ECONO

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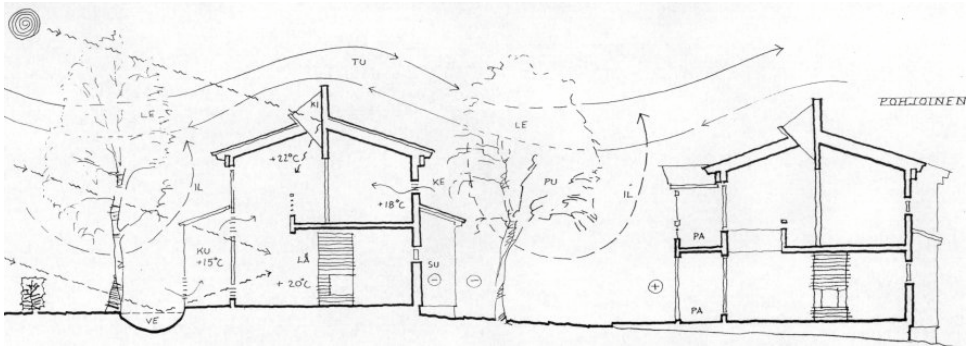

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INFLUENCE OF CLIMATE ON THE DESIGN OF HOUSES

24.3.2005
Ab CASE consult Ltd

CONTENTS

1 OBJECTIVES OF THE REPORT

The objective of this report is to collect the know-how with which the parties who participate in the ECONO project can improve the environment, micro-climate and energy economy of buildings and plans. The aim of this report is the introduction of practices which supplement and facilitate everyday planning work. Climate-conscious design can be reached with the following improvements to the present practices:

- to improve the micro-climate around buildings which makes being and going outside in built areas more pleasant, thus also affecting the inhabitants' health
- to reduce the cooling effect of the wind on the structures which improves energy economy
- to direct the accumulation of snow which for its part reduces the management expenses of buildings
- to improve the wind protection and snow protection of pedestrian and bicycle ways and to reduce slipperiness.

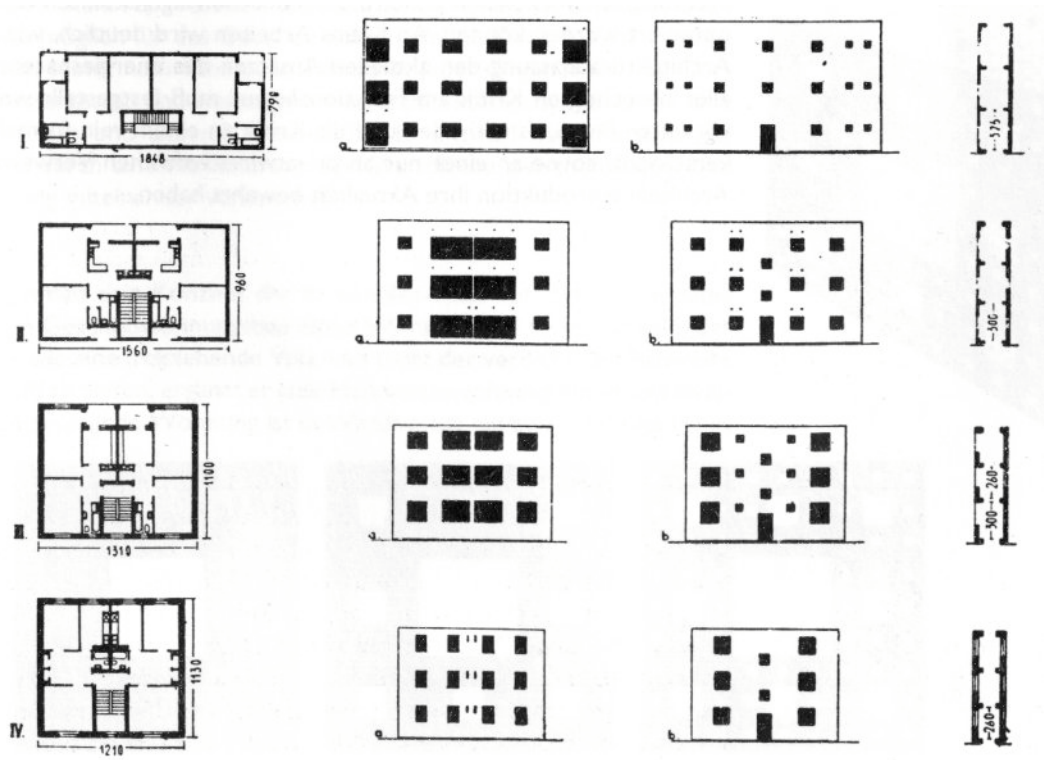


Figure 1.1 Variation of the building according to climate, I Haifa, II Tel-Aviv, III Berlin, IV Oslo, A. Klein 1942. (Oswalt s. 55, drawing Klein)

2 CLIMATE OF THE NPP AREA

2.1 Moderate 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.

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. (Haggett, Serra p 9).

The cold and snowy season forms usually 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)

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 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 long darkness in the northern latitudes. (Mänty, Pressman)

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 stand. Due to 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 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 has been required colourfulness, forming of space and small-scale. (Norberg-Schulz, Wikberg)

In a dark season there will be its own phenomena of 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.

2.2 Climate of the arctic region

In higher regions of Northern Scandinavia and arctic areas the temperature will be low throughout the year. Also permafrost appears in places. In extreme conditions snow will not melt during the summer but accumulates in certain places in ever growing high drifts which gradually become a glacier. Windiness varies strongly and particularly inland there also are long windless periods.

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 p 8)

In this kind of climate the prevention of the effects of wind and snow is a starting point in the 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 rejection of problems caused by snow.

Snow will accumulate most if the building is located with the cross direction against the dominating wind direction. 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, which measure is 1.3 or about 1.5 times wall height of the building. (Børve p. 48-49, Glaumann & Westerberg p. 138-141)

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.

When building in arctic areas, the climate analyses and wind testing of scale models must always be done.

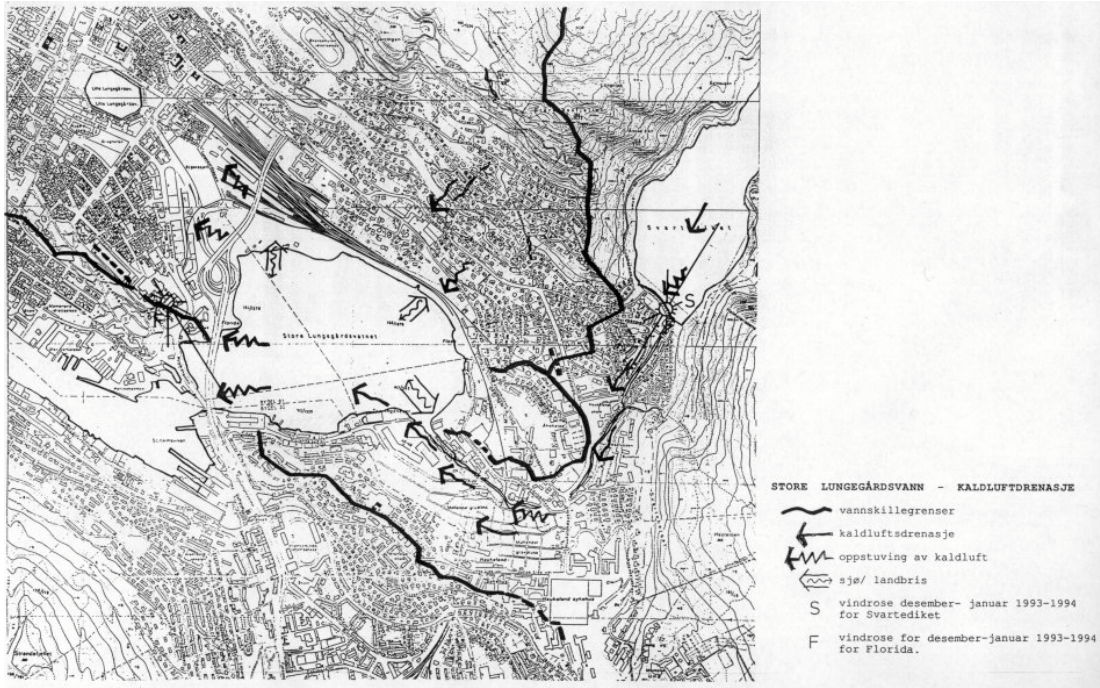


Figure 2.1 Analysis of the landscape structure on a map, Bergen Store Lungegårdsvann. (CASE Store, drawing Børve/Bjørge/Kuismanen)

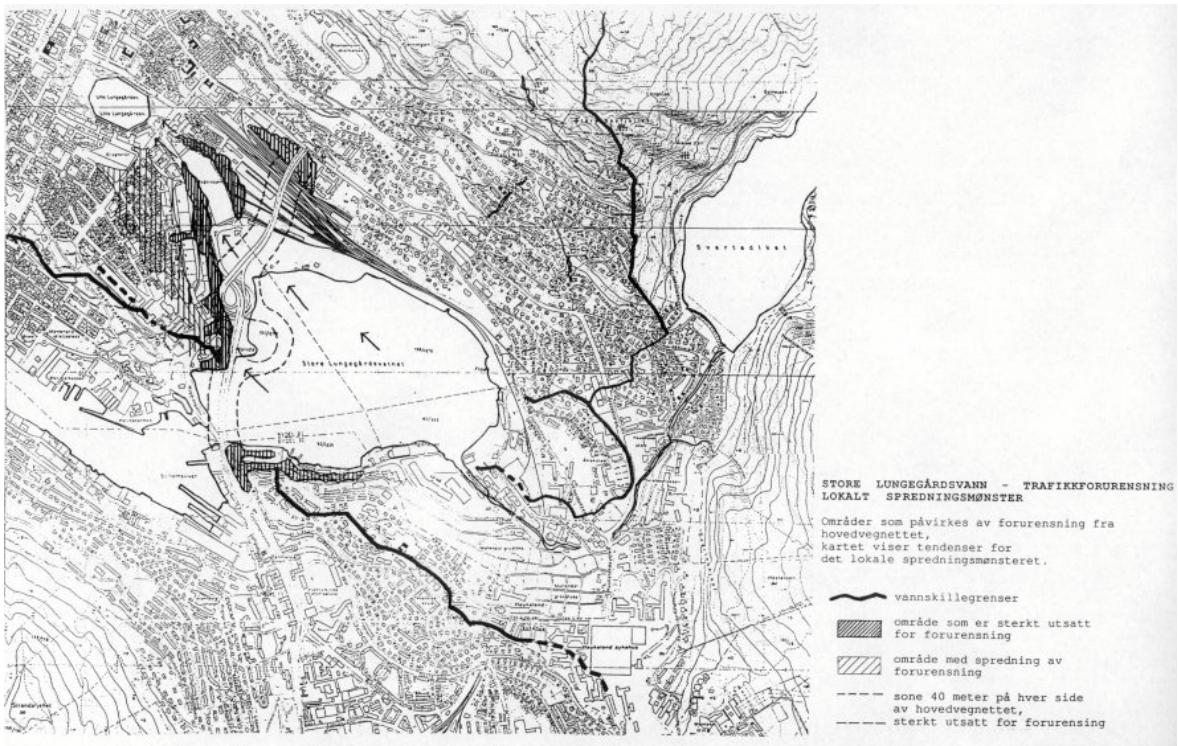


Figure 2.2 Definition of problems on a map. The accumulation of air pollutants, Store Lungegårdsvann. (CASE Store, drawing Børve/Bjørge/Kuismanen)

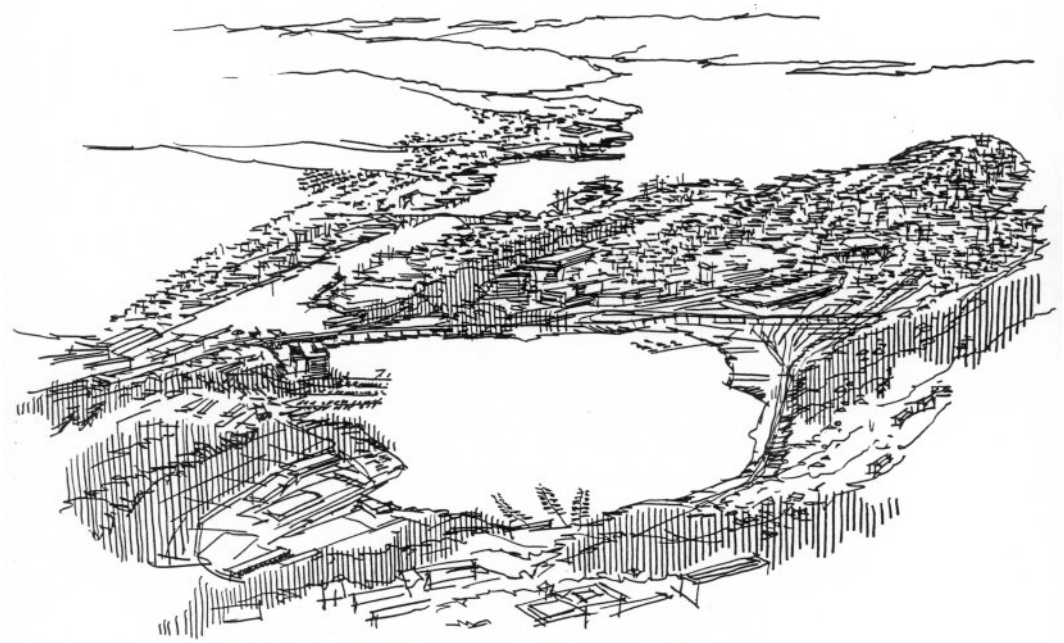


Figure 2.3 Structure of the landscape, Bergen Store Lungegårdsvann. (CASE Store, drawing Eilif Bjørge)

Figure 2.4 Windiness around existing building stock on the basis of scale model wind testing, Oulu Rajakylä. The windiest areas are marked with a raster in which the wind direction is crosswise to the lineation. (CASE Rajakylä, drawing Kuismanen)

2.3 Local climates

Different types of terrain forms have certain effects on the forming of the micro-climate depending on the macroclimate.

Hill

A hill strengthens the speed differences of a weak air flow. 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 to the windward slope an increase in gusting. A calm area will be formed on a treeless slope on the leeward side when the inclination is bigger than 1:3. 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 turned over. A hill which is only under a hundred metres high can increase rain by tens of per cent. See figure 2.5. (Glaumann & Westerberg p 60, 88-89, Mattsson p 76-79, 95-96)

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 on the open areas. (Glaumann and Westerrberg p. 56-65, Mattsson p. 105-110)

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 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. 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 on the slope. (Väkipyörä)

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. (Kivistö p 123, Mattsson p 113-120)

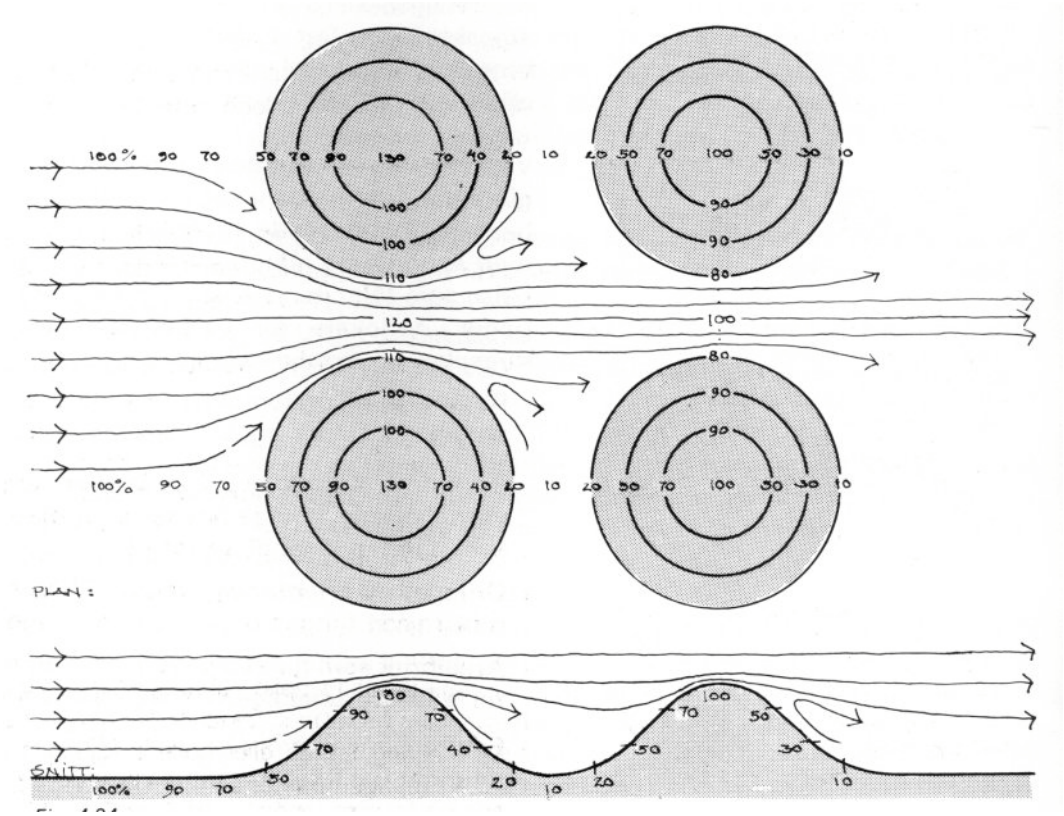


Figure 2.5 Relative speed of the wind around a hill group. (Børve & Sterten p. 58)

Coasts

Due to the slow warming and cooling of 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 dries. 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 affects in addition 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 moisture contents of the air than average explains the abundance of rain there.

The climate of the coast will be affected in spring and early summer by the earth-sea wind-phenomenon, see figure 2.6.

The facts presented above signify from the point of view of design in Northern Europe that the outdoor areas at 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 snowing with the south-westerly winds, the air flow has often a relatively high speed which affects drifting.

Diurnal wind systems

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 to a valley the flow rate increases 10-20%. A valley slows down cross direction flow with 20-30%, landslide valleys even 40%. In the bottom of valleys or of even smaller dents there are easily created cold air lakes, 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, figure 2.7. As heavier cold air begin to slide downwards and at the same time it gathers behind obstacles to make pockets of cold air and to the valleys as cold air lakes. Thus in Finland, the higher the terrain the building is located on, the warmer the place. Figures 2.8 and 2.9 show the wind system of valleys.

The coasts of seas and of big lakes affect the land- and sea-wind 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 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. Figure 2.6 describes the sea- and land-wind systems. (Børve & Sterten, Kuismanen Oulun, Venho, Väkipyörä)

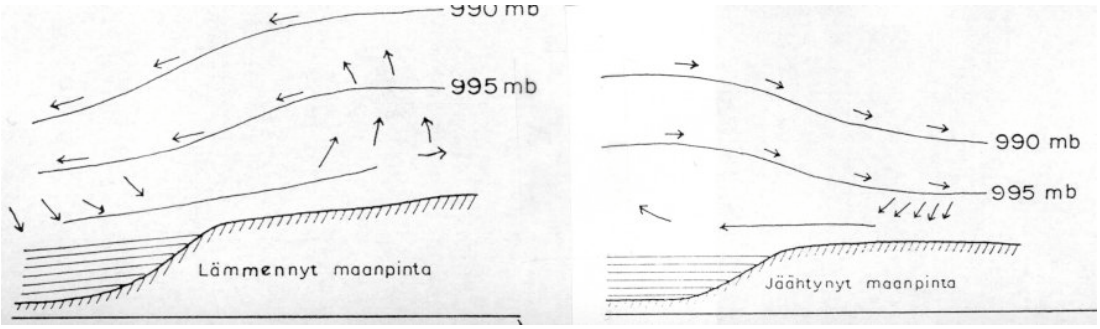


Figure 2.6 Sea-wind will be created during sunny days when the terrain will warm up and the land-wind when the sea retains it's heat at night. (Venho)

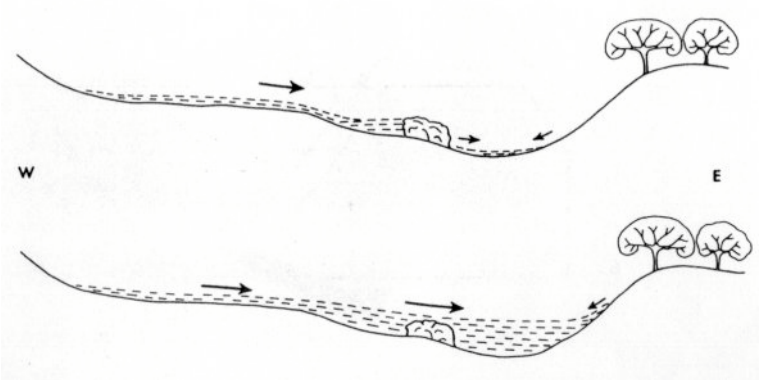


Figure 2.7 Forming of cold air lakes on night. (Mattsson p. 86)

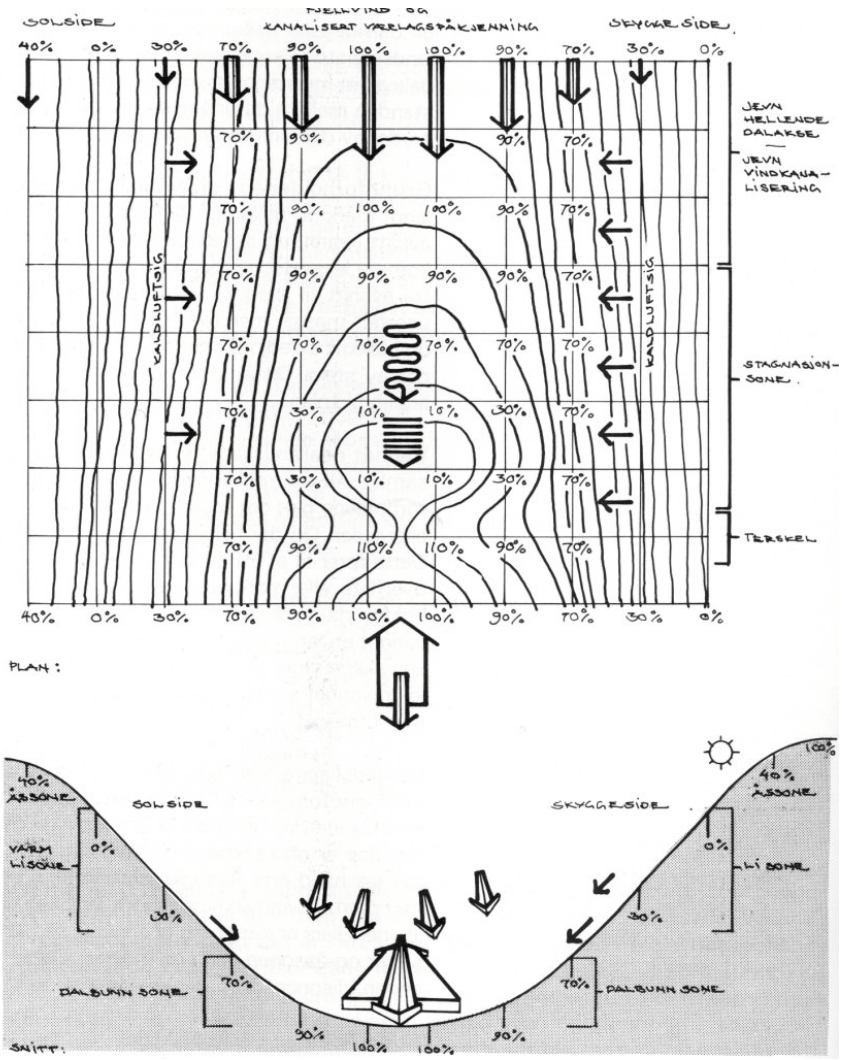


Figure 2.8 Wind speeds in a valley, where a valley wind dominates, and a cold air lake which is at the bottom. (Børve & Sterten p. 74)

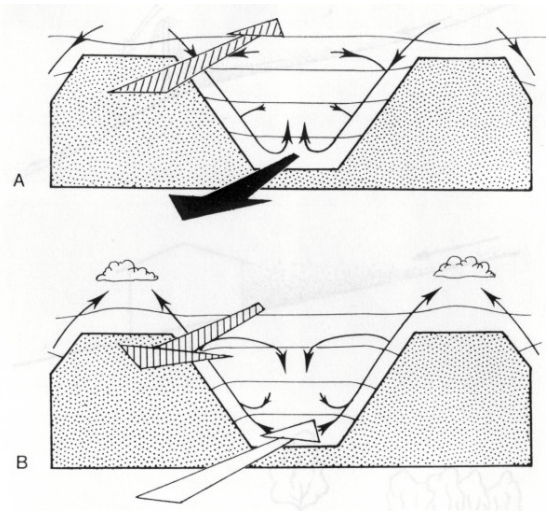


Figure 2.9 Diurnal wind system which functions in most valleys. A: At the bottom of the valley on clear nights from mountains coming mountain wind parallel with the valley. Higher it's upstream. Marked with small arrows are cross direction air masses descending by the slopes of the valley. B: Lower the daytime valley wind rising up the valley. Higher it's counter-stream in the upper layers. The cross flows are rising by the slopes. (Mattsson p. 85)

3 EFFECT OF THE WIND ON BUILDINGS

3.1 Air flows around buildings

The wind powers which are directed towards a building are divided into three components which have effect on axes x, y and z:
- parallel with the wind power (on both sides in the walls)
- to sides directed power (in both gables)
- raising power (on the roof)

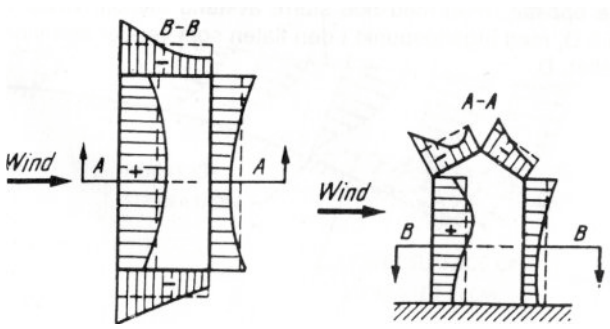


Figure 3.1 Wind loads directed towards a building. (Ghiocel, Lungu, cit. Børve p. 22)

1. Effect of the wind on wall structures

The wind powers are directed at the maximum towards a wall which is located perpendicular to the flow, particularly when the wind is a little turbulent. At the same time low pressure powers are caused on the wall. The biggest low pressure power is directed to the upper part of the gables 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 a 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 already new factors to the wholeness. (Børve p. 22-23)

Buildings which are higher than their environment direct the wind towards the ground, which strengthens the flows near the surface of 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. Also on the leeside of a building strong gusts of wind can be created even if the average speed of the wind were 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 (Broas p. 22-24, Glaumann & Westerberg p. 12120, Murakami)

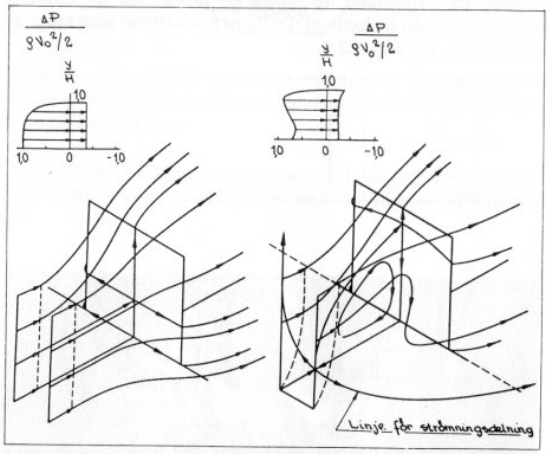


Figure 3.2 Even laminar (at left) and turbulent (at right) flows will have different patterns when their meet a building. (Baines, cit. Børve p. 30)

Evans has done 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 figure 3.4. 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 air flow at a right angle causes a larger whirl on the leeside than a building which is set obliquely (G). (Evans)

At higher storey levels it 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. At the uppermost storey the eaves of the ridge roof adds to the speed of the air flow compared with a flat roof. (Glaumann & Westerberg p. 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. At flat roofs negative pressure usually dominates and a different kind of turbulence appear. Wind pressure will change to overpressure 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 30º pressure effects will be the smallest. (see figure 3.3)

A pitched roof is lifted by negative pressure at angles between 0-15º. Over 15º inclination causes slight overpressure on the middle area of the roof, and at about 25º 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. (Jensen, Matson p. 122)

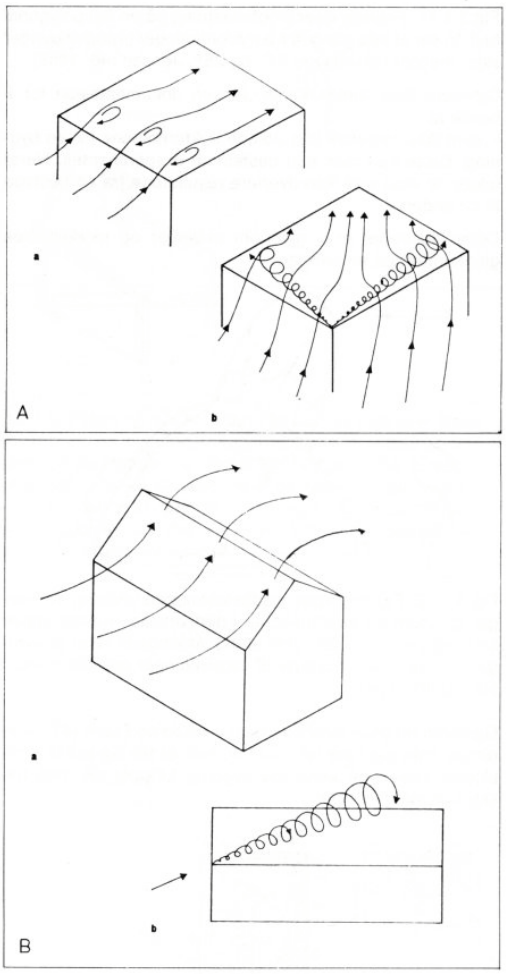


Figure 3.3 Patterns of the air flow on a flat roof (A) and on a gable roof (B). (Lawson, cit Børve p. 32)

3.2 Effect of the wind on building groups

Usually surrounding buildings weaken wind speeds around individual buildings in a building group, but a wrongly shaped 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 p. 29, CASE Rajakylän tuulitestaukset, Glaumann & Westerberg p. 120)

Gandemer's principles give a simplified picture about the wind flow patterns around long rows of buildings (see figure 3.7):

1. A 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 a 45º angle to the dominating wind direction. The length of the building group is more than eight times the building height.

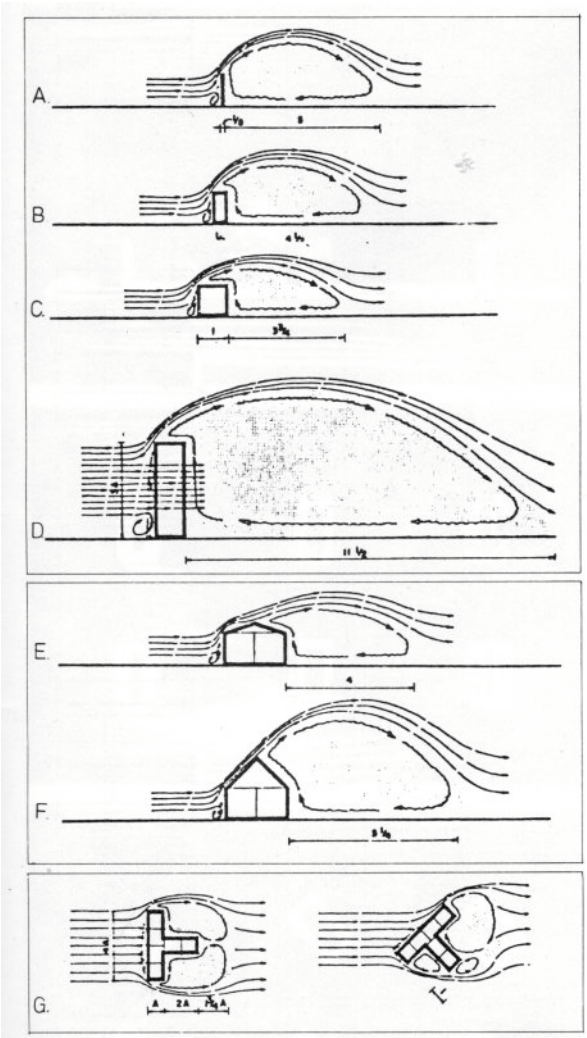


Figure 3.4 Effect of different building masses on the downwind eddy. (Evans p. 5-12)

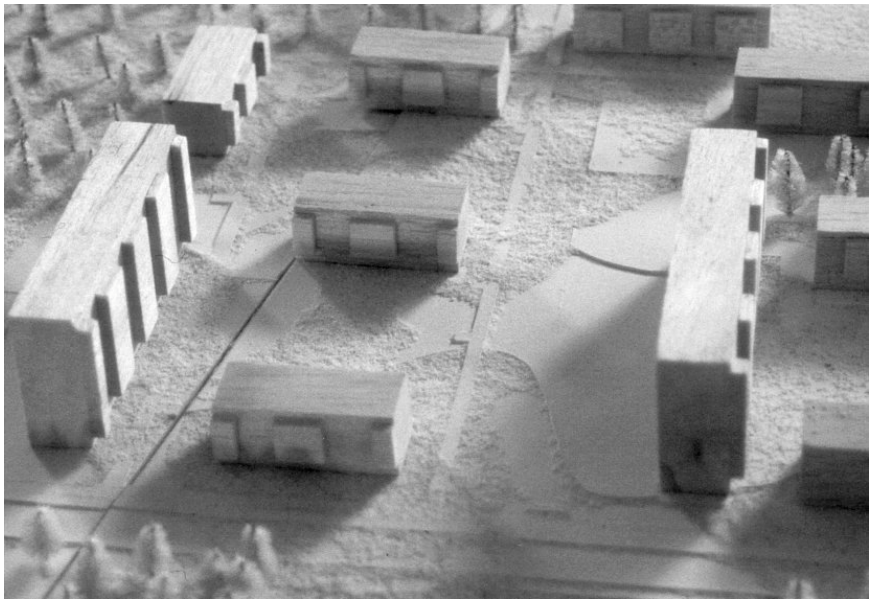


Figure 3.5 The wind channels caused by the high buildings are seen in the model photo as distinctly bare sections. In the picture the wind will come from the left. Oulu Rajakylä. (CASE Rajakylä, figure Kuismanen)

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

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

4. A wind channel will be formed, when the width of the passage 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 p 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:

1. The 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 the building and continues as a large whirlwind which is directed at the facade of the opposite building. These currents are created most easily in a town structure, which is located at an angle of 30-60 degrees to the dominating wind direction.

2. In a closed block, where the width of the yard is about 60 m and in which the buildings are less than 12 m high, the wind continues over the block to the street space. If the same block is built over 12 meters high, the air will stay in the block as a whirl current.

3. In a street space, whose width is more than 30 m, a horizontal whirl which develops from the flows around the buildings is created. If the street space is narrower, the horizontal whirl will not be created.

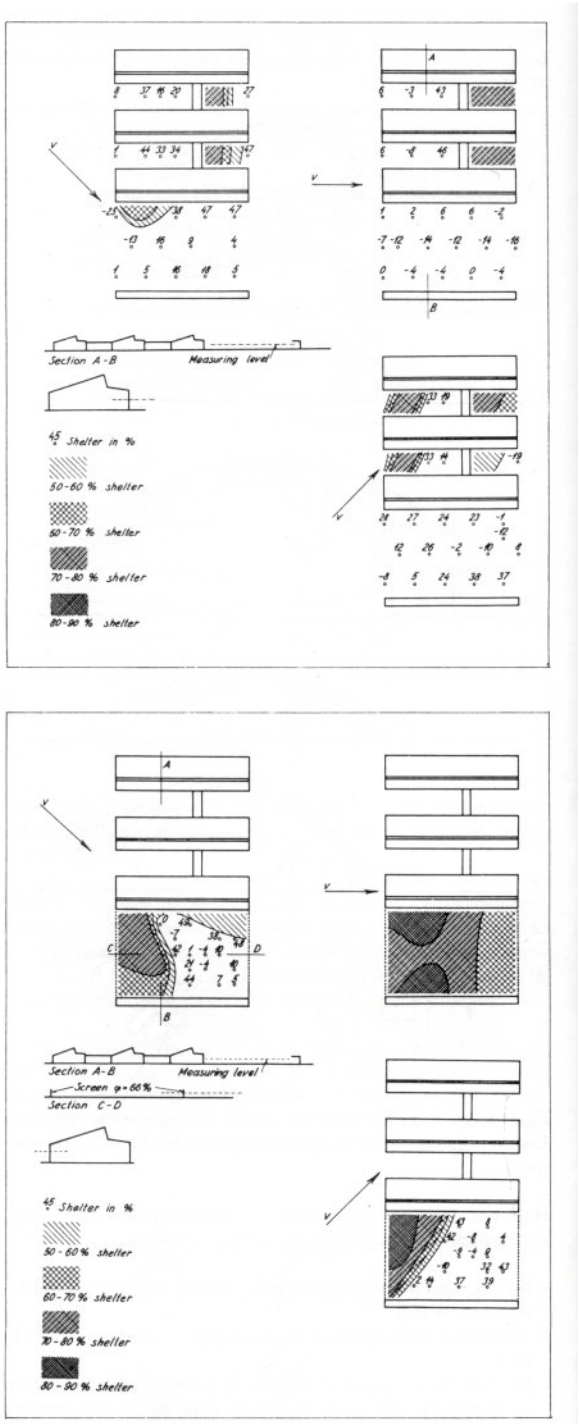
4. In a broad street space the largest current will be created, when the direction of the wind is parallel with the street. In narrow streets the wind that blows at an angle of 45 degrees with respect to the street network causes the highest flow rate.

5. A massive building causes more windiness in its immediate surroundings, than a building mass as big, which is divided properly.

6. The longest uniform street canyons are also the windiest. (Alberts)

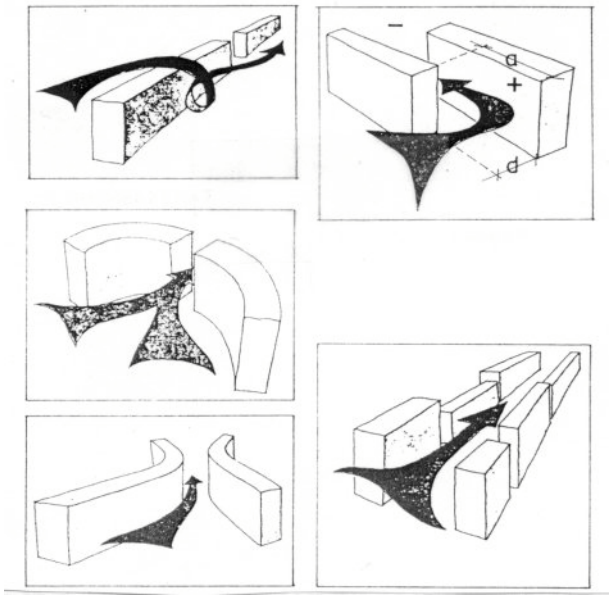
As a rule of thumb one can state about the dimensioning of a closed courtyard surrounded by no more than three storey building that the air flow begins to have a greater effect on the yard, when the distance between the buildings compared with their height is over three-fold. When the courtyard measure 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. The dimensioning of a yard that has been protected from the winds is often in conflict with the distances required by the sun angles. (Alberts, Børve p. 148)

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 diagram has a relatively good microclimate when carried out with one-family houses (figure 3.12). (Alberts, Børve p. 37, Kuismanen Kemijärvi)



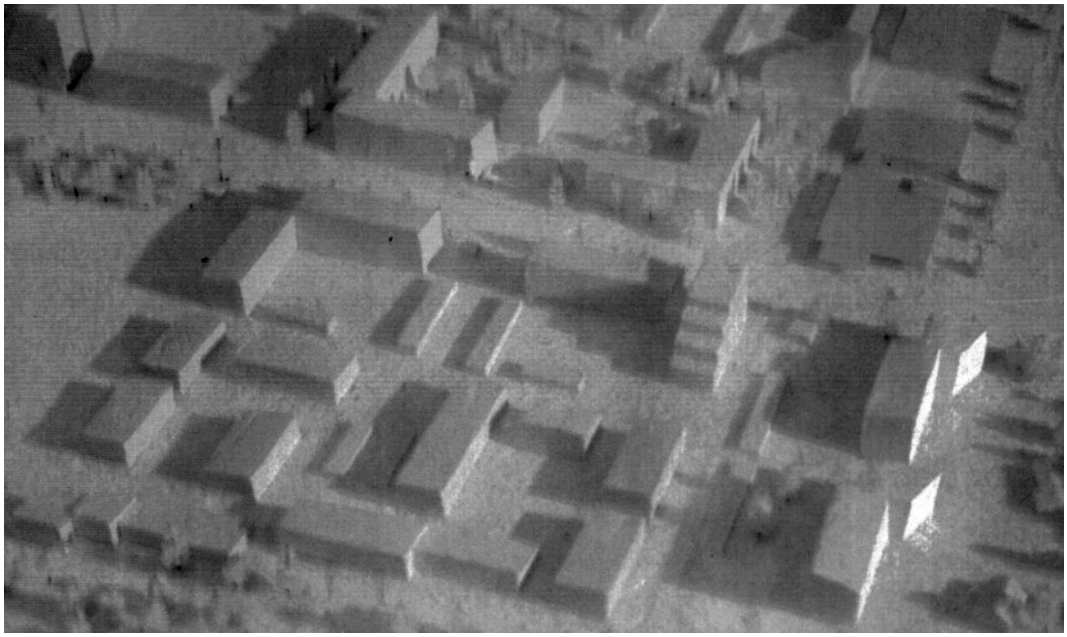
Kuva 3.6. In the upper figure the wind protection effect of row buildings with different wind directions. In the figure below the yard is protected with a wind-protection wall that has 66% openings. (Jensen)

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 should be led over the yard and to create a sheltered recess by a v-shaped building 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.



Kuva 3.7 Gandemer's principles, air flow patterns between buildings. (Gandemer cit. Dubinski)

A building can direct towards the neighbouring buildings' air flows that cool structures or yards 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. (Børve p. 155-174, Kuismanen Tervolan)



Kuva 3.8 Half closed block that has been shaped to protect against the wind, Rajakylä Oulu (Case Rajakylä)

From the point of view of air quality it is necessary to arrange sufficient area ventilation in sections where there are air pollutants. 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 microclimate. The

wind can be utilised in cooling, but in the North-European countries usually shading is experienced as a more pleasant method of cooling than wind.

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. 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. (Climatic p. 47-49, Halvorsen p. 39-42, Hideki, Miller p. 85)

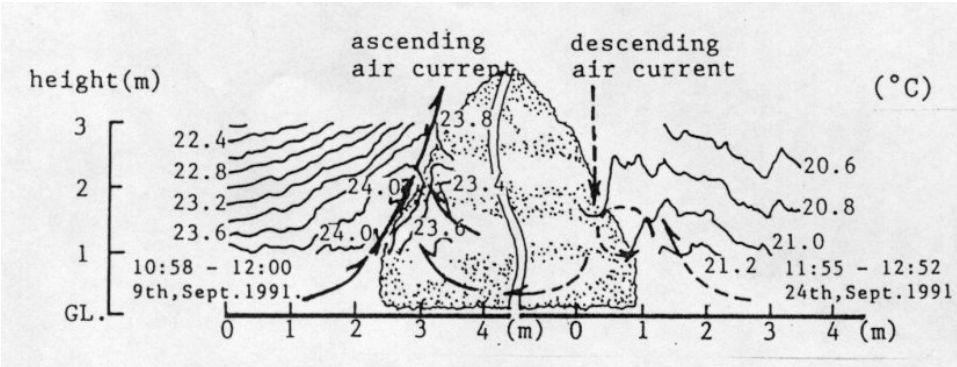


Figure 3.9 Distribution of air temperature and air flows at sunny and shade sides of a tree. (Hideki)

Summary of the planning recommendations:

- retain the protective tree stand
- place residential areas and building masses according to the sun, avoiding the shading of neighbours
- avoid cold winds and cold air lakes
- water stabilises temperature differences and improves air quality
- dense, low and small-scaled building facilitates the creation of good microclimate
- high buildings direct air flows towards the ground
- dimension and direct streets so that wind speeds do not increase; ventilate exhaust gases
- arcades protect from rain, slipperiness and solar radiation.

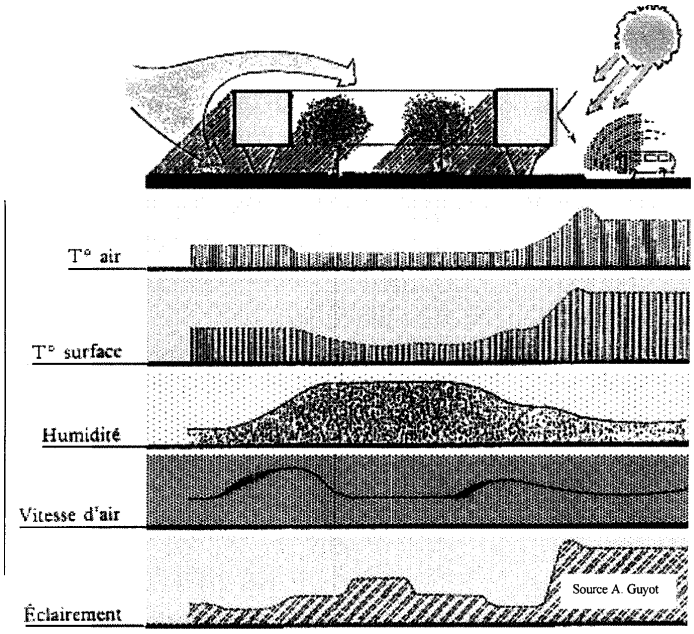


Figure 3.10 Air temperature, surface temperature, humidity, air flow speeds and natural lighting affect the microclimate of building sites. (Ecole)

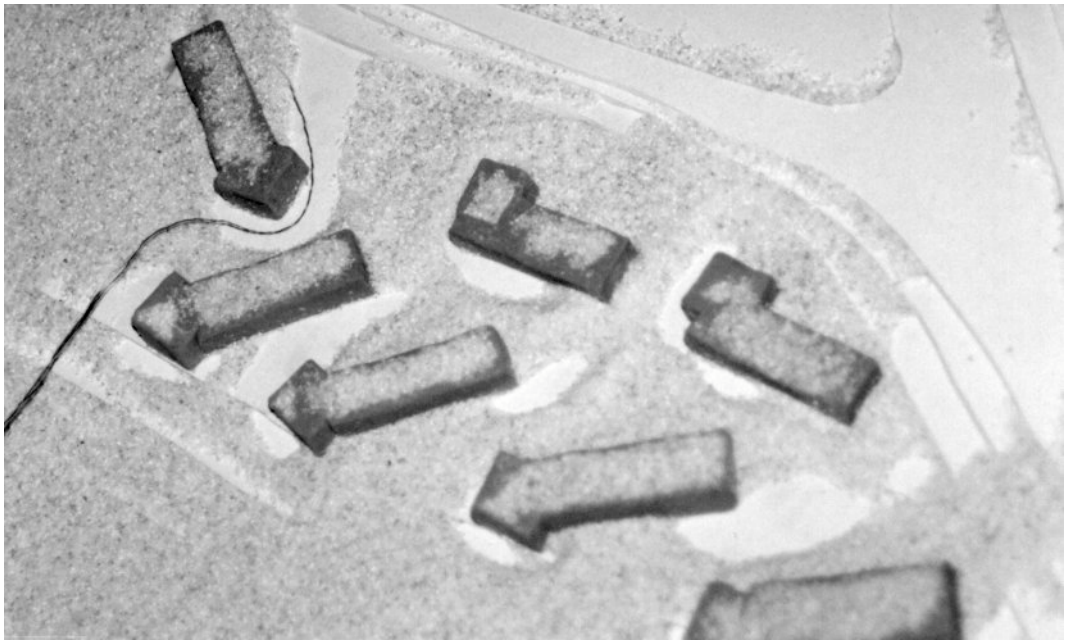


Figure 3.11 Open building way is very exposed to the winds, which is a problem in cold climates. The thread shows the air flow. (Kuismanen Kemijärvi)

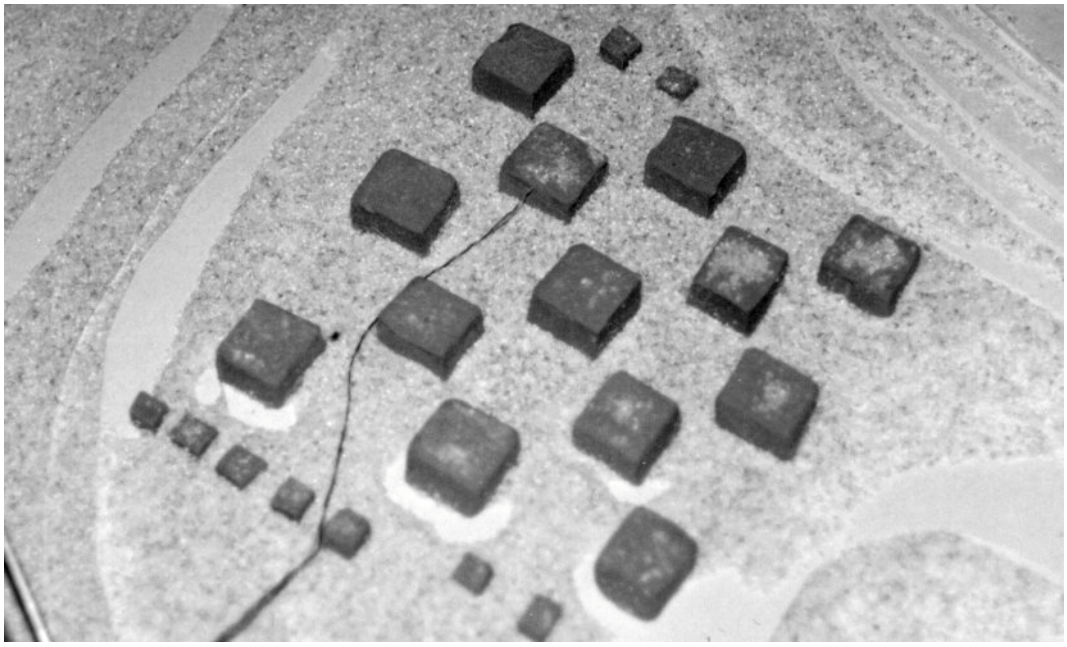


Figure 3.12 Small-scaled relatively dense pattern of building considerably reduces the power of wind. In the model the air flow goes between the houses but is considerably weakened. (Kuismanen Kemijärvi)

4 DESIGN OF BUILDINGS AND RESIDENTIAL BLOCKS

4.1 Architecture

The climate does not determine the form of a building but affects it. 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 house technical concepts of the houses are different in all of these climates.

Attention has to be paid immediately in the first stage of sketching to the environment and climate. 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 figure 4.1), which illustrates the conditions. In addition to winds, on the rose there can be also other environment factors, which describe solar radiation, protective elements, noise sources and views.

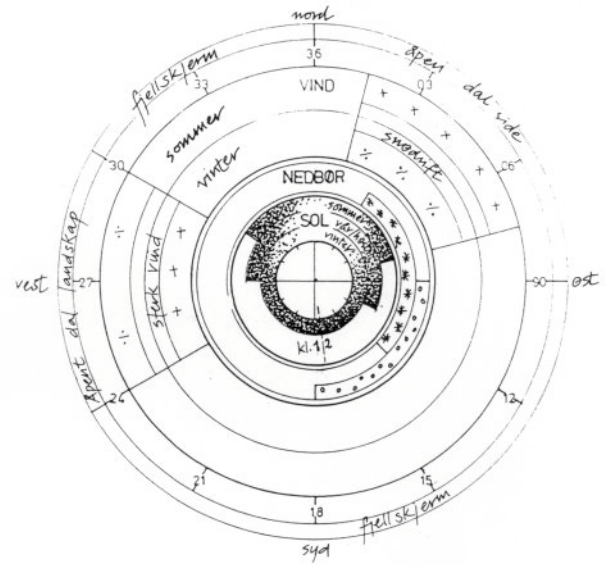


Figure 4.1 Example of a “climate rose” in which the most important microclimate factors of the site during the different seasons are shown. On the outermost circle are shown the protective features of the terrain, on the middle circles the most common winds and rains brought by them and in the centre sunniness. (Miller p. 50)

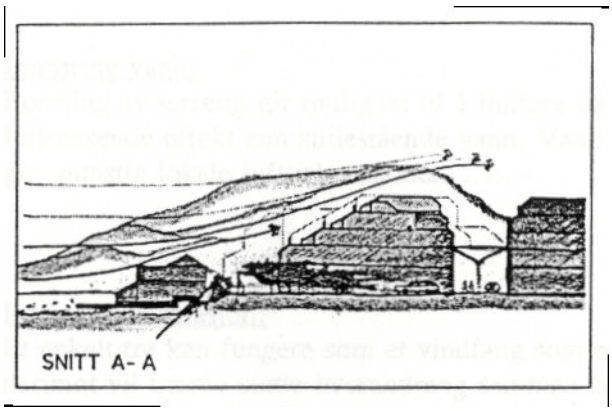


Figure 4.2 Directing the wind above a building group by grading construction heights. (Halvorsen p. 61)

Usually low construction and abundant vegetation reduce the effect of winds, and high buildings strengthen it. In the corners of buildings the air flows are the most difficult to command. 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 building the buildings as closed blocks. With L-shaped buildings it is easier to make a positive microclimate than with those that have rectangular masses. Round and pyramidic 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. Properly placed wings and bay windows also promote the making of a good microclimate. 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 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 of 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. (Broman p 22-24 p 28-29 Glaumann & Westerberg)

Norway's housing bank *Husbank* grants an additional loan for carrying out design solutions for harsh climates. The loan terms of detached houses built in Hammerfest give a good picture of the demands of building in north:

- 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 at 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 (Lånetillegg, Husbankhus)

In housing the use of interior and exterior spaces interrelates 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 facade. *Hortus Conclusus*, the secret garden, is a centuries-old example of a small positive territory made by man for himself. (Climatic p 23-28 p 556-558 Pietilä)

4.2 Structures

Industrial building has brought many new materials and detail solutions, which have not had a sufficient long-term durability in a harsh climate, and as a consequence of this structural damage. Even many established solutions which are in accordance with a good mode of construction have failed in the long run or during exceptional years. (Berg, Kauppinen)

The starting point in a cold and windy climate is that the buildings are made wind-protective and well insulated. Traditionally in snowy and rainy areas the roofs have been made protective with multi-layered structures and long eaves. 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, Rapoport)

In all the climates there are periods when overheating caused by the radiation of the sun must be repelled from buildings. Passively this can be done with different trellises, sheds and other protection structures, which can be designed using scale models with the help of the sundial. For active cooling air flows and sometimes storing of coolness in massive structures are used. The microclimate around and air flows inside a building can be studied and the ventilating devices developed with a wind test blower. (Maas p 78-81, Daniels p 170-173)

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 planning of facades:

- warm 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. (Aicher p 100-103)

Figure 4.3 Protective double façade was made by gratings and garlands, kindergarten Sodankylä (Kuismanen)

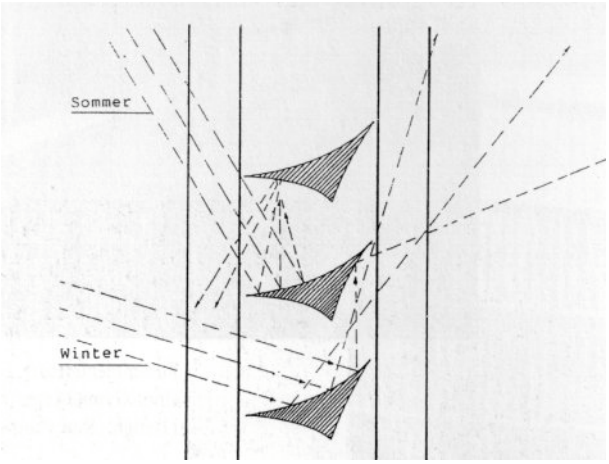


Figure 4.4 Façade laths that can regulate solar radiation in different seasons. (Oswalt p. 110, drawing Helmut Köster)

4.3 Protection of outdoor areas from wind, positive micro climate

A good microclimate should be created to the built environment primarily with the planning and design of buildings and by retaining the existing tree stand. Particularly in connection with renovations, if necessary, special wind protecting elements can also be built. The prevention of the cooling effect of wind can also be used to improve the heat economy of buildings.

If an acceptable quality of microclimate is not reached by shaping the urban structure and the buildings, conditions are improved by wind protection. The measures can be divided into distant (area) protection (*fjärrskydd*) and near protection (*närskydd*). Protecting plantings, which reduce wind in the whole area are an example of the 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 low 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 p 24-31)

As area protection several parallel shelters in each other's sphere of influence give a better result together than separate ones. 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. 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 p 126-132 Kuismanen Tervola)

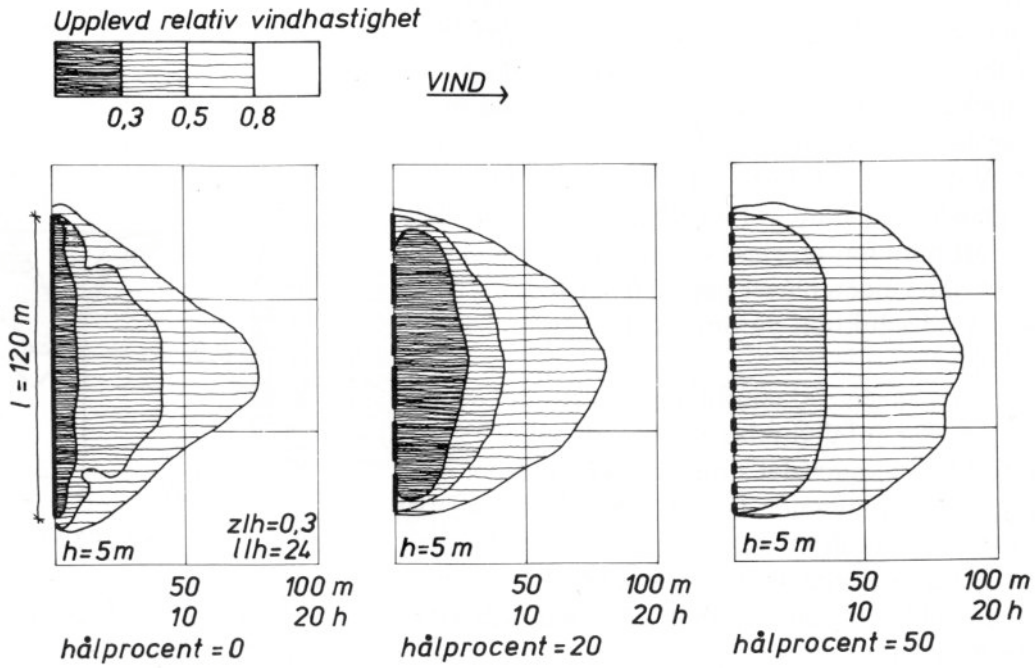


Figure 4.5 Relative wind speeds at 1.5 m height with 0%, 20% and 50% open structures (Gandemer, cit. Glaumann p. 127)

Figure 4.6 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)

The joint of a protecting element and building should be tight. One problem of tight wind protecting walls is turbulence on their lee side, which can be reduced by making openings at the edges of the protecting structure. Walls that permit some air flow through 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. (Broas p. 22-24, Glaumann & Westerberg p. 128-131)

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 Tervolan, Mattsson p. 132-133)

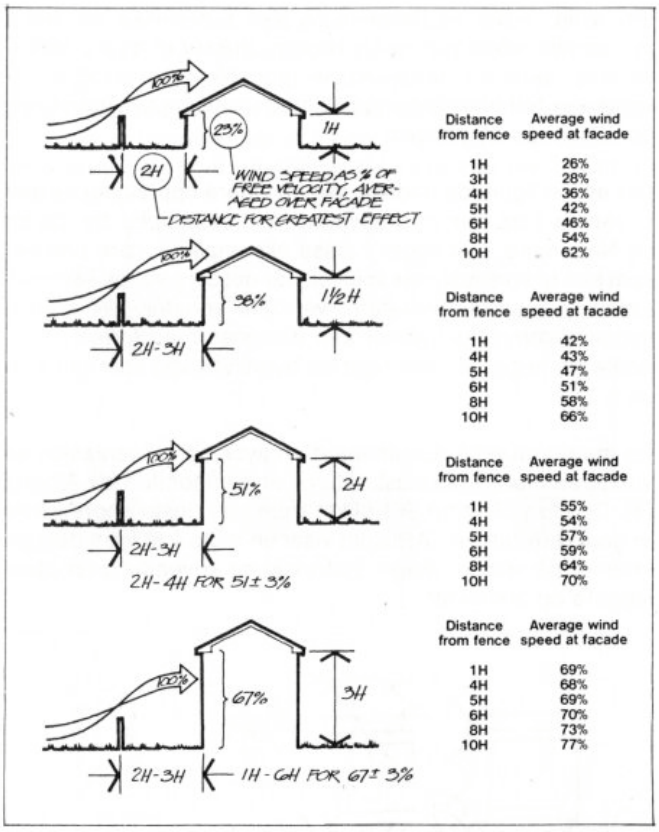


Figure 4.7 Effect of height relations of facades and of protective walls on the speeds of air flows of the facade. (Watson, cit. Børve p. 40)

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 tree stand to increase its durability should be made about five years before construction. (Maaninen, Miller p 88-90)

Farming and gardening set their own demands on the microclimate and protection in different climatic zones. In the north some of the main things are the supply of heat and the avoiding 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 p 125-131)

Summary of the planning instructions:

- 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
- rainy and snowy climate requires a large sheltering roof
- by opening the building to the sun free energy and daylight are utilized
- arrange interior spaces according to warmth zones, and place a buffer zone on the windward side
- protect against cold winds
- protect against over-heating by the sun
- by forming the microclimate and shaping the building, stack ventilation can be intensified.

5 PROBLEMS CAUSED BY SNOW

5.1 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 dictated 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 protecting elements made the whole construction understandable.

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, Mänty)

The effects of snow for building have been studied in Canada, Norway, Russia and the USA. However very little examined information is available for building design and planning for the accumulation of snow. Probably the most comprehensive report on the subject has been made by Anne Brit Børve. (Zrulo)

To manage the problems caused by snowiness in the planning stage in a harsh climate weather charting must be done, in which the amount of snow and the dominating winds are shown. 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. 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. (Stavnov, cit. Børve p. 24-25)

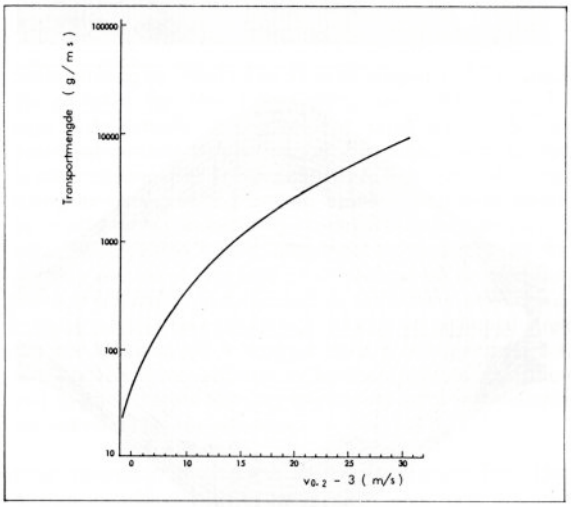


Figure 5.1 Carrying of snow in wind. On the vertical axis the snow amount, on the horizontal axis the wind speed. (Børve p. 25, drawing Dyunin)

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 friction 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 p 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 microclimate.

After snowstorms the forms of snow drifts around buildings are usually exact in form which tells about permanent turbulences. 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. (Glaumann & Westerberg p. 138-141, Havas p. 18-20)

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. (Husbankhus)

6 ENERGY SAVING, VENTILATION

The placing of a building, its directing and wind protection have a considerable effect on the consumption of energy in the conditions of Northern Europe. 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 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 Raportti 2 p. 22, Pienilmasto)

Winds cause pressure differences to 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. (Climatic, Kivistö p 127-130)

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. However, the winds do not have significance to the ventilation of houses in practice, if the average wind speed around the building is less than 2 m/s in the heating season

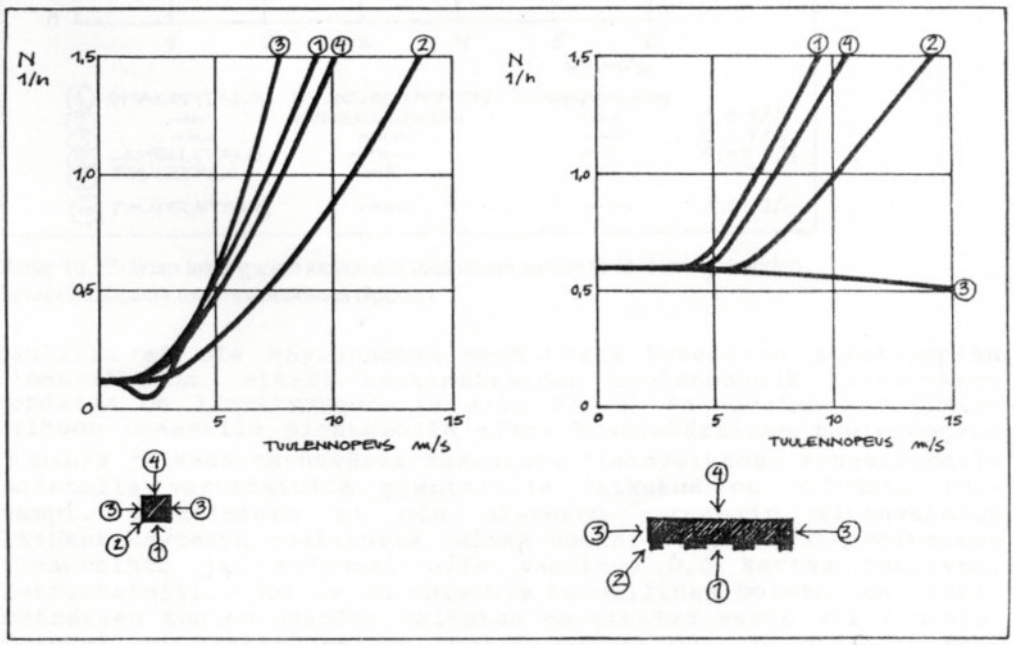


Figure 6.1 The average ventilation amounts of some building types depending on the average wind speed of the heating season. (Kivistö Raport 2 p. 24)

In detached houses which have been equipped with stack ventilation, the difference between the maximum and the minimum will be about 30 kWh/k-m² 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. With mechanical output ventilation a 0.5 times in an hour wind increases the heat consumption of the same small house even 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-m² 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 (2)) p 26-28, 36-37.

The effect of winds on the heat consumption of buildings in Finland is on average only 0.7 kWh/k-m² (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-m², 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. 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. (Daniels p. 165, Kivistö (2) p. 36-37)

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 planning. When the amount of window area on the main facade increases, also the affect of their direction on the heat consumption will 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 already about 12 kWh/k-m², in other words less than 8%.

The total effect of the microclimate consists of the wind, sunniness and warmth of the building site. According to ASTA II study the difference of the relative heat consumption between the maximum cases and the minimum cases is 40 kWh/k-m² (28%) in small houses, more than 37 kWh/k-m² (27%) in multi-storey buildings and for tower blocks 35 kWh/k-m² (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 (2) p. 36)

According to the ASTA II study with planning which takes the microclimate into consideration it should be possible to lower the average heat consumption in residential areas 2.5-5%. On the basis of the study it can be estimated that in Finland within one area microclimate can cause at most an about 20% difference in the heat consumption of individual buildings. 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 p 8 p 40-42 Kivistö Raport 2)

Air movement caused by temperature differences is utilised in the gravitational, in other words natural ventilation of buildings. In the lower part of a room the air is cooler than at the ceiling level, which makes the warm air at the upper part of the room flow out through ventilation shafts or high windows, and the room is ventilated. However, temperature differences which are big enough to change the air do not always occur in summer conditions. In that case natural ventilation must be intensified by the ventilation through windows, solar ventilation flues, with under-pressure ventilators or pressure differences caused by the wind on different sides of the building. (Climatic p. 63-66, Evans p. 1-4, Kossak p. 45-49)

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
- air flow caused by the evaporative cooling (patio or wet chimney).

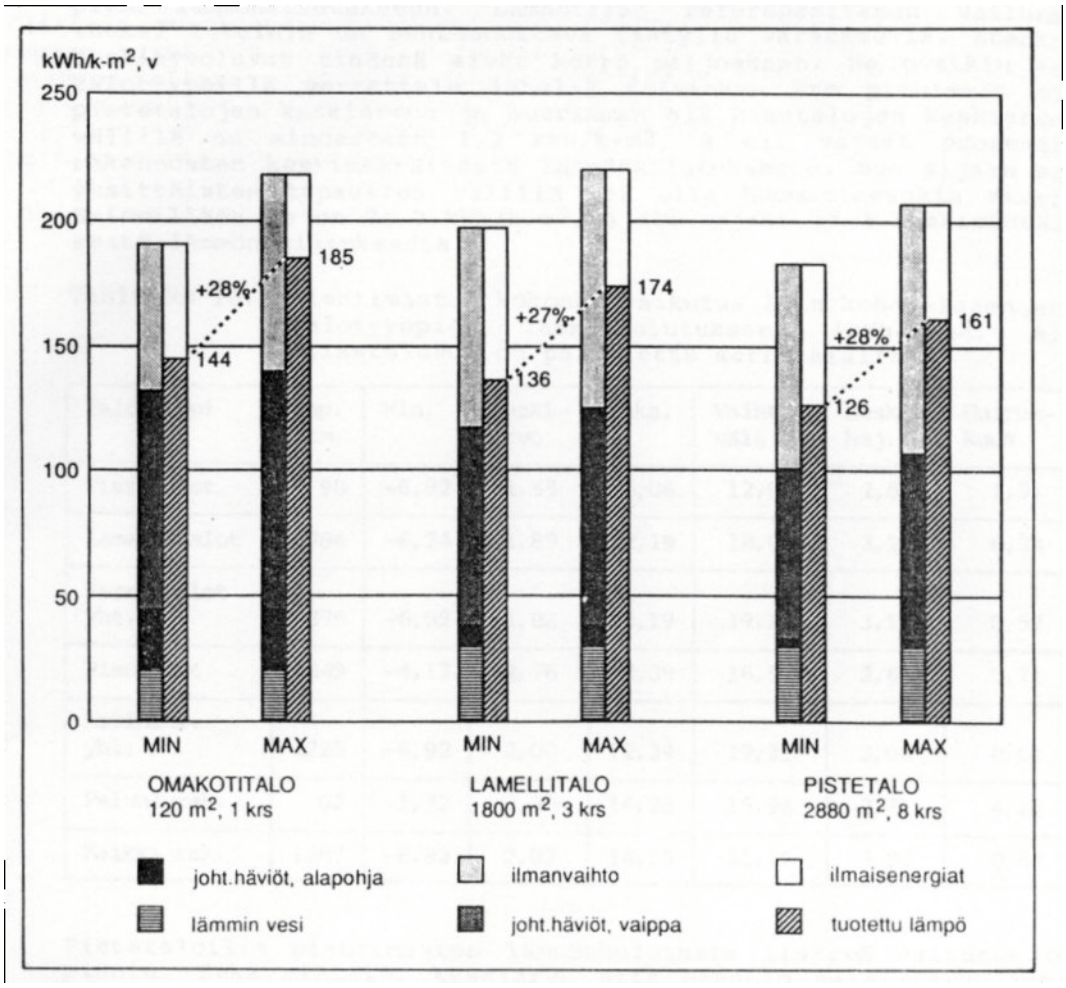


Figure 6.2 Heat balance of three different house types in regard to microclimate in a as good as possible and bad situations. (Kivistö Raport 2 p. 37)

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 up 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. (Daniels p. 164, Kossak p. 45-49)

Summary of the planning instructions:

- 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 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.

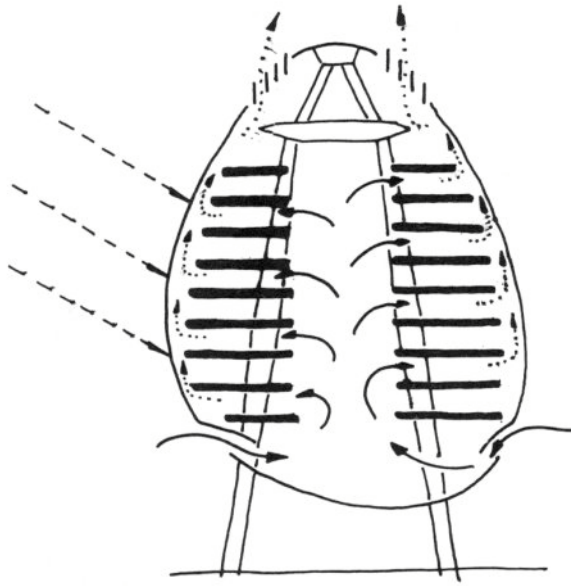


Figure 6.3 Solar facade as air conditioning system. (drawing Future Systems, cit. Oswalt p. 138)

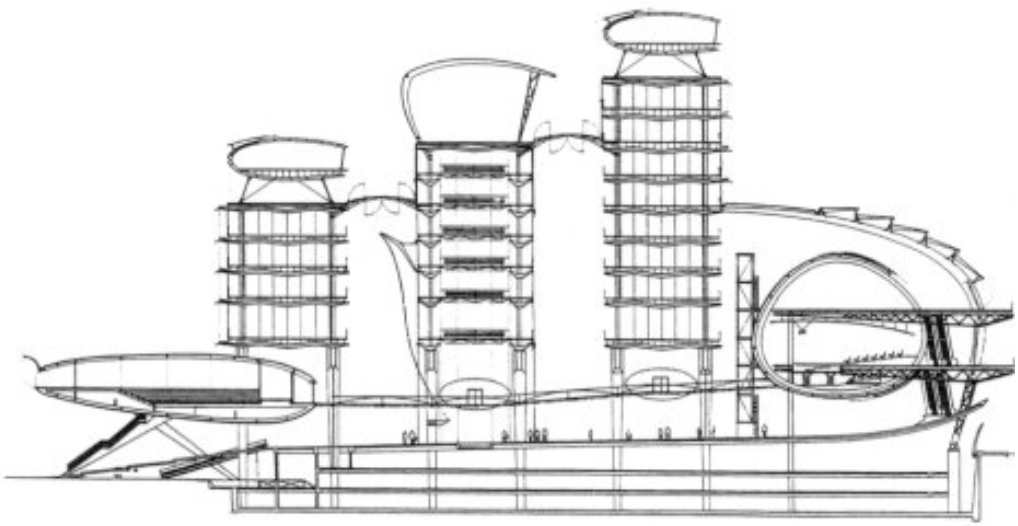


Figure 6.4 Big building complex in which the ventilation of atriums is natural, Hotel du Department Marseille. (drawing Alsop & Lyall, cit. Oswalt p. 48)

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