snow accumulation formed by the wind was exceptionally clear. Snow accumulation created in the scale model with the same air-flow direction using semolina as indicator resulted in similar forms, Fig. 96. (Kuismanen 1993)
Fig. 94. Air flows at the Tervola test house in the scale model and around the test house. The study employed a northwest wind. The length of the arrow indicates the air currency speed and direction. The results from the real house are shown on the left and the results from the scale model are on the right. The numbers are the average wind or airflow speeds at that measurement point. (Kuismanen 1993)
Fig. 95. Air flows at the Tervola test house in the scale model and around the test house. The study employed a southwest wind. The results from the real house are on the left and the results from the scale model are on the right. The flow patterns and speeds are quite near each others. (Kuismanen 1993)

Air flows observed and measured in the scale model and at the test buildings corresponded well to each other. The accumulation of indicator material in the scale model corresponded to snow accumulation around the building. Based on the comparison measurements, the method can be considered reliable in ascertaining both wind speeds and snow accumulation. But the instabilities of the test air-flow field and the measurement technique used cause that the results are rather qualitative, instead of the quantitative measurements of boundary layer wind tunnels. The results of the Tervola project supported the results obtained in studies done earlier in Norway and Sweden. (Kuismanen 1993)

5.6 Applicability and accuracy requirements of the equipment

From the beginning the purpose of this research has been to develop a test method and equipment that is suitable for all architectural and planning offices because it is easy to handle, requires only a little space and is cheap. Also one requirement
was that the system would not require major changes in present design practices, but rather support them.

Preliminary studies showed that in nature air-flows are always irregularly turbulent, and therefore a wind tunnel cannot perfectly simulate reality. Also small variations in the simplified forms that are used when studying flows in wind tunnels can significantly change the real situation around a building. In the case of a round form the possibility of error in model tests increases. The equipment that measures air flow also causes some inaccuracy in the results. Only carefully calibrated anemometers give less than a 5% margin of error. (Børve 1987: 173–175; Glaumann & Westerberg 1988 112–118; Petersen)

The degree of accuracy required of the method was specified as a level that shows relative wind speeds, flows and turbulence around buildings correctly using approximately 800x1500 mm terrain models which also allow studies of snow accumulation.

The equipment was not required to be accurate enough to allow measurement of structural wind loading.

During the test projects it was noticed that the wind field the equipment creates is wide and high enough to be used in normal building design and planning on a scale of 1:50–1:500 and model sizes up to 80 x 80 cm and about 50 cm high. Wide planning areas need to be tested in sections. Vertical flow rate distribution similar to nature can be worked into the model. By using this method a reliable picture of snow accumulation on a plot can be obtained, if wind directions that control and bring snow have been studied beforehand. However, the air permeability of fences and plants should be realistic for snow accumulation studies.

Till now the sand erosion technique has been regarded as a qualitative tool, used for visualization. Deszö-Weidinger et al have proven that with the sand erosion method it is also possible to get quantitative information about pedestrian wind comfort (Deszö-Weidinger et al. 2004: B.4.1–B.4.10). Deviations observed in the measurements were of the size to show that the method is not exact enough for the quantification needed in evaluation of wind pressures on buildings or bridge planning.
Fig. 96. Snow accumulation observed around the Tervola test building. Hatched areas are either the windiest and blown bare or protected by canopies. (Kuismanen 1993)

Test projects in Kemijärvi, Oulu (Rajakylä) and Sodankylä indicated that the method is well suited for town planning, fast to use, and gives new information about how different planning solutions affect the micro-climate of the area. Working with a model created a better picture of the project area and different options than
can be obtained with simple plane drawings, axonometric drawings or CAD modelling.

The great advantage of this method is that it gives a spatial overview that is easy to understand. The method and equipment can be well used in the following cases:

- a quick comparison of the first ideas using scale models made of modelling clay on a scale of 1:500
- planning the micro-climate of a build environment using scale models on a scale of 1:500–1:200.
- building design with 1:100 or 1:200 scale models
- planning important details such as entrances and balconies using scale models on a scale of 1:50
- determining the type and placement of wind baffle plantings
- determining the wind circumstances of roads, bridges and tunnels
- preliminary design of wind power areas.

When more exact data on wind fields and/or dynamic loads is needed, the work can be continued either in a boundary layer wind-tunnel or with CFD modelling.

By using a sundial the same scale models can be used to analyse the amount of sun and the formation of shadows in the area (Fig. 87).
6 Guidelines

L’architecture: "Le jeu savant, correct, et magnifique des volumes assemblés dans la lumière". (Le Corbusier)

6.1 Climate-conscious planning

This chapter gives climate conscious-planning and architectural design guidelines according to the case method. Possible solutions for energy saving, natural ventilation and different climates are presented.

6.1.1 Criteria of climate components of built environment, and the need for wind testing

Wind

The choice of the wind comfort criteria for a region depends on the nature of the climate. In some points cold and hot areas would have opposite objectives. In cold climate there is a need to protect against winds, while in hot regions the need is to maximize wind exposure. But the perception of climate conditions is individual and subjective and consequently difficult to parameterise or standardise. Energy use and damages caused by winds and storms are objective, and therefore easier to handle with exact numeric values.

The findings and conclusions from different studies mentioned in Chapter 3.1 have been used when establishing the following wind comfort criteria, see Table 14. These values can be used even in warm climates, but in those areas also minimum wind speeds should be used for pedestrian comfort and building ventilation.

The criteria developed are based on the definition of typical pedestrian activity categories (PAC); the four categories are:

A SITTING. Street café, terrace, pool, kindergarten yard.
B STANDING. Bus-stop, playing field, pedestrian street, school yard.
C WALKING. Walkways, building entrances.
D FAST WALKING. Walkways, car park.
For practical reasons the criteria are based on annual mean winds, the system used by SIB. This gives a characterisation exact enough for planning and architectural design purposes.

In regions with cold winters the acceptable values are also maximum tolerable values in winter. In those hot-dry regions, where windborne sand causes problems, the average wind speed should not exceed 4 m/s.

**Table 14. Criteria for acceptable yearly mean wind-speeds (m/s) of the pedestrian activity categories.**

<table>
<thead>
<tr>
<th>PAC</th>
<th>Cold and moderate climates</th>
<th>Warm and hot climates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acceptable</td>
<td>Tolerable</td>
</tr>
<tr>
<td>A</td>
<td>1.5 m/s</td>
<td>2.0 m/s</td>
</tr>
<tr>
<td>B</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>C</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>D</td>
<td>4.5</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Solar radiation**

The amount of desirable solar radiation varies from region to region. Sometimes the criteria could be different even for neighbouring buildings; for instance for a building that has a solar ventilated double façade, or a building with mechanical air-conditioning. That is why the author proposes limited recommendations for solar access only for cold climates.

**Table 15. Criteria of sun conditions in northern climates.**

<table>
<thead>
<tr>
<th>Sunshine hours / day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common outdoor areas must have access to at least 4 h of sunshine daily between 9–17 during the equinoxes.</td>
</tr>
<tr>
<td>Kitchen and living room should together have access to at least 4 h of sunshine daily during the equinoxes.</td>
</tr>
</tbody>
</table>

**When climate analysis and wind testing are needed**

As a summary of the recommendations of different research institutes and the criteria in the previous chapter, the following recommendations are given in Table 16. Climate analysis should be made and scale model wind tests carried out in the circumstances presented in the following table.
Table 16. Criteria of the circumstances when wind testing is needed.

<table>
<thead>
<tr>
<th>Criteria in different circumstances</th>
</tr>
</thead>
<tbody>
<tr>
<td>– In cold and moderate climate regions when the average annual wind speed of the planned area is more</td>
</tr>
<tr>
<td>than 5.5 m/s.</td>
</tr>
<tr>
<td>– In (sandy) desert regions when the average wind speed of the whole area exceeds 4.5 m/s.</td>
</tr>
<tr>
<td>– In the climates of tornadoes and hurricanes all larger projects.</td>
</tr>
<tr>
<td>– When designing cross-ventilation for large complex buildings.</td>
</tr>
</tbody>
</table>

When designing sky-scrapers, high towers or long bridges aeroelastic scale models should be tested with a boundary-layer wind tunnel.

6.1.2 Impact of the local climate on construction

With the awareness of the climate change there is a growing demand for planning tools for environmentally sound urban structure. A sustainable area can be described as an area which requires as little as possible energy and raw materials (especially non-renewable materials) and causes as little as possible undesirable emissions and wastes, including all the building and operating processes. A sustainable area should also offer people a good living environment and be economically affordable. (Harmaajärvi 1996: 10–12)

Ecologically and environmentally conscious planning can be defined in many ways, and it varies in different climates. The goals of the Norwegian NAMIT project give a good example (Natur 1993: 5):

– Minimise energy consumption and traffic
– Protect natural resources and the environment.
– Decrease realisation and running expenses.
– Decrease pollution and noise.
– Create possibilities for outdoor activities and recreation.
– Protect the landscape and cultural values.
– Promote welfare and social goals.

Climate-conscious planning requires consideration of the local climate during the planning phase. Circumstances can be actively improved in a natural way.
Fig. 97. Example of a “climate rose” in which the most important micro-climate factors of the site during the different seasons are shown. On the outermost circle are shown the protective features of the terrain, on the middle circles the most common winds and rains brought by them and in the centre sunniness. (Miller 1993: 50)

Attention has to be paid immediately to the environment and climate in the first stage of sketching. Planning is begun by determining the climatic conditions of the building site and the need for wind protection, and for that place a climate rose is drawn see Figs 97 and 98, which illustrates the conditions. In addition to winds, there can be also other environment factors on the rose, which describe solar radiation, protective elements, noise sources and views. (Miller 1993: 50; Chatelet 1998: 27)

When it comes to the circumstances affecting planning and designing, many countries can be divided into inland and seacoast. The effects of wind on the coast need special attention, which is basically realised by means of building placement and wind protection. The cooling effect of wind can sometimes be much greater than temperature differences. On the other hand, coastal areas often have less cloudiness and more sun. With appropriate measures this can be utilised to decrease power consumption and improve thermal comfort both in cold and warm climates. The wind speeds during storms vary greatly on different coasts. In Scandinavia the wind speeds are seldom more than 30 m/s. In warm regions
tornadoes, hurricanes and downbursts are such local events that it is very unusual to catch their resulting wind speeds at meteorological stations. It has been estimated that during the Hurricane Katrina the maximum 3-second wind speeds for the region were 46 m/s, 102 mph. (Kareem 2006: 8–10; Nagao 2006: 10–14)

If the area will have tall buildings and it is known to be windy, mistakes can be avoided by examining model cases presented in the literature that describe wind behaviour with alternative building layouts and the effect of wind barriers. In practice, the field of wind flows around buildings is often so complex that definite knowledge of wind behaviour cannot be obtained without wind tunnel tests. When a planning situation with apparent wind disadvantages is identified, it is worth relying on specialists to determine the micro-climate. The disadvantages of wind can be eliminated by changing the relative location, size, and shape of the buildings. Similarly, wind tunnel tests can be used to design the details of buildings in order to affect their energy consumption and the formation of a micro-climate in their vicinity.

Within an urban area the wind conditions and solar radiation are the major climatic factors affecting the comfort and healthy of the inhabitants, and the energy use of buildings. Wind and storm cause great economic losses in the built environment. The importance of windiness is highlighted in coastal areas and at high elevations. For example, energy consumption of the Pihlajisto area which is situated on open windy hills in Helsinki is about 50% higher than in the city centre. In cold regions the affect of wind is mostly regarded as negative because of its cooling effect. In warm areas wind refreshes and carries away air pollutants and therefore attitudes to wind are mainly positive. Winds in an urban environment are not randomly distributed but they are canalised by built structures and streets. The airflow has a lower average speed but higher speed variation and turbulence, as compared with the surrounding open land. (Pienilmaston 1997; Marquette 2003; Edwards 2005: 40; Kareem 2006: 9)

**6.1.3 Climate change and building sector**

According to the United Nations Framework Convention on Climate Change to reduce the emissions that cause climate change interventions in each field of activity are needed. The building sector is very important in this. Approximately 30 per cent of the projected baseline emissions in the residential and commercial sectors – the highest rate amongst all sectors studied by the IPCC – could be reduced by 2030 with a net economic benefit. Energy consumption and embodied
energy in buildings can be cut through greater use of existing technologies such as passive solar design, high-efficiency lighting and appliances, highly efficient ventilation and cooling systems, solar water heaters, insulation, highly-reflective building materials and multiple glazing. Government policies on appliance standards and building energy codes could further provide incentives and information for commercial action in this area. (United 2007: 12–14)

The building sector is one of the biggest users of different kinds of materials. The greatest potential for reducing industrial emissions is located in the energy-intensive steel, cement, pulp and paper industries and in the control of non-CO₂ gases such as HFC-23 from the manufacturing of HCFC-22, PFCs from aluminium-smelting and semiconductor processing, sulphur hexafluoride from use in electrical switchgear and magnesium processing, and methane and nitrous oxide from the chemical and food industries. (United 2007: 12–14)

There is a need for information on how the various structures of a community can be made more sustainable in new climate conditions. It is necessary to examine how assessment of the impact of climate change and adaptive measures should be included in land use and town planning in practice.

Taking climate change into consideration may require reviewing of planning principles. It would be especially necessary to study the regional and local impacts of climate change. Assessment of the impact of climate change should be included in long-term land use and town planning. A mandatory supplementary study on adaptation to climate change should be included in the zoning process in particularly vulnerable areas. Regional and local impacts and methods of adapting should be investigated.

It is important to take climate change into consideration early, because communities are renewed slowly and the effects of new planning principles become apparent in community development only after several decades. Different parts of the built environment have a varied life-circle, and the following table makes it clear why planning and building design have to take the changing circumstances into consideration (Edwards 2005: 10):

### Table 17. Life-circle of the different parts of the built environment.

<table>
<thead>
<tr>
<th>Built structure</th>
<th>Life-circle in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical installations</td>
<td>20 a</td>
</tr>
<tr>
<td>Buildings</td>
<td>50</td>
</tr>
<tr>
<td>Traffic arteries</td>
<td>100</td>
</tr>
<tr>
<td>Cities, towns</td>
<td>500</td>
</tr>
</tbody>
</table>
Most of the world’s planned population centres from the 20th century are built according to the functionalistic idea of a city based on a separation of functions. In addition to greenery and sunlight this has also brought increased traffic, huge parking areas, windiness and a break-up of social bonds. Increased criticism, as well as growing environmental and social problems, forces us to develop new urban patterns.

The city model chosen as a basis for a master plan largely defines the future traffic volume, the functionality of public transport, the possible formation of a thermal island phenomenon and thus, to a certain degree, the amount of energy consumed. According to Zahn each new motorway junction spawns the formation of a new community. On the other hand, compact construction unavoidably brings with it concentrated traffic emissions, and therefore the need for area ventilation. Some researchers consider natural green areas left between buildings or constructed biotopes so effective as carbon sinks that they favour a more spacious structure. However, most calculation models prove that a dense urban structure is also the most ecological. (Harmaajärvi 1996; Zahn 2006: 17–18)

Town planning can provide circumstances for functioning public transport systems and promote non-motorised transport thus reducing emissions. Management strategies for reducing traffic congestion and air pollution can also be effective in reducing private-vehicle travel.

Already today three billion persons are lacking the possibility for daily hygiene, and one billion are at risk for diseases caused by polluted water. Climate change will further reduce the precipitation in large areas. The strategies to reuse gray waters and rainwater, and the protection of groundwater are essential with architecture, planning and agriculture projects in most regions. (Edwards 2005: 41)

The vulnerability of the infra-structure is the cause of the large majority of the indirect losses associated with major wind storms. As an example, the failure of components of electrical power plants, transmission lines, transportation networks and bridges can be the cause of induced losses which are by far larger than the value of the failed structure itself. During the last years more damage has been reported.

In all weather conditions the purpose is to keep cities running and ensure vital services. Major failures in engineering facilities and main infra-structures have to be avoided. When planning infra-structure or industrial plants, the future “eolian risk” should be considered. The existing elements and structures should be investigated as well, and continuous control systems developed.
In many localities where tourism or winter sports are an important part of economic life, a climate change could significantly affect operational preconditions, not only a change in the climate in one’s own locality, but also in the competitors’ situation. For this reason in the strategy work of tourism regions it would be beneficial to examine climate change, not only in one’s own area, but also worldwide in different competing countries.

The main factors affecting greenhouse gas emissions are:

- area location
- area efficiency
- distribution of building types
- residential density
- proportion of sparsely populated areas
- proportion of infill construction
- energy consumption of buildings
- type of heating
- type of energy production
- transport need
- transport system
- prerequisites for walking, biking and public transport
- dependency on passenger cars
- distribution of modes of transport.

Possible lines of action in land use and community planning are:

- assessment of the impact of climate change is included in long-term land use and community planning
- a mandatory supplementary study on adaptation to climate change is included in the planning process in particularly vulnerable areas
- flood-prone areas and structures are mapped
- warning systems are developed in anticipation of extreme phenomena
- regional and local impacts and methods of adapting are investigated
- the need to make changes in land use and building regulations and statutes and municipal building codes is investigated
- if necessary, recommendations are made for plans at different levels.

For building design the document Architecture 2030 gives clear targets how many percentage less greenhouse gases should be produced, compared to the standard energy performance of that building type as defined by the U.S. Department of
Energy, Table 18. Carbon neutral means that no fossil fuel energy is needed to operate the building. The American Institute of architects (AIA) and many counties have given the recommendation to adapt these targets. (Architecture 2030, 2008: 57, 69–72)

Table 18. Architecture 2030 CO₂ targets.

<table>
<thead>
<tr>
<th>Year</th>
<th>Targeted greenhouse gas level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>60%</td>
</tr>
<tr>
<td>2015</td>
<td>70%</td>
</tr>
<tr>
<td>2020</td>
<td>80%</td>
</tr>
<tr>
<td>2025</td>
<td>90%</td>
</tr>
<tr>
<td>2030</td>
<td>Carbon neutral</td>
</tr>
</tbody>
</table>

6.1.4 Regional and town planning

In the second half of last century the urban population increased fourfold, from 732 million inhabitants in 1950 to estimated 3,475 in 2010 (Starke 2007: 7). Continuing urbanisation and climate change will put new demands on regional planning. Planning should be started with the basic evaluation of the actual region: Urban, nature and climate analyses, and the charting of the qualities of different areas for different functions and the need for protection.

When new settlements or traffic arteries are planned, the ecological footprint should be calculated. The actual criteria for the choice of a location for a town within a given region depend on the nature of the climate. Warm and cool regions would have opposite objectives. In a cold region one of the criteria is protection from the winds, as in Norway. In a warm region the preference is for locations with maximum wind exposure, as in south-east Asia. The choice of a climatically favourable location enhances the comfort, health and productivity of the inhabitants, and reduces the energy demand for heating and cooling.

When choosing a location for a new neighbourhood or town in a cold climate, a sheltered, sunny area should be preferred. Year-round safe transportation corridors are also needed. In warm-arid regions locations with lower summer temperatures and good ventilation conditions should be looked for. These can be windward slopes of hills, higher altitudes, etc. In warm-humid climates sites with moderate winds or sea breeze should be favoured. Valley slopes may experience catabolic down-slope air currents during windless nights, thus contributing to sleeping comfort. Future flood-prone areas should be avoided. Flood-risk can...
increase along rivers in areas where precipitation grows or coastal low-lands because of the rising sea level. (Pressman 1995: 61–73; Givoni 1998: 239–298)

There is a range of settlement models, as presented in Chapter 6.13 and 6.15, and each of them has a different ecological footprint and affect on the climate and climate change. The arrangement of everyday routines – living, work, services – already on the regional level forms the basis for bioclimatic detail planning. For instance in Uusimaa, a relatively dense region in South Finland, traffic greenhouse gas emissions in 2003 were 1.9 tons/resident, and Helsinki area traffic emissions were 1.5 tons/resident. (Huuska 2006: 15).

Traffic causes about 50% of all air pollution and in most cities between 60–80%. The placing of functions and areas within a region, and the possibilities to arrange effective public transport determine traffic volumes, and thus the use of energy and amount of emissions. The separation of activities and the creation of isolated neighbourhoods and “green” detached house areas cause more transportation, and it is mostly private car traffic. That is why the spatial arrangement of functions and neighbourhoods in a region or metropolis is the key to bioclimatic urban planning. A regional structure consisting of a net of dense multifunctional nodes, interconnected along public transit arteries, reduces the need to commute, and thus the use of energy and emissions. Industrial air pollutions spread with winds, and come down as soot and acid-rain. The analysis of dissemination patterns of wind-borne emissions should precede the placing of residential quarters. (Espil 2006: 24–34; Higueras 2006: 15)

Improvements in the level of housing in recent years have been increasingly accomplished through town planning, by developing city centres and suburbs. The urban structure in Finland is exceptionally sparse, and studies show that the rate of use of public utility services is among the worst in Europe. Indeed, in terms of municipal finances and calculations of ecological balance, infill development has proved to be the most advisable path for development. A larger base of inhabitants also facilitates the arrangement of public transportation. That is why increasing the number of inhabitants using the existing infrastructure is part of urban and suburban renewal. (Lahti 1996)
6.1.5 Urban typology

Urban categories

To get an overall picture of the built environment where climate analyses will be done, it is useful to do urban morphological analyses first. Blocks can be divided into those that have buildings linked together and those with freestanding structures. With the wind climate in mind, the author divides urban districts (French quartier) into four categories:

1. **Functionalistic town;** open plan, free-standing buildings, open street space.
2. **Court block town;** closed blocks, continuous built structure, distinct street spaces.
3. **Garden town;** isolated houses in a green environment, bounded home streets or park streets. **Suburbia;** islands of efficiently built isolated areas dedicated to different purposes or low density detached houses, hierarchic traffic network, flowing outdoor space, idle land.
4. **Megastructures.** Interconnected systems of structures and indoor spaces in a continuous structure.

1. Functionalistic town. The functionalistic city emerged as a reaction against decorative classic cityscapes on the one hand, and unhealthy and slumified stone cities on the other hand. Different functions were arranged in their own areas, which led to a growth in traffic and all of its consequences. Residential blocks were made to be green and sunny. A large proportion of the world’s planned population centres from the 20th century are built according to functionalistic guidelines. Growing criticism and cumulative environmental and social problems have forced the development of new urban models. (Krier 1985; Dunin-Woyseth 1991; Halliday 2002: 3; Higueras 2006: 15–21)

   The climatic characteristics of functionalist cities are complex. These towns have greenness and light, which contribute to the use of solar energy and the sunniness of courtyards and dwellings. Because buildings are not effectively shading each other, in warm climates overheating can cause problems. As to wind climate, basically all outdoor spaces are the object of variable wind-fields and turbulence, and around high buildings wind-speeds can be dangerously high. The climatic and townscape problems of huge parking areas, windy open places and idle land in cold climates are eased by closing the wind channels with buildings...
and plantings. According to the life-cycle calculation models of the VTT Research Institute, the gigantic need for transportation can be alleviated by developing new multi-functional in-fill building. (Harmaajärvi 1996; Givoni 1997: 256–259; Lahti 2002)

An open building structure suits best the warm-humid regions and Mediterranean climate, see Chapters 6.8.3 and 6.8.5. Flowing space lets the refreshing winds into the urban texture, and tall buildings lead air-currents down to the street level. In cold and moderate climates the open plan-types (functionalistic town and open suburbia) are mostly regarded as negative. Sky-scrapers in these regions should have a some stories high broader base-volume, with a setback of the tower, with respect to its base. In warm-dry areas open plans can generate sand storms. (Givoni 1997: 259–265; Higueras 2006)

2. Court block town. Especially in Europe and Latin America the stone city is often the centre of a community. This type of city is characterized by closed blocks, multi-purpose street space as a stage for public and private life, dominant public buildings, and separately bounded parks. At the present there is a growing appreciation for old stone cities, and planning and functional renewal projects are timely. There has been a return to closed block construction in many new areas, as well. (Ålander 1954; Rossi 1984; Krier 1985; Givoni 1997: 281–286; Espil 2006; Higueras 2006)

The basic space unit in stone cities is the street canyon, and their geometry, materials and façade design have a great influence on the urban climate. In cold climates wind energy should be absorbed with plantings, street level furniture and façade details. In warm regions the air-flow should not be prevented, and downward currents can be created with higher building volumes. There can be problems with the contamination of air in the streets with heavy traffic.

Buildings often shade each other, which can lead to the lack of sunshine in courtyards and dwellings. In warm climates the mutual sheltering against solar radiation can be the strategy against overheating. Evaporation is reduced in stone cities, which in cold climates can be regarded as negative. In warm-dry regions, and also other climates in summer, there is the need to raise the relative humidity with plantings and water-tables. The raising of the amount and diversity of vegetation has positive consequences on air quality and atmosphere. Because of the usually densely-built structure, ways of collecting and use of rainwater, reducing runoff volumes and making water present in the townscape should be considered. (Givoni 1997: 266–272: 291–293; Espil 2006; Higueras 2006)
The closed urban structure well suits cold and moderate climates, and as a climatically adapted internal courtyard or patio type many situations in warm-dry regions, see Chapters 6.82, 6.83 and 6.84. If court blocks are planned in warm-humid climates, the use of towers of different heights is recommended for area ventilation, as described in 6.85.

3. Garden town, open suburbia. Garden cities are characterised by freestanding buildings, an irregular network of streets, boulevards and planted lots. Depending on the building scale and heights, open suburbia has often characteristics from both the functionalistic town and garden town, through islands of dense, closed structure can occur in a fragmented manner.

Small-scale, well-protected garden towns suit cold and temperate climates, and also warm-humid regions, if the vegetation and street network let the winds into the built fabric. Gardens are positive also in warm-dry areas, but they are seldom realistic because of the great amount of irrigation needed.

Solar access can be adjusted according to the latitude. In cold and moderate climates in the northern hemisphere the main façade should face to the south. In tropical areas the main facades should be oriented away from the sun or shaded.

There has been criticism of the micro-climate and cityscape, directed at implementations of garden towns in the past decades, which also entail functionalistic features, for their loss of shelter, street space and disappearance of collective city life. Buildings have become individual objects in scattered blocks, and the use of high building efficiency has led to the construction of high volumes, and thus to the emergence of windy no-man’s land. Ineffective land-use causes traffic and thus air pollution.

Open suburbia with large-scale buildings is negative in a cold and most part of temperate climates, because of the windy outdoor spaces. In warm-humid and Mediterranean regions the area ventilation of this urban type contributes to human comfort and energy saving. In warm-dry areas moderate winds could be a part of good micro-climate, if only the wind-borne dust could be prevented. (Dunin-Woyseth 1991; Givoni 1997: 293–295; Sigler 1997; Espil 2006; Higueras 2006)

4. Megastructures. As a fourth type we can discriminate continuous systems of indoor spaces, the aim of which is to give total shelter from the climatic environment. The indoor circumstances are usually cosy, because of the artificial climate is produced by air-condition. In most cases the planners have not paid too much attention to the outdoor conditions, and the remaining outdoor spaces are usually windy and forbidding in cold weather, and unpleasantly hot during warm days.
Some “Winter Cities” have taken this kind of development as their strategy, and the largest ones can be found in Canada and the north of the USA. Despite the high national income in many cold climate countries, millions of their inhabitants cannot afford, or do not want these kind of “winter cities” with their glass-covered shopping streets, air conditioning and artificial milieus. Because of the negative impact of total (24/7) indoor life on health, cities that offer a possibility to be outdoors and where travel is based on light traffic should have high priority. (Kuismanen 1989; Pressman 1995)

As a conclusion Table 19 presents a summary of the climatic qualification of the different urban types.

### Table 19. Urban typology and climate.

<table>
<thead>
<tr>
<th>Climate</th>
<th>Funct. Town</th>
<th>Court Block</th>
<th>Garden Town</th>
<th>Open Suburbia</th>
<th>Mega-structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>cold</td>
<td>--</td>
<td>++</td>
<td>++</td>
<td>--</td>
<td>--/-+</td>
</tr>
<tr>
<td>temperate</td>
<td>-/+</td>
<td>++</td>
<td>+</td>
<td>-</td>
<td>-/+</td>
</tr>
<tr>
<td>warm-dry</td>
<td>+/-</td>
<td>++</td>
<td>--/-</td>
<td>--</td>
<td>--/-</td>
</tr>
<tr>
<td>warm-humid</td>
<td>++</td>
<td>--</td>
<td>+</td>
<td>++</td>
<td>--/-</td>
</tr>
</tbody>
</table>

++ very appropriate, -- unsuitable (see the descriptions above).

### Density of urban structure

Recent studies show that the greater the intensification of urban population, the lower the energy consumption per inhabitant (Fig. 98). Intensification of residential density from 3.9 units/hectare to 39 can reduce travel by 40 percent. Public transport becomes viable at residential densities of around 30 units, and walking at more than 100 units per hectare. Infill development plays an important role in making more efficient use of infrastructure and public transport and in saving nature areas from construction. The dispersed layout of buildings disrupts natural ecosystems over a wide land area. (Yeang 1999: 20–25; Newman & Kenworthy 2007: 67–70, 77)

The use of cars greatly depends on the structure, density and traffic policy of cities. People in Atlanta use 2,960 litres of gasoline annually, New York 1,240, in Australian, New Zealand and Canadian cities 700–1,200, in Europe around 450, wealthy Asian cities some 280, and in the poorest cities 50–300 litres annually. There is surprisingly little correlation between the car fuel use and city wealth.
Cars use 2.92 megajoules per passenger kilometre, bus 1.56, light rail 0.79 and heavy rail 0.44. That is why urban planning should favour such dense linear built structures that enable the development of rail-based traffic. Some cities, such as Copenhagen, Portland, Vancouver and Zürich, have already decided not to build more motorways, but invest in green transport instead. In Vancouver the amount of cars has started to drop, probably a world first. Public transit-based cities spend 5–8% of the GDP on transportation, but in heavily car-based cities the figure is about 12–15%. (Newman & Kenworthy 2007: 68, 76–82)

**Fig. 98.** Gasoline consumption and urban densities. (Yeang 1999: 20)

Architectural design and planning should be seen as a whole. High buildings can seem to be un-ecological as such, but they help to make denser communities. The climatic properties of tall buildings vary in different climates, as described in Chapter 6.8.

Many families would like to live in a detached house, and demands set by residents create pressure for urban development; on one hand many people want to
live in single-family houses, but on the other hand they also want services that are hard to implement in such areas. The low-dense way of building that has become common around the world is one way to meet these challenges. Efficient low-dense housing types can be divided into four categories, as presented below. In cold climates such areas are usually micro-climatically positive, and their details, like block enclosure, street forms and building configuration can be finished with wind testing (Fig. 99)). In warm-humid regions there can be difficulties to arrange efficient area and building ventilation with this kind of structures especially with categories 2. and 3. Categories 3. and 4. are the most sensitive to winds.

1. Detached house on a small site, detached house on the border of the building site, atrium house.
2. Attached houses, linked houses, clustered houses, linked atrium houses.
3. Terraced house, row house
4. Small apartment house, ”city villa” (*Stadtvilla*, ”cube-like house”)

Expectations are different. Many suburban people want large building sites, and think that there should be some untouched land left inside their living area. In urban areas expectations regarding the availability of space are smaller. In Finland 20–30 inhabitants per hectare is the minimum density for public transport. In Denmark, 15 to 20 detached houses, i.e. 40–60 inhabitants is considered a suitable density per hectare, which means that the plot ratio is 0.3–0.4. Building at such densities makes a small-scale outdoor milieu, which is easily well protected from winds. (Päivänen 2001: 3; Lahti 2002; Higueras 2006: 147–150)

As a conclusion, from the sustainable point of view, the proposed densities are:

- in detached house areas, more than 20 houses per hectare
- low-dense areas, more than 35 housing units per hectare
- dense built structure, more than 80 units per hectare
- 500 – 1,000 units per hectare in the surroundings of railway or metro stations and in city centres.
6.1.6 Fill-in building

According to the Ecobalance calculation model developed by VTT, the community structure has to be denser and mixed activities need to be developed if the objective is to decrease traffic and improve services. Sparsely-built areas at the edge of urban settlements are gradually surrounded by the growing urban structure and become a part of efficient land use. This often happens through gradual complementary construction. (Harmaajärvi 1996; Lahti 2002)

The starting point for suburb planning has been freestanding buildings in the middle of green areas. In many places, townscapes are fragmented, there in an abundance of idle land, yards are large and vegetation is badly worn out in places. The possibilities for infill development are usually relatively good as far as the architectural side of town planning is concerned; in most cases the problem is connected with attitudes and administration.

As towns and cities grow, infill building is becoming more important. Areas suitable for infill development include idle land between buildings, as well as many noise barrier zones, so long as shielding is done by structural means instead. Infill development improves the hierarchy of space, which aims at having a versatile city block structure and revitalising kerbsides with small services and workplaces. Ancillary buildings can also reduce the traffic noise load in yards and
enhance micro-climates. The recommendation for city blocks is construction of shops and yard dwellings on the ground floor, construction of greenhouses, ancillary construction on attic floors, and defining the boundaries of courtyard areas with outbuildings. Infill building and co-operation with inhabitants have become tools when fighting local warming. (Dunin-Wyżewski 1990; Hagan 1996: 22–27; CASE Rajakylä)

The infill development plan should provide possibilities for utilizing the nature:
- orientation of buildings toward the sun
- protective belts on the sunny side as well as on the side of chilling winds
- atriums and covered gangways/passages that utilize solar energy.

Infill construction using low-dense building types is justifiable in various cases:
- when making detached house areas denser the most natural way is to build more detached houses
- multi-storey building areas can have a more humane scale and cosy architecture (Fig. 100)
- monotonous multi-storey building areas can be diversified and balanced.

Fig. 100. Urbanisation of a high-rise block with a low-dense urban structure, Gennevilliers. (Kroll 1995)
6.1.7 **Detail planning**

The main goals of a climate-conscious town plan are:
- Harmonize the needs of nature environment, functions, traffic, built structure and the needs of inhabitants.
- Acclimatise actively and passively urban structure and buildings to local circumstances.
- Protect and strengthen the circular processes of nature, especially water cycles.
- Take pedestrian and public transport as the starting points of planning.
- Strengthen social community, boost safety and health, and secure inhabitant’s participation in planning.
- Develop sustainable ways of using nature resources in urban infrastructure and industry; minimising the ecological footprint.
- Create a harmonious multi-functioning urban structure; abandoning the zoning of mono-functional areas (Fig. 101).
- Create a continuous net of nature spaces.
- Plan areas dense enough to maintain services, employment, local economy and public transport.
- Unify and harmonise the cityscape, and create a pleasant environment and a good micro-climate.

Town plans should give the building design possibilities to make good use of natural circumstances, like solar energy or area ventilation. Proposed building configurations, atriums, buffer zones, arcades etc. should give protection against cold winds, overheating, rain and snow. The most important decisions are made during the first steps of a planning project:
- Placing of functions.
- Typology of quarters.
- Width and types of streets.
- Heights of buildings.
- Orientation of streets in respect to the winds and the sun.
- Use of slopes and mountains.
The design challenges of densely-developed areas are different from those of low-density. Each building plays two roles, it creates a protected internal environment, and it is accountable for the production of the urban micro-climate. A single building by virtue of its shape, height and treatment at street level may harm an urban space and eliminate pedestrian activities.

In cold and moderate climates, from the climatic and social points of view, the recommended block structures are closed or semi-enclosed and divided into private, semi-private and semi-public areas. Buildings are arranged into zones for the purpose of reducing energy consumption: cold structures and vegetation wind shields are located on the north (or cold winds) side, and balconies, gardens, bay windows and greenhouses on the south or west side. Utilization of passive solar energy is taken into account in the blocks. Gross floor areas permitted should be defined in such a way that it influences to build zones which utilize solar warming. (Grimme 1984; Yeang 1999)

In hot-dry desert climates there is high heat stress on summer days, glare, dust in the air and in some regions cold winds in winter. Therefore sidewalks should be shaded by trees or buildings, and area ventilation should be arranged. If east-west facing buildings are near each other they will shade each other and make the solar stress smaller in summer. Recommended free space is one fifth of their height. When north-south oriented buildings are build with short distances they will shade each other in winter and thus reduce the possibilities of solar heating. For sunlight
access a distance of 1.5–2 times the height of the building is needed. Dense coverage of the land surface with a combination of white roofs and trees can significantly lower the urban temperatures. (Givoni 1998: 369)

Flooding will grow along many rivers because of storms and the fact that most cities themselves increase the excess of water runoff due to the reduced water absorbing ability. Flood-risks can be diminished by increasing rain absorption, preserving land features of natural drainage and collecting excess runoff in reservoirs or mini-lakes. Preserving vegetation and permeable topsoil is important, and parking lots and the like can be surfaced with permeable pavements. Delaying the peak and spreading the duration of the runoff water involves temporary storage of water over a land surface or within a gravel layer over the soil, using excavations and dams, etc. Availability of natural drainage in the small-scale topographical features also diminishes the risk of floods. (Givoni 1998: 409–411)

Planning regulations can effectively steer the quality of the future building:

- plan multifunctional neighbourhoods and blocks (Fig. 101)
- new water surfaces can stabilise temperature differences and improve air quality
- place residential areas and building masses according to the sun and winds
- avoid cold air lakes
- buildings can have a buffer-zone and an open-zone
- dense, low and small-scaled building facilitates the creation of a good micro-climate in most climate types
- arcades protect from rain, slipperiness and solar radiation
- buildings should not cause (unwanted) shadows or redirected winds to their neighbours
- roof angles can be regulated for micro-climate and aesthetic reasons
- dimension and direct streets so that wind speeds do not increase; ventilation, if needed
- regulate the amount of trees on building sites and wind/avalanche protecting zones
- timing; demand to plant the wind-screen planting some years before residential building.

The structure of a town planning project can be approximately as following:

1. Climate data and analysis. This is done using the method described in Chapter 4, with special attention given to the different seasons, diurnal temperature differences, prevailing winds and precipitation. Making estimation
about the effects of the climate change is recommended. Targeted micro-climate quality in open street spaces, and comfort criteria of yards, playgrounds, pedestrian and bicycle ways, and bus stops should be defined. Temperatures and winds are analysed with the shielding required both for pedestrian comfort and energy conservation in mind. Drifting of pollutants into the area is modelled, and the need to air out exhaust gases is determined.

See Chapters 4.3 and 4.4.

2. Model. A scale model is needed for wind testing. The best scale is 1:500, but a simplified model in scale of 1:1000 is also possible for areas to be implemented with large buildings. Nature and built environment analyses give the information about the roughness and other affects of the green and built zones in the project area and its surroundings. The most problematic wind directions found in the climate analysis are tested in the model representing the present situation, and a summary is made of the need to enhance the micro-climate.

After the plan sketches have been made and analysed, alternatives for (infill) development are added to the model and wind-tested. Alternatively a 3D CAD-model can be made, but there are certain limitations on its use.

See Chapter 5.2.

3. Analysis of the natural environment. This work is mainly done by observation, and the information gathered is supplemented with data available from maps. The main objective is to analyse the effects of vegetation and water cycles on the micro-climate of the project area. Biotopes and their interrelations, areas susceptible to wind and flood erosion, existing damage to the environment, and sectors that resist and do not resist wear are charted. Wind shield vegetation, sites with a diversified natural environment or locally rare areas are recorded. The collected information serves as the starting point for the defining of buildable sites, nature protection and the need for new wind screening plantings.

See Chapter 4.5.

4. Urban analyses. The work is started with the evaluation of the urban typology and built structure roughness of the project area and surroundings. Effects of the built structure on the micro-climate are analysed.

There are many methods for townscape analyses which can be used, but they are outside the limits of this study, see Chapter 1.56. In addition to focusing on an aesthetic cityscape, attention should be given to activities, population, social milieu, etc.

See 4.6.
5. Alternative plans. Proposals for block and building types are made on the basis of previous analyses, and cost and feasibility calculations. Areas that can be built are presented on the basis of nature and context analyses. A continuous unbroken network of green belts should be formed, in which the most valuable areas are preserved in their natural state. An evaluation is conducted from the present urban structure for sections where infill development can improve the cityscape, the privacy of yards, and the feeling of urban space, and close bothersome wind channels. Models of alternative plans are wind-tested and developed further. After comparisons the definitive proposal is selected and finished.

6. Participation of inhabitants. The results of analyses and later drafts of town plans and detail plans should be presented with clear, graphical drawings to residents, decision-makers and property owners in order to achieve an interactive planning process. Inhabitants are also a good source of information on climatic problems, and the flora and fauna of the actual area.

7. Guidelines. One essential part of town planning is the making of design guidelines, the aim of which is to guarantee that climatic and other quality aspects are realized in the architectural design and building process.

**Summa summarum:**

- planning has impacts on the climate change:
  - mixed land-use and short distances diminish the need for traffic; prefer walking, cycling and public transport
  - intensification of existing built-up areas; maximal use of existing infrastructures and constructions
  - use of multi-functional areas and buildings
  - efficient, diverse, integrated transport system
  - reclaiming, reuse and recycling of resources and nutrients.
- building and street orientation according to the climate and sun
- avoiding the placing of long building masses in the direction of contour lines, because this interrupts water flow and gathers cold air that naturally flows downhill.
6.2 Outdoor areas

6.2.1 Positive micro-climate

A good micro-climate should be created primarily with town planning and design of buildings and by retaining the existing nature. Particularly in connection with renovations, if necessary, special wind protecting and shading elements can also be built. In addition to outdoor temperature and wind speed the micro-climate is greatly affected by humidity, solar radiation and long-wave nocturnal radiation. From the point of view of air quality it is necessary to arrange sufficient area ventilation in sections where there are air pollutants.

Cold climates

If an acceptable quality of micro-climate is not reached by shaping the urban structure and the buildings, in cold climates conditions are improved by wind protection. The measures can be divided into distant area protection (fjärrskydd) and near protection (närskydd). Protective plantings, which reduce wind in the whole area are an example of area protection, and they are usually high in their form and sparse in their structure, consisting of low and high plants. The near protection elements are lower and tighter, made of building materials or dense vegetation. The near protection is designed to protect rather small outdoor areas and pedestrian ways. (Glaumann & Westerberg 1988: 24–31)

Several parallel shelters in each other’s sphere of influence give a better result as area protection together rather than separate ones. The most efficient combination is obtained when protecting elements with 20% openings are located at a distance which is 8–10 times the height of the element. With 15–20% openings the sheltered area forms near the protection structure. The largest protected area with a moderate flow rate is obtained when using a 50% open structure (Fig. 102). The effect of a direct protecting element always remains worse compared to a winding protection because the direction of the wind in practice changes all the time. In nature the same effectiveness as with model wind tests will not be reached because in the test the direction of the air flow is constant. (Glaumann & Westerberg 1988: 126–132; Kuismanen 1993)

The joint of a protecting element and building should be tight. One problem of tight wind protective walls is turbulence on their lee side, which can be reduced by making openings at the edges of the protecting structure (Fig. 103). Walls that
permit some air flow through to cause a smaller pressure difference between the leeward and windward sides, which is why turbulence becomes small at the edges of the protection element. The best interaction of a building and a parallel protecting wall in front of the building will be obtained with 15–25 per cent openings when the distance of the protection wall from the building is about two times the building height. The effects of different kinds of protecting walls are presented in Fig. 104. (Broas 1992: 22–24; Glaumann & Westerberg 1988: 128–131)

Fig. 102. Relative wind speeds at 1.5 m height with 0%, 20% and 50% open structures (Gandemer, cit. Glaumann 1988: 127)

Fig. 103. To avoid turbulences the edges of the wind protecting elements had openings (a black concrete slab). The safety net that has been installed on the roof stepladder reduces air flow parallel to the facade according to the measurements at 3–5 m distance. Kiint. Oy Tuulihaukka Oulu. (Kuismanen 2000)
In design attention must be always paid to the effects of measures on the surroundings, because air flows that go around a building or a fixed wind protection element can be harmful to plants and cool neighbouring buildings. (Kuismanen 1993; Mattsson 1979: 132–133)

The micro-climate of residential areas can also be actively changed with construction material choices, plants, fences, and roofs. Nevertheless, if the micro-climate is to be changed advantageously, compromises often need to be made in planning and objectives need to be specified in detail. If the objective is to raise the temperature of outdoor areas during the day when the sun is shining, dark sheet metal construction materials that absorb solar radiation and warm up quickly, and in turn warm the surrounding air should be chosen. If people are in an outdoor area mostly in the evening, a construction material like stone should be chosen, which warms up slowly, but is capable of storing much thermal energy and releasing it into the surroundings in the evening.

In summer cooling is needed also in cold and moderate climates, but usually shading is experienced as a more pleasant method of cooling than wind.

![Figure 104. Effect of height relations of facades and of protective walls on the speeds of air flows of the facade.](image-url)

Fig. 104. Effect of height relations of facades and of protective walls on the speeds of air flows of the facade. (Watson, cit. Børve 1987: 40)
**Warm climates**

In warm and Mediterranean climates it is necessary to arrange sufficient area ventilation and ensure the possibilities for natural building ventilation. This can be done by opening wind channels and by utilising thermal flows. The temperature differences caused by the solar radiation and the shade of buildings and plantings cause thermal air flows which can be used in the improvement of the micro-climate. The wind can easily be utilised in cooling in regions with cooler nights or a dominant wind direction.

Some of these measures may also be needed in cold regions to ensure the thermal comfort in summertime.

**Design of roads and streets**

Although the major issues relating to traffic planning are pollution and congestion, the orientation and placing of roads and streets also have significant effects on urban climate. The width of the street determines the distance between the buildings with impacts on the ventilation and solar utilization potential, and sun and shade in the sidewalks. The street system determines the ventilation potential of the buildings and outdoor areas in the whole built area.

Different kind of streets and open places affect the temperatures. Highest temperatures are measured in wide modern avenues, and lowest in very narrow alleys with a height-width ratio of about 10. In dust-prone areas, which are common in hot-dry regions, wide streets parallel to wind direction often have serious dust problems. On the other hand street ventilation is often needed for other pollutants. (Givoni 1998: 248, 287; Gallo 2002: 15; Higueras 2006: 55–61)

Narrow streets have a higher night temperature because of the heat island phenomenon, but during sunny days the temperatures are lower. The highest temperatures in hot regions are measured in the wide modern avenues. The smaller streets can partly be treated as linear green zones, which greatly enhance the air quality, and temperature and wind comfort in the streets and the buildings along them.

When long rows of buildings along streets are perpendicular to the wind direction, shielded zones are established between the buildings. When the blocks of buildings and the streets are parallel to the wind direction, wind blows along the streets and between the buildings. In this case the buildings are exposed to about the same air pressure on both sides, which reduces the potential for natural
ventilation. With oblique wind, with medium high buildings two times higher than
the width of the street, the situation will be different along the two sides of the
street. The wind pressure, air-flow speeds and solar radiation differ on both sides.
The desirability of higher or lower wind speeds depends on the climate zone.
Especially in warm conditions oblique placing is highly recommended. (Givoni

In cold climates it is essential to enable the inhabitants to make comfortable
and economical daily journeys to work, shops, schools etc., which for traffic
planning means (Pressman 1995):

– pedestrian protection with colonnades, galleries, through-block passages,
  connected atriums, sky-walks, subways etc.
– accessibility of transit facilities, services and bus stops
– integrated development of mixed-land uses and transportation
– concepts for the use of public spaces and transportation corridors during the
  four seasons.

In Northern countries the most important stage in terms of clearing snow from
roads and passageways is the placement of roads in the terrain. Studies show that
ploughing costs go up as the angle between the road and the prevailing wind
direction increases. Ploughing problems decrease when a road travels along a
continuous embankment, while cut-outs and backfills cause snow to build up. The
correct slope of an embankment would be 1:2. When the direction of the wind is
from the filled in side, there must be a ditch approximately 3 m wide on the cut out
side. When the prevailing wind direction is on the side of the cut-out, an
embankment is made according to the directions in Fig. 105. (Norem 1974: 25–30)

Fig. 105. Road bank in snowy terrain. G is determined by the average depth of snow in
the area (Norem 1974: 29)
In particularly difficult snow conditions, the recommendation is to set the level of the road embankment according to the average amount of snow, adding 50 cm to the average depth of snow. In ordinary snow conditions it is enough to have the level of the road set to the average depth of snow. In designing roads and passageways, consideration is also given to the space needed for ploughing and piling snow. (Norem 1974: 29)

Installing snowmelt systems for high-traffic walkways, transition areas, sloped areas and steps should be considered.

6.2.2 Design of snow barriers

Snow fences are designed mainly for the needs of traffic, but with the exception of arctic areas, seldom for residential areas.

The effectiveness of a snow barrier depends on the height of the fence, on the distance to the ground surface and on the permeability. Based on experience, the Norwegian snow fences are in areas with 1–2 m snow depth are 3.5–4.5 m high. Snow fences which are more than 4.5 m high are uneconomic in use, and therefore if necessary more fences are placed consecutively. (Norem 1974: 30–32)

Solid fences create problems of eddying and swirling, but solid barriers with sloping baffles prevent wind turbulence since the baffle directs the wind upwards in a gentle arch. When the baffle is sloped away from the wind, a large protected area is created. The best snow barrier is obtained with about 50% penetration. A totally tight fence holds only 30% compared to the previous one and snow accumulates immediately behind the barrier. A fence with 25-percent penetration holds about 60% compared to a fence with 50-percent penetration. A thin hedge reaches the level of an about 50-percent wooden fence. (Glaumann & Westerberg 1988: 138–141; Pressman 1995: 170)

A fence which consists of several narrow strips accumulates snow closer than one made of broad boards. Usually at least 100 mm wide boards are used. As the distance between the fence and the ground surface about 1/10 of the total height is recommended, at least 0.3 m. Snow fences are built upright for practical reasons, even though the leaning position is the most efficient. The effect of the protection extends to an area which is 15–25 times the height of the protecting element. (Børve 1987b: 48–49)
**Placing of wind energy production**

Wind energy is plentiful, renewable, widely distributed, clean, and reduces toxic atmospheric and greenhouse gas emissions if used to replace fossil-fuel-derived electricity. The intermittency of wind seldom creates problems when using wind power at low to moderate penetration levels. Weather and climate impacts on energy supply, demand and price are multi-faceted. Climate and weather data and products are being increasingly used by energy-related agencies in planning, design and operations. (World 2007: 5–8) Tailored climate information can help enhance the exploitation of sustainable natural sources such as wind (Fig. 106), solar energy, biomass, and hydraulic sources, which are also environment-friendly. (Czich 1999)

![Fig. 106. Mean annual production of a 1, 5 MW variable speed wind turbine in full load hours. The height of the axis is 80 m. ERA-15 is a re-analysis project for the period 1979 to 1993. (Czich 1999: 5)](image)

At the end of 2006, worldwide capacity of wind-powered generators was 73.9 gigawatts. Although it currently produces just over 1% of world-wide electricity use, it accounts for approximately 20% of electricity production in Denmark, 9% in Spain, and 7% in Germany. Globally, wind power generation more than quadrupled between 2000 and 2006.

Wind power is used in large-scale wind farms for national electrical grids as well as in small individual turbines for providing electricity to rural residences or grid-isolated locations. Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electrical current by
means of an electrical generator. In windmills (a much older technology), wind energy is used to turn mechanical machinery to do physical work, such as crushing grain or pumping water. (DEWI 2008)

Windiness is a primary criterion in the selection of windmill locations, since for example an average wind speed of 7 m/s provides 40 times more energy than 2 m/s conditions. The planning of wind energy production starts with the overall estimation of the mean energy contents of the wind over a large area, regional assessment. This is a very important stage, because 5% error in wind-speed approximation means 15% difference in the mean power production. (Petersen) After the “wind-farm” location is chosen, the detailed planning continues with the prediction of the annual energy production potential of each specific wind turbine location, called siting.

The European Wind Atlas (Fig. 107) presents one possible assessment method. The map depicts the geographical distribution of five wind energy classes, bound to wind speeds and topographical conditions. (Troen 1989) The climate analysis and wind testing of scale models developed in this study also serve micro-climate analyses needed by wind power plants.

Wind turbines should ideally be placed about ten times their diameter apart in the direction of prevailing winds and five times their diameter apart in the perpendicular direction for minimal losses due to wind park effects. As a result, wind turbines require roughly 0.1 square kilometres of unobstructed land per megawatt of nameplate capacity. A 2 GW wind farm, which might produce as much energy each year as a 1 GW base load power plant, might have turbines spread out over an area of approximately 200 square kilometres. The clearing of trees around onshore and near-shore tower bases may be necessary to enable installation. Areas under onshore and near-shore wind-farms can be used for farming, and are protected from further development. (DEWI 2008)

Some offshore locations are uniquely located close to ample transmission and high load centres however that is not the norm for most offshore locations. Most offshore locations are at considerable distances from load centres and may face transmission and line loss challenges.
Fig. 107. Diagram of the principle of converting meteorological measurements to local conditions when planning wind energy parks. Computer analyses require basic meteorological data, the dimensions of buildings, the roughness of the terrain from the standpoint of wind and contour lines. The software calculates local wind conditions on the basis of this information. (Troen 1989: 17)

6.2.3 Design of coastal structures

The average sea level may rise more than 1 metre by the year 2100, and will overflow the heavily populated coastlines of such countries as Bangladesh, cause the disappearance of some nations entirely, such as the island state of the Maldives, and spur mass migrations. A new feature that has been studied related to
extreme conditions over the oceans is wave height. Studies have shown that for many regions of the mid-latitude oceans, an increase in extreme wave height is likely to occur in a future warmer climate. (Church 2001: 23–28; Meehl 2007; United 2007: 12)

A rise of about 1 m in the level of oceans, and the danger of higher floods along inland waters, cause alterations in the recommended foundation heights. As regards shores of seas, the rise of water level, bigger flood margins and higher wave margins will result in the need of considerably higher foundation heights and better quay construction than the norms demand today. The foundation height can be calculated by adding the 1 m rising sea level, flood height, height of wave climb and a security factor. For instance, at an open sheer bank of the Baltic Sea the flood height can be almost 3 metres, wave climb 3 metres and security factor 30 cm, which means that the lowest foundation height is more than 6 metres above the normal sea level at present. At a well protected beach the corresponding height is 3.3 metres. Splashes caused by storm waves against a sheer coast or upright quay construction can even reach 10 metres height. The wave climb ratio depends on the salt content of water. The heights in the Baltic Sea are presented in Table 20 (Kahma; Ollila 2002: 10–18)

Table 20. Height of wave climb on a flat-bottom shore of the Baltic Sea.

<table>
<thead>
<tr>
<th>Length of open sea</th>
<th>Height of wave climb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gently sloping shore, 1:10</td>
</tr>
<tr>
<td>1 km</td>
<td>30 cm</td>
</tr>
<tr>
<td>5 km</td>
<td>60 cm</td>
</tr>
<tr>
<td>10 km</td>
<td>100 cm</td>
</tr>
</tbody>
</table>

The increasing amount of water in many rivers will raise the need to take the risk of floods and land-slides into account. A new phenomena in the Northern countries are frazil ice floods and the winter floods caused by the growing precipitation and warmer winters. In such areas where precipitation does not increase, the risk of floods in summer is expected to decrease because of the growing evaporation.

Winds, waves, floods, and availability of deep navigable channels affect the design of marinas and harbours. All the facts above show that new challenges will burden the marinas, quays and other structures near seashores during the 21st century. Examples of rebuilding guidelines in a hurricane region are presented in
Fig. 108. The following chapters deal with different shore construction alternatives; the measures apply to the situation in Finland. Because of higher waves, the construction heights should be increased along ocean shores.

<table>
<thead>
<tr>
<th>FACTORS FOR REBUILDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOOD</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>UNDER NEW DAMAGE</td>
</tr>
<tr>
<td>NOW</td>
</tr>
<tr>
<td>WHEN FLOOD MAP CHANGES</td>
</tr>
<tr>
<td>NEW HOUSE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>OUTER NEW DAMAGE</td>
</tr>
<tr>
<td>NOW</td>
</tr>
<tr>
<td>WHEN FLOOD MAP CHANGES</td>
</tr>
<tr>
<td>NEW HOUSE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>NEW HOUSE</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Fig. 108. Example of new rules for foundation heights in New Orleans after the floods. (Perkes 2008: 30)

*Sloping shore*

On a sloping shore the bank rises from deep water quite steeply, with a slope of 1:2 or 1:3, to a height of two metres, see Fig. 109. Such a steep shore reflects 90% of the wave that hits it, and the waves do not break until they reach the shore. Thus, the midpoint of a wave breaking on the bank rises significantly higher than the level of calm water.
Upon hitting the shore the water continues on in a thick layer. If this layer is even a little thicker and has not lost all of its speed upon hitting a building, it may form a strong upward spray of water. Such sprays have been observed to damage steel structures located high up on coffer lighthouses. During storms the splashes may rise to heights of up to ten metres, and water flies far inland.

**Abrupt shore**

An abrupt shore (Fig. 110) consists of a steep, rock-filled 1:3 slope that begins in deep water and from which a vertical wall rises. A sufficiently coarse rock fill improves conditions somewhat.
Fig. 110. Abrupt shore. (Kahma)

The vertical wall reflects 100% of the waves that hit it. If the shore were straight in the horizontal direction, depending on the openness and salt content of the sea, the height of waves at the wall during the worst storms of the year would be several metres. The splashes rise to a height of several metres and reach the wall of the building. Because the end of the building in Fig. 110 is less than 10 m from the wall, regardless of the steps visible, in an extreme situation it is possible that a thick layer of water could hit the wall of the building.

**Quay shore**

A quay shore is the best protected of these three shore types (Fig. 111). In addition to the quay form in the figure bellow, the deeper water further from the bank diminishes the waves somewhat compared with the abrupt wall shore. The steep 1:2 or 1:3 slope of the bank reflects about 90% of the waves. The embankment near the surface, with a 1:1 slope, reflects even more.
If the shoreline is well protected, the average wave height during the worst storm of the year is calculated to be clearly less than one metre in Finland, and the largest single wave is less than 1.5 m. Even this may be too high for a boat dock. Furthermore, the waves often approach from the side and rock the boats badly. The largest waves rise above dock level nearly every year. Depending on the direction of the waves, the layer of water may hit the wall of the building. The amount of splashes depends on the types of protrusions on the dock.

Changing the height and slope of the bank and the depth of the water of the shore types affects the waves and splashing. Even a small increase in the height of the shore has a significant effect on both the water that flows over it and splashes. The slope of all the presented shore types is so steep that the waves are reflected. This nearly doubles the height of the waves at the shore compared with their height offshore, and additionally sea level rises because of the effect of the waves. If the waves break, they break at the shoreline. If the slope is decreased sufficiently, instead of being reflected, the waves will break. Breaking takes place offshore, and the higher the waves, the further away they will break. The height of the breaking waves increases from what it is offshore, but since breaking occurs before they reach the shoreline, the flow of water caused by breaking does not reach as far as it does with the presented shore types.

The depth of the water affects the height of the waves at the shore where the slope is small enough, no more than 1:5. The greatest wave height is reached at the
shore if the shore rises gradually to a depth of one metre and then forms a steep, reflecting bank. A steep slope before the vertical wall decreases wave height a little. A gradual slope that does not reach the surface increases wave height. (Ollila 2002: 16–21; Kahma)

**Summa summarum:**

- strengthened outdoor constructions against the growing loading due to the climate change
- street system and orientation according to the prevailing winds and solar conditions
- integrated, weather protected transportation
- pedestrian protection and accessibility of transit facilities
- wind; protection or ventilation, wind energy
- area ventilation and cooling
- water; grey water, rain water use
- channelling of rainwater and surface water, flood protection.

### 6.3 Natural environment

#### 6.3.1 Construction and nature

The purpose of the analysis of green structures in connection with climate-conscious planning is to give the necessary complementary information about the affects of the vegetation of the project site on the micro-climate and water cycles. In connection with bioclimatic planning the objectives are larger, the understanding of the dynamics of the nature of the site. But even the design of wind screen plantings and planning of flood protection demands a basic understanding of the nature of the site and the interactive processes with its surroundings. The use of the CASE method will give the planner the basic understanding of the nature of the project area.

Construction has changed the balance of nature in large areas. Recent studies show that there are limits to the natural environment’s load-bearing capacity, which have been exceeded in many places. Landscape design tries to strengthen the natural environment by maintaining the biodiversity of ecosystems and connecting separated nature areas to each other. Wind shield vegetation is an important part of climatic-conscious planning.
The global ecosystem is composed of three nutrition groups: producers (plants), consumers (usually animals) and decomposers (bacteria and fungi). The biosphere is composed of many bio-cycles, which are broadly in balance, but evolve in the course of time. Unfortunately, human activities, and especially construction, tend to upset this balance. The purpose of good planning practice is to maintain this balance. A rich natural environment and large free areas can be seen as a feature that makes the micro-climate better, strengthens the competitiveness of the area, and nature preservation should not be considered a hindrance to development. (Yeang 1999: 22–40)

The cyclical flow of materials is essential to ecosystems, but in most environments, especially man-made ones, the cycle remains incomplete. Producers bring energy into an ecosystem, and it is reused by other plant and animal species. Greenery found in urban areas is negligible as a food source and has quite a small role in the total flow of energy. Cities are dependent systems that draw their energy from other external ecosystems, operating in a linear one-way fashion. (Yeang 1999: 22–40)

There are four main ecosystem cycles:
1. Atmospheric cycle.
2. Hydrologic cycle.
3. Cycle of organic materials and wastes.
4. Energy cycle.

The notion ecological footprint describes the area needed per person to supply all resources consumed by one person; the production of food, supply of energy, oxygen and water, absorption of CO₂, pollutants and wastes etc. Examples of ecological footprints: the USA 9.6 ha, Canada 8.8 ha, Sweden 8.0 ha, France 5.3, Spain 4.2 ha, Mexico 2.5 ha and the Republic of Congo 0.6 ha. The global average is 2 ha/person. It has been estimated that in 2003 the ecological footprint of mankind exceeded the bearing capacity of the earth by 30%. One important task of regional planning and green area arrangements is to diminish the ecological footprint of a given project area. (Higueras 2006: 61–69)

Ecological environment analysis and defining of wind shield greenery should be the starting points for all architectural design and planning, which is often not the case today. Besides viewing the landscape, vegetation and animal life in an aesthetic sense, more attention ought to be paid to living ecotypes and their maintenance and enrichment. The borders between different areas or biotopes,
where biodiversity is usually especially rich, are especially rich. Only an understanding of natural processes gives the potential for designs in which the biodiversity of the flora and fauna are maintained. The ecosystem’s capacity to assimilate is limited, and if the threshold is exceeded, the ecosystem will deteriorate.

Nature areas can also be used for many purposes without destroying their flora and fauna. Hiking, nature schools and ecological silviculture can be allowed. Some biotopes like meadows, pasturelands and fields, even depend on human activities and certain kinds of agriculture. (Storstockholms 1991: 55–58; Miller 1993; Yeang 1999: 30–35)

Ever-growing urban settlements threaten the food supply in many countries and even globally. The remedy suggested is the preservation of agriculture land, and the increase of urban farming. Rooftop gardens are a spreading pattern to answer the growing urban need for food, and for instance the municipal government of Beijing has plans to cultivate gardens on 3 million square metres of roof space over the next 10 years. In many developing countries wastewater is used to irrigate the urban fields and aquaculture ponds, which is a good way of recirculating, but may bring health risks along with it. (Halweil & Nierenberg 2007: 48–63)

There are many biological and geographical methods of analysing flora and fauna, but most of them require the use of specialists. These analyses are often left undone for cost reasons. Experiments in Sodankylä and Oulu show that with relatively simple field work it is possible to get a sufficient and reliable understanding of the environment of the project area (Appendix 2).

In evaluating natural green areas it is seldom possible to compile a complete chart of flora and fauna species. A relatively good picture of the situation can be achieved when the number of different biotopes is estimated by using a classification system. In many countries standard classification systems for forests are used. The easiest analysis consists of outlining different kinds of biotopes on a map:

- forests
- wetlands
- water systems
- open fields
- deserted areas
- meadows
- special landscape features.
Nature can also be classified by the presence of key species in the area. The boundary zones between different biotopes, like forest edges, shores and wetlands are usually especially rich in the number of species (high biodiversity), and therefore worth charting. It is possible to draw a comparison between the degree of natural versatility of different areas by marking the number of different natural types and boundary zones on the squares of a map. Barriers and disturbing factors should be marked on the same map. (Børve & Sterten 1981: 8–10; Anttila 1996; CASE Kuismanen 1995; Kuismanen 1996)

With the climate change the availability of water is growing in importance in most settlements. Charting of water resources, protection of surface water and groundwater, and planning of optimal use of the water resources also in the future are essential parts of a nature analysis. The quality of water determines the possibilities for recreational uses, and the need for purification.

Analyses on maps should always be complemented by observations of the project area. Complementary information can be achieved from the environmental studies of communal planning authorities, regional plans, aerial photos and local nature or bird associations.

Green areas of a region

The regional green structure forms the basis for the greenery of any area, thus affecting the biodiversity and climatic affects of vegetation in the sub areas. In regional planning, the size of the target area is an important starting point of the whole process. Project areas should be large enough to ensure that large, enduring and diversified support areas for different populations are available for planning. Regional wind screening, this is areas of tens or hundreds of kilometres, needs a regional green structure as well. In many climate zones the climate change threatens the existing wind and erosion protecting regional greenery.

There should be a sufficient variety of biological support areas, which are chosen according to their biodiversity and capability to survive. To enable a continuous interchange of genetic material, these kernel areas, which will be kept in their natural state, should be interconnected with green corridors. At the same time care must be taken that their connections with larger nature areas in the country are preserved. To encourage species migration and contribute to greater diversity, it is crucial to ensure physical contiguity between green areas. Otherwise, according to the biogeographic studies of McArthur and Wilson, there
is a danger that the biodiversity of the support areas will be impoverished. (Nyhuus 1991: 22–28; Storstockholms 1991: 35–40; Yeang 1999: 92–101)

The climate change sets high requirements for nature area networks. There should be possibilities for the fauna and flora, actually whole biotopes, to migrate to propitious territories as the changes proceed. In terms of area use, in Finland in most cases south-north oriented green corridors fulfil that demand. (Wahlgreen, Kuismanen, Makkonen 2008)

The size of necessary green areas will vary according to the circumstances. Observations made in Scandinavia indicate that the number of species grows significantly in nature areas that are larger than 3 km. Because kernel areas are usually encumbered with disturbing factors and monoculture sub-areas, 4–5 km can be regarded as their targeted size in planning. (Nyhuus 1991: 15–18; Storstockholms 1991: 41–42; Yeang 1999: 93–95)

By connecting the support areas with green corridors, migration routes, a dynamic functioning green structure will be created, which also maintains species variety in smaller and endangered green areas and parks (Figs 112–113). A width of a few hundred metres can be considered sufficient for a green corridor. Depending on the local circumstances, this green net can surround a city – London, Moscow, Havana – it can penetrate the urban structure as green fingers – Stockholm, Helsinki – or in the case of a linear city, the natural environment can form a ribbon that runs along the urban structure, as in Costa del Sol.

In this sense a support area does not mean a virgin forest or nature reserve, but instead it can be a small amount of low-volume traffic routes (less than 2000 vehicles a day), a few houses, electric lines, etc. Noise is not an overly disturbing factor for most animal species, either. But, agricultural fields, golf courses, yards and similar areas cannot be considered to belong to nature areas, unless their biodiversity is not strongly enhanced with plantings and landscaping. Severe barriers in a green corridor include big buildings, groups of houses, wide roads, gravel pits and large bodies of water. The affect of roads can be diminished by constructing part of the road on a bridge, under which nature can continue freely. (Storstockholms 1991: 22–27; Yeang 1999: 92–97)
Fig. 112. A network of green corridors suggested for the City of Bergen by CASE architects. New corridors are yellow. E, ecological coast zone; B, green bridge; T, green tunnel or passage. (drawing: Bjørge, Børve, Kuismanen)

At least the following information about the planned support areas and green corridors should be given:

- location (municipality)
- area
- nature reserve areas and regulations
- information about land use plans
- monuments, protected buildings, historic sites, etc.
- recreational use and recreational areas
- description of the landscape, nature, problems, threats, etc.
- estimation of the biodiversity and originality of the natural environment
- estimation of the capability of the vegetation of an area to withstand climatic changes.
6.3.2 Urban parks and street greenery

Often in large urban areas biotic ecosystem components have been completely eliminated, and the remaining ones are usually monocultures. Construction projects can bring new vegetation and animal life even to city centres. Although their micro-climatic affect can be big, small green areas have only a local effect on air quality in dense urban areas, and therefore they should be linked together to form larger entities. By increasing the biomass in city centres, it is possible to diminish the negative effects of the urban heat island phenomenon. Near-surface air temperatures over vegetated areas are 1–2° C lower, and vegetation may lower urban temperatures in the boundary layer by 1° C. One large tree can transpire 450 litres of water a day, thus binding 960,000 KJ of energy. (Mattson 1979: 57, 117; Givoni 1998: 304–307; Serra 1999: 12–15)
There are three alternative strategies for adding vegetation to buildings and small open places (Yeang 1999: 239–250):

- Juxtapositioning.
- Intermixing.
- Integration.

In juxtapositioning plantings are centralised in their own areas or greenhouses. Intermixing means dispersed planting as small entities all over the whole urban structure. Integration means continuous green structures, which are designed as organic functional parts of urban places or building facades, thus contributing to passive or active modes of natural energy, wind screening and ventilation strategies. (Mattson 1979; Givoni 1998: 320–323; Serra 1999: 12–15)

In an urban environment it is not possible to create the cycling of materials and energy flows found in nature. But, planting can contribute much to the urban milieu and human comfort (Figs 114–115). Greenery provides shelter against winds and overheating, and can also prevent solar energy gain. Plants increase the humidity, reduce the reflected solar radiation and lower the temperature of semi-enclosed spaces. But, the climatic effects of small green areas and spaces depend greatly on their detailed design and treatment. For instance, a line of trees without lower vegetation beneath them can increase wind speeds at ground level. Bodies of water have a moderating influence on temperature changes. (Givoni 1998: 320; Serra 1999: 12–15)

Fig. 114. A planted viaduct acts as a linear park in the densely built-up quarters of eastern Paris. (Jones 1998: 213)
Traffic areas also contribute to urban greenery and micro-climate (Fig. 116). Street sides may have trees and other planting, roads can be lightly vegetated to make them porous to dust and water, and car parking bays can have reinforced grass. Toxins in rain are absorbed or destroyed in the soil, and storm water is retained for slow discharge. Vegetation, especially trees, affects air quality directly by absorbing and emitting particles and gases, but also indirectly by changing meteorological conditions. Continuous belts of plants steer airflows in the area. A wooded shelter belt by the roadside reduces concentrations of coarse particles. The effect on fine particles (PM2.5) and several gaseous contaminants is smaller, since vegetation absorbs them more weakly. However, trees intensify the turbulence of air flows and so dilute the concentrations of all traffic-originated contaminants in the air. Dense hedgerows and noise barriers have a significant effect on the concentration of only the coarsest particles.
Green shelter belts should be located as close to the roadside as possible, keeping traffic safety in mind. The edge of the vegetation should be high, steep and irregularly curly, and the greenery should be quite dense and in multiple layers. The structure of the vegetation should be irregular and include plenty of height variations. Richness of species, shrub layers and different-aged stands of trees stand strengthen absorption. Coniferous trees are particularly effective in absorbing particulate contaminants, and they do it throughout the whole year, but the nearest strip on a street side should be deciduous forest-dominated, since they tolerate contaminants better. The width of a green belt alongside a busy road should be at least tens of metres, and formal avenue plantings are not enough. Plantings of trees with an open under storey actually increase wind speed by jetting the wind between the crown of the tree and the ground. (Caborn 1965; Yeang 1999: 238; Niemi 2002)

When designing streets, the following information should be included (Stadtgrün 1984):
- sections of biotopes and the permeability to water
- images and/or description of all seasons
- history of vegetation (on maps)
- planned flora (full-length)

The smallest semi-enclosed green areas, roof gardens, sky courts of skyscrapers (Fig. 115) and closed yards are attached to the buildings and affect the micro-climate and the interaction between the indoor and outdoor thermal environments. Such areas are especially important for children, seniors and other less mobile persons, and their planning must happen hand in hand with building design. If underground garages are planned, unbuilt zones should be left in the yard, making it possible to grow big trees there.
Trees affect the air quality in many ways by shadowing, increasing humidity, cooling by evaporation and binding moist particles. Greenery evens the extremes of the climate; it lowers the hottest daytime temperatures in summer by as much as 5–8°C and makes winter cold milder. Local airflows between cold and warm areas pass through the plants, which cleans the air. The amount of dirt particles in air that has been flowing through densely-foliated trees is only one eighth compared with air on the nearby street. Hedges offer privacy and also clean the air. Even a one-metre-high dense hedge by a heavily trafficked road can halve the amount of lead, for instance, and dense rows of shrubs should therefore be used to protect pedestrians even in central urban areas. By building closed blocks with green
yards, noise-protected cells of clean air can be designed within cities. The air-purifying function of trees can be enhanced with good micro-climate design.

Plants can be used as green filters to remove formaldehyde, benzene and airborne microbes, see Table 21. For instance, bamboo palm, peace lily, aloe, philodendron, chrysanthemums and English ivy can absorb most office and domestic emissions. The Boston fern removes 90 percent of chemicals that cause allergic reactions. The required concentration is one plant per square metre of internal space. (Lötsch 1981: 135–151; Yeang 1999: 238)

Table 21. Green filters: percentage absorption of contaminants after 24 hours. (Daniels 1995: 30)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Formaldehyde</th>
<th>Benzol</th>
<th>Trichloroethylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>69</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Bowstring hemp</td>
<td>–</td>
<td>53</td>
<td>13</td>
</tr>
<tr>
<td>Chrysanthemum</td>
<td>61</td>
<td>54</td>
<td>41</td>
</tr>
<tr>
<td>Dracaena deremensis (Janet-Craig)</td>
<td>–</td>
<td>78</td>
<td>18</td>
</tr>
<tr>
<td>Dracaena deremensis (Wameckii)</td>
<td>50</td>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>Dracaena deremensis (massangeana)</td>
<td>70</td>
<td>–</td>
<td>13</td>
</tr>
<tr>
<td>Dracaena deremensis (yellow-variegated)</td>
<td>–</td>
<td>79</td>
<td>13</td>
</tr>
<tr>
<td>True aloe</td>
<td>90</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ivy</td>
<td>–</td>
<td>90</td>
<td>11</td>
</tr>
<tr>
<td>Devil’s Ivy</td>
<td>67</td>
<td>73</td>
<td>9</td>
</tr>
<tr>
<td>Spathe flower</td>
<td>–</td>
<td>80</td>
<td>23</td>
</tr>
<tr>
<td>Creeping hairy spurge</td>
<td>67</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ficus benjamina</td>
<td>–</td>
<td>–</td>
<td>11</td>
</tr>
<tr>
<td>Gerbera</td>
<td>50</td>
<td>68</td>
<td>35</td>
</tr>
<tr>
<td>Green lily</td>
<td>86</td>
<td>81</td>
<td>–</td>
</tr>
<tr>
<td>Chinese evergreen (Agöapme,a</td>
<td>–</td>
<td>48</td>
<td>–</td>
</tr>
<tr>
<td>Philodendron (domesticum)</td>
<td>86</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Philodendron (oxycardium)</td>
<td>71</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Philodendron (selloum)</td>
<td>76</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

6.3.3 Vegetation in different climates

The possibilities of plant and animal life vary strongly in different climates and latitudes, thus affecting biodiversity (Fig. 117). As a rule of thumb it can be said that the further towards north or south we go from the equator, the less biodiversity there is and the more the natural environment is affected by any human actions.
Biodiversity is the number of different species of plants and animals found in a given place. Biodiversity has four levels (Cranbrook 1994; Yeang 1999: 100):

1. Diversity between and within ecosystems and habitats.
2. Diversity of species.
3. Diversity of niches.
4. Genetic variations within individual species.

Fig. 117. Typical diversity of species in relation to latitude. (Cranbrook 1994)

Cold climate. The most important aspect of plants is protection against the wind without blocking the sun. In regions with northerly winds this can be easily fulfilled with conifers and shrubs planted on the north side of the planned free space. Leaf trees on the south side provide shelter from the sun in summer, while they let the milder winter sun shine in winter. In regions with southerly or westerly winds, lower hedges or shrubs are recommended.

Hot-dry climate. The heat island phenomenon makes urban environments warmer than the surrounding countryside, which is especially unpleasant in a hot-dry climate. Green areas provide shade and protection from dust. Irrigated urban parks elevate the humidity level of the air and lower temperatures by as much as 4-11° C. Large lawns and flowerbeds without shade offer only limited recreational possibilities to inhabitants. Low hedges are effective in reducing wind speed and filtering dust near the ground, while not blocking the wind at higher elevations. In
many countries, like Iraq, effective irrigation systems for urban trees have been arranged for centuries.

Desert climate. In desert regions the possibilities for any kind of vegetation are limited. To diminish the amount of dust in the air the windward side of settlements should be sheltered against the wind. The natural ground cover of desert plants should be preserved.

Hot-humid climate. Here the wind around and air movement inside buildings are important for comfort. A reduction of wind speed and elevated humidity are negative effects of dense greenery. Parks and other green areas should provide shade, but they should not block air movement, and therefore trees with a high trunk and wide canopy are the most suitable. Thanks to the high precipitation, local plants usually do not need irrigation.

In all climates the loss of plant cover is dangerous, because then water and wind can race across the land, taking valuable topsoil with them. New green areas prevent erosion, and they can even be economically feasible. For instance, in some places green areas can bring back the flood control capacity that nature provides, thus preventing human and economic losses. With each one-percent increase in wetlands, flooding downstream is decreased by 2–4 percent. (Givoni 1998: 357, 396, 428; L ötsch 1981: 135, 153)

Generally as much indigenous local vegetation as possible should be used. They require little maintenance and less water and fertilizers.

Free areas between buildings can lead to different results in different regions, because communal or private care varies. In some cases the result is a green park, while in other cultures open land leads to neglect, dust and wind erosion. Especially in arid and desert regions, care of free areas is more expensive and there can be a lack of water. What is a park in a city plan can be a no man’s land in reality.
Wet biotopes are often the richest ones in an area, and therefore it is especially important to analyse them and include them in every plan. The presence of water offers possibilities for rich flora, which is a vital necessity for insects, frogs and other fauna. Bodies of water, water jets etc. positively affect the quality of air in warm-dry climates and moderate climates during warm seasons. In many cases rainwater from traffic areas should be cleaned biologically in different kinds of ponds or wet biotopes before it is allowed to run into rivers. (Lötsch 1981: 135, 153; Yeang 1999: 41, 100, 244)

6.3.4 Wind protecting plantings

The starting point for natural wind shield greenery that is easy to tend is to select plants that are suitable for the type of earth and the climate. The starting point for garden planning is obtained from a field analysis, on which basis the biotope of the construction site is specified. This already gives a direction for future plant selection and greenery plantings. The categorization presented by Alanko and Kahila provides a clear-cut starting point for planning in moderate climates (Alanko 2004):
1. Heath garden
2. Rock garden
3. Woodland garden
4. Rhododendron garden
5. Aquatic garden
6. Arable land; field, meadow, perennial meadow

Best screening against winds is achieved with multilayered plantings, just like natural landscapes; an example of three-layered effective wind screen is given in Fig. 119. Under the trees are plants that thrive in the shade, cover plants, shade perennials, and in the spring, bulbous plants. Shrubs and cover plants are dense and varied. Flowers and food plants are not placed in separate beds, but interspersed with other plantings. Weeds are controlled with dense cover plants, by avoiding open ground, with covers and shade. On the basis of the above description, it is apparent that a natural garden is not suitable for all locations, and there are situations where a parterre, a cultivated rose garden, or a similar type of garden is more suitable.

Vines or other plants growing on the wall lower energy consumption, a 5 cm layer of plants improves the k-value from 0.30 to 0.27. A facade lattice has a similar effect.

Fig. 119. Wind shield plantings. (drawing Kuismanen 2008) Mixture of plants of different heights provides the best protection against the wind. Coniferous trees provide the best protection in the winter. Especially in the first years, plants should be supplemented with wind barrier lattices (30–60% passage).
One type of natural garden is perma-culture. The purpose is to get by with less garden tending by working in harmony with nature. For example, the soil is not tilled and fallen leaves are for the most part left on the ground to nourish organisms and control weed growth. The whole idea is based on the age-old agroforestry practiced by native peoples in warm climates. Trees – often fruit trees – are planted sparsely, and shrubs and other useful plants are planted between them. Local native plants are used whenever possible.

The shape of the terrain provides the starting point for the elevations of the land, but it is often advisable to use the masses of earth produced during construction to create small mounds, which strengthen the wind screening effect of vegetation.

Diversity can also be applied to practical garden work. While shrubs are traditionally planted at regular intervals in separate planting holes, it is also possible to plant a large number of different types of shrubs at varying intervals, and even in the same planting hole. In that case the objective is to create "family shrubs", which behave like single shrubs in spite of their diversity. Distance rules can also be ignored when planting trees. Groups of trees can be created by planting several saplings in the same planting hole. Over the years the different species of plants will assume their natural status. This kind of vegetation functions also better as wind shelters. (Alanko 2004; Lust auf Garten 2006)

When planning the surroundings of buildings:
- Collect and store the surface soil from the building site and use it when planting greenery.
- Unless you need a ball field or something similar, avoid large lawns.
- When possible, use natural cover and wind shield plants.
- Avoid large asphalt surfaces; use materials that do not prevent absorption of rainwater into the ground.
- Use self-caring plants (ecological garden) lower property maintenance costs.
- Plan the layout of plants and colours of different seasons.
- Favour evergreen plants.
- Favour natural meadows, which purify the air tens of times better than a cut lawn does.

6.3.5 Different types of plantings as wind shelters

Heath garden. A heath garden is a plant community in a dry, permeable, often sunny growth area with barren, sandy, morainic or gravelly earth. A Scandinavian
heath garden basically resembles a dry heath forest, where the ground is covered with evergreen undergrowth. The quantity and diversity of evergreens in the British Isles and in Central Europe (Heidegarten in Germany) are much bigger, and dense groups of evergreens add much to the wind screening quality of the whole. (Riikonen 2001; Alanko 2004; Lust auf Garten 2006)

Rock garden. Urbanization and construction of transport channels together with the development of efficient rock excavation methods have left permanent scars on a large portion of the world’s rock formations and created new wind and water channels. An untouched natural rock formation is an increasingly rare sight, which should be protected when planning both transport channels and yards. Once a rock formation is marred, it can never be restored.

In a wind screen belt a rock theme may consist of either on-site natural rock formations or stones found on the site or brought from elsewhere, and evergreen trees and plants are placed between them (Fig. 118). This kind of wind screen needs minimum maintenance, and in many regions will tolerate the increasing dryness best.

Woodland garden. A woodland garden refers to a plant community created in a good herb-rich forest or a moist grove-like heath forest, which is often also located on clayey terrain. A woodland garden may also be created in a field, but this requires much time and patience before it works against winds.

The starting point for this biotope is formed by trees, which offer shade to shrubs, cover plants, grasses and bulbous plants. Cover plants have an important role in keeping the ground spongy and moist all the way to the surface, and they also prevent frost from penetrating very deeply.

Rhododendron garden. A Scandinavian moist, shady coniferous forest with moist sod, humus or partly sandy earth that is suitably acidic forms a good starting point for a rhododendron garden. As a wind shield planting, a rhododendron garden refers to an entity comprised of coniferous trees, evergreen shrubs, rhododendrons and azaleas, other shrubs, ferns, undergrowth, other cover plants, and mosses.

Coniferous trees, whose shade provides growth conditions for other types of plants, form a good base for this biotope.

Aquatic garden. From the standpoint of the quantity and diversity of flora and fauna, wetlands and aquatic themes are among the most important parts of greenery. In this conjunction, an aquatic garden means all places that are connected to water. It is of primary importance to preserve natural aquatic themes
and wetlands in the construction area, and their water supply can be enhanced with correct handling of rainwater.

Larger bodies of water give a free place to winds, and therefore it is important to consider the possibilities to create wind shelter vegetation along the shore lines.

Field, meadow. Especially when it is constructed in a field or similar open place, a garden naturally contains large open areas. The moisture conditions of a level clay field, in particular, are difficult for most types of plants, and for this reason development of arable land often should be started by shaping the terrain, to possibly create both mounds and water basins. Various trees and shrubs that provide wind protection and shade can be planted at the construction site. In open areas it is recommended to use textured and natural materials and create habitats for butterflies, birds and lizards. (Riikonen 2001; Alanko 2004; Lust auf Garten 2006)

The air quality of street space can be improved by adding ventilation and by circulating air through the foliage of trees with the help of thermal flows (Fig. 120). A full-grown big tree can bind up to 1000 kg of impurities per year. There may be 15000 dirt particles per cubic metre in the street with heavy traffic when in parks the value can be 2000. Pools and fountains intensify the effect of greenery. (Miller 1993: 85; Halvorsen 1995: 39–42; Climatic 1996: 47–49; Hideki)

![Fig. 120. Distribution of air temperature and air flows on the sunny and shade sides of a tree. (Hideki)](image)

The most effective are wind shield plantings with 0–50% opening, and the width of the green zone plays a minimal role when the openness is small enough. But in dry arid areas the planted belt should be wide enough to resist dryness and other climatic stresses, and the green belts should be so near each other, about 200–250 m, that the fertile soil doesn’t fly away with the wind. For best results greenery should have a high side against the prevailing winds, and there should be trees
with different heights to diminish turbulence. A tight row of trees is effective also against oblique winds up to about 45° angle.

Earth walls are often used against traffic noise, but they have only a marginal effect against wind and can cause turbulence on the leeside. With trees and shrubs their wind shield performance can be improved notably. (Njalsson 1983)

The effect of deciduous trees on the wind speed will vary 20–30% seasonally because of the wind reducing effect of the foliage. High trees in the middle of a building group reduce windiness effectively. The protecting effect of a tree stand reaches the level of the crowns and therefore it is important that in a windy region the buildings are not extended above the crowns. More preferably the areas to be protected are surrounded with protection plantings and regularity of planting lines is avoided, because the wind direction can often vary up to 90°, even if the average wind direction is the same. The preparation and thinning of a tree stand to increase its durability should be made about five years before construction. (Miller 1993: 88–90; Maaninen)

From different studies one can conclude that from the point of view of the binding of wind energy and from the point of view of prevention of turbulence, the most efficient is a three-level planting, where a part would consist of evergreen species:

– At the ground level dense bushes which are 0.5–1.5 m high.
– At the intermediate level bushes which are 1.5–3 m high and trees which are 30–50% air open.
– At the top level tree stand; more than 50% air open.

Tight wind shield plantings can also have negative effects for the environment (Njalsson 1983):

– risk of night frost is bigger in cold climates
– farmland or buildable area is diminished
– maintenance costs can be high
– in wet areas surplus humidity is dried slowly
– roots of trees can harm drainage or gardens nearby.

Farming and gardening set their own demands on the micro-climate and protection in different climatic zones. In the north some of the main things are the supply of heat and the avoidance of winds and cold air pools. Passive protective measures include protection plantings, because a tree stand prevents the forming of cold air and controls cold air flows. In Japan an attempt has been made with conifer plantations that are parallel with the shore to reduce the coming of mist from the
cold sea. Active protection methods include the making of artificial fog or smoke, the protection of cultivation areas by running water and the blowing of air from warmer layers along wind channels which are opened in the landscape. (Mattsson 1979: 125–131)

**Summa summarum:**

- analyse the natural environment of the building site
- avoid splitting green areas or green corridors; large areas can keep their biodiversity and adapt to the climate change
- unite separated small green spots into continuous green networks
- define nature protection and building areas; concentrate construction
- limit clearing and restrict cleared areas; use uncleared areas as wind and flood buffers
- restore damaged areas and increase biomass and biodiversity
- create bodies of water and wetlands for habitat and rainwater storage
- use porous surfaces to protect ground water and diminish runoff
- instead of lawns, create low-maintenance diversified landscapes; in cold climates use local plants that are dense enough for wind protection; in warm climates use trees that shade but let refreshing winds blow
- choose the basic theme and types of plants according to the type of earth and the biotope
- avoid unnecessary levelling and use masses of earth to shape the land; improve micro-climate with landscaping
- favour wetland and aquatic themes; they humify the air, lower temperatures and diminish flood risks
- use stones as wind breaks, and leave rocks untouched.

### 6.4 Buildings

#### 6.4.1 Building design

The climate does not determine the form of a building but affects it. Many architectural features affect a building’s interaction with its surroundings and its climatic and ecological effectiveness:

- Building’s mass and layout (room orientation).
- Material and colours of the walls and the windows.
Shading and ventilation solutions (see Chapter 6.7).

For example a cube as a building form serves as shelter in hot deserts, as a Palladian villa on the windy British Isles and as an energy house in Scandinavia, but the structures and the energy and ventilation technical concepts of the houses are different in all of these climates, as described in Chapter 6.8.

There are many forms of interaction between buildings and their environment:

- Solar exposure and heat gain.
- Rate of conductive and convective heat gain from, or loss to, the ambient air.
- Potential for natural ventilation and passive cooling of the building.

A compact building has less heat exchange by conduction, which reduces the need for heating or cooling. On the other hand, a spread-out building provides more opportunities for cross-ventilation and natural daylight (Givoni 1998: 49). One strategy to cope with the climate is to divide the building into a core zone, protective buffer zone and solar zone (Figs 121–123).

Core zone
- carefully isolated, warm year-round core
- natural materials, thermal mass
- warmest activities in the middle of the frame.

Buffer zone
- wind shield elements (Fig. 122))
- unheated spaces and rooms
- low temperature rooms with small windows.

Solar zone
- unheated zone which is in use only part of the year
- functions as a solar collector
- preheats incoming air
- subtropical vegetation, which requires a cooler winter period
- heat storage in massive structures

Greenhouses and solar zones do not increase the size of a block, although they add to the liveable space of a building. Instead, closed areas decrease the exclusion distance needed between neighbours and sources of noise. (Seidel 1984: 88–91)
Fig. 121. Zones in a building (from above): I cold buffer zone, II bedrooms + 18, III warm zone +22, IV living zone +18–22, V sunny wind-protected outdoor space, sketch Tervola. (drawing Kuismanen 1993)

Fig. 122. Protective double façade was made by gratings and garlands, kindergarten Sodankylä. (Kuismanen)
Fig. 123. Passive solar house principle. (drawing Kuismanen 2008) Orientation toward the south-easterly to south-westerly direction. Dark façade to the south gathers heat. Build in the poorest area of the plot, preserve the best areas in their natural state. Do not place the building in the middle of the plot (the yard will be splintered). Buffer zone: storage buildings, carports. Parking places in the shady part of the plot or along the street. Deciduous trees provide shade in the summer, but not in the winter. Coniferous trees on the northern edge (should not shade the neighbour).

In housing interior and exterior spaces interrelate with each other and many processes continue through the exterior shell of the building. The facade zone should make possible the utilising of the climatic conditions of the different seasons in the ventilation and energy economy of the building and positive outdoor stay near the façade (Fig. 124). *Hortus Conclusus*, the secret garden, is a centuries-old example of a small positive territory made by man for himself. (Pietilä 1971: 556–558; Climatic 1996: 23–28)

Shading can be used either inside or outside the house. External shading can eliminate 90% of solar radiation and is much more effective than internal shading. Light coloured internal shading is more effective than darker. (Givoni 1998: 74)

The orientation and colour of walls affect the amount of solar gain of buildings. In most regions the objective is to maximise solar exposure in winter and minimise it in summer (Fig. 125). In hot climates the question is how to minimise overheating. The colours of façades and roofs either absorb or reflect the sun’s rays. In cold climates it is preferable to use darker colours which make the walls warmer, thus making the micro-climate around the house warmer, too. In warmer latitudes a light, reflecting envelope for a house is preferred. The absorptivity of white walls is only 0.15–0.2, while the absorptivity of dark colours can be 0.7–0.8, and for black walls, 0.9. Massive absorbing walls hold warmth long after sunset and make their surroundings warmer. (Givoni 1998: 75)
Fig. 124. Directing the wind above a building group by grading construction heights. (Halvorsen 1995: 61)

Fig. 125. A block designed and dimensioned on the terms of wind and sun. A proposal for the West Harbour of Helsinki. (drawing Eckhardt, Kuismanen)
6.4.2 Impact of climate on structures

The building materials industry has brought many new materials and detail solutions, which have not sufficient long-term durability in a harsh climate, and as a consequence of this structural damage results. Even many established solutions which are in accordance with a good mode of construction have failed in the long run or during exceptional years. (Berge 1990: 47–105)

Roofs and facades are the boundary surfaces between a building and climatic phenomena. The tasks of a roof are usually simple, to shelter and isolate the building beneath. In some cases roofs can function actively, for instance in connection with naturally ventilated atriums or radiant cooling. Facades of buildings regulate the processes between the outdoor climate and indoor climate, as shown in the Fig. 126. The tasks of a facade and its openings have become more versatile with the appearance of new building types and functions. The following list clarifies matters which should be solved in the design of facades (Aicher 1994: 100–103):

- insulation
- transfer of heat in, preventing overheat (passive solar heating, protection from unwanted solar radiation)
- to prevent heat radiation out
- letting natural light in, protection from unwanted light
- privacy protection, offering views out
- connection with the outer world, protection from outsiders
- ventilating, filtering of air
- wind and rain protection, climate shelter
- adjusting the air humidity, progress of vapour in structures
- acoustic insulation
- mechanical wear
- fire protection.
Fig. 126. The range of interactions between a building and its environment is large. (drawing Kuismannen 2008)

IL  Thermal air flow in the yard caused by shade and sun
KE  Summertime transfer of air from the shady side
KI  Skylight for ventilation in the summertime
KU  Air transferred from the sunny porch during the heating season
LE  Leaf trees protect from the sun in the summertime
LÄ  Heat-producing functions in the middle
PA  Balconies can be used to preheat transferred air
PU  Trees clean the air
SU  Unheated structures form a buffer zone
TU  Small-scale building style keeps the wind above the roofs
VE  Pool of water reflects light and acts as a snow collector during the wintertime

Simple wind testing equipment is suitable for testing structural details on scales of 1:50 - 1:1. Wind barrier lattices can also be developed with 1:100 scale models. For this purpose a cross-section of the structure is constructed between two sheets of glass (a so-called flatfish tunnel), where the flow of water can be observed from the side. If it is necessary to detect moisture, moisture sensors or strips of blotting paper can be installed in the model. For instance several different eave structures were tested in a wind tunnel in conjunction with the design of the experimental buildings in Kilpisjärvi. Wind testing of details proved to be relatively simple, and it revealed much new information, such as how snow penetrates structures. (Kääriäinen 1989: 12–17)

The climate change has serious consequences for an increasing share of the world’s buildings and population. There is therefore a need to develop building codes for reducing vulnerability in high-risk areas, and adapting to new statistics of extreme values. To address this issue, WMO is updating a Technical Note on
building climatology, and a project has been formulated on Integrating Hydrometeorological Risk Assessment in Planning and Building Design.(World 2007)

The effects of single climate factors are treated in the next Chapter, 6.5. The design solutions needed in different climates are dealt with in Chapter 6.8.

Summa summarum:

- large protective roof with eaves is recommended in rainy, snowy and hot regions
- building planning in zones; the functions of zones vary in different climates
- low-dense way of building protects against winds; avoid high structures
- buildings’ wind protection and/or cooling with wind taken care by balconies and double facades
- downward flows along facades prevented by balconies and overhangs
- pedestrian level of pilotis buildings should be protected against downward air flows with a canopy or a double deck
- corners can be protected against winds with lower building parts, vegetation or porous elements
- free energy and daylight can be obtained by facing buildings to the sun
- leaf trees on the sunny side, ever green trees in shade
- parking areas in the shade
- insulation is needed for air-conditioned buildings in warm areas and for all buildings in regions with cold seasons.

6.5 Climate factors in building

6.5.1 Wind

The climate change will cause more storms and higher wind speeds in many areas, and therefore more attention should be paid to the strength of roofs, facades and glazing.

The measured wind speeds during tropical storms in the US are considerably under ASCE 7–05 norm (2005) design winds of 130 mph (58 m/s), but in spite of that heavy damage has been reported. The gathered evidence suggests that the majority of the damage was likely caused by windborne debris. The windborne debris included pea gravel, cement plates, roof tiles, rooftop appurtenances, siding
and penthouse structures. Another cause of damage can be contributed to poor connections and lack of redundancy. (Kareem 2006: 8)

According to aerodynamic principles it is possible that the wind speeds in street canyons in reality are much higher than those measured. In that case it means that the normative design wind speeds are not sufficient. The abundance of damage caused by wind-borne debris suggests that new kind of solutions should be developed for flat roofs, sidings and connections. All material at the facades and rooftops should be anchored properly. Free standing panels at the top of a high-rise building are subject to applied load that is more than twice as much as the load to panels on facades. This is due to the strong negative pressure generated behind them. The roofs of existing high-rise buildings should be inspected carefully.

In outdoor areas traffic signals, antennas and billboard constructions often do not withstand the stormy wind speeds. Soffits and canopies are often damaged or blown off. Wind loads on soffits and canopies are not often included in wind-resistant design standards. (Nagao 2006: 12)

The starting point in a cold and windy climate is that the buildings are made wind-protective and well insulated. Structure damages to facades caused by stormy rain are prevented with the design of building parts, with proper materials and, if necessary, with wind-protective panels, a so-called raincoat. On very windy coasts the use of a double facade has proved to be the best method to protect the house against stormy rains. For example in Norway in traditional houses a stone wall is used which stands freely in front of the wooden facade or junipers that have been hung on a grating. (Bjørge & Børve 1992; Rapoport 1969: 98–101)

Usually low construction and abundant vegetation reduce the effect of winds, and high buildings strengthen it. At the corners of buildings the air flows are the most difficult to control (Fig. 130). Turbulence caused by large buildings can be reduced by stepping their height at the corners or by connecting lower maintenance buildings to the corners. The best protection at ground level is obtained by constructing the buildings as closed blocks. With L-shaped buildings it is easier to make a positive micro-climate than with those that have rectangular masses. Round and pyramidal masses cause less turbulence to their environment, but their protection effect is also small.

The windiness at ground level can be reduced by making the ground floor broader than other floors, in which case the highest winds wipe the roof of this wider part (Fig. 129). Properly placed wings, balconies and bay windows, lattices, fences etc. also promote the making of a good micro-climate (Figs 127–128). In order to redirect the air flows that come down the facades, the entrances should be
protected with long canopies, the depth of which is at least 15% of the building height. If the shed is not as long as the facade, air-flows which come obliquely from above or from the sides are stopped by the side parts of the shed. Overhangs which are merely over or at the sides of the entrances seldom help to totally prevent the windiness in the entrance of a big building, because they either strengthen the pressure differences on the facade or lead flows along the facades towards the entrance. (Glaumann & Westerberg 1988: 112–122; Broas 1992: 22–24, 28–29)

Fig. 127. A calm air pocket can be formed also on the windward side of a building. (drawing Kuismanen) Sun reflectors gather rays from the low-lying winter sun and reflect them indoors. They provide shade in the summer.

Fig. 128. Eaves protect the facade regardless of the type of roof. (drawing Kuismanen 2008) A fine net decreases the strength of airflow around the corner. A colonnade shields the sidewalk and entrances from downward airflows, rain and snow.
Fig. 129. Vertical cold structures shield the facade against the wind. (drawing Kuismanen 2008) Roof and roof terrace structures must be reinforced against storm winds. A lower corner structure protects against winds that go around the corner. A balcony shields the entrance from downward airflows. Gates and fences are part of the wind protection.

Windborne sand can be a health risk or inconvenience in some regions, and some industrial buildings cannot allow any particle to penetrate inside. Especially in desert areas or near beaches sand poses a severe problem. First the sand should be sampled in order to measure the typical size of the grains. Sand eolian transport occurs when a certain threshold of wind speed is reached. Some authors’ works define mean speeds ranging from 2.5 to 3.5 m/s. In order to prevent the building from direct penetration of sand (or snow), the architecture should contain specific designs (Niang 1996: 48-55; Moreau 2004: E.2.2):

- “porous” access stairs and slopes (metallic grill)
- in hot-dry climate walls made of “porous” bricks
- coffered windows
- leeward protecting walls and canopies (against wake)
- protective tubes or pressure-balancing canopies for loading platforms.

In cold areas windborne snow can cause almost similar problems.
6.5.2 Temperature

Extreme temperatures cause stress to structures and outdoor fittings. Diurnal temperature cycles often increase the effects of temperature variation by mechanical fatigue, and rapid changes of temperature accelerate the ageing of structures and equipment. Temperature may change the operation of machinery and equipment by changing the physical properties or dimensions of the materials. The most common effects are (Kuismanen 2000; Palier 2002: 126):

- ageing of materials, fatigue
– melting and other changes of state
– distortion, jamming due to differential thermal expansion
– deterioration of tightness
– increase of internal pressure
– modification of the viscosity of lubricants
– modification of the thermal capacity and conductivity
– initiation or acceleration of chemical reactions.

One of the basic laws of thermo-physics is that temperature differences tend to even out. To keep the interior spaces warm in cold climates, the basic demand for a building envelope is sufficient warm insulation. New standards, like Passiv House in Germany and Minergie in Switzerland, have been developed to increase the insulation and energy efficiency of buildings. (Minergie®, 2008; Information, 2008)

In warm circumstances correspondingly overheat should be kept out with sufficient insulation. Cooling of buildings can be arranged with active mechanical or natural means, or passive natural methods. The natural methods include comfort ventilation, nocturnal ventilative cooling, nocturnal radiant cooling, evaporative cooling of the ventilation air, wetted walls or windows, soil cooling and sometimes the storage coolness in massive structures. Prevention of overheat is possible by minimizing the solar heat load. (Maas 1992: 78–81; Daniels 1995: 170–173)

These strategies are discussed in detail in Chapters 5.7 and 5.8.

6.5.3 Solar radiation

All climates include phases in which overheating caused by solar radiation must be prevented in buildings. This happens passively by using various lattices, roofs and other protective structures that can be designed using scale models and a sundial.

The best results are achieved, when the protection against solar radiation is taken into account with the whole design of a house. There are different ways to do this (Izard 1993: 32–45):
– building body is stepped inwards (reverse pyramid)
– protecting outer roof (toit-parasol)
– vérandas, trellises, pilotis building, brise-soleils etc.
– closed facades with small windows
– isolated or ventilated walls, double walls
– light colours.
Shading the windows with internal white louvres reduce the solar gain about 60%, while external louvres give about 90% reduction. Solar heat gain can be reduced by balconies, recessed windows and *moucharabiehs* or *brise-soleils*, as well. For example, in Britain at the latitude of 56 °, a horizontal shelf-type screen of 70 cm width will be required to shade each 100 cm height of south-facing glass in summer. East and west facades need different devices, because the morning and evening sun is shining at low angles. (Izard 1993: 32–45)

Tinted glass is not a substitute for sun shading, because it reduces the solar gain by only 20%. Tinting also cuts out daylight, affecting the lighting quality of internal spaces and increasing the need for artificial lighting (Aicher 1994: 87). According to Yeang looking at the world through coloured glass has negative psychological effects (Yeang 1998: 219–232). New intelligent glazing, like photo-chromatic or holographic glasses or phase-change materials, are being studied, but they are not ready for wide use yet.

Conventional windows can provide good day lighting within about 5–7 metres. Horizontal shelf-type shading devices can be located partly inside to provide a light shelf to throw light deeper into the space. Also special optical films are available. With these methods a sufficient amount of daylight can be provided about at 9 m distance from the outer wall. With the use of glass covered atriums the depth of a building can be increased without losing day lighting. (Aicher 1994: 89)

At the same time careful detailing is needed to avoid glare and overheating (Fig. 132). Glare is a function of contrasts and brightness, when a bright light source is viewed from a surrounding area that is in relative darkness, or it can occur if a space is “over-lit”. The first kind of glare is the most common and it can be relieved by increasing the brightness of the surroundings or reducing contrasts. For instance light coloured walls distribute more even daylight to all parts of a room. For human eyes light that comes from different directions is better, which means that solutions with windows on two walls or light wells or interior courts should be favoured in architectural design; this is especially important in kindergartens and schools. (Aicher 1994; Yeang 1998: 219–232)
Fig. 132. Façade laths that can regulate solar radiation in different seasons. (Oswalt 1994: 110, drawing Helmut Köster)

To diminish the use of energy or achieve a zero energy house, the issue of energy generation has to be addressed. This means a change from fossil fuel to solar energy. For instance in Berlin the target is to incorporate solar water heating into 75 percent of new buildings annually, in Oxford solar hot water use or photovoltaic (PV) in 10 percent of homes, and in Mexico City solar heating systems are due to be installed in some 50,000 residences. In Rizhao, China 99 percent of households use solar water heaters and most traffic signals and street lights are powered by PV. (Sawin & Hughes 2007: 103)

### 6.5.4 Humidity

The humidity of an area is affected by the climate, vegetation, soil conditions and handling of surface water.

High humidity has effects on structures and the human body. Temperature and humidity variations may trigger condensation, and below 0° C it becomes frost. Low humidity can make some building materials, like wood, too dry and weaken them. It can cause irritation to respiratory passages and eyes. Fig. 22 shows some consequences of too high or too low relative indoor humidity. Recommended relative indoor air humidity lies between 40–60%, or according to other sources 30–70%.

Effects of high humidity to buildings include (Palier 2002: 126):
– decay and fungi growth in structures
– decrease in mechanical strength
– swelling or deterioration of materials
– seizure due corrosion
– galvanic corrosion of materials
– loss of elasticity
– condensation
– change of thermal characteristics of insulations
– acceleration of chemical and biological reactions.

There are only very limited possibilities to change humidity conditions caused by climate, but the other factors, like vegetation, soil conditions and handling of surface water can be changed to a certain degree. Too high humidity can be lowered with drainage, leading away surface water, area ventilation and eliminating shading elements which prevent solar radiation and evaporation. Too low humidity can be raised with vegetation, shading the solar radiation, water jets and by creating bodies of water or other evaporative elements. But the most important task of a building designer is to make such constructs and details that they resist the negative effects of too high or low humidity. Traditionally in snowy and rainy areas the roofs and sometimes the wind exposed walls have been made protective with multi-layered structures and long eaves.

Too high indoor humidity can be caused by climate, leaking building envelope, other building damage or internal sources, like bathrooms. Good detailing and sufficient ventilation are the remedy against interior humidity. Both with mechanical and natural ventilation the system should be designed in such a way that in all circumstances the minimum rate of air changes per hour is guaranteed. The use of hygroscopic materials on interior surfaces greatly evens out the extremes of indoor humidity, and therefore is highly recommended especially in sleeping rooms. Such materials include untreated wood, unburned clay products, wallpapers without plastics and the like. Diffusion-open wall structures can add much to the humidity balance of a building.

Too low indoor humidity is common in cold areas in winter and in dry-hot climates. Besides mechanical humidifiers, there are also natural methods to raise the indoor humidity, such as green plants, conservatories, evaporative elements and open ponds.
Summa summarum:

- use “raincoat” or double facades and large roofs in windy rainy situations
- in snowy and rainy areas use long eaves
- avoid damage by wind-born debris
- design also soffits, roof tiles etc. to stand heavier wind loads than common today; normative design wind speeds are not sufficient
- existing constructions in stormy climates or areas where wind speeds will increase with the climate change should be inspected
- overheating can be avoided by appropriate orientation, light external colours, shading or other type of solar control, vegetation, insulation and roof ponds
- humidity extremes outdoors can be evened out with planting and handling of surface water
- indoor humidity can be evened out with hygroscopic materials.

6.6 Climate and the use of energy

6.6.1 Effect of the climate on the use of energy

The effects of the climate on the use of energy are different in cold and warm regions, and that is why specific guidelines should be developed for all climatic zones (see also 6.8).

Building activities and the use of buildings consume globally about 50% of the material resources, 45% of energy, 40% of water, 60% of fertile land and 70% of wood used by mankind. The known oil fields will be emptied in 40 years and gas recourses in 60. This is why construction and use of buildings are central when saving natural resources and fighting climate change. (Edwards 2005: 11, 23)

Recent studies show that the best results in energy saving can be achieved through passive design solutions and recycling strategies. This means avoiding electro-mechanical devices and using the climatic conditions of the site locality as the starting point for architectural and house technical design. In practice this means the building’s particular morphological organisation according to the climate and the solar conditions. Warming and ventilation modes determine a building’s lifespan impact. (Jones 1998: 35–40; Yeang 1999: 202)

The placing, direction, shading and wind protection have a great effect on the energy use of individual buildings. The main contributors to energy consumption and pollution are heating and air-conditioning. The heat flow between a building
and its environment takes place as conduction, convection and radiation through windows and the envelope of the building. There are many processes between the interior and the exterior of a building, see Fig. 126. The standard heat loss calculations assume mechanical ventilation and constant indoor and outdoor average temperatures. In many cases solar heat gain and the impact of the thermal mass of a building are not included in the calculations. The supply of the solar radiation affects the amount of free energy received, even though this point had not been taken into consideration separately in design. When the window area in the main facade increases, the affect of its orientation on the heat consumption will also grow distinctly. With an about 25% window percentage, in which case the window field includes nearly the whole façade, the difference between the best and the worst direction is about 12 kWh/k-m, in other words less than 8%. (Kivistö 1982/1987)

According to Yeang the green skyscraper and intensive building type should seek to achieve energy use of about 100 kWh/m per year or less, compared with 230 kWh/m per year for fully air-conditioned – and in temperate zone heated – buildings and about 150–250 kWh/m for non-air-conditioned offices. (Yeang 1999: 266)

In North Europe the placing of a building, its direction and wind protection have a considerable effect on the consumption of energy. Wind and cold air lakes have the biggest effect on local temperature differences which can be over 10° C at times and on an average 1–2° C. The Meteorological Institute of Finland has estimated that cold air lakes will raise the degree day ratio of some buildings 90–225 Kd/a in a year. This means, depending on the house type and case, 1.6–7.9 kWh addition to the heat consumption per square metre in a year. It has been estimated that warm south slopes will reduce annual degree day ratio in some cases by 90 Kd/a compared to the normal. This corresponds depending on the building to a 1.6–3.2 kWh reduction per square metre in the annual heat consumption. (Kivistö 1987: 22; Pienilmaston 1997: 16)

The total effect of the micro-climate consists of the wind, sunniness and warmth of the building site. According to the ASTA II study the difference of the relative heat consumption between the maximum cases and the minimum cases in Finland is 40 kWh/k-m (28%) in detached houses, more than 37 kWh/k-m (27%) in multi-storey buildings, and for tower blocks 35 kWh/k-m (28%) in a year. However, it can be estimated that in real situations the maximum addition from the minimum to the maximum will be about 20%. (Kivistö 1987: 36)
According to the ASTA II study it should be possible to lower the average heat consumption in residential areas 2.5–5% with planning which takes the micro-climate into consideration. On the basis of the study it can be estimated that in Finland within one area micro-climate can cause at most an about 20% difference in the heat consumption of individual buildings. (Kivistö 1987) According to Glaumann and Westerberg, about 10% of the heating need of buildings can be reduced when the wind conditions are taken into consideration in the design of structures and building form (Glaumann & Westerberg 1988: 8, 40–42).

In addition to micro-climate another phenomenon which affects the energy consumption is the forming of the heat islands, especially in big cities. It has been stated that the annual mean temperature of big cities is usually about 1–2°C warmer than the temperature of surrounding areas. In the degree day ratio of the whole heating season this means differences of 300–600°Cd/a. This means a difference of 5–15 kWh/k-m in the annual heat consumption of similar buildings. According to this the heating expenses in the centre of a big city can be 5–10% smaller than in its surrounding areas. (Mattsson 1979: 113–117; Kivistö 1982/1987: 123–124)

6.6.2 Solar energy

Most important decisions concerning the potential of solar energy use are made at the planning stage. Latitude of the site, and placing and heights of buildings determine the solar exposure of facades. In the northern hemisphere south slopes offer the best conditions for solar energy production, but in the subtropics this has no role. Solar gain of buildings can be improved with the altering of building heights. (Erat 1995: 55–63)

The orientation and detailing of walls has a considerable effect on the use of energy of walls (Fig. 133). Walls orientated towards the sun and fitted with transparent insulation material (e.g. Trombey walls) can even have a positive warm balance in relatively cold circumstances.

Placement of solar collectors greatly affects their energy gain. In the north the direction towards south and mounting at an angle between 60–80° is important. Near the equator most part of the solar radiation is directed towards east and west walls and roofs.

To passively gain the maximum amount of solar energy in the latitudes of Central Europe, the following amounts of glass on a building’s façade are recommended (Gauzin-Müller 2001, 93):
- south 40–60%
- east and west less than 20%
- north 10–15%.

Massive constructions inside buildings can be used to store the solar heat. The thermal capacity of materials varies greatly, as presented in Table 22. For instance 1 m of concrete can store 15.9 kWh when its temperature rises 30°C. (Erat 1995: 89)

**Table 22. Thermal capacity of some building materials.**

<table>
<thead>
<tr>
<th>Material</th>
<th>KG/M Specific heat</th>
<th>kWh/M 30°C</th>
<th>kWh/M Capacity</th>
<th>Relative storing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1000</td>
<td>1.16</td>
<td>34.8</td>
<td>1</td>
</tr>
<tr>
<td>Concrete (dry)</td>
<td>2200</td>
<td>0.53</td>
<td>15.9</td>
<td>0.46</td>
</tr>
<tr>
<td>Light concrete</td>
<td>600</td>
<td>0.15</td>
<td>4.5</td>
<td>0.13</td>
</tr>
<tr>
<td>Brick (full)</td>
<td>1800</td>
<td>0.46</td>
<td>13.8</td>
<td>0.40</td>
</tr>
<tr>
<td>Clay (17% humidity)</td>
<td>1500</td>
<td>0.63</td>
<td>18.9</td>
<td>0.54</td>
</tr>
<tr>
<td>Glauber salt (Na2SO4)</td>
<td>1500</td>
<td>0.75</td>
<td>22.5</td>
<td>0.65</td>
</tr>
<tr>
<td>Wood</td>
<td>600</td>
<td>0.45</td>
<td>13.5</td>
<td>0.37</td>
</tr>
<tr>
<td>Air (0 ° C)</td>
<td>1.25</td>
<td>0.000347</td>
<td>0.01041</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

![Fig. 133. The energy use of differently oriented normal walls, traditionelle Wand, and warm collecting walls, Kollektor Wand. (Grimme 1984: 15)](image-url)
Summa summarum:

- the frequency of high-speed winds (over 6 m/s) and a high average wind speed (over 4 m/s) have a significant impact on the heat consumption of buildings
- the impact of a micro-climate on the heat consumption of an airtight, well-insulated building is smaller
- in calm conditions, relatively little attention needs to be placed on wind when designing the energy economy of a residential area
- the impact of wind is great on the coast, in wide open spaces and on high hills, and in planning such areas there is reason to conduct windiness analyses and wind tunnel tests with scale models, especially if the area includes high building masses
- windiness can be utilised in natural ventilation and energy production.

6.7 Ventilation

6.7.1 Wind and ventilation

Building ventilation has four functions:

1. To maintain indoor air quality: air change.
2. To provide thermal comfort: air movement.
3. To cool the mass of the building during the night.
4. To warm the mass of the building during the day.

Winds cause pressure differences on different sides of a building which usually tend to add ventilation and correspondingly heat consumption. According to the ASTA II study, balanced (mechanical in- and out-blowing) and stack (natural) ventilation are considerably more sensitive to the winds than one with only mechanical output. On the other hand, wind can be utilised in the operation of stack ventilation. (Kivistö 1982/1987: 127–130; Climatic 1996: 88)

According to the results of ASTA II, wind begins to affect ventilation at more than a 3–5 m/s speed. Small houses are more sensitive to the winds than multi-storey buildings, because considerably smaller pressures in their blowers are used (Figs 134–135). However, the winds do not have significance on the ventilation of houses in practice, if the average wind speed around the building is less than 2 m/s in the heating season. (Kivistö 1982/1987)
Fig. 134. The average ventilation amounts of some building types depending on the average wind speed of the heating season. (Kivistö 1987: 24, redrawn)

Fig. 135. Amount of ventilation as the function of the annual mean wind-speed. 1 detached house, natural ventilation, 2 detached house, mechanical ventilation (0.3 l/h), 3 detached house (0.5 l/h), 4 multi-story building (0.65 l/h), 5 high-rise building, 6 service apartments. (Kivistö 1987: 24, redrawn)

In detached houses which have been equipped with stack ventilation, the difference between the maximum and the minimum will be about 30 kWh/k-m in a
year, in other words the wind causes an about 22% addition to the average heat consumption in the maximum case compared to the minimum (Fig. 136). With mechanical output ventilation a 0.5 times in an hour wind increases the heat consumption of the same small house by as much as about 15%. For the heat consumption of a multi-storey building and a tower block the effect of winds is a maximum of 12 kWh/k-m only. So the relative addition to the heat consumption of multi-storey buildings caused by the wind is at the maximum less than 10%. (Kivistö Raportti 2. 1987: 26–28, 36–37)

The effect of winds on the heat consumption of buildings in Finland is on average only 0.7 kWh/k-m (0.5%) in a year. The building-specific differences in the effects of winds are considerably bigger than the average effect, over 10 kWh/k-m, in other words about 7% in a year. If in ASTA II calculations a more high-quality balanced air conditioning had been used, the effects of winds would have become bigger in that case (Fig. 136). The Oulu district heating company has registered that the wind will raise the maximum heating power consumption during cold days by a few megawatts. According to Daniels, the growth of the average speed of the wind by 1 m/s increases the consumption of heat 4–9% depending on the place and the form of the building. (Kivistö Raportti 2. 1987: 36–37; Daniels 1995: 165)
Placing of ventilation outlets is an important detail when considering the spreading of pollutants in a built environment (Fig. 137). For open fetch situations the stack should be situated near the centre of the roof. In this way, the leading edge recirculation zone is avoided, and the required plume height is minimized. When there is a taller building upwind of the emitting building, concentrations over most of the roof can be reduced by placing the stack near the leading edge. However, this stack location will result in higher concentrations on the leeward wall of the adjacent building. For open fetch situations, increasing the stack height from one to three metres reduces concentrations near the stack by approximately a factor or two. Far from the stack the effect is negligible, and a stack height of at least five metres is needed. For an emitting low building in the wake of a taller building and wind coming from the direction of the taller building, the intakes on the emitting building should be placed on its leeward wall. Intakes should not be placed on the leeward wall of the upwind building. (Stathopulos 2005: 8–10)

Fig. 137. To avoid pollution concentrations the location and height of the stack must be planned correctly. (Stathopulos 2005: 9)

Summa summarum:

- amounts of high wind speeds (more than 6 m/s) and high mean wind speeds (more than 4 m/s) affect the heat consumption of buildings
- on the heat consumption of a tight and well isolated house the effect of microclimate is smaller
- from the point of view of energy economy, in sheltered calm conditions the wind circumstances in the designing of residential areas can usually be given fairly little attention
- in windy places, such as coasts, wide plateaus and high hills the effect of the wind is considerable, and in connection with the planning of the area wind
analyses and model wind tests must be made, especially if the area is comprised of high building masses
- wind can be utilised in stack ventilation and the production of energy.

6.7.2 Natural ventilation

Air movement caused by temperature differences is utilised in the gravitational, in other words natural or stack ventilation of buildings. In the lower part of a room the air is cooler than at the ceiling level, which makes the warm air in the upper part of the room flow out through ventilation shafts or high windows, and the room is ventilated (Figs 139–141). However, temperature differences which are big enough to change the air do not always occur in summer conditions. In this case natural ventilation must be intensified by ventilation through windows, solar ventilation flues, solar facades (Fig. 138), with under-pressure ventilators or pressure differences caused by the wind on different sides of the building.

Stack ventilation can be achieved in many different ways:
- cross ventilation at the same level
- chimney effect
- solar ventilation-chimney or attic
- under pressure ventilator on the roof
- wind tower
- airflow caused by evaporative cooling (patio or wet chimney).

Understanding the local wind patterns during the seasons and different hours of the day is a *conditio sine qua non* for the design of natural ventilation. Data about the diurnal temperature differences during the seasons is needed, too. For large buildings and skyscrapers the use of wind tunnel testing is recommended. Testing can be used in natural ventilation system design, façade design, structural calculations, to demonstrate how smoke will behave in fire situations, and shape the micro-climate around the building. In ventilation design it is possible to determine the ventilating inlets and outlets, design wing-walls, test the functioning of double façades and design different ventilating devices.
Fig. 138. Solar facade as a part of air conditioning system. (drawing Future Systems, cit. Oswalt p. 138)

Fig. 139. Big building complex in which the ventilation of atriums is natural, Hotel du Department Marseille. (drawing Alsop & Lyall, cit. Oswalt 1994: 48)
Fig. 140. Natural ventilation in a detached house in winter. Temperate climate. (Kuismanen 2007) Pre-heated fresh intake air. Leaf tree lets solar radiation through in winter. Open fire functions also as ventilation. Air is rising in high space. Chimney warms exhaust ducts. Intake air through windows or vents. Wind enhanced ventilation ducts. Small windows on the north side.

Fig. 141. Natural ventilation in a detached house in summer. Temperate climate. (Kuismanen 2007)
Natural ventilation has become again interesting also in industrialized countries, because properly designed solutions can save both capital costs and energy. The energy consumption of buildings with natural ventilation is typically only half compared with air-conditioned ones, as shown in Table 23 and Fig. 142. Also maintenance and renovation needs are reduced, and there are fewer incidents of sick building syndrome. For this reason many research centres, like the Tokyo Polytechnic University, are developing guidelines for natural ventilation design methods. (Evans 1972: 1–4; Kossak 1994: 45–49; Climatic 1996: 63–66; Wind 2008: 5–6)

Experiment houses in Finland show that the energy consumption of naturally ventilated houses is about the same as equivalent low-energy houses fitted with mechanical ventilation and heat recovery (Jääskeläinen 2008: 48; measurements of Kuismenan 2003–2008).

Properly designed natural ventilation and mixed-mode conditioning can provide 50–80 percent HVAC energy savings, 0.3–3.6 percent health cost savings, and 0.2–18 percent productivity improvements. (Jones 1998: 35–40; Kellert et al. 2008: 125)

Table 23. Comparison of energy use between an air-conditioned office and a naturally ventilated office.

<table>
<thead>
<tr>
<th></th>
<th>Typical air-cond. office (kWh/sq.m.)</th>
<th>Good practice open-pland office with nat. vent. (kWh/sq.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating and hot water</td>
<td>222</td>
<td>95</td>
</tr>
<tr>
<td>Lighting</td>
<td>67</td>
<td>32</td>
</tr>
<tr>
<td>Fans and pumps</td>
<td>61</td>
<td>5</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Catering</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>390</td>
<td>136</td>
</tr>
</tbody>
</table>

(Yeang 1999: 256)
Wind mixes ventilation, but on the other hand natural ventilation can be improved by using micro-climate analysis and scale models. This happens by increasing the pressure of incoming air and negative pressure at the exhaust air terminal (Fig. 144). Natural ventilation is cheaper and lasts longer than mechanical ventilation. The importance of developing natural ventilation and ventilation that uses solar energy is highlighted in developing countries, which are dependent on imported energy. Ventilation usually consumes 70% of the energy a building needs. If
mechanical ventilation is used, buildings have to be insulated and extra warmth needs to be repelled. This happens by means of room layout and shading, which requires an analysis of how much the sun shines and from which direction. (Coulibaly 1992: 38–41; Matilainen 1997)

The depth of mass of a building that has been ventilated naturally must be small enough, and the rooms directed to outdoor air or to an inner court which brings replacement air. Rooms ventilated from one side only should not be deeper than 2.5 times their height, but cross ventilation makes a five-fold depth possible. In a warm climate high indoor spaces in which over-heat can rise are recommended, whereas in a cold climate unnecessary air cubic metres increase heating expenses. To make sure the functioning of ventilation and in fire situations the right dispersal of smoke it is recommended that the ventilation of deep bodied and high buildings is studied in a wind tunnel or in a climate laboratory with smoke tests. Alternatively CFD-modelling can be used to design natural ventilation, use of thermal mass and evaporative cooling. (Daniels 1994: 164; Kossak 1994: 45–49; Narayan 2005: 3–7; Natural 2008)

Natural ventilation functions well when there are ventilation openings which have different levels of air pressure. This happens when the temperature of the outdoor air is lower than the indoor air, or when windflow against the building causes such a difference. In hot dry climates the stack effect does not function during daytime, but natural nocturnal stack ventilation can be used. The capacity of the building’s materials to store heat/cold during diurnal temperature cycles in non-air conditioned buildings is important in areas with large diurnal temperature swings. In hot-humid regions natural ventilation caused by wind is desirable because it minimizes the discomfort resulting from a wet skin.

Pressure and temperature differentials between inside and outside are used to power natural and stack ventilating systems. The air near floors is cooler than the topmost layer near the ceiling, and the warm air flows out through ventilation ducts or windows. The flow rate is quite small in summer, and summer ventilation by wind force or solar vents is needed. The effective vertical distance between inlets and outlets should be 5–7 metres, which can be difficult to obtain in low buildings. In winter and during strong winds there is the danger of over-ventilation. In large buildings hybrid ventilation systems are often the most effective.

On the skyscraper’s façade wind performance grows exponentially as it moves upwards. Therefore a series of modified natural venting devices are needed for different height zones of the building’s walls. Often in polluted city centres hybrid
systems give the best results in tall buildings: natural ventilation for entrance halls, lift-lobbies, staircases and toilets, and mechanical devices for offices (Fig. 138). For residential towers in warm climate natural ventilation is frequently used. In temperate climate each season should be treated separately, and the mechanical devices are used only during the coldest and warmest periods. (Evans 1972: 1–4; Kossak 1994: 45–49; Climatic 1996: 63–66; Matilainen 1997; Yeang 1999: 245–256)

Fig. 144. Wind enhanced ventilation in the Strasbourg airport. A “wing” above the ventilation outlets uses the venturi effect to cause negative pressure, which moves the air. (Gauzin-Müller 2001: 97)
Cross-ventilation is a phenomenon of a very complicated turbulence flow because of the interaction of internal flow with the envelope flow. The pressures near the opening exhibit reversible and irreversible changes of energy between dynamic pressure and static pressure associated with extreme deformation of airflows. Placement and size of openings affects greatly the air flow pattern inside the buildings (Figs 144–145). Even with winds oblique to a wall up to about 60 degrees it is possible to use windows as inlets for the wind. Cross-ventilation can be made better by adding to a single vertical projection – a wing-wall – to each opening to increase the air pressure (Fig. 147). Enclosed central courtyards or atriums can be used to bring fresh air into the building and for pre-heating of the air. One residential unit should have openings both on the windward and leeward sides. (Kossak 1994: 45–49; Daniels 1995: 164; Wind 2008: 5–6)
Current standards for building ventilation systems recommend that rooftop stacks from industrial, laboratory or hospital buildings be designed such that their emissions do not contaminate fresh air intakes of the emitting building or nearby buildings. This might require extending the height of the stack or increasing its exit velocity. However, field studies have shown that even with high exit velocities and moderately high stacks, pollutant concentrations may be unacceptably high at particular locations. Several factors such as the location of the stack relative to regions of flow separation and flow reattachment, the presence of rooftop structures, like penthouses, and high upstream turbulence, may account for the occasional poor performance of rooftop stacks. Usually it is better to place the stack near the centre of the roof; see also Fig. 137 and the accompanied text. (Stathopoulos 2005: 9–10)

It is important not only to evaluate the wind-driven ventilation environment quantitatively but also evaluate the thermal comfort of the occupants from the qualitative aspect of the airflow and from the thermal viewpoint. The cross-ventilation airflow through the upwind opening turns steeply downward near the opening inside a room thus affecting people inside. In a cold climate people can experience this as unpleasant. In humid areas with high summer temperatures, effective cross-ventilation can greatly improve the thermal comfort of occupants; see also Chapter 6.85. Studies in Belem show that with wind-assisted ventilation it is possible to create indoor circumstances which are inside the comfort zone. In a dry hot climate, like Luxor Egypt, the indoor temperatures can be 4–5° C lower, when using nocturnal ventilation. (Chatelet 1998: 138–150; Ohba 2006: 12)

6.7.3 Cooling

In most countries over-heat is a big problem for buildings, at least during summer. Very often passive low-energy cooling systems can provide sufficient indoor comfort even in hot climates. These cooling options include (Izard 1993: 54–74; Givoni 1998: 185):

- Daytime ventilation.
- Heavy mass, with or without nocturnal ventilation.
- Direct evaporative cooling.
- Indirect evaporative cooling by roof ponds.
- Radiant cooling.
- Soil cooling.
- Cold water cooling.
Cooling and ventilation are often linked together, and have a direct effect on human comfort. In cold climates ventilation brings fresh air in when the indoor temperature is too high. In warm climates it provides higher airspeeds thus extending the upper limits of acceptable temperature and humidity.

Nocturnal ventilation can be used in such climates where night temperatures are lower than about 25° C. A building with high mass is ventilated during evening and night hours thus cooling the mass which absorbs the overheat during day time. In areas with cold nights warm air is ventilated in during the day and stored in the structure of the house or in special storage enclosures. During the following night hours the mass will keep the indoor temperature above the outdoor level. Indoor air temperatures can be lowered with night ventilation about 4–8° C also during warm days. (Izard 1993, 63, 79; Givoni 1998: 191, 198)

In direct evaporative cooling the temperature of the outdoor air is lowered before it is led indoors. This can be done either by mechanical systems – like swamp coolers or desert coolers – or by passive means, such as cooling towers. In cooling tower fine drops of water are sprayed downward like a shower. The falling water creates airflow down. The evaporation from the fine drops cools the water, as well as the air. This kind of cooling functions best with warm or hot dry climate, in tests in Saudi Arabia the outdoor maxima was +44° C and the indoor maxima about +28° C. In a World Fair pavilion in Sevilla the use of an evaporative cooling tower lowered the indoor temperatures about 10° C. Passive indirect cooling can be realised by providing a shaded water pond over an uninsulated roof.

All spaces with glassed roofs or even other uninsulated material, such as concrete, lose heat by the emission of long-wave radiation toward the sky. During the daytime the absorbed solar radiation counteracts the cooling, and operable insulation is needed against overheating. Studies in Japan show that roof windows are very effective and secure way of nocturnal ventilation especially in dense city blocks. (Izard 1993: 63, 79; Givoni 1998: 191, 198; Wind 2008: 5–6)
A simulation made in south France showed that with passive means it is possible to lower the indoor temperatures of an office building during warm days 5–8°C, thus making the use of mechanical cooling devices unnecessary. The cooling concept consisted of night ventilation, reorientation of the building and windows, protection of the windows and shading façade elements. (Chatelet 1998: 151–157) With the use of evaporative cooling and thermal mass, the indoor air is 8–14°C cooler than outside temperatures in the Jaipur house, Fig. 146 (Narayan 2005: 3–5).

The temperature of the soil is almost constant all the year round, and the simplest soil cooling system is the traditional cellar. A 100 m long pipe underground can cool the air about 7°C in summer, and warm it in winter, respectively. Cold ground water can be used for cooling by using cold radiators on the ceilings or letting a thin water layer flow down on certain surfaces outside or inside the building. The later system will increase the humidity of the indoor air, too. Indirect evaporative cooling of the roof can happen with roof ponds. Cooling of outdoor spaces, which are adjacent to a building, can be a part of the concept. (Chatelet 1998: 106; Yeang 1999: 258; Gauzin-Müller 2001: 94) Careful placement of trees can reduce the energy required for cooling by 7–40 percent (Sawin & Hughes 2007: 95).
Fig. 147. The effect of different kinds of openings for wind force ventilation. (Climate: 62)
Fig. 148. Airspeeds in different configurations, with and without projections, at different wind directions. (Givoni 1998: 102)

**Summa summarum:**

- Bioclimatic design techniques involve both architecture and technical planning as a functioning entity; target is to minimize the demand for energy used to arming and cooling.
- Natural ventilation can be obtained either with temperature difference or pressure difference.
- Stack ventilation can be enhanced with high ventilation chimneys and solar warming.
- Ventilation with wind can be enhanced with the creation of high and low pressures around the building (wind walls etc.).
- When there is a dominant wind direction, use wind towers or venturi outlets.
- Cooling can be obtained with movement of air, evaporation or transporting from cold water or earth.
- Preventing overheat is an essential part of cooling concepts.
6.8 Guidelines for different climates

6.8.1 Architecture and world climate zones

Climate zones

There are many different climatic situations, but for building rules the world can be divided into a few global zones. Global material marketing tries to sell similar solutions to all areas despite the differences of climate and other circumstances. Architects and engineers are more and more working with international projects, which are situated in different climatic zones. Understanding the climate of the project area is essential, but today it is not always the case. Basic climate data can be taken from different publications, homepages or the publications of international organisations. It is also recommended to make oneself acquainted with the local building tradition, because vernacular architecture is almost always well adapted to the climate.

Concepts of climate zones are intellectual constructs to help us understand the nature and distribution of phenomena. The landscape, way of living and other qualities also contribute to the overall perception of a region. The term sunbelt, for example, summarizes the chief attraction of a perceived region in the southern USA, for persons retiring to a more comfortable climate. As seen in Chapter 2.5, there are many climate zone systems, but for instance the Köppen classification is too detailed to the purposes of the CASE method. The concepts of Givoni, Serra, and Liébard and de Herde on the other hand are quite practical. (Liébard 1996: 10; Givoni 1998: 331; Serra 1999: 15–20)

The author in the study “The Seven Belts of Architecture” has used seven global zones, which are defined by the climate, architecture, culture and “atmosphere” (Kuismanen 1989):

1. Arctic
2. Four Seasons
3. Meadow
4. Mediterranean
5. Desert
6. Tropical
7. Arid.
From the building and planning points of view important aspects, which come from climatic circumstances, are the need for cooling and/or warming, dryness or humidity and the wind patterns. Some of the zones, which Jones and others are using, are so near each other in terms of climate that they can be put together. Such are Ice Caps + Tundra, Subtropical + Tropical and to some degree also Uplands + Continental. In the authors list Four Seasons + Meadow and Desert + Arid have quite much in common, and can be joined, if we talk only about climate. After these modifications most of the lists above have about four similar zones, which are summarized below.

From the building design and planning points of view following classification is valid and practical, and is used in this study as the basis for the building and urban development guidelines of the following chapters:

1. Cold.
   - arctic
   - cold
2. Temperate.
   - northern latitudes
   - Mediterranean
   - cold winters, hot humid summers
3. Warm arid.
4. Warm humid.

It must be remembered that even inside a climate zone there is a great variety. For instance winter can mean different experiences to cope with: wind chill in Winnipeg, snowfall in Sapporo, ice fog in Fairbank, glaze in St John’s, cloud in Copenhagen, darkness in Tromsø and cold in Irkutsk. (Mänty 1988)

**Architecture and climate**

Building means the making of indoor shelter for man, but the creation of comfortable conditions must also include the space around the building. This is particularly important in countries where people are used to spend a great deal of their time out of doors. It has been said that the inhabitants of cold climates live in their houses while those of warm climates live around their houses. In particular poor people who can afford only one or two rooms tend to treat the adjoining ground as an extension of their homes. The outdoor activities are preparation of
food, baking, washing, drying of laundry, all kind of repairing, eating, sewing, gardening, supervising children, playing, sleeping and social life. It is especially hard to find good solutions for outdoor living in high urban densities. The streets are not reserved for traffic, but they are multiple-use spaces, and the patterns of street life changes according to the time of the day.

Before starting architectural sketching it is often useful to make an “activity chart” (Fig. 149), which relates the use of a space to the climatic conditions at the time of use. It helps to determine the general pattern of the plan and the relative position of rooms and open spaces. It helps to determine specifications for the performance of walls, openings, floors and ceilings. (Climate: 50–60)

![Fig. 149. Activity chart for Khartoum, Sudan, hot season. (Climate: 55)](image)

The passive methods used in the building design recommendations of the following chapters include the building’s orientation, built-form configuration, site lay-out, façade and solar technical design and ventilation and heating systems, Figs 150, 151 and 152.
Planning and architecture solutions which make the micro-climate better even have an impact on the attractiveness of the city, and thus an effect on the tax-base of the city. So climatic-conscious design has a significant economic value, too.

Fig. 150. Variation of the building according to climate, I Haifa, II Tel-Aviv, III Berlin, IV Oslo, A. Klein 1942. (cit. Oswalt 1994: 55, drawing Klein)

Fig. 151. The best orientation of main facades and the distribution of primary mass to achieve maximum solar shading or solar gain respectively. (Yeang 1999: 205)
Fig. 152. The optimal placement of building’s vertical service cores. (Yeang 1999: 206)

As a conclusion the following Table 24 presents the relationship of the most important climate and nature factors to the built environment.

Table 24. Relationship of climate and nature factors to the built environment.

<table>
<thead>
<tr>
<th>Built environment</th>
<th>Sun</th>
<th>Wind</th>
<th>Water</th>
<th>Vegetation</th>
<th>Geomorphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street net</td>
<td>orientation width</td>
<td>orientation forms</td>
<td>humidity fog, frost adaptation</td>
<td>location density</td>
<td>heights sheerness</td>
</tr>
<tr>
<td>Nature areas</td>
<td>orientation exposure</td>
<td>orientation terrain forms</td>
<td>humidity watercourses biodiversity</td>
<td>type, quality density</td>
<td>soil quality landscape type</td>
</tr>
<tr>
<td>Quarter</td>
<td>orientation solar angles density</td>
<td>orientation bld. volumes density</td>
<td>water tables protection-needs</td>
<td>existing flora adaptation</td>
<td>contours</td>
</tr>
<tr>
<td>Site</td>
<td>solar access density</td>
<td>exposure bld. heights occupation</td>
<td>ground water absorbing</td>
<td>existing flora adaptation</td>
<td>contours</td>
</tr>
<tr>
<td>Building</td>
<td>sun hours solar heating protection</td>
<td>exposure protection ventilation wind channels</td>
<td>re-use</td>
<td>green facades</td>
<td>-</td>
</tr>
</tbody>
</table>

6.8.2 Cold and arctic climate

A common definition for cold regions is that the average temperature during the winter months is below freezing, 0°C (32°F). In arctic areas temperatures are low the whole year, and permafrost is common, which means that only the topmost layer of the ground will be defrosted during summer. In some areas snow will not melt during summers, but instead it is collected into deeper layers, which will
become ice or glaciers because of the pressure. Wind conditions vary strongly and especially in continental regions there are also windless periods. (Rogers 1980: 15–18)

Some cold regions enjoy warm summers, and in such cases some solutions discussed in later chapters are also valid.

Wind together with low temperatures causes the so-called wind-chill. The main climatic design needs are to minimize heating energy consumption and to give shelter against cold winds without blocking the sun. On the North American continent the winter winds are mainly from the north and the sun radiation from the south, and in South America vice versa, which make architectural design relatively easy. In Europe and North Japan there are often south and west winds, which make the wind protection without blocking the sun more difficult.

In the traditional construction the emphasis has been on protecting from the winds and on the storing of heat. The envelope of buildings has been minimized, for example, by a mass which has the form of a hemisphere, as in the igloo. The openings are small and the access of cold air has been prevented. On the other hand, the front of a building can be designed to stay snowless by blowing wind. More even conditions have also been sought by digging into the ground or snow. (Serra 1999: 8)

Through many of the countries in the cold regions have relatively high national income, millions of northern inhabitants cannot afford or will not have the technical “winter cities” facilities, like glass covered shopping-malls, mechanical ventilation etc. Also from the health and ecological points of view settlements with possibilities for outdoor life and limited need of transportation are to be preferred. High urban density with land-use mixing reduces vehicular traffic, and with climatic conscious planning, makes the micro-climate better.

Town and detail plans should reduce winds in built areas. Winding or angled street patterns lower the air movement in the street, especially when the street is parallel to the prevailing wind direction. Bridge constructions built over streets reduce the overall wind speed in the street, but they can increase the air movement directly under them.

To prevent psychological stress and symptom complexes like SAD, planners and designers should ensure adequate provision of outdoor recreational facilities and natural lighting in indoor working and living spaces. (Givoni 1998: 256; Pressman 1995: 57)

Buildings with different heights generate high speed air movement downwards, and at ground level the wind speed can be higher than the ambient
wind speed. Therefore the buildings should be about the same height and there should not be too wide open places between them. Often used configurations of building blocks have a U- or V-shape, and according to the authors measurements in Oulu and Tervola closed blocks around courtyards are functioning well from the climatic point of view, too. (Børve 1987; Kuismanen 2000; Pressman 1995: 168–169)

Wind shelter can be made with small buildings, protecting walls or plants. Evergreens with species of three different height categories are the most effective.

For energy saving the insulation of the buildings should be better than what is conventional, and more attention should be paid to the energy and ventilation concept as a whole. A building’s thermal performance can be further developed with buffer zones, special windows, windbreakers and passive solar heating. To ensure long lasting structures the vapour pressure gradient on the envelope must be taken into account with the use of vapour barriers or breathing walls and ceilings to prevent condensation.

In cold regions the sun is always relatively low, and therefore only equatorial-facing walls and windows can be used for solar energy collection. To guarantee enough sun hours for dwellings the distance needed between the houses grows the further north we go. In the northernmost latitudes in summer the sun is shining from all directions and that is why north oriented windows have psychological value for the inhabitants, through they do not count as solar collectors. The use of moderate or dark colours that absorb the solar radiation is recommended. (Givoni 1998: 417; Sterten 2001: 23–3; Solklart)

For the Fuglenesdalen project in Hammerfest Norway’s housing bank Husbank granted an additional loan for carrying out design solutions for harsh climates. The loan terms of detached houses give a good picture of the demands of building in the north (Husbanken 1987):

- snow must not accumulate in front of the entrance of the house
- there must be a security entrance
- the rear of the house should be aerodynamically shaped against the wind
- rooms that can have a lower temperature should be situated on the windy side
- living room is open to the sun
- with the house a connected wind-protected sunny terrace, which is located high enough considering snow
- building materials and structures that withstand a harsh climate.
In extremely difficult snow conditions, as in North-Norway, the starting point for planning on a windy plateau is often the directing of drifting. In the plans there are exact instructions for the placing of buildings and about the forms which are based on the climate analyses. The areas are surrounded with snow fences to reduce drifting of loose snow, and snow fences are also placed between building sites. (Husbanken 1987; Husbanken 1994)

On the windward side nearly snow-free channels will formed by the side of the walls (in the Inuit language *anjmanja*), but on the lee side snow will be packed in drifts. On a sharp ridge roof or dome snow drifts on the leeside of the roof. On a long slope of roof on the leeside less snow will be accumulated than on a short one. Heaviest loads will be on sections of level differences on a roof. In most areas regional norms and regulations exist about the snow loads of roofs and their dimensioning, but these are not enough in all cases. (Havas 1987: 18–20; Glaumann & Westerberg 1988: 138–141)

Arctic climate

In an arctic climate the prevention of the effects of wind and snow is a starting point in building design. Due to the constant accumulation of snow in the arctic areas there is only a temporary advantage of snow-protection fences, and the design of buildings is the most important thing in the mitigation of problems caused by snow.

Snow will accumulate most if the building is located with the cross direction against the dominating wind direction (Fig. 153). A longitudinally placed building will not hold snow, if the angle in respect to the dominating wind direction is less than 30 degrees. When meeting an obstacle, snow will accumulate, when the flow rate slows down by 30–50%. On the windward side of the building a whirl is created, which causes the accumulating of snow and a snow-bank is created close to the wall of the building to the distance, whose measure is 1.3 or about 1.5 times the wall height of the building. When wind meets the building, the air current will rise upwards in the place where the distance from the wall is about 2–3 times the height of the building. When the height of the dune on the windward side is about half of the height of the wall, the effect which raises the current of the building will decrease and a dune can gradually cover the whole building. (Børve 1987: 48–49; Glaumann & Westerberg 1988: 138–141)

The interaction of a building group for the accumulation of snow can be avoided if the minimum distance between buildings is designed to be 14 m. The
space between buildings should be at least 10–20 m in an area of single-storey buildings and 33–47 m in an area of two-storey buildings. When a house has been built to act as a wind protecting wall which is located crosswise in the dominating wind direction, the following buildings must be placed as separate buildings in rows according to the wind direction (a comb placing). It is recommended that quadrangular buildings are placed at an angle of 45 degrees in the dominating wind direction. The configuration of free standing buildings would have to be near a square.

Fig. 153. Examples of the accumulation of snow around buildings in arctic areas. (Mitsuhashi, cit. Børve 987: 45)

The entrances must be protected from drifting. If under a building, which has been built on pillars, there is more than a 1.5 metres high space, it will minimise the accumulating of snow. Gravelled terrain under the building should be built at an inclination 1:6, if the space between the lower surface of the building and the earth's surface is less than 1.5 m, and 1:4 when the space is more than 1.5 m. (Børve 1987: 41–47)

When building in arctic areas, the climate analyses, especially wind, windborne snow and solar access, together with field analyses of climate stress
and vegetation form the basis for all planning and design. Wind testing of scale models must always be done.

**Summa summarum:**

- wind tested settlement patterns for better micro-climate
- compact, small-scale built structure and mixed land-use with short walking distances
- create bends in the street network to prevent wind channelling
- consider snow removal and snow storage
- create possibilities for winter cycling
- open spaces between houses should not exceed 30 x 30 m
- increase the height of buildings gradually in the same direction as the predominant wind direction
- pedestrian protection with covered arcades, glass-covered semi-climatised spaces, protected outdoor places etc.
- public transport, sheltered waiting spaces
- minimise surface area and use high insulation level
- buffer zone of cold structures should be placed on the north or windy side, a warm heart in the middle and indoor and outdoor spaces on the sunny side.

### 6.8.3 Temperate climate

In a four season climate the conditions will change strongly according to the seasons and the nearness of large bodies of water. On the coasts air is moister, windy and the temperature differences are moderate. Farther from the coasts the climate becomes continental in which case diurnal and annual temperature differences increase and air is drier. The vegetation is mainly abundant and luxuriant, but in the south it can be scanty and leathery leafed.

From the point of view of architecture in the moderate climate there are features from both warm and cold climatic zones. The significance of the micro-climate is important in this climatic area, which requires a careful analysing of conditions. Good connection of interiors and outdoor spaces is recommended. (Haggett 2001; Serra 1999: 9)
Northern latitudes

The cold and snowy season usually forms the main problem in the northern parts of the zone. In that case the starting point in construction will be minimising of the exterior shell, insulating and the placing of a warm heart in the middle of the building. In some areas cattle also have been placed in connection of residential buildings to improve the heat economy. Snow has been often used as a supplementary thermal insulation or even as a building material in the northern cultures. (Rapoport 1969: 98–100)

In the placing of houses, directing them and the design of openings, an attempt is usually made to maximise the exposure to the sun, which in the summer season will require the possibility to protect oneself from over-heating. On the shores of water systems, in the valleys and in open terrain solutions are used, which reduce the cooling effect of the wind and prevent the penetration of the rain water into the structures. The wind is prevented by the placing and design of buildings, by layered facades, by protective fences and buffer plantings which require a good knowledge of the local micro-climate.

The passive utilisation of the sun is made possible by building half warm spaces and play zones which are particularly recommended to be built as a complement to outdoor areas due to the long darkness in northern latitudes. (Mänty 1988; Pressman 1995: 183–202)

The nature and the relationship to nature are important factors in this zone. In summer time nature is quite gentle and in the north the round-the-clock flooding, varying light will give nearly a magical sheen to the whole area. It seems nearly that in summer time the human being does not really need buildings and structures at all. In the northern parts of Scandinavia and in Scotland the sun is relatively low. As a counterbalance to the underarm shining sun the sky seems to be very high due to clean, and in inland dry, air, and low or totally missing tree stands. Due to the high sky which has varying tones there is even a certain cosmic character in the landscape. This might require a certain generosity, even solemnity, from the buildings and particularly the roof should take a stand on the quality and colours of the vault of heaven.

In a dark season there will be its own phenomena of the firmament, like stars, moonlight and northern lights, the effect of which is further strengthened by the reflecting snow. However, experiencing them requires darkness and therefore perhaps some unlit parts should also be reserved in parks. During the dark time street lighting, facade lighting and neon lights form a very important factor which
affects the quality of the environment. A lighting plan should be drawn up and, in relation to the granting of the building licence, the necessity of facade lighting should also be discussed. For elderly and disabled persons who cannot take outdoor exercise during the winter season, a sufficient supply of natural light should be guaranteed, for example by building glass covered, half warm or warm premises.

Climate in the different regions of Northern Europe has its own effect especially on wooden buildings:

- gales and oblique rain on the coasts of Norway and Scotland as well as in Iceland
- large amounts of snow in northern Norway and powder snow inland that penetrates structures
- coldness and the chilling effect of wind in northern Sweden and Finland.

Because of the climate, the main task of building is to give protection, which in practice traditionally means to build a strong roof and eaves. Constructing broad covered areas is still justified. Walls are often protected against wind and moisture, by using durable materials, and in Norway sometimes by constructing a separate protective wall. To prevent moisture and powder snow from penetrating structures, the details of a building should be designed to be tight. Wooden structures should be able to dry sufficiently often.

In northern latitudes the sun always shines at a relatively low angle and that is why windows and walls facing south collect solar radiation. The further north the building is, the larger is the free area that has to be left in front of solar panels. In the Arctic summer the sun shines from all directions, and that is why windows facing north have their own psychological meaning during the season of the midnight sun. (Givoni 1998: 417–430; Sterten 2001: 10–13; Solklart)

In most parts of Scandinavia the terrain is more small-scale and vegetation more abundant. The landscape becomes more defined and more labyrinthine and light is often filtered through the trees. The landscape and the quality of light have been described as romantic and from the architecture colourfulness, forming of space and small-scale has been required. (Wikberg 1963; Norberg-Schulz 1980)

**Mediterranean climate**

In a Mediterranean climate, the long hot, dry season is most important from the standpoint of designing. There is barely any winter along the coast, but inland and
in the mountains there are periods of freezing temperatures and snow. If arid conditions predominate, rules for a hot dry climate will provide the starting point for design. In winter some coastal regions can have high relative humidity, and rainfalls can be heavy.

The most important architectural requirements are creating shade, shielding from hot daytime winds and preserving heat at night. Buildings have traditionally been constructed with thick, light-coloured walls that reflect direct heat radiation. Windows are relatively small and equipped with shutters. Courtyards shaded by pergolas and plants and often cooled by water themes are an important part of the buildings’ micro-climate and ventilation concept.

In winter the coastal climate is relatively humid and many buildings suffer from moisture and mould problems. Then it should be possible to allow solar radiation inside. Light is intense in a Mediterranean climate, which has often led to sculptured white architecture that reflects solar radiation, thus protecting against overheat. The scenery has prominent features and it is divided into clearly defined spaces (also micro-climate zones), but on a scale that is easily manageable; it has also been described as classical landscape. (Norberg-Schulz 1980; Serra 1999: 9)

Cold winters and hot-humid summers

Regions with cold winters and hot-humid summers are mostly between the latitudes 30° N and 45° N in the eastern parts of the continents, i.e. China, Japan and the United States. In this area the summers are warm and humid, while the winters are cold. If humid conditions predominate, guidelines for hot humid climate will provide the starting point for design. Climatic and design requirements for winter are discussed in Chapter 6.72 and for summer in Chapter 6.75.

Often the solutions for different seasons are contradictory, and the architect’s and other designers’ task is to make a balanced solution. The urban ventilation should be maximised in summer by encouraging the south-eastern winds. The penetration and speed of cold winter winds mostly from north must be minimized. There is a need to protect sidewalks in summer against the sun and rain, and maximize solar exposure in winter. Buildings of different heights and lengths can be zoned in parallel north-south strips with the highest volumes and wind barriers at the northern edge, leaving the southerly segments more open. If we consider both urban and indoor ventilation, streets in the eastern USA should be oriented southwest-northeast, and in China east-west. (Givoni 1998: 437–441)
Summa summarum:

- compact small-scale urban forms, which act as wind protection as well
- use buildings to protect outdoor spaces (wind, solar radiation)
- in cold climates avoid building orientations which will create a wind tunnel effect
- orientation to the sun, shadow pattern analyse
- wind simulation
- closed blocks, enclosed residential courtyards, even building heights between 4 –10 stories
- south/south-east facing main façade
- buffer zone on the north side (or cold winter winds direction)
- windows which prevent solar overheating in summer, but enables winter solar gain
- reduce plan depth or use glassed atria to maximise possibilities for natural ventilation and daylight
- design roofs and outlets to protect the building from rain, snow and overheat
- green roofs reduce the urban heat island, purify air, retain storm water, enable urban farming, and save energy used in cooling
- cover ramps and stairs, provide handrails.

Warm arid climate

Warm and dry regions are characterized by low humidity and high daytime temperatures, especially in summer. Solar radiation is strong, but during the nights long-wave radiant loss cools the air, and therefore the diurnal temperature range is wide, from 18° C to 40° C, and in some regions night-time temperatures can fall below zero. The vegetation is arid and the ground temperature can be as high as 70° C. During afternoon hours winds are often strong and dust storms are common.

The biggest climatic problem is overheating and for this reason the architecture in these regions should minimize heat stress and glare. In some areas nocturnal heating is needed. Traditionally, the extreme variation of temperatures has been balanced by using heavy building materials that have a high thermal capacity, like stone, earth and brick. Small openings, between 15–25 per cent of the wall area, are used. Different kinds of shading devices, overhangs over windows, pergolas, small windows with shutters and light colours are used against
solar radiation. During the daytime the indoor temperature can be kept significantly lower than outdoor air by closing off ventilation. Humidity does not cause discomfort in such regions, and if a higher air speed is desired, it can be provided by fans rather than by ventilation. Various types of natural ventilation systems have been developed for the buildings. Ventilated double wall and roof structures are also used. Because evaporation binds thermal energy, air can be cooled by moistening it with pools of water, patios equipped with fountains and moistened ventilation ducts. Cooling can also be achieved with underground fresh air ducts, shading and evaporative cooling. In some areas residences are located underground in the coolness of caves.

Colonial architecture also often met the climatic requirements mainly by means of passive adaptation to the conditions. The methods included thick structures with a large thermal capacity, protective verandas, building orientation, natural ventilation, etc. In some cultures residences are constructed at least partly underground, where conditions are more even. (Rudolfsky 1964; Rappoport 1969: 86, 91)

Fig. 154. Proposal of a new quarter in Kuwait, Pietilä. Narrow streets and long eaves give protection against the burning sun, and sea-breeze is encouraged between the houses. (photo Heikki Kastemaa, Rakennustaiteen museo 2008)
Single-family houses have the highest envelope surface area, and their cooling and heating need is the biggest among the various building types. On the other hand, detached houses are more flexible in terms of orientation and can best utilize surrounding vegetation and other natural features in an effective way. Walls with a high thermal resistance can be achieved with double-layered, cheap, sun-dried adobe blocks containing an internal air space.

Row houses are more sensitive to design details and orientation, with respect to both the sun and wind direction. A north-south orientation of the external walls will minimize exposure to the sun in summer and maximize the potential for solar heating in winter.

Double-loaded corridor buildings minimize heat gain, but have poor ventilation characteristics. Therefore, they are not suitable for hot climates unless a high level of ventilation can be ensured. Single-loaded corridor buildings may be appropriate if the corridor is oriented to the leeward side of the building, which enables cross-ventilation. The ventilation possibilities of direct-access multi-storey apartment buildings depend on how many apartments are accessed from the staircase on each floor. With two units per stair it has good ventilation and solar orientation potential. In terms of the sun, the long facades should be oriented northward and southward. With more than two units per stair, some of the dwellings will have poorer climatic conditions. In such cases the one-sided units should face north. (Givoni 1998: 363)

To minimize heat inflow, buildings should be compact and the daytime ventilation rate should be low. During cooler evenings and nights the ventilation system and the architectural form of the house should enable rapid cooling of the interior space, see Figs 146 and 147. In subtropical latitudes, the most intensive solar radiation in summer shines on the east and west walls, which means that north- and south-oriented main facades minimize solar stress.

In principle, two different types of ventilation can be used in a hot, dry climate. The flow of air inside can be increased, which results in evaporation from the skin. If the wind usually blows from the same direction, the air can be forced downward by means of wind towers integrated into the buildings. However, it is difficult to use wind for ventilation near a desert because the wind carries sand along with it. Penetration of sand into buildings can be prevented with a double facade or a breathing wall made of special blocks. (Rudofsky 1964: 113–115; Niang 1992: 89–93)

Another possibility is to use night ventilation to cool the building’s structural mass. The use of nocturnal cooling requires sun shading, large openable windows
with insulated shutters and a ventilation system that adjusts to the circumstances at different hours of the day. Especially the roof should be insulated and light in colour. Air inlets should be on the windward side and outlets should be high enough. In multi-storey buildings the outlets ought to be much larger than the inlets. There are simple formulas for designing cooling. (Maas 1992: 78–81; Climate)

Large south-oriented windows bring solar heating into buildings. In some regions shutters or filters against dust and screens to keep out insects are needed. Pipework for solar heating of water can be put in a concrete or earth roof. This kind of solution makes the indoor air about two degrees cooler during the warmest hours of the day. (Sambou 1992: 82–89)

Design tools for open spaces include enclosure, inward-looking plans, limited planting that can survive with little water, evaporative cooling and shading. Heat-generating functions, like preparation of food, are often performed outdoors. In hot dry areas street life really begins after sunset, but slackens in the early afternoon hours when it is cooler inside the houses. (Climatic 1996)

A courtyard protected by walls is quite common in a hot, dry climate. The yard can be cooled with a water theme, which causes a downward airflow that can be channelled into the building. A shady yard can be connected to a sunny yard, where warm air rises and causes cool air to flow through the building. It is possible to even acclimatize open outdoor areas. Open spaces can be made comfortable at temperatures up to 30° if the relative humidity does not exceed 60% and wind speed is greater than 1 m per second. In the open spaces of the Seville Expo in 1992, a series of experimental passive cooling techniques were tested, among them cooling towers. (Rudofsky 1964; Rappoport 1969: 89–90; Serra 1999: 7, 54–56; Gallo 2002: 16)

A densely built area, with white roofs and walls, would reflect most of the solar radiation toward the sky. A north-south orientation of a street results in an east-west orientation of buildings, which will cause unfavourable solar exposure. Around the latitudes of 20–30 degrees, a small distance between buildings in the east-west direction provides mutual shading for the walls (Fig. 154). If solar access is needed in winter, a distance of 1.5–2 times the height of the building would be needed in the north-south direction. A street grid in “diagonal” orientation, between the cardinal points, provides more shade in summer and sun exposure in winter. In dust-prone areas wide streets parallel to the wind direction may aggravate the dust problem, but light winds which have a speed lower than 3.5 m/s are desirable in the streets. (Givoni 1998: 24, 289, 374)
Summa summarum:

- short distances between houses, avoid untreated wasteland that can cause dust problems
- “diagonal” street net
- avoid detached houses, houses on stilts and high cluster or point blocks, because they lead to excessive exposure to solar radiation.
- south (on the Northern Hemisphere) or north (SH) facing main facade
- minimize the solar heat load; use white and other light colours for facades and roofs (glare can cause discomfort)
- minimize solar reflection from the surrounding ground; shaded courtyards
- use nocturnal ventilation
- use the building’s mass to store heat and coolness
- shading, cooling with wind and whitewashing are important in warm and hot countries

6.8.4 Warm humid climate

A warm and humid climate has a lot of rain and sunshine, the humidity is high (often around 90%) and diurnal changes in temperature are not large. Most hot and humid regions are tropical and they are warm all year round, but some areas, like Japan, can have cold winters. Many regions have more than one rainy season, when sunshine and rain alternate during the same day. Solar radiation is very strong. Wind conditions are different, which must be taken into consideration in planning and architectural design. Coastal winds near the sea make the climate less stressing, but in inland areas calms are frequent.

The targets of planning and design are the prevention of heat build-up as the day unfolds and encouraging convective cooling at night. Where possible, westerly trade winds in the tropical zone are a good basis for climatic design.

More than 40% of the global population lives in warm and humid countries, most of them in relatively poor conditions, which means that they cannot rely on modern building technology. From the inhabitants’ point of view, afternoons and especially the summer climate are uncomfortable and beset by frequent storms – called typhoons or hurricanes – and floods are dangerous and destructive. Warm humid air makes the building materials decay rapidly, metals rust, fungi growth is intensive and insects are plentiful.
In a hot humid climate indoor comfort is largely dependent on the control of air movement and radiant heat. The buildings need to have shading, a low thermal capacity and the possibility for continuous movement of air, which helps cool the body. The buildings are often roofed frame structures that allow air to pass through. Light materials do not store heat and they cool rapidly after sunset, which is positive, but lightweight buildings can be dangerous in areas with typhoons or hurricanes. The walls are often missing or they are replaced by loosely woven textures, which on the other hand make it difficult to arrange visual barriers and sound barriers. In many areas screens are needed to keep out insects. Because of floods, houses are often raised on stilts, which also make ventilation easier, and the space under the house can be used for many purposes (Fig. 155). (Rappoport 1969: 92–95; Climate; Emmanuel 2008: 3; Perkes 2008: 45–52)

During rainy periods there are heavy rains daily. Nature areas can collect rain water, but in urban environment absorbing surfaces, a green network in the form of small “valleys”, ponds and drainage pipes is needed. Roof ponds of houses collect rain water and reduce the heat load on the buildings.

In the hot-humid climate the movement of the air is important for comfort, if another kind of cooling is not used. This can be achieved by climate conscious-architecture and planning. In most regions the wind patterns are constant, which enables the use of wind in a part of buildings ventilation concept. For urban ventilation a good street lay-out for main streets is when the streets are at an oblique angle to the prevailing winds, which enables penetration of the wind into the town, and exposes the buildings to different air pressures, thus enabling cross-ventilation of the interior spaces. A city structure with different building heights next to each other and long buildings oblique to the wind enhances the area ventilation. The air temperature is lower in a block with buildings of varying height than in a block with buildings of uniform height. (Gery 1992: 8–24; Annual 2007: 7)

Air-conditioned buildings should be as compact as possible and have small windows which do not raise the solar heat gain. The service cores can be positioned on the warmer east and/or west sides of the building to serve as solar buffers (Fig. 152). In this case windows are placed on the north and south facades. This placement prevents solar heat gain and maximises heat loss from the interior. The double-core configuration described above uses about 20–30 percent less energy than the common centre-core type building. A south-north arranged long building needs 1.5 times more air-conditioning energy than a east-west oriented one.
For most inhabitants natural ventilation is the only solution affordable, and in this case a spread-out building with large vertical openable windows is the best starting point for architecture. East and west walls receive most of the solar radiation, and mostly the winds come from the east. If the main spaces of a house are situated on the east side for natural ventilation, then the windows should be protected from the solar heat. If there is no need for thermal storage, the openings should be between 40–80 per cent of the wall area. In this climate many activities can take place in shadowy areas outdoors, and porches can be designed to be interspaced between rooms and yards. The ideal building has units in a row with cross-ventilation possibilities and long verandas or balconies to give protection from sun and rain. Open plan or ventilative coupling of rooms leads easily to acoustic problems. This problem is most serious in bedrooms where cross-ventilation is needed throughout the night.

Fig. 155. Flood and wind-resistant building types for the rebuilding of New Orleans. (Perkes 2008: 48)
In this climate roofs can be problematic. To prevent solar overheating white colour is preferable because it can cut peak cooling needs by up to 40 percent, but because of rapid vegetation and fungi growth constant painting is needed. Common roofing materials are galvanized steel corrugated sheets or clay and cement tiles, which materials let warmth penetrate the spaces under them thus causing thermal stress to the inhabitants. Shading or insulation is needed for such roofs. During the night their performance is better owing to long-wave radiation to the sky, which cools down the houses. The roof can alternatively be of double construction and provided with a reflective upper surface.

Roofs can be designed as vegetated areas. This solution improves insulation, helps to store rain water and cools the surrounding by evaporation. The depth of soil needed varies between 150–600 mm, but big trees need about one metre.

Detached houses are exposed to the winds and cool down rapidly in the evenings, thus providing comfort. Two or three storey houses are often more easy to ventilate naturally than single storey ones. Internal staircases can serve as natural shafts for vertical airflow. Especially the upper floors also enjoy better cross-ventilation potential from the wind. Principally row houses give the same possibilities for climatic comfort, but they are more sensitive to their orientation.
with respect to the wind direction. These house types can easily be protected with trees, which can reduce cooling needs by as much as 30 percent.

In multi-storey apartment buildings it is more difficult to arrange cross-ventilation if all the units do not have windows at both opposing facades. Buildings with double-loaded corridors need exhaust fans or other kind of mechanical ventilation. High-rise buildings increase the ground level airspeed around them, which is positive even for their lower neighbours. The inhabitants of the high stories have lower temperatures and humidity. But this building type requires a sophisticated structure and mechanical systems, and costs therefore more than most inhabitants in developing countries can afford. (Givoni 1998: 379; Yeang 1999: 207; Wind 2008: 8)

An urban area of high density, with a mixture of high and low buildings, has better ventilation conditions than an area with lower density but with buildings of the same height, Fig. 156. A good street lay-out from the urban and building ventilation aspect is when main avenues are oriented at an oblique angle to the prevailing winds; this will cause a pressure difference at both sides of buildings and at the same time provide ventilation within the streets.

Design tools for open spaces in hot humid climates include wind, shade, planting of shade trees, shelter from rain and clearly defined open places. Outdoor life in a hot humid climate is pleasant if there is breeze, shade and protection from rain. Open space must be maintained and defended against intruders and all kind of misuse. Covered verandas and covered passages along main town roads are invaluable. No enclosure wall should be used, but instead perforated screens. Long rows of houses should be avoided because they can make an obstacle to wind. Instead it is better to raise the buildings on stilts and interrupt long rows of houses. At high urban densities, an increase in height is preferable to an increase in ground coverage. In hot humid tropics streets are crowded except during rain showers, and are all times less uncomfortable than the overcrowded houses. The uses of streets include working in stalls and workshops, making food and eating, children play and home work, night market, waste removal, washing and even pedestrian and motorized traffic. (Givoni 1998; Climate: 78–85)

Summa summarum:

- minimize the hazards of heavy rains, and tropical storms and floods
- arrange plans and street lay-outs so that area ventilation is possible (30–45 ° angle to the prevailing winds)
– open blocks, variable building heights, also skyscrapers (air temperature and
  vapour pressure decrease in higher stories)
– north and south facing main facades
– minimize solar stress and cooling energy need; minimizing the heat island
– large openings, covered verandahs and walkways, reflective outer surfaces
– enable good (natural) ventilation
– provide sun and rain protection for pedestrians and children playgrounds
– spread-out building will enhance ventilation
– avoid back-to-back apartment types, internal-corridor solutions and courtyard
  houses, because they preclude cross-ventilation.
7 Discussion

"Barbarus hic ego sum, quia non intelligor illis". (Ovidius, cit. Kivimäki)

7.1 Objects of development

The research was focused on the development of climate-conscious building design and town planning methods and wind testing equipment. This work spawned development ideas related to design, construction, administration and education, and several areas requiring further research emerged.

7.1.1 Development of building administration

During the development work the management of the organisations that planned or constructed pilot sites – Tervola building, Rajakylä plan, Sodankylä plan – participated in the programming and planning of environment-conscious planning revisions and experimental construction. However, apparently the entire organisations did not understand the objectives of the pilot projects and were not fully committed to them, as later on decisions were made at the administrative and executive levels that hindered implementation of the set, climate-conscious objectives. In several localities it became apparent that it was not easy for engineers or building inspectors to grasp the requirements of bioclimatic planning.

Implementation of wide-ranging research and construction projects requires extensive preparation at different levels of the actual organisation, and therefore the administration must be committed to the goals of the project and necessary methods at all levels. Before both political and technical decisions are made it is necessary to arrange discussion about the project and sufficient education. Mere publicizing does not guarantee that information reaches everyone. Especially in experimental construction projects it is necessary to make sure the construction organisation understands the objectives of the work and the work methods, and that all decisions support the primary objective. Every decision and detail is important, and many times even small successful steps increase the credibility of the entire project.

Compilation of environment-conscious building norms and guidelines does not help much if their requirements are not implemented at all levels of execution. The quality of urban planning could be improved in practice by developing climate-conscious criteria, which must be fulfilled before the acceptance of a plan.
In many countries there are already strict demands about the energy economy of new or refurbished buildings, but less attention is paid to the bioclimatic aspects of construction. Bioclimatic building design criteria should be implemented during the building permission process, and the environmental qualities of execution should be checked by the building authorities and entrepreneurs themselves.

7.1.2 Development of compilation of climate statistics

Climate statistics are compiled around the world according to an international system. According to experience gained during this research and other similar studies, available wind statistics are poorly applicable to the needs of designers and architects (Børve 1987; Glaumann & Westerberg 1988; Kuismanen 2000). For this reason compilation of statistics and the way of presenting local climate need to be developed. Quarterly statistics and wind charts of at least the most important localities should be made available, presented by season.

In mountain and coastal areas this material should be supplemented with field measurements. The most significant local climate phenomena, like sea wind/land breeze or valley winds should be measured and the phenomena and their impact should be described for use in building design and town planning.

7.1.3 Meteorological material needed because of climate change

In order to take climate change into consideration in town planning and building design, it is necessary to compile appropriate design guidelines, which in turn requires production of a completely new type of climate material. Numeric information about extreme climate phenomena is important in order to compile local design guidelines. In order to assess in more detail the need to develop norms and strength calculation equations, it would also be necessary to compare current maximum values with future values in 2100. For this reason the following information about the target area is needed (current value and estimated value in 2100):

- average wind speeds
- maximum storm wind speed
- maximum gust wind speed in a storm
- minimum temperature
- maximum temperature
- duration and average temperature of hot weather period
- annual precipitation
For this research the author has prepared the meteorological material needed with the method described in Chapter 4.3. The prediction of the effects of climate change is based on the material presented in Chapter 2.3 and Appendix 5. But it would be better if such material were available, for instance, in public statistic handbooks.

The effects of the climate change are area specific, and vary even inside countries. Construction norms and regulations must be developed by country to correspond to changing climate conditions. To develop these norms, the above-mentioned material, which covers the entire country, must be produced so that the country’s most important climate areas and their changes are itemized and presented.

Compilation of design and construction guidelines requires creation of comparative climate information by locality. Appendix 5 is an example of the kind of material which is available today, and it contains the predicted changes in Helsinki’s climate. True, the manner of presentation in the Appendix does not fully correspond to the requirements presented in this chapter. Designers and meteorologists need to further develop the methods used to calculate and present material concerning the year 2100.

Annual averages, as such, are indicative and they provide a base for design guidelines. From the standpoint of norm development and planning, the information would be much more valuable if it were divided according to the seasons.

7.1.4 Development of construction norms

Building safety

According to the UN Climate Panel there seems to be general agreement about the increase of storms due to global warming of the planet. After the huge windstorms during the 1990’s, many research programmes were launched to investigate the
reasons why so many roofs and other structures suffered severe damage (van Beeck 2004; Wind Effects Bulletins 2005–2007). This issue is important for its safety aspects, but it interests insurance companies, as well.

Several collapses of footbridges, chimneys, tubular towers, etc., due to damage accumulation have also recently pointed out the importance of wind-induced fatigue. Therefore, reliable analyses of wind loads are needed, and criteria and permanent control routines should be created. (van Beech 2004)

*Pedestrian comfort*

Especially in cold and warm circumstances there is a need to protect pedestrians from the inconveniences and dangers of weather; winds, rain, snow, slipperiness, solar radiation, humidity, windborne sand and dust, fog, and air pollutants. The first step in any country, climate zone or metropolitan area is to define pedestrian comfort criteria, and after that find area-specific means for realizing the comfort objective in practice.

*Indoor air quality*

There is constant interaction between the climate and indoor air, and this is especially important in naturally ventilated buildings.

Many countries have criteria for indoor air quality. In Finland, for instance, indoor air quality criteria are specified one-sidedly on the terms of mechanical ventilation. The range of acceptable temperatures is narrow, without taking into consideration the effects of air movement, which leads to unnecessary mechanical ventilation and cooling, thus increasing energy demand. However, from Chapter 3.18 we know that indoor airspeeds and a comfortable temperature zone can be extended to about 2 m/s and 30 °C, and even slightly more in developing countries. Thus, there is a need to develop indoor air quality norms based on user comfort research.

*7.1.5 Supplementary funding for climate-conscious construction*

Experience has shown that a good way to introduce new ideas and know-how to the field of construction is through pilot projects in which the various parties involved learn new solutions and their implementation by executing them in practice.
Through such projects knowledge about better solutions and their credibility gain wider approval most quickly.

For example, to improve the quality of the environment and save energy, Norway's housing bank, Husbank, grants a project supplementary funding if a thorough assessment of the area's local climate and sunniness conditions is done during the construction project and if the buildings are adapted to the local climate conditions better than in normal practice. The possibilities of providing supplementary funding for construction plans that adapt to the climate and especially save energy should be investigated in other countries, also.

7.1.6 Climate studies

Windiness studies

If the town plan area or building site is located in a windy area, micro-climate analyses and, if necessary, wind testing of scale models of the project area should be required already at the planning stage. In very windy sites, or if skyscrapers will be built, wind testing of the architectural model should be carried out as well. The need for wind testing can be judged, for instance, with the criteria presented in Chapter 6.11 and Appendix 9, Tables I and II.

Sunniness studies

The building law and construction regulations require sufficient sunniness for buildings and yards, but implementation is not usually verified in practice. In compiling town plans and housing designs the solar access of buildings and yards should be verified by requiring a study of sunniness. In warm climates the sun radiation studies serve the arrangement of shading.

7.1.7 Education

The method developed in this study is part of a renewal of town planning and building design methods according to the principles of sustainable development. To fully benefit from the use of the method and to make sure correct information is used as a basis for planning, it is necessary to arrange education in the use of the method for design professionals and consulting offices already operating in working life.
Architects’ education should include more basic information about environmental and climate analysis, and architects’ schools should acquire wind testing equipment and establish teaching laboratories. Continuing education should be arranged for those who have already graduated. The CASE method is very illustrative, and therefore increases the new student’s understanding of the basic principles of town planning and building design. In addition it would be important to bring up Mahoney tables (Appendix 8, and one of the tables in Fig. 149), the world’s climate zones, Nature and built environment roughness categorization, etc. It is important to include field work right from the beginning and to learn to make on-site observations.

7.2 Further work

Impact of climate on the energy consumption of buildings and areas

The impact of the micro-climate on the heat consumption of buildings at the area level has been studied in VTT’s ASTA II project, which was based on computer modelling and wind tunnel tests (Kivistö 1982 & 1985). As further work, measurements that determine the effect of placement in the terrain and wind protection on energy consumption in actual experimental buildings are needed.

Other further work that is needed involves development of building types suitable for different climates as integrated design where architecture and HVAC technology are examined as a single functional concept based on natural ventilation, heating and cooling design principles. In this conjunction micro-climate studies should also be extended to the building group and block levels, and the impact of different town plan lay-outs on the outdoor micro-climate, building energy consumption and ventilation possibilities should be tested. Compilation of such model plans and pilot building projects would also serve international planning and building export. In this way developers and building authorities would get a tested assessment base for comparing plans presented to them.

In recent years natural ventilation has again become a focus of attention and development in many countries, and many research institutes have included it in their development programmes. However, in some countries, like Finland, official regulations have made it practically impossible to use natural ventilation. Additional research resources should be channelled to the development of natural ventilation and cooling technology suitable for different climates. Studies have shown that building codes need to be changed accordingly.
7.2.1 Design criteria

Planning

There is no consensus on the methods or content of bioclimatic / environment-conscious planning, but instead many researchers have developed their own systems (Becker 1975; Børve & Sterten 1981; Sterten & Børve 1995; Jones 1998; Sterten 2001; Higueras 2001; Kellert & al 2008). To enable the development of environment-conscious planning, some kind of criteria should be developed, against which different projects could be judged. The information and calculation programmes needed partly exist already, but especially in the field of micro-climate processes, there is still work ahead. (Westbury 2002: 172–181; Jensen 2004: A.2.2–5; Stathopoulos 2005: 9–10; Wind 2006: 4–6; Annual 2007: 2–5)

To complement the wind protection criteria discussed earlier, there seems to be a demand to develop lower-limit criteria for air movement associated with different levels of pollutant concentrations.

The roughness classification should be made more precise with wind-tunnel tests as a further study.

Pedestrian comfort

Only a small number of studies have investigated the subjective individual perception of wind conditions, and therefore we do not have enough basic material to specify reliable comfort criteria in different climates. A study comparing the criteria based on gust winds and those based on mean wind speeds also needs to be done. It is important for the establishment of a more global assessment to perform a decent large-scale study of the effect of additional climate boundary conditions on individual comfort perceptions. Such a study should address the specific problems of all climate zones.

Research institutes and some cities have developed their own definitions of comfort criteria and climate analysis methods (Alberts 1981; Børve 1987; Glaumann & Westerberg 1988; Daniels 1994; Koss 2002). A large-scale coordination project will be needed to co-ordinate the different methods, verify the results and make a set of criteria that will make different research results comparable. In Chapter 6.11 outdoor comfort criteria are proposed, but the next step in this process could be an exact definition of wind climate criteria and
development of design guidelines for different climate zones and special local-climate areas.

### 7.2.2 Development of guidelines and information

Different countries have different levels of practical guidelines and handbooks for designers. In Finland guidelines and norms are given in a set of RT cards, whose content has become more general in nature in recent years. There is very little material available that serves the practical planning needed in environment-conscious and climate-conscious design, and it is necessary to concentrate on producing such information.

An example of a special climate related handbook is the European Wind Atlas that gives the basic information needed for wind power planning in the EU countries of the year 1989 (Troen & Petersen 1989). Besides the updating of the Atlas, similar information, adapted to the needs of planners and architects, should be produced. Today this kind of basic information would most easily be available on the web, hosted by some official organisation, like the European Union or the United Nations.

Research and openly available information on the effects of climate change in different countries or climate areas is needed, as described in Chapter 7.13. An international information bank should be developed for instance by the World Meteorological Organisation or the United Nations.

E-wind is an interesting attempt to provide wind engineering analysis, calculation and service on the Internet (Chi-Ming and Jenmu 2007: 6–8). Similar consulting services could supply planners with basic climate data needed for urban design.

### Educational material

It is necessary to produce education material on how to conduct climate and sunniness analyses, wind-test scale models and conduct nature and townscape analyses. In practice, several levels of material are needed, from basic courses to focused education for experienced professionals.

### 7.3 Use of climate-conscious architecture

The developed CASE method consists of:
– techniques to collect and handle meteorological data, make micro-climatic and environment analysis, and field-work techniques
– interprete the observations, describe the climatic conditions, assess comfort criteria
– predict the effects of climate change
– wind test of scale models
– guidelines to make practical solutions in planning and building design.

Climate-conscious planning with the developed CASE method, make it possible to design a better micro-climate for new or old built-up areas. Winds can be used to ventilate exhaust fumes and other pollutants, which improves the quality of air and the healthiness of the urban environment. The analyses and scale-model tests make it possible to shield cold windy areas and to diminish the cooling effect of wind on facades. According to studies in Scandinavian countries this will bring energy savings of 5–15 per cent.

Micro-climatic analyses together with scale-model tests make it easier to protect playgrounds, yards, balconies, etc. against wind, which makes these areas more comfortable and extends the duration of the outdoor season of the inhabitants in northern countries. Control of turbulent and thermal airflows in streets and yards makes it possible to filter dirt particles from the air by recycling the air through groups of vegetation used as filters. There is the possibility of using the method in desert areas where the problem is the windborne sand, and its penetration also to interior premises and to ventilation equipment.

In building design the method can be used to make houses which have better wind protection and do not cause redirected winds to their surroundings. The use of wind-test equipment enables the development of the kind of gutter, window and wall details where snow or sand and oblique rain cannot penetrate. It is possible to use the method in desert areas where the problem is the penetration of sand to interior spaces and to ventilation equipment. Structures that function better reduce the amount of damage to the building and repair costs and also extend the life of the structures.

Wind affects the mechanical and natural ventilation systems of buildings. Having the micro-climate around a building in control is the condicio sine qua non to the design of well functioning natural ventilation. In warm climates it is possible to use wind for cooling houses.

Construction related to tourism has many sites where it is necessary to control windiness and the micro-climate, such as outdoor swimming pools, sun terraces,
airports and marinas. In ski resorts, slopes and ski jumps are places where the control of windiness affects the possibilities for operation. Climate change will affect the competitiveness of resorts and tourist centres, and the prediction of the climate change is especially important for ski resorts. When developing a resort it is also important to analyze the changes in the competing areas globally, as this can cause changes in the consumers’ behaviour.

The method can be used to evaluate sites for wind-power plants. Carefully made wind analysis has to be done when placing energy producing windmills. The Institute of Meteorology can provide the basic information needed for windmill park placement and production calculations. Wind statistics have to be adapted to fit the circumstances at the building site. Especially if the environment is hilly or tree-covered, the analysis needs to be specified using scale model wind testing.

7.4 Finale

“L’image poétique n’est pas l’écho d’un passé”. (Bachelard)

The target was to develop an effective and easy-to-use method for bioclimatic planning and architectural design. In practice this meant a combination of know-how about architecture, urban planning, flow physics, meteorology, geography, biology, mechanical engineering and information technology. Building six different prototypes of the blower was quite an effort, too. In fact, all this would be a cocktail impossible for one person to take. But this is a “postmodern” phenomenon; the classical borders between the various fields of science are called into question, overlapping occur, and new territories are born.

Most of the targeted tasks could be carried out, but the present state of art in the predictions of the effects of climate change set some limitations to the development of exact guidelines against the effects of changing climates. Terra incognita is there waiting for new conquistadores.

In spite of the limitations, the pilot projects and the Ecobalance calculations show that the CASE method come up to expectations. New know-how has been developed: the wind test instrument, analysis practices, roughness classifications, climate criteria, ways of energy saving, natural ventilation practices, and planning and architecture guidelines for all global climate zones.

The method developed supports environment-conscious design in accordance with sustainable development and prevents climate change for its own part. However, the design instructions are ready for solutions which are needed, if
climate change continues. In doing so, damage caused by storms, floods, heat and sea level rise can be diminished in the future. The following improvements are to be expected with climate-conscious design:

– improvement of the micro-climate around buildings and in the streets, which makes outdoor activities in built areas more pleasant, thus also affecting the inhabitants' health
– ventilate air pollutants from a given area
– use of wind and the sun in a way which improves energy economy, ventilation and user comfort; this will also diminish the amount of greenhouse gases
– enhancement of the use of simple, sustainable ventilation and building techniques
– possibility to take the effects of climate change into account thus diminishing damages caused by weather
– in cold climates improvement of wind protection and the snow protection of pedestrian and bicycle paths and reducing slipperiness
– in warm climates improvement of area and building ventilation, and protection from overheating caused by solar radiation.

The focus of this research has been on climate-related phenomena and planning. However, the use of the developed nature and built environment analyses will enlarge the character of the CASE method to cover the field of bioclimatic planning methods, thus giving the user a toolkit with which to handle the majority of planning and design commissions.

Nevertheless the CASE method is not only a set of rules and denotative statements. The author wants to talk about knowledge (savoir) in its larger meaning: savoir-faire, savoir-vivre, savoir-écouter (know-how, knowing how to live and how to listen). Besides technical qualifications, the fields of ethics and aesthetics are always involved in planning and architectural design. This is why research in architecture should always be regarded with a certain tolerance when it comes to the methods of research, verification and falsification.
Bibliography

Augusti, Giuliano, Borri, Sacre. Impact of Wind and Storm on City life and Built Environment, COST ACTION C14, Nantes, 2002.
Becker, F. Bioklimazonen in der Bundesrepublik Deutschland, in Deutscher Bäderkalender, Gütersloch, 1975.
Berge, Bjørn. De siste syke hus, Universitetsforlaget, Otta, 1990.


Bioclimatisme, L'inertie, la chaleur tranquille, *La Maison écologique*, n° 43 / février-mars 2008


Brown, Peter H. Neo-traditional Towns and Neighbourhoods. Paper, s.a.


CASE Kuismanen. *Rajakylän lähiöaudistus*, plan and description of Rajakylä, Oulu, 1995b


Climate Conscious Architecture Charette, Architecture of Israel Quarterly, 15.4.2007 <http://www.aiq.co.il>


Comment s’adapter au changement de climat, *Ca m’intéresse* N° 324 Février 2008.


Coulibaly, Arona. Problematique de l’efficacite energetique dans les batiments au Mali, in *Confort thermique et economie d’énergie*.


Daniels, Klaus. Simulationen im Windkanal und im Klimalabor, in Oswalt. *Wohltemerrierte Arkitektur*. 391


Dezs-Weidinger, Gábor, etc. *Interpretation of the Sand Erosion Technique for Microclimate Studies by PIV*; in van Beech, 2004.


Evans, Benjamin H. *Natural Air Flow around Buildings*, Tests were made at the Texas Engineering Experiment Station, article 1972.


Hideki, Ishida. *The Outdoor Micro Area Climate Near Buildings and Trees in Summer*. Moniste, Hokkaido Tokai University, Asahikawa, Japan, s.a.


Heininen Lassi. 1.4. 2008 <http://www.nrf.is/Publications/The%20Resilient%20North/Plenary%204/3rd%20NRF_Plenary%204_PP_Heininen.pdf>


Ilmarinen, Jouni. Rakennettu ympäristö ja tuulisuus, study report, University of Oulu 1. 6. 1996.
Ilmastonmuutos lisää sähköjälkelun häiriöitä, newspaper Kaleva 3.3.2008


Jackson, P. The Evaluation of Windy Environments, Building and Environment 13, 1978


KONZEPT 3 – Die Stadt als Text, Tübingen, 1976.


Krampen, Martin. Wie sieht die Stadt der Zukunft aus?, in Ohlbrock, Solar Architektur in der Stadt, Frankfurt am Main, 1984.

Ledoux, C. N. *L’architecture considérée sous le rapport de l’art, des murs et de la législation*, Paris, M. D. CCCIV.
<www.ouluntarmo.fi/.../tiee/cold_injuries.htm>.


Lynch, Kevin: Image of the City.

Lyotard, Jean-François. La Condition postmoderne: rapport sur le savoir, Les Editions de Minuit, Paris 1979

Lützkemeyer, Ingo. Tageslichtsimulation, in Oswalt, Wohltemperierte Architektur.


Maaninen, Anna. Kylmän ilmanalan rakentaminen, paper, s.a.


Mourion, Alain. La haute qualité environnementale. a & e, 8.


Niang, M’Backé. *Les innovations technologiques pour une architecture climatique*, in *Confort thermique et économie d’énergie*


Pietilä, Reima. Character of local geography and climate vise versa architectural design of urban entities in Finland, paper, Lacustrine Climatology, Como, Italia, 20–23.5.1971.

Pirinen, Matti, Vauhkonen, Kari. Asemakaavamallien tuulitunnelikokeet. In Kivistö ASTA II.


Statens Institut för Byggnadsforskning. Solur för modellstudier, Instructions of use of sundial. (Statens Institut för Byggnadsforskning SIB, BOX 785, 80129 Gävle, Sverige). s.a.


Westerberg, Ulla. Solvärden, Statens Institut för Byggnadsforskning, Gävle s.a.


Appendices
Appendix 1 CASE wind test instrument development.

WIND TEST INSTRUMENT

The instrument and method developed during this research can be considered as an open space wind tunnel. It is based on the calibrated CASE blower.

Figure 1. The CASE wind test blower.

Scale model wind test methods can be divided into two categories on the basis of their objectives:

1. Methods that chiefly indicate ground-level flows (erosion tests).
2. Methods that indicate the entire flow field around buildings.

Within both of the above-mentioned categories it is possible to pursue various perception and measuring accuracies. A 1:500 - 1:1000 scale model is sufficient for town plan design, while larger 1:200 - 1:100 scale models are needed for building design. Indication of the entire flow field around buildings was chosen as the objective of the method. In prototypes I–III a lower, approximately 60–200 mm high, flow field was experimented with. In subsequent tests with the prototypes IV–V the goal was to raise the field to 500 mm, which would make it possible to test an over-10-story building, for example, with a 1:100 scale model. This goal was slightly lowered in prototype VI.

Measurements

The properties of the device were studied by means of tests conducted at VTT’s building laboratory in Oulu in 1991. Flow measurements were done using five Alnor GGA-165 thermoanemometers fitted with Alnor flow transmitters. The measurement setup is presented in figures 2 and 3. The results were stored in a Doselog data logging system. The flow speed at each point was stored at one-second intervals for about one minute. The data files were converted with a DoseConv application to make them compatible with Symphony spreadsheet
files. In the spreadsheet computation a 15-second period was deleted from the beginning and end of each measurement, resulting in a 30-second undisturbed measurement result. The measurement was repeated at each point using three different flow speeds, 30 times at each speed. A thermoanemometer with a direct readout, intended for individual measurements, was used for verification. Based on the results, less repetitions of measurements were used in later prototypes.

The measurements of the prototypes V and VI were made at the end of 90’s in Architects’ Office Kimmo Kuismanen’s facilities in Oulu by the author and Olavi Himmelroos. To measure the flow field a 100 x 100 m grid of thin steel wire installed in a 1200 x 1000 mm framework was constructed, which could be moved to various distances from the fan. The measurements were done at 200 mm intervals from the fan opening.

Figure 2. Measurement setup for the prototype wind test instrument prototypes at VTT. A movable stand with affixed anemometers at centre. (drawing Vakkuri)

Figure 3. The horizontal measurement positions (mm), A is the central line of the flow-field. The heights were 50, 130, 220, 320 and 425 (mm). (drawing Vakkuri)

At the beginning the air-flow field of the Norwegian blower system (“vifte”) was measured. It can be seen that the air-speeds weaken dramatically between the heights positions 25 and 110 (mm), see Table I.
Table 1. Air-field of the Norwegian blower system

<table>
<thead>
<tr>
<th>Nopeus 1/3</th>
<th>Mittauspiste</th>
<th>K25</th>
<th>K110</th>
<th>K200</th>
<th>K300</th>
<th>K400</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>550</td>
<td>4,8</td>
<td>0,7</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>D</td>
<td>950</td>
<td>4,8</td>
<td>0,7</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>B</td>
<td>1150</td>
<td>4,6</td>
<td>1,7</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>E</td>
<td>1650</td>
<td>3,8</td>
<td>0,9</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>C</td>
<td>1750</td>
<td>3,9</td>
<td>2,4</td>
<td>0,3</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>A</td>
<td>2050</td>
<td>3,6</td>
<td>2,5</td>
<td>1,0</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>D</td>
<td>2050</td>
<td>3,3</td>
<td>2,2</td>
<td>0,7</td>
<td>0,1</td>
<td>0,1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nopeus 2/3</th>
<th>Mittauspiste</th>
<th>K25</th>
<th>K110</th>
<th>K200</th>
<th>K300</th>
<th>K400</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>550</td>
<td>6,0</td>
<td>0,9</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>D</td>
<td>950</td>
<td>6,0</td>
<td>0,9</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>B</td>
<td>1150</td>
<td>5,3</td>
<td>2,4</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>E</td>
<td>1650</td>
<td>4,9</td>
<td>1,4</td>
<td>0,1</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>C</td>
<td>1750</td>
<td>4,8</td>
<td>2,9</td>
<td>0,8</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>A</td>
<td>2050</td>
<td>4,4</td>
<td>3,2</td>
<td>1,2</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>D</td>
<td>2050</td>
<td>4,0</td>
<td>2,7</td>
<td>0,9</td>
<td>0,1</td>
<td>0,1</td>
</tr>
</tbody>
</table>

K = height position in mm, nopeus 2/3 = air speed at 2/3 power of the maximum.

Together with the flow-speed measurements the turbulence of the air-flow was also registered. Figures 4 and 5 show examples of the turbulence when using one or two blower units. The air-flow was more turbulent near the ground with all prototypes tested.

Figure 4. Example of the graphical presentation of turbulence measurements; prototype I that has one blower unit. The figure clearly shows air flow turbulence, which is greatest in the lowest layers. Korkeus = height, mitt.piste = measurement position, aika = time, nop. = speed.
Figure 5. Example of the graphical presentation of measurements; prototype VI that has two blower units. The figure clearly shows air flow turbulence, which is greatest in the lowest layers. Korkeus = height, mitt.piste = measurement position, aika = time, nopeus = speed.

Prototypes

1. The first prototype constructed in 1990 was based on a Ziehl cross-flow fan installed in a simple framework, figure 6. The uniform wind field of this device was only less than 60 mm high, quite narrow and too weak.

Figure 6. In the first prototype one blower unit was used. (drawing Vakkuri)

2. In the second prototype air flow was created with two stacked 120 W Ziehl cross-flow fans. The size of the fan opening was 980 x 350 mm. It was located 200 mm above the base of the device and the flow of air was directed 30° downward. The flow output at maximum speed 100 mm from the front edge of the opening was 6.8 m/s. Figure 7 presents the technical data and a cross-section of the cross-flow fan which was used.
A flow area suitable for model testing was attained, it was 600 mm wide and 900 mm long, located 850 mm from the opening of the device. The flow field was only 60 mm high, which was considered as inadequate. Based on the results, the equipment was developed further.

Figure 7. The second prototype consisted of two blowers. (drawing Ziehl)

3. The third modified prototype was completed in July 1991, figures 8 and 9. In this prototype the flow openings were directed upward and a flow equalizer, consisting of a plastic honeycomb with 8 x 8 mm perforations, was placed in front of the openings. The size of the opening was 966 x 268 mm.

Minor revisions were made to the device on the basis of the tests. In the end the measurements indicated that the wind field 100 mm from the opening was 7.5 m/s, relatively even, but only 200 mm high, which was considered too low for testing of high buildings.

Figure 8. Prototype III, (drawing Kuismanen)
4. A completely different approach was used in prototype IV, figure 10. The test equipment was comprised of two 180 W axial fans with a diameter of 400 mm and a rotation speed of 1360 r/min placed side by side. The fans were placed so that there was a 100 mm gap between them. The bottom edge of the 405 x 995 mm (height x width) opening was 95 mm above the surface of the table. The openings were covered by a flow equalizer consisting of a honeycomb with 8 mm perforations 100 mm deep. There was 330 mm of free space between the fans and the flow equalizer. The external dimensions of the device were 1000 x 750 x 550 mm (width x height x depth). Flow speed at maximum speed 55 cm from the front edge of the fans, measured at the centre of the opening, was 7 m/s.

Measurements revealed two problematic zones of low flow at the hubs of the fans. Flow speeds in these areas were significantly lower than in the surrounding areas. It was attempted to even the flow field by installing various mesh sheets in front of the high-flow areas. The blower opening was also narrowed and lowered, as equalizers placed inside the device dropped flow speed below 4 m/s, which was found to be too low to move the indicator material.

The measurement field of prototype IV narrowed to 600 mm, which is too small for the dimensions of larger scale models, figure 11. Even a modified prototype did not remedy the errors in the flow patterns at the hubs. In the following prototype it was decided to study the possibility of increasing the air pressure created by the fans, which would offer the possibility of using better guide elements.
5. The fifth prototype contained two Woods axial fans, which created a higher air pressure inside the device than did the earlier prototypes. This made it possible to modify air flow with internally mounted guides without having the flow speed drop too low. Measurements revealed that air flow in this prototype, also, was slightly slower at the fan hubs, although no direct evidence of the significance of this phenomenon to scale model testing in the scale model tests we conducted was found. The size of the measurement field was: width 800 mm, height over 500 mm and length over 1700 mm. The prototype was relatively heavy, over 80 kg.

6. Sixth prototype. In August 1998 it was decided to conduct one more experiment using more powerful Ziehl cross-flow fans, model DZR*QK12A-4EM.98.GK, which are thyristor-controlled.

Measurements indicated that the size of the flow field suitable for wind testing created by the fan, where air flow was at least 4 m/s, was over 400 mm high, 800 mm wide and 1800
mm long. The flow field of this prototype was found to be sufficiently even for wind testing with the CASE method. The produced air flow is slightly turbulent, but so is natural wind, also. The air flow area created by the fan is sufficiently broad for testing of most architectural and scale models, cf. the requirements in Chapter 4.

The measurement results are published in more detail in Vakkuri’s research report. (Vakkuri 1993)
Appendix 2 Sodankylä pilot site.

Targets

The purpose of the analyses and planning of Raviradan alue, a former trotting-track, in Sodankylä, was to develop the field work practices and test the reliability of the CASE nature analyses method. Wind test was used with the planning of the housing area, and the eco-effectiveness of the plan was checked by VTT by using their EcoBalance calculations.

Analyses and the plan

Nature analyses were made with the analysis method developed in this research by the author. To test the reliability of the method, the same areas were analysed by biologists, Anttila and Brusila. Both analyses were made independently, and the results compared. The conclusion was that both methods had given relatively similar final results, thus ensuring the reliability of the method developed. This speaks in favour of the use of the quick and cheap CASE method in ordinary planning tasks. (Anttila 1996)

Based on the nature analyses the buildable and protected areas of the project site were decided, and the means with which to develop the nature environment of the area. The climate analysis gave the basis for the wind testing programme.

To test different possibilities, block configuration qualities and ecological properties of different solutions, three plan variations were designed by the author, with the assistance of architect Juhonen and students of architecture Rajajärvi and Tamminen. Alternatives A and B were made and tested with the developed instrument at first. The alternative C was developed on the basis of the wind testing and EcoBalance calculations.

The monitoring made by Harmaajärvi at VTT Research Institute confirms that the planned area requires less energy and raw materials and causes lower emissions and wastes than an average Finnish area of small-scale housing, both at the building phase and with its use. The calculation was made for 50 years period. The study area also causes lower infrastructure costs. According to a study of the ecological balance of the Sodankylä trotting track area, the effects of all the factors are smaller than those of a typical Finnish neighborhood of single-family houses. The impact of the trotting track is about 20% smaller than that of the reference areas, on average. The greenhouse gas emissions are 24% lower per resident and 28% lower per square meter of floor space than they are in the reference areas. (Harmaajärvi 1998)

Based on the assessment, the residential area of the Sodankylä trotting track has good preconditions for becoming a model area of northern ecological construction. (Harmaajärvi 1998)
Figure 1. Green environment charting. Different kinds of natural and cultural green areas - like dry sandy pine forests, meadows etc., - were defined on the map. Also the most important trees are shown. (drawing Kuismanen)

Greenery instructions

These analyses and accompanying preliminary instructions relate to the map that presents the locations of the areas, figure 2. The planting instructions were made after the analyses and comparisons together by Anttila, Brusila, Kuismanen K. and Kuismanen M. Because of increasing rainfall due to the climate change, plants that withstand moisture need to be emphasised in the lower portions of the plot, such as is presented in the following items: 1. b) moss, 5. ditch and 11. ditch.

1. Border of Kasarmintie, Pilotti I area
   - a partially eroded sandy pine ridge; preserve the area in its natural state
   - repair the fence along Kasarmintie (main street)
   - plant pine trees
   - repair the eroded ground cover:
     a) lay peat and plant natural grasses
     b) if this is not successful, pour sour milk products on the peat to increase moss growth.
2. Pilot 1 yard connection to the wooded area
   – dry woods with large pine trees, no undergrowth
   – create an irregular border between the yard and the woods, with gradually thinning soil.
3. Slopes of the entrance street
   – eroded sandy slopes
   – add a thin layer of peat, plant ground-covering plants.
4. South end of the trotting track
   – blueberry-type pine and spruce forest; preserve the forest as is.
5. Southeast corner of the trotting track
   – currently mixed forest
   – level the slope and fill the pit
   – preserve the good trees at the edge and fill in with similar trees
   – ditch: moisture-resistant plants, willows.
6. Pasture
   – natural pasture; preserve, cut the grass in August
   – horse rut: try transplanting pasture.
7. Park area in the middle (between the detached houses and row houses)
   7.1
   – currently sandy field and driving ruts; preserve
   – trees: aspen and mountain ash.
   7.2
   – currently barren, partly grassy; preserve a portion as a field
   – construct rocky areas and plant rock garden plants.
8. Green corridor
   – currently grass, underbrush and coniferous saplings
   – plant pine trees.
9. Stable surroundings
   9.1 lush lawn and trees on the south side of the stable; preserve.
   9.2 preserve the stable: snowmobile storage, small animal shelter.
   9.3 uneven horse pasture
   – considerable earth fill for a playground.
   9.5 snowmobile trail from the edge of the row house plot to the open line in the forest
   – willows, birches
   – preserve in its natural state, clear the snowmobile trail.
10. Gravel portion of the old trotting track; preserve for a length of 200 m
    – no changes are allowed
    – the gravel area is graded once a year.
11. Horse pasture
    – plant greenery around the buildings
    – create a wetland in conjunction with the ditch.
12. Wooded area, lingonberry-blueberry-type pine forest
    – dry, old pine forest; preserve in its natural state
limit wear by constructing paths and protective fences.

13. Kame
- dry, eroded kame-hill
- lingonberry-type forest on the north side; preserve
- preserve the pasture, add earth to sandy places and allow the pasture to spread itself
- repair worn places on the slope and add earth to cover bare tree roots
- increase moss growth as in item 1.

Figure 2. Nature analyses of the Sodankylä, Raviradan alue. The numbers refer to the description above. (drawing Kuismanen)
Figure 3. Plan, alternative C. The buildings of the town plan are situated so that a maximum amount of existing nature is preserved and wind protection formed. (drawing Kuismanen)
Appendix 3 Rokua, ecological tourist resort.

DEVELOPMENT OF ROKUA’S ECOLOGICAL TOURISM CENTER

Rokua Life is a development project that is a part of the EU’s Life Environment program. The project was started in the autumn of 2002 and it ended in 2005. The purpose of the project was to develop Rokua’s ecological tourism environment. Rokua is situated about 60 km southeast of Oulu. The area is comprised of sandy, hilly terrain that grows pine trees and lichen, and is very vulnerable to erosion. On the other hand more abundant rainfall and storms and on the other longer dry and warm periods caused by the climate change further increase the danger of erosion and forest damage.

The starting point for the development of the Rokua area is safeguarding the endurance of the environment and ecological implementation of activities. Challenges are posed particularly by the area’s vulnerable ground, which is worn by tourism and major sports events arranged in the area. Furthermore, principles and criteria for ecological design and construction of buildings and municipal engineering have not been formed. More information about environmental analyses and ways to repair environmental damage is also needed.

VTT’s EcoBalance assessment model was used to make a general assessment of the ecological impact of carrying out the current and proposed new plans for the Rokua area – the so-called ecological balance. It is comprised of the effects during the area’s entire life cycle (e.g. 50 years): energy and raw material consumption, greenhouse gas emissions and other emissions, water consumption and waste water, solid waste and costs.

![Figure 1. Building floor area according to the old plan (left) and the draft of the new plan (right) in different sub-areas. (Harmaajärvi 2005a)](image)

The task of doing an environmental analysis and compiling drafts of new plans was given to Kimmo Kuismanen, whose idea the entire development project was. First of all the area’s climate, nature, wear resistance, type of terrain, activities, land use, municipal engineering efficiency, etc. were analyzed. The drafts of the new plans bring more permitted building volume, but they save naturally beautiful and sensitive places from construction. At the same time the area’s year-round use is more efficient and peaks in consumption are leveled.
Table 1. Comparison of the amount of construction

<table>
<thead>
<tr>
<th>Building type</th>
<th>Current plan, m²</th>
<th>Revised plan, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residence, leisure-time residence</td>
<td>15,600</td>
<td>19,690</td>
</tr>
<tr>
<td>Hotel, lodging, services</td>
<td>22,850</td>
<td>26,650</td>
</tr>
<tr>
<td>Technical maintenance</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>Total</td>
<td>39,150</td>
<td>47,040</td>
</tr>
</tbody>
</table>

The number of residences or leisure-time residences in the area is 176 according to the current plan and 227 according to the new plan.

Table 2. COMPARISON OF THE AMOUNT OF MUNICIPAL ENGINEERING

<table>
<thead>
<tr>
<th>Structure</th>
<th>Current plan</th>
<th>Revised plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area of traffic areas</td>
<td>92,410 m²</td>
<td>78,430 m²</td>
</tr>
<tr>
<td>Length of transport network</td>
<td>16,030 m</td>
<td>13,920 m</td>
</tr>
<tr>
<td>Length of water line network</td>
<td>8,130 m</td>
<td>5,950 m</td>
</tr>
<tr>
<td>Length of sewer line network</td>
<td>7,230 m</td>
<td>5,450 m</td>
</tr>
<tr>
<td>Length of power line network</td>
<td>19,360 m</td>
<td>17,240 m</td>
</tr>
<tr>
<td>Length of telecommunication network</td>
<td>11,530 m</td>
<td>9,410 m</td>
</tr>
</tbody>
</table>

According to the completed assessment, energy consumption is 24 MWh/m² under the current plan and 23 MWh/m² under the new plan, which is 4% less. Raw material consumption is 7.9 tons/m² under the current plan and 6.7 tons/m² under the new plan, which is 15% less. Greenhouse gas emissions total 5.6 tons/m² under the current plan and 5.3 tons/m² under the new plan, which is 5% less. Other emissions total 28 kg/m² under the current plan and 27 kg/m² under the new plan, which is 3% less. Water consumption is 62,000 l/m² under the current plan and 59,000 l/m² under the new plan, which is 6% less. Waste formation is 381 kg/m² under the current plan and 374 kg/m² under the new plan, which is 2% less. Costs total 2,700 €/m² under the current plan and 2,500 €/m² under the new plan, which is 6% less. Proportionally, the largest reduction is achieved in raw material, mainly mineral aggregates used in traffic channels. See Figure 3.

The Rokua Life project will improve conditions in many respects. Planned environmental work will improve the quality of the scenery and repair erosion damage. Diversification of activities will level seasonal variation, which is advantageous both economically and environmentally. The need to construct municipal engineering will decrease, which will lower the municipalities’ total costs by around €3 million. Private developers will also realize savings. (Harmaajärvi 2005a: 50-54)

The environmental impact of the draft of the new plan is positive:
- lower energy consumption
- less use of construction materials
- less formation of greenhouse gases and other emissions
- additional construction takes place in already built-up areas
- the best natural areas and scenery remain untouched.

The municipalities should now start officially renewing their development plans.
Building instructions were compiled for Rokua with the purpose of taking the environment and ecology into consideration. The goal is to inspect new building permits according to the instructions.

VTT conducted its own studies in conjunction with the project:

1. The environmental impact of the draft of the new plan was calculated:
   - the draft was found to be better than the old one from the standpoint of the environment
   - renewal of the plan would bring cost savings to the municipalities
   - also economical for private builders.

In summary, it was determined that the new land-use draft is more advantageous than the current plan in all its effects. There is a significant reduction in relative consumption of natural resources.

2. Use of light municipal engineering in Rokua was studied:
   - light municipal engineering would save the environment and scenery
   - the municipalities’ costs would decrease.

Careful environmental analyses make it possible to also use light municipal engineering in building the infrastructure network. The main environmentally friendly principles of municipal engineering, which should be applied in the Rokua area wherever possible, are: minimizing construction in the terrain, avoiding construction of unnecessary traffic channels and utility lines, minimizing the size of traffic channels, shallow installation and insulation of utility lines, local handling of rainwater, planning excavations to minimize leveling and cutting, utilizing slopes, and taking the environment into consideration on the general level in the vertical and horizontal directions. Basic information about the environment is essential, and emphasis should be placed on planning. Many of the examined solutions are also inexpensive. Although environmentally friendly solutions may sometimes be more costly, over the long term they are less expensive than ordinary solutions. The climate change makes it easier to construct light municipal engineering. (Harmaajärvi 2005b)

3. Goals were set for developing ecological and environmental protection in the Rokua area in the future:
   - energy consumption will be decreased
   - public transport will be developed
   - waste formation will be decreased and recycling will be developed
   - the aesthetic and technical quality of construction will be improved
   - formation of greenhouse gases and emissions will be limited
   - environmental wear will be prevented and existing damage will be repaired.

4. VTT produced educational material, which makes it possible to start environmental education in Rokua.
Figure 2. Construction costs per square metre during 50 years; current plan on the left, new draft plan on the right. (Harmaajärvi 2005a: 52)

Figure 3. Impact of carrying out Rokua’s new land-use draft plan compared with implementation of the current plan per constructed square metre. From the left: energy, construction materials, fuels, greenhouse gases, other emissions, water, waste and costs. (Harmaajärvi 2005a: 55)
Figure 4. Construction of municipal engineering using ordinary methods leaves deep scars in the landscape. Light municipal engineering would save the environment and could even be less costly.

Figure 5. Rokua's terrain is vulnerable to erosion.
Figure 6. In the current plan, building areas are scattered and often situated in very vulnerable terrain, where construction would destroy natural values and scenery.

Figure 7. In the current plan, construction would take place in locations that are vulnerable to erosion. In future the climate change will worsen the situation.
Figure 8. Proposal for revising the area's general plan. Areas where, based on the environmental analysis, permitted building volume should be moved to areas better suited for construction are marked in blue. Proposed construction areas are marked in orange. The light blue line is the local light-rail line. (drawing Kuusinen)
Figure 9. Southern part of the area. Construction areas that should be moved and left un-built are marked with lineation. (drawing Kuismanen)

Figure 10. Proposed new construction in the southern part of the area, (drawing Kuismanen)
Appendix 4 Relative wind speeds at 2 m height above ground. (Glaumann & Westerberg 1988: 63)
Appendix 5 Example of the effects of climate change, Helsinki.

MEMO 27.10.2006 Lasse Makkonen / VTT

PREDICTED CLIMATE CHANGE IN HELSINKI BASED ON RESULTS FROM A SIMULATED REGIONAL CLIMATE MODEL

The results are based on Sweden’s meteorological institute’s Rossby Centre’s RCAO simulated regional climate model for land and sea areas. Analyses of the extremes were done as a co-operative effort by the University of Helsinki and VTT. The simulations were done using the limit conditions of two global models and two different end scenarios specified by the Intergovernmental Panel on Climate Change, IPCC. The results concerning changes depict the average value of the results obtained from four simulations for a point in Helsinki corresponding to a 50 km x 50 km area in the model.

The reference period ("current state") is a simulation period from 1961 to 1990 and the scenario period ("prediction") is a simulation period from 2071 to 2100.

The extremes, i.e. maximums and minimums, depict values that are exceeded once in 50 years, on average.

Estimated changes:

- Annual average temperature: +4 °C
- Maximum temperature: +4 °C
- Minimum temperature: +16 °C
- Thaw-freeze cycles: -40%
- Annual average wind speed: +2%
- Maximum wind speed: +15%
- Annual rainfall: +15%
- 6-hour maximum rainfall: 0%
- 5-day maximum rainfall: +15%
- Water content of annual snowfall: -60%
- 6-hour maximum snowfall: 0%
- Maximum water content of snow cover: -50%
- Duration of snow cover: -70 days
- Duration of sea ice cover: -120 days
Appendix 6 Wind direction measurements in Raahe, west coast of Finland.

Wind directions and speeds were measured in the morning (coloured left column), afternoon and evening, June 1989. Red means land breeze, blue sea breeze. It can be clearly seen that often there was land breeze in the morning and evenings, and sea breeze during the days.
Appendix 7 Example of combination map.

A combination of a topographic map and thematic maps can give useful information to planners. This example from Norway consists of vegetation and topsoil data shown on an economic map on a scale of 1:10000. (Sterten 2001: 84)
Appendix 8 Mahoney Tables.

The Mahoney tables are a set of reference tables used in architecture, used as a guide to climate-appropriate design. They are named after architect Carl Mahoney, who worked on them together with John Martin Evans, and Otto Königsberger. They were first published in 1971 by the United Nations Department of Economic and Social Affairs.

The concept developed by Mahoney (1968) in Nigeria provided the basis of the Mahoney tables, later developed by Königsberger, Mahoney and Evans (1970), published by the United Nations in English, French and Spanish, with large sections included in the widely distributed publication by Königsberger et al (1978). The Mahoney tables proposed a climate analysis sequence that starts with the basic and widely available monthly climatic data of temperature, humidity and rainfall. Today, the data for most major cities can be downloaded directly from the Internet (from sites such as http://www.wunderground.com/global/AG.html, 2006).

The tables use readily-available climate data and simple calculations to give design guidelines, in a manner similar to a spreadsheet, as opposed to detailed thermal analysis or simulation. There are six tables; four are used for entering climatic data, for comparison with the requirements for thermal comfort; and two for reading off appropriate design criteria. A rough outline of the table usage is:

1. Air Temperatures. The max, min, and mean temperatures for each month are entered into this table.
2. Humidity, Precipitation, and Wind. The max, min, and mean figures for each month are entered into this table, and the conditions for each month classified into a humidity group.
3. Comparison of Comfort Conditions and Climate. The desired max/min temperatures are entered, and compared to the climatic values from Table 1. A note is made if the conditions create heat stress or cold stress (i.e. the building will be too hot or cold).
4. Indicators (of humid or arid conditions). Rules are provided for combining the stress (Table 3) and humidity groups (Table 2) to check a box classifying the humidity and aridity for each month. For each of six possible indicators, the number of months where that indicator was checked are added up, giving a yearly total.
5. Schematic Design Recommendations. The yearly totals in Table 4 correspond to rows in this table, listing schematic design recommendations, e.g. 'buildings oriented on east-west axis to reduce sun exposure', 'medium sized openings, 20%–40% of wall area'.
6. Design Development Recommendations. Again the yearly totals from Table 4 are used to read off recommendations, eg 'roofs should be high-mass and well insulated'.

(Climate: 25-39; Mahoney 2008)
Appendix 9 Tables.

Table A/I Characterization of average wind speed and necessary design measures. (Glaumann/Westerberg)

<table>
<thead>
<tr>
<th>Average speed in M/S at a height of 2 M</th>
<th>Characterization of windiness</th>
<th>Design measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>over 5.5</td>
<td>Very windy</td>
<td>Buildings and areas require protection. Wind tunnel testing may be required.</td>
</tr>
<tr>
<td>4.0-5.5</td>
<td>Windy</td>
<td>Lounging areas, bike and pedestrian routes should be located in calm areas and equipped with wind barriers.</td>
</tr>
<tr>
<td>2.5-4.0</td>
<td>Slightly windy</td>
<td>Yards and balconies require protection.</td>
</tr>
<tr>
<td>under 2.5</td>
<td>Calm</td>
<td>Wind is not a problem, and protection is needed only in some special cases.</td>
</tr>
</tbody>
</table>

(Glaumann & Westerberg 1988)

Table A/II Windiness criteria for outdoor areas

Windiness criteria for outdoor areas expressed as prevalence (%) and experienced wind speed (m/s). The criteria apply to the results of both field and wind tunnel measurements.

<table>
<thead>
<tr>
<th>Alternative limit values</th>
<th>Outdoor areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of the year when a wind speed of 5 M/S should not be exceeded</td>
<td>50%</td>
</tr>
<tr>
<td>Average annual wind speed in M/S that should not be exceeded</td>
<td>5</td>
</tr>
</tbody>
</table>
Table A/III  Units that depict experiencing the environment (Serra 1999)

<table>
<thead>
<tr>
<th>Type of experience</th>
<th>manner of expression</th>
<th>Unit</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>light intensity</td>
<td>lux</td>
<td>bright/dim</td>
</tr>
<tr>
<td></td>
<td>contrast</td>
<td></td>
<td>strong/weak</td>
</tr>
<tr>
<td></td>
<td>type of radiation</td>
<td>K</td>
<td>direct/reflected</td>
</tr>
<tr>
<td></td>
<td>colour temperature</td>
<td></td>
<td>cold/warm</td>
</tr>
<tr>
<td></td>
<td>colour tone</td>
<td></td>
<td>neutral/live</td>
</tr>
<tr>
<td>Acoustic</td>
<td>volume of sound</td>
<td>dB</td>
<td>loud/weak</td>
</tr>
<tr>
<td></td>
<td>tone of sound</td>
<td>Hz</td>
<td>low/high</td>
</tr>
<tr>
<td></td>
<td>direction of sound</td>
<td>s</td>
<td>focused/dispersed</td>
</tr>
<tr>
<td></td>
<td>echo period</td>
<td></td>
<td>short/long</td>
</tr>
<tr>
<td>Climatic</td>
<td>temperature</td>
<td>°C</td>
<td>low/high</td>
</tr>
<tr>
<td></td>
<td>heat radiation</td>
<td></td>
<td>strong/weak</td>
</tr>
<tr>
<td></td>
<td>relative humidity</td>
<td>%</td>
<td>dry/humid</td>
</tr>
<tr>
<td></td>
<td>air movement</td>
<td>m/s</td>
<td>slow/fast</td>
</tr>
<tr>
<td></td>
<td>air quality</td>
<td></td>
<td>clean/polluted</td>
</tr>
</tbody>
</table>

Altogether 75 enquiries were sent and 21 answers received.

Table A/IV Climatic problems faced by finnish designers. Summary of questionnaire results

<table>
<thead>
<tr>
<th>Item</th>
<th>N:o of remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problems associated with buildings and yards:</td>
<td></td>
</tr>
<tr>
<td>Penetration of moisture into structures</td>
<td>8</td>
</tr>
<tr>
<td>Floodwater</td>
<td>1</td>
</tr>
<tr>
<td>Snow accumulation</td>
<td>10</td>
</tr>
<tr>
<td>Snow storage sites</td>
<td>2</td>
</tr>
<tr>
<td>Ice (slipperiness)</td>
<td>4</td>
</tr>
<tr>
<td>Ice (eaves, structures)</td>
<td>6</td>
</tr>
<tr>
<td>Plaster damage</td>
<td>2</td>
</tr>
<tr>
<td>Windiness</td>
<td>10</td>
</tr>
<tr>
<td>Shadiness</td>
<td>8</td>
</tr>
<tr>
<td>Cold air pockets</td>
<td>2</td>
</tr>
<tr>
<td>Impact of wind on ventilation</td>
<td>1</td>
</tr>
<tr>
<td>Problems associated with the environment and zoning:</td>
<td></td>
</tr>
<tr>
<td>Snow accumulation</td>
<td>4</td>
</tr>
<tr>
<td>Snow storage sites</td>
<td>1</td>
</tr>
<tr>
<td>Rising seawater level caused by climatic warming</td>
<td>1</td>
</tr>
<tr>
<td>Windiness</td>
<td>7</td>
</tr>
<tr>
<td>Transport of dust</td>
<td>5</td>
</tr>
<tr>
<td>Cold slopes</td>
<td>1</td>
</tr>
<tr>
<td>Difficulty in processing climate data</td>
<td>2</td>
</tr>
<tr>
<td>Use of aids or specialists:</td>
<td></td>
</tr>
<tr>
<td>Equation for calculating sunniness</td>
<td>1</td>
</tr>
<tr>
<td>Biologist, nature analyst</td>
<td>7</td>
</tr>
<tr>
<td>Meteorologist, climate analyst</td>
<td>1</td>
</tr>
<tr>
<td>Other environmental specialists</td>
<td>3</td>
</tr>
<tr>
<td>Own on-site observations</td>
<td>1</td>
</tr>
<tr>
<td>GPR study, dentological study</td>
<td>1</td>
</tr>
<tr>
<td>Air quality measurement and monitoring</td>
<td>1</td>
</tr>
<tr>
<td>Scale model wind tunnel testing</td>
<td></td>
</tr>
<tr>
<td>Places where help has been used:</td>
<td></td>
</tr>
<tr>
<td>Outdoor area planning</td>
<td>1</td>
</tr>
<tr>
<td>Zoning</td>
<td>5</td>
</tr>
<tr>
<td>Water flow on a facade surface</td>
<td>1</td>
</tr>
<tr>
<td>Noise and pollution studies</td>
<td>1</td>
</tr>
<tr>
<td>Restoration of historic parks</td>
<td>1</td>
</tr>
<tr>
<td>Car-free residential areas</td>
<td></td>
</tr>
</tbody>
</table>
## Itemisation and prevalence of problems:

<table>
<thead>
<tr>
<th>Problem Description</th>
<th>Often</th>
<th>Occasionally</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windy/snowy balconies</td>
<td>6</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Windy balcony walkways/open stairways</td>
<td>6</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Windy entrances</td>
<td>7</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Moisture/snow transported into structures by wind</td>
<td>7</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Accumulation of snow in walkways</td>
<td>8</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Accumulation of snow in entryways</td>
<td>4</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Accumulation of snow in parking garages</td>
<td>1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Snow/ice damage to roofs</td>
<td>8</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>Snow/ice damage to plants</td>
<td>6</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Increased energy consumption due to cold winds</td>
<td>6</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

## Need to develop environmentally aware design methods:
- To assist architectural design: 19
- To assist environmental planning and zoning: 19

## Which tasks require methods and wind testing equipment:
- Micro-climate analysis of areas and building sites: 15
- Sunniness analysis of town plans or block plans: 12
- Active improvement of the micro-climate of yards and play areas: 15
- Specification of locations for energy windmills: 7
- Planning of wind barrier plants: 14
- Study of windiness at tunnel entrances or other traffic areas: 10
- Consultation in scale model wind testing and result analysis: 12
- Sales, installation and user training of scale model wind testing equipment: 1
- Ecological analysis of the environment: 15
- Analysis of scenery and the built environment: 10
- Air quality analysis: 6
- Water quality analysis: 6
- Planning of natural purification of surface and waste water: 14
- Evaluation of the visual quality of the environment: 1
Table A/V Impact of location on the prevalence of climate problems. Summary of questionnaire results

<table>
<thead>
<tr>
<th>Problem</th>
<th>Coast 10 respondents</th>
<th>Inland 8 respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QTY</td>
<td>%</td>
</tr>
<tr>
<td>Windiness</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td>Wind increases energy consumption</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Structural damage</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Snow accumulation</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>Need to test scale models</td>
<td>7</td>
<td>70</td>
</tr>
</tbody>
</table>

Table A/VI Kemijärvi real estate owners' stands on the built environment. Summary of questionnaire results

<table>
<thead>
<tr>
<th>What was expected of the building guidelines</th>
<th>N:o of remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of the cityscape as a common issue with the goal of a</td>
<td>7</td>
</tr>
<tr>
<td>tidier milieu</td>
<td></td>
</tr>
<tr>
<td>Guidelines for snow and climate problems</td>
<td>6</td>
</tr>
<tr>
<td>Detailed construction instructions</td>
<td>4</td>
</tr>
<tr>
<td>Guidelines for outdoor areas</td>
<td></td>
</tr>
<tr>
<td>Promotion of business/tourism</td>
<td>4</td>
</tr>
<tr>
<td>Binding regulations</td>
<td>2</td>
</tr>
<tr>
<td>No overly binding guidelines</td>
<td>2</td>
</tr>
<tr>
<td>Voluntary guidance, no instructions</td>
<td>1</td>
</tr>
<tr>
<td>Study of the cityscape</td>
<td>1</td>
</tr>
</tbody>
</table>

Problems brought up in the responses:

<table>
<thead>
<tr>
<th>Problem</th>
<th>N:o of remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unfitting building sites/areas in the town plan</td>
<td>4</td>
</tr>
<tr>
<td>Poor town plan economy, expensive infrastructure</td>
<td>3</td>
</tr>
<tr>
<td>Too much bureaucracy</td>
<td>2</td>
</tr>
<tr>
<td>Not enough parking places</td>
<td>2</td>
</tr>
<tr>
<td>Poor supplementary buildings in the cityscape</td>
<td>2</td>
</tr>
<tr>
<td>Scenery was not taken into account during planning</td>
<td>2</td>
</tr>
<tr>
<td>Poor town plans and base maps</td>
<td>1</td>
</tr>
<tr>
<td>Too little use of advance permit procedures</td>
<td>1</td>
</tr>
</tbody>
</table>


291. Lyöri, Veijo (2007) Structural monitoring with fibre-optic sensors using the pulsed time-of-flight method and other measurement techniques


294. Gore, Amol (2008) Exploring the competitive advantage through ERP systems. From implementation to applications in agile networks


298. Rabbachin, Alberto (2008) Low complexity UWB receivers with ranging capabilities


304. Popov, Alexey (2008) TiO2 nanoparticles as UV protectors in skin


Kimmo Kuismanen

CLIMATE-CONSCIOUS ARCHITECTURE—DESIGN AND WIND TESTING METHOD FOR CLIMATES IN CHANGE