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Climate change and risks to the built environment

Seppo Saarelainen

FINADAPT Working Paper 9

FINNISH ENVIRONMENT INSTITUTE

CLIMATE CHANGE AND RISKS TO THE BUILT ENVIRONMENT

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FINADAPT WORKING PAPER 9

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Preface

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"[1]. The IPCC lists two reasons why adaptation is important in the climate change issue. First, an understanding of expected adaptation is fundamental in evaluating the costs or risks of climate change. Second, adaptation is a key response option or strategy, along with mitigation. Even with reductions in greenhouse gas emissions, some climate change is regarded as inevitable, and it will be necessary to develop planned adaptation strategies to deal with the associated risks as a complement to mitigation actions.

In Finland, there has been substantial progress during the past decade in investigating the potential impacts of climate change on natural and human systems. In contrast, there has been much less attention paid to adaptation. This was recognised by the Finnish Parliament as early as 2001, when it recommended that a separate programme for adaptation to climate change be initiated. As a result, a task force co-ordinated by the Ministry of Agriculture and Forestry completed Finland's first National Strategy for Adaptation to Climate Change in 2005.[2]

At about the same time as the Strategy document was being drafted, a research consortium named FINADAPT also began its work. The goal of the consortium, involving 11 partner institutions co-ordinated by the Finnish Environment Institute, was to undertake an in-depth study of the capacity of the Finnish environment and society to adapt to the potential impacts of climate change. FINADAPT was funded for the period 2004-2005 as part of the Finnish Environmental Cluster Research Programme, co-ordinated by the Ministry of the Environment. It comprised 14 work packages (WP) covering: 1) co-ordination, 2) climate data and scenarios, 3) biodiversity, 4) forests, 5) agriculture, 6) water resources, 7) human health, 8) transport, 9) the built environment, 10) energy infrastructure, 11) tourism and recreation, 12) economic assessment, 13) urban planning, and 14) a stakeholder questionnaire. The primary objective of FINADAPT was to produce a scoping report based on literature reviews, interactions with stakeholders, seminars, and targeted research.

This report, from work package 9, examines the implications of climate change for the built environment in Finland. It considers the essential infrastructure on which the vast majority of the Finnish population depends – for housing, for utilities (e.g. water, electricity, heating, telecommunications, sewerage), for commerce and for a range of services. These are likely to be vulnerable to changes in climate, especially to changes in the frequency and magnitude of extreme weather events. A range of engineering solutions to the design and construction of infrastructure are proposed that would help to minimise the risk of damage and disruption.

Timothy Carter, Consortium Leader
Helsinki, December 2005

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[1] IPCC, 2001a. *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds)]. Cambridge University Press, Cambridge and New York, p. 982.

[2] MMM, 2005. *Ilmastomuutoksen kansallinen sopeutumisstrategia* (Finland's National Strategy for Adaptation to Climate Change) [Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatuki, J., Järvinen, H., Liski, J., Merivirta, R. and Paunio, M. (eds)], Ministry of Agriculture and Forestry, Helsinki (available in Finnish, 276 pp., Swedish 212 pp. and English, 280 pp.) http://www.mmm.fi/sopeutumisstrategia/

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CLIMATE CHANGE AND RISKS TO THE BUILT ENVIRONMENT

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Executive Summary

Introduction. The vulnerability of the built environment to climate change impacts depends on the response level of the buildings and infrastructure. Most impacts should be taken into account in normal design and construction practices. The risks anticipated with climate change are manifest in a higher occurrence of extreme values, which increases the risk of damage and costs. Climate change is normally analysed as a change of various climate components like temperature, precipitation, temperature, wind speed, etc. The manifestation of impacts on buildings and infrastructure may be either sudden or extended.

Damage is caused if the climate-based impact exceeds the design level. The damage can increase dramatically with a rising impact level. Normally, the design criteria are set following common, international practice or national safety standards or costs. Recent years have shown that the Finnish society is not properly prepared for extreme effects. Some recent events include:

- storm rain flooding in central and western Finland in July/August 2004
- sea coast flooding in the Gulf of Finland in January 2005
- snow melt and storm rain flooding in the river courses at Kittilä and Ivalo, May 2005

To provide for extreme climatic events, the investigation and documentation of damage occurrences is important. Investigations should cover, besides damage costs, the prevailing weather conditions and resulting damage, including the damage process, mapping of damaged objects and evaluation of technical causes. On the basis of the damage investigations, necessary and possible protection measures can be implemented and longer-term measures introduced for adapting communities to withstand climate change impacts.

The need for adaptation. Adaptation can be seen as risk assessment considering:

- *Contingency (emergency) planning,* which is needed to create appropriate preparedness and provision for extreme climatic impacts, like floods and storms. The needs and measures of provision can be considered on the basis of recent damage investigations.
- *Structural enhancement of the existing built environment* to limit and prevent damages. Feasible protection measures can be evaluated and planned during the re-planning of existing communities.
- *Improving design criteria of new construction* (design wind speeds, flood levels, etc.). New buildings can be adapted by changing design principles.
- *Implementation in urban planning.* Consideration of natural conditions, including climatic conditions (storms, floods, temperatures) should be emphasized. These aspects should be studied in the planning of new areas as well as in the renewal of old communities.
- *Improving general building regulations.* Guidelines and recommendations concerning structural loadings, moisture-resistant properties, vulnerability to floods and storms etc. should be improved.
- Important municipal utility services (clean water, sewage treatment, waste management, industries handling hazardous materials, etc.). Risk analyses as well as emergency planning and improvements concerning networks, devices and facilities should be carried out regionally and at sites.

Research needs. New knowledge is needed to develop and maintain sustainable communities in a changing climate. In the case of the built environment and communities, the main responsible body is the municipality.

Thus, the development and implementation of practical measures should be carried out together with the local municipality. The following research will be needed to improve the capability for adaptation:

Basic knowledge

- *Determination of weather statistics*. These include available climatic data on critical parameters as well as estimates of future changes in extreme values and probability of occurrence
- *Development of efficient methods for the inventory and monitoring of terrain conditions and vulnerability over large areas*. These are needed for evaluating the response and vulnerability of natural terrain and built areas at a large scale.
- *Development of early warning systems for critical weather events.* These systems facilitate early, proactive and appropriate preparation and resemble normal contingency planning against sudden accidents like fire, explosion, earthquake, etc.

Damage investigations

- *Documentation and physico-economical analysis of damage processes in actual cases of damage.* The processes leading to damage should be investigated and documented to recognise the basic mechanisms involved and possible avoidance measures. Comparing damage costs and possible improvement costs, the concept of optimum solutions can be studied.
- *Development of preventive measures for acute hazards.* To limit flooding, efficient protective materials, structures and equipment suitable for temporary use should be developed. Also a protection strategy (emergency planning, operational planning) should be developed.
- *Development of repair and rehabilitation methods for damaged buildings and structures.* Efficient and reliable methods for physical investigations of wetted structures as well as technology for repair and rehabilitation.

Building technology

- *Development of sustainable solutions for design and construction of buildings and infrastructure.* The design of buildings should be studied to examine effects of enhanced wind loads, stronger horizontal rains, and increasing moisture loadings from the ground. The efficiency of drainage around buildings and their foundations should be improved to minimise flood damage.
- *Improvement of building regulation concerning climate-induced hazards.* Current regulations and recommendations should be checked to account for possible climate change impacts on buildings and other structures in the built environment.

Community planning

- *Development of methods for planning a sustainable urban environment.* Consideration of natural conditions requires testing and implementation of efficient methods for analysis and description of natural conditions. This kind of knowledge is needed, for example, in mapping of flood risks and regional drainage planning and design. Planning tools for a safe environment can be developed applying the method of prototype planning.
- *Development of guidelines for city planning*

1. The components of climate change

1.1. Environmental, climate-induced loadings on the built environment

Climate is a variable environmental state of the atmosphere that has different outcomes on living conditions. Many of these may be positive but some can be negative, depending on the considered aspect or activity. When discussing the effects of climate change, it is usual to consider those influences that are threats to society.. The benefits of climate change are not discussed so much – they are rather considered as opportunities.

The climate system and its impacts on the built environment are illustrated in Figure 1. To adapt the built environment to changed climatic conditions, the different structures and activities in them need to be changed so that the living conditions are not seriously jeopardized and the lifespan and maintenance costs of structures are tolerable and optimized to account for the new climatic hazards. Though the immediate concern is about anthropogenically-induced climate change, it is worth pointing out that the Finnish climate has fluctuated continuously for natural reasons throughout the historical record (Eronen and Olander, 1990).

Most climate-related impacts are already considered in the current practice. The tolerance limits for hazards normally correspond to extreme values recorded historically. Changes in mean values mainly affect the conditions of use.

The anticipated change in climate in the terms of some important climate components is described by Carter et al. (2005) and Ruosteenoja et al. (2005). In the following, the importance of different climatic factors for buildings and the built environment are discussed.

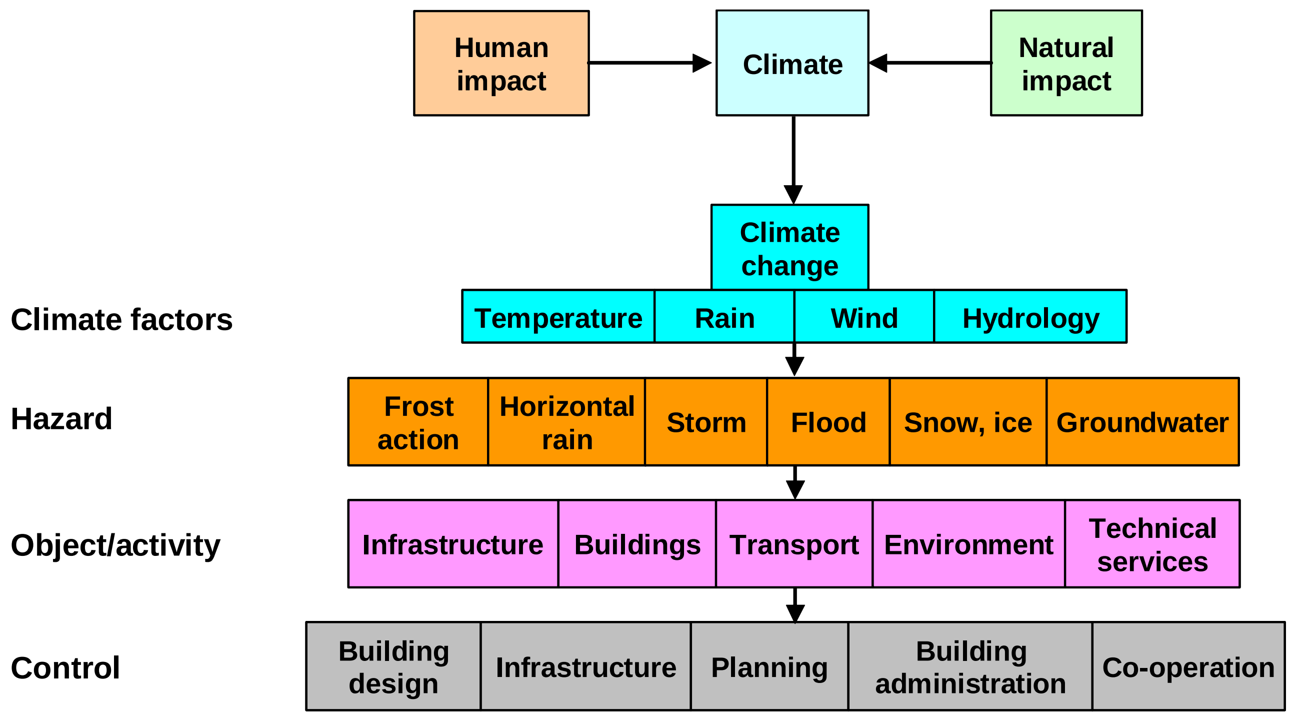

Figure 1. The interaction between climate, the built environment and building regulation.

1.2. Air temperature

Atmospheric temperature follows the seasonal rhythm of solar radiation, which is disturbed by low pressure activity, bringing moist air, cloudiness and rains over Finland from the Atlantic. In winter the effect of low pressures is more distinct, largely determining the severity of low temperatures. In summer the influence of low pressures on atmospheric temperature is usually less.

In recent climate scenarios, air temperatures are expected to rise 2-8^{o}C in the coming 100 years (Ruosteenoja et al., 2005). Higher winter temperatures will result in a lower freezing index and thinner frost penetration. Maximum frost penetration into snow-free roads and streets has been estimated to decrease in an average winter to about 1.2m in southern Finland and about 2.2m in northern Finland. The decrease of frost penetration would be about 0.5 metres. The thaw will be completed about 1 month earlier than today. It has also been estimated that frost protection would still be needed for foundations and structures, even under a changed climate (Ala-Outinen et al., 2004). Similar changes in seasonal freeze-thaw have been projected more generally in the Arctic (U.S. Arctic Research Commission, 2003).

1.3. Precipitation

In urban areas, surface runoff may become a problem if it accumulates in the wrong places. Precipitation infiltrates over natural terrain forming groundwater, and surface water usually has minor impacts on the landscape and structures. Infiltration is reduced in developed areas due to the use of impermeable surfaces, and surface water flow is therefore increased, causing erosion damage as well as surface flooding following extreme rainfall. In Finland, the paved areas such as streets are designed for storm rains with an intensity of about 7mm/10min (the maximum precipitation in 10 minutes, occurring once in 2 years). This is based on rainfall observations between the 1920s and 1965 (Katajisto, 1969). Rain intensity has also been continuously monitored and analysed using the observational data of 100 pluviographs from the years of 1961-75 (Kuusisto, 1980). Pluviograph observations continue, and observations in Helsinki have now been digitised. Observations using precipitation radar have been carried out since the 1970s, although the methods to improve their reliability have clearly improved since the late 1990's (Jylhä, personal communication, 2005).

In climate change scenarios, the precipitation is expected to increase in autumn, winter and spring, though summer rainfall could decrease under some projections (Ruosteenoja et al., 2005). According to simulations , the change of extremes seems to roughly follow (Carter et al., 2005) or significantly exceed (Makkonen et al., 2006) the increase of mean precipitation. If the drainage systems have been designed for a stated design rainfall amount, then with increasing precipitation the frequency of overflow can be expected to increase.

1.4. Wind

Wind speed is the measure of the flow of air. The pressure of the wind, which is of importance for structures, is roughly relative to the wind speed cubed. Winds cause damage in various ways: horizontal wind force may bring down trees and masts, remove roofs, cause wave action on the sea and lakes, and temporarily raise water levels. Storm winds are often connected to deep low pressure systems, which also have a tendency to raise water levels. Trombis (whirlwinds) are local wind phenomena that cause damage within a limited area (hundreds of square metres) in Finland. They form under conditions of high air temperature and are difficult to forecast.

The concept of a design wind has been estimated using long-term wind observations. The intensity of storms in northern Europe has been projected to increase in some climate models. Increased wind speeds have recently been accounted for in the main building regulations in Finland.

1.5. Watercourse flooding

An increase in precipitation increases surface runoff from land to lakes and rivers. In natural watercourses, flooding events are connected to snowmelt in spring and/or excessive storm rainfall. Flooding of watercourses is also discussed by Silander et al. (2006). The current knowledge on floods is based on research work over the past 10 years (e.g. MMM, 2003, Ollila, 1999, Ollila et al., 2000).

Regulated lakes, where the water level is controlled between stated limits, are continuously monitored and seldom flood. Problems may arise on natural watercourses, where occasional large flows may lead to an unconstrained rise in water levels, causing damage to the built environment.

The sensitivity of water levels to rainfall or snowmelt has been observed and analysed widely on major watersheds. More problematic are unregulated minor watercourses, whose response to excess runoff is unknown.

1.6. Shoreline flooding

1.6.1. Rising world sea level

Estimates of about a 0.5m rise in world sea level has been projected due to thermal expansion of the oceans and melting of major glaciers (IPCC 2001b, ACIA 2005). At the same time, the rate of land upheaval on the western coast is up to 10 mm/year and at the eastern end of the Gulf of Finland less than 2 mm/year. Water levels vary around the average within certain limits on the Baltic Sea coast. The main influences are air pressure variation, oscillation of the water mass in the Baltic Sea basin and winds.

1.6.2. Flooding in the Baltic Sea

The flooding event along the coast of the Gulf of Finland in January 2005 illustrates how atmospheric conditions can combine to cause high sea levels (Figure 2). The maximum observed sea levels were reported to be the highest ever monitored since the late 1880s. The flooding was forced by strong westerly winds pushing surface water towards the eastern end of the Gulf. Thus the sea level rise was not caused by normal fluctuation of the basin, but a combined effect of low air pressure and persistent westerly storm winds. The sea level corresponds to the prevailing air pressure. Waves rise above it, reaching a maximum water level rise of about half of the wave height.

The flooding caused significant local damage in the form of traffic disruption, road damage, flooding in the urban area (wetting of ground floors in buildings), damage to property, etc. totalling altogether about 1-2 million Euro.

1.6.3. Preparing for coastal flooding

Constructive provision includes inspection of actual conditions and investigations to determine the flooding risk with respect to local, anticipated flood levels. Proactive, preventive measures should be applied if needed. This means not only the design and construction of new buildings and structures, but also consideration of the prevailing environment, buildings and infrastructure.

Station	Max	Min	Obs. since
Kemi	+201 cm (22.9.1982)	-125 cm (21.11.1923)	1922
Oulu	+183 cm (14.1.1984)	-131 cm (14.1.1929)	1922
Raahe	+162 cm (14.1.1984)	-129 cm (4.10.1936)	1922
Pietarsaari	+139 cm (14.1.1984)	-113 cm (4.10.1936)	1922
Vaasa	+144 cm (14.1.1984)	-100 cm (14.1.1929)	1922
Kaskinen	+148 cm (14.1.1984)	-91 cm (31.1.1998)	1926
Mäntyluoto	+132 cm (14.1.1984)	-80 cm (10.4.1934)	1925
Rauma	+121 cm (6.12.1986)	-77 cm (10.4.1934)	1933
Turku	+130 cm (9.1.2005)	-74 cm (10.4.1934)	1922
Föglö	+100 cm (9.1.2005)	-71 cm (10.4.1934)	1923
Hanko	+132 cm (9.1.2005)	-78 cm (10.4.1934)	1887
Helsinki	+151 cm (9.1.2005)	-92 cm (22.3.1916)	1904
Hamina	+197 cm (9.1.2005)	-110 cm (20.11.1975)	1928

Figure 2. Highest sea levels along the coastline of Gulf of Finland during 09.01.2005 (Finnish Marine Research Institute).

An operational plan for limiting and preventing losses is needed for proper actions during a flooding event. This concerns both reservation of materials and equipment and the training of people. The role of the responsible local administration is to organize investigations and documentation of the damage processes following a flood event, to analyse operations with a view on improving response actions, to identify research and development needs and measures, and to compile better guidelines and codes of practice for construction and repair.

1.7. Drought

Drought conditions, involving a continuous deficit of precipitation, causes decreased storage of surface and groundwater. It can also lead to excess drying of surface soils, including shrinkage and settling of some soil types with associated damage to structures resting upon them

1.8. Groundwater level/soil moisture

A rise of groundwater levels due to excess precipitation leads to a rise in the moisture content at the ground surface. This may lead to an increase in moisture-related hazards for adjacent structures and, if the high water table persists, the risk of moisture damage.

1.9. Snow and ice

In northern Finland, milder winters with more snowfall are forecasted for the future. In a similar way, more variation of temperatures around the 0°C threshold is anticipated, requiring more salting operations, and implying more damage to the asphalt surfaces. Snow accumulation in the urban environment may decrease due to higher snowmelt in winter, though snowfall may be more intense during short periods. The local need for snow removal may decrease overall and the snowfall season may be shortened.

1.10. Complex impacts

There are some compound weather extremes, involving a combination of several weather phenomena. Examples include horizontal rain, due to strong winds during storms, which can have damaging effects on vertical building surfaces, improperly secured roofs, etc.

2. Main impacts

2.1. Land use and communities

Climate change introduces new problems into urban areas that are not covered by current guidelines, requiring improved knowledge on the local impacts and adaptation measures for planning purposes (Table 1). Communities are increasingly dependent on technical systems and more vulnerable to disturbances caused by external impacts. In the long run, the functioning of communities can be ensured with proper land use planning. Technical services, such as water, waste water, waste, energy and communications are all vulnerable to disturbances, and more attention should be paid to the risks associated with each service. In particular, coastal flooding, watercourse flooding and overflow flooding in urban areas have resulted in significant damage. Besides direct damage to structures, disruption to the normal use of facilities and indirect, long-term effects may be important, too. Flooding causes a rise of water pressure in basins, but the groundwater level will rise at the same time, usually prevailing at a high level for longer periods. Indirect effects that may cause a shortening of the lifetime of structures include slope erosion, slope failures and other defects in the built environment (Rydell et al., 2001; Rankka and Rydell, 2005; Hulten et al., 2005).

Table 1. Summary of the anticipated effects of climate change on land use, community planning and waste management in Finland (MMM, 2005).

Problem	Advantage
- Storms, floods, humid winters and dry summers will become more common - The sea level will rise - Increased water concentration in soil will decrease firmness and increase the risk of erosion - Absorption of rain water will be retarded - Variations in the groundwater level will cause problems for water availability in sparsely populated areas and cause a risk that wood pole footings in old buildings may dry up in urban areas	+ The distribution of plant species in parks and recreational areas will become more diverse and growth will be accelerated

2.2. Waste management and water services

Waste management is an essential technical service in the community. The principle of waste management is the minimisation of wastes applying pre-handling and circulation.

The main risks associated with climate change are connected to impacts on the transport of wastes and storage of waste materials in landfills. As long as sufficient cover layers are applied, an increase of rainfall is not a problem on landfills. However, if surface floodwater reaches a landfill site, there is a risk of leaching if there is damage to the landfill and the water makes contact with the waste deposit. Problems may then arise with the collection and treatment of the leachate. The risks are decreased with a better level of waste management. Flooding may also degrade by-product storages that have been collected for further use.

Old, underground sewage lines suffer from continuous leakage of groundwater into the pipeline due to fissures, leaking sealings and joints. In normal cases this may enhance the total flow by up to tens of percents. During a flood that causes rising groundwater levels, leakage flow may dramatically increase, resulting as a need for overflow at the sewage plant. Instances of this were observed in July/August 2004 at Riihimäki, where flooding led to contamination of the drinking supply.

2.3. Building construction

Higher average temperatures in winter may decrease the overall need for domestic heating energy (Table 2). However, there is still a risk for the design heating effect of a community, which should be determined according to short-lived but severe minimum temperature conditions ("Siberian winter") associated with outbreaks of radiatively cooled air under winter high pressure systems.

Table 2. Summary of the anticipated impacts of climate change on buildings and construction in Finland (MMM, 2005).

Problem	Indifferent or unclear impact	Advantage
- Precipitation will increase, causing rise of groundwater level, lowering soil strength, risk of surface erosion, and flooding of underground spaces. - Moisture problems and need for maintenance increase. - Increased corrosion - Rising groundwater may damage structures - Increasing wind loads - Horizontal rain may cause new distress to external walls	• Frost protection need may be reduced, but damage risk prevails. • Flood risk at sea coast may be partially affected by land upheaval.	+ Need for heating energy may be reduced + Buildings may stay dryer, excluding, however, roofs and external walls.

Higher summer temperatures are likely to mean a need for cooling in housing. They may also pose risks to structures built on soft soils, such as small dwellings constructed with “slab-on ground” techniques, to subsurface pipelines, and to street surfaces (due to melting of asphalt)..

Higher rainfall implies an increase of moisture content in the ground and moisture distress to connected structures like building foundations, ground floors, cellars etc. Horizontal rains may cause an increased leakage and inflow of rain water through walls and roofs, and thus an increase of moisture leading to moisture damage in building structures. Higher temperatures will also increase the frequency of freeze-thaw cycles on exterior surfaces, requiring higher levels of maintenance.

2.4. Buildings

Buildings may be residential, industrial or service buildings according to their main use. They are normally sited in a densely built area according to a city plan, where the location and floor levels are catalogued. The city plan also determines the networks linking buildings, including streets, water supply, energy and communication networks. The location of buildings in their natural setting (e.g. surrounding vegetation, exposure to sun, winds, microclimate, proximity to water courses) determines their vulnerability to environmental hazards.

Building and service infrastructure are designed to ensure an accepted safety level and comfort for living, and to ensure an overall economy of the building investment and maintenance that may be regulated according to accepted general standards.

Impacts of climate may be characterized according to safety or economic criteria. Climate-related safety features of residential buildings include:

- Wind loads vs. structural design
- Snow loads vs. structural design
- Flood levels vs. ground level
- Storm flooding vs. drainage capacity

The economic aspects include:

- Temperature vs. energy consumption
- Soil moisture vs. drainage
- Horizontal rain vs. tightness

There are many other location-dependent, natural characteristics affecting the building solution, like topography, subsoil, specific uses of the building and economic aspects. For industrial sites, the above principles are also valid. Here more emphasis is laid on the operational characteristics of the building.

Built areas are provided with various service facilities and networks that distribute clean water, dispose of sewage, and supply energy or communications. Traffic uses streets, entrances and pathways. All of these are planned and designed applying certain standards of safety and economics, and they are regulated by legislation, statutes and local decisions.

2.5. Infrastructure

Urban areas contain many service systems that are needed in a modern society: various traffic routes and facilities (streets, walkways, yards, car parks etc.), energy and communication networks, water and sewage pipelines, parks, green areas, water features (ponds, streams, shoreline structures, wetlands, etc.). These are strongly affected by change in temperatures, winds, storm rains, flooding and other impacts.

Storm rains cause problems of flooding in a dense built environment, if they have not been properly accounted for. Besides flooding, poor water quality may cause pollution risks for outlet water courses.

2.6. Water and sewage facilities and networks

Serious risks for public health can be induced if floodwater reaches a water reservoir or a ground water source which are used for the clean water supply of a community. A similar risk is also associated with the accidental outflow of untreated sewage water, if it is combined with floodwater. Besides the problems of water quality, flooding may disturb purification activities, cause excess leakage in sewage nets and require urgent dispersal through overflow channels.

Storm winds may also contribute an additional hazard by disrupting overhead cables for electricity and telecommunications, through falling trees, and by disturbing the functioning of pumping stations due to moisture problems.

2.7. Waste management facilities

In a similar manner, flood risks may also jeopardize waste treatment facilities and landfills. In extreme cases, flood water may saturate the fill and later cause slope failure risks and increased outflow of polluted water (e.g., Nilsson et al., 2005).

2.8. Traffic areas

The main drainage system in an urban area is normally the storm drain, which is located in streets with inlets from the pavement. If necessary, inlets can be constructed also from private buildings, yards and other areas. Design rainfall amounts are calculated as the rate during a 10 min period, occurring once in 2 years. The discharge can be roughly adjusted according to the infiltration/delay characteristics of the drainage area The intake wells as well as pipelines should be capable of transmitting this accumulated flow. For storm rains exceeding the design level, the designer should check for the overflow route to minimize damage.

If the drainage capacity is not sufficient, overflow and surface flooding may cause damage through erosion of surfaces, traffic delays, damage to property and softening and weakening of pavements. Shoreline flooding at watercourses or the sea coast may cause erosion damage, traffic disruption, damage to road facilities and weakening of pavements. Storm winds may cause falling trees, and together with storm rain or snowfall, risks to traffic safety.

Under current conditions, ice and snow on roads are controlled with maintenance, and road users are familiar with the normal risks. However, snowfall followed by rapid warming may cause specific conditions that can be very dangerous to traffic, and difficult to influence by maintenance operations. The formation of black ice is another example. These cases may require enhanced use of preventive salting.

3. Control methods and measures

The development of control measures can be seen in three areas:

- need for preparation against acute impacts (contingency or protection planning)
- need for a change in the design of buildings and structures
- need for administrative actions and research

The first category belongs to the area of civil service, where the central tasks are to protect life and property against unnecessary losses and limiting any damage incurred. It includes analyses of damage and disturbance risks in the urban environment, preparatory planning for raising the alarm, safety measures to minimise impacts, and rescue planning for extreme cases. Material preparation is also needed.

In the planning and design of buildings and infrastructure, risks induced by climate change should also be considered. The facilities should be designed not only on the basis of current design values, but should also checked for excessive values. This means checking for overloading response, which may be a risk for safety or having technical, economical, environmental or social consequences.

A more immediate problem is the built environment of today and how it can be protected. One way of learning is to document damage occurrences during and after impact events (storm rains, floods, storm winds). The damage may reveal vulnerability patterns of various facilities in the built environment. Certain proactive measures may be applied, like improvement of drainage, limiting flooding with dams, cutting dangerous trees before they fall victim to storm events, etc.

Contingency planning helps in limiting and preventing the damage during impact. Emergency planning and reserves against expected flooding, snowfall and icing result in minimal losses in property, and increased safety. This kind of planning is normal for the case of war, fire, explosion, etc. and could also be prepared for climate change impacts.

4. Cost risks of damage

4.1. Impact level vs. damage response/damage costs

Major damage due to an extreme climatic event is normally referred to by the media as exceptional, catastrophic or unavoidable. The recurrence of climatic events is not so well remembered – commonly recall periods are relatively short, and negative impacts are easily forgotten.

Buildings and infrastructure are designed to account for major climatic events up to a certain design level of impact, and to an even higher standard in the safety margin for materials and systems. The impact level is treated according to its occurrence interval and significance: Safety, public health and economic consequences are considered, based mainly on experience and practice, both national and worldwide.

Impacts can be described in terms of damage cost (Figure 3). This is a useful approach, because it gives a further option to better study the rational level of economic responsibility.

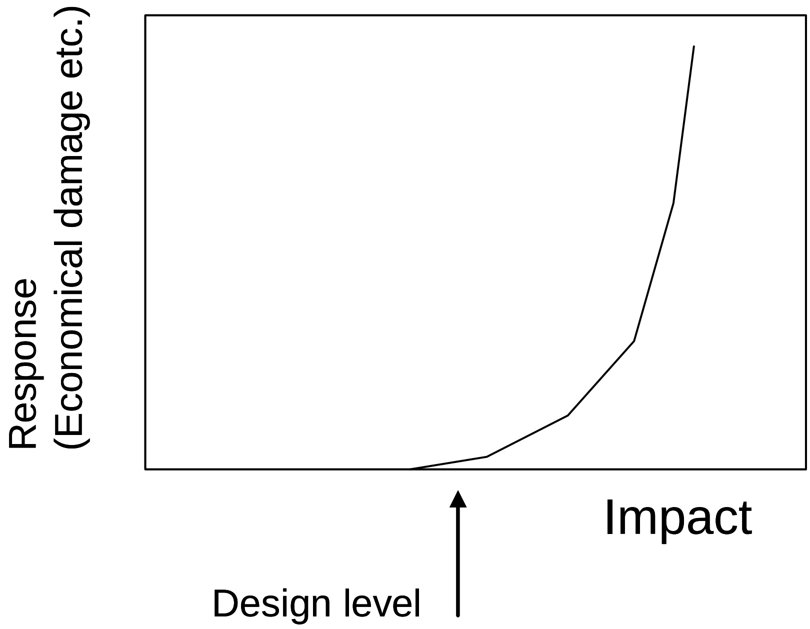

Figure 3 Intensity of an impact vs. damage response.

Normally, damage cost is the acute, immediate cost that results from rehabilitation of buildings, structures etc. to a satisfactory working level. In a broader sense, the damage cost may be divided into the following impacts:

- immediate damage cost
- reduction or suspension of the service
- secondary or long-term impacts, hidden effects

The reduction of service means costs due to suspension or higher costs of availability of the use of the facility (like use of a building, water services, transport etc.). This impact may be widespread.

Long-term effects are due to lowering of the property value, shortening of the lifetime period, lower quality of use, higher maintenance costs. These are not normally considered or counted.

To assess the damage risks, more case studies are needed. These can provide a comprehensive view of the whole impact process, hence facilitating a technical-economic analysis concerning risks, responsibility and prevention/repair methods. Studies concerning the optimal design are not possible without realistic data on past events.

4.2. Damage risk vs. preventive measures

Damage prevention can be also studied in terms of the costs of proactive preparation. Thus, flood prevention may be considered comparing damage costs and improvement costs on an annual basis. Damage insurance may be seen as an alternative. In this context, prevention may be more profitable.

Damage results from inadequate response of the facility to the impact. Repair should not only recover the level of service, but also improve the response above the expected impact level. This may need application of more developed analysis and design tools than is the current practice.

Example 1: Improvement to prevent flooding due to inadequate storm water drainage on a street. In Finland the common practice is to design the tube diameter of a storm water drainage line, considering a certain relative paved area and construction density. If conditions (new construction, more asphalt) are changed, the old drainage is not capable of handling all the runoff directed into it, and causes surface flooding.

Example 2: Location of a village in the flood plain of an unregulated watercourse. Limiting and preventing flooding needs dam construction and, in the worst cases, movement of homes to a safer location. Improvement operations require investments, and their rationality should be analysed comparing costs and benefits.

4.3. Damage costs for some storm rains and flooding in Finland

4.3.1. Flooding damage 1974-2000

Floods cause problems to buildings, industries, farming and forestry on an annual basis. However, massive floods affecting wide areas occur very seldom. In a recent study of large floods, it was estimated that a mean maximum flood occurring once in 200 years would cause damage of about 550 M€, half of which would consist of damage to buildings and the rest damage to industries, farming and forestry (MMM, 2003).

The problem has been illustrated using evaluated flood damages and compensation paid for them (Figure 4). On average, annual flooding damage was about 700 000 €, and the compensation paid was about 400 000 €. The largest damage occurred in the mid-1980s.

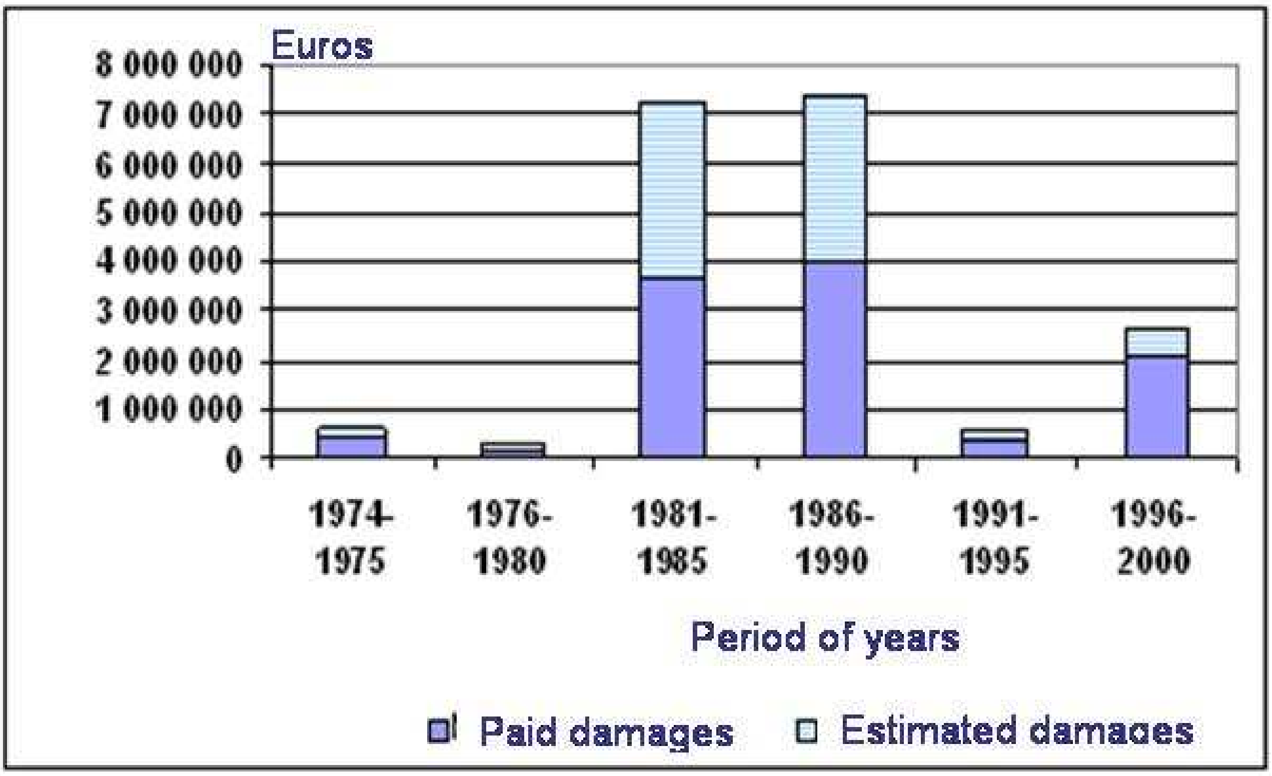

Figure 4 Damage to buildings, industries, farming and forestry in Finland due to exceptional floods in the years 1974-2000. The compensation criteria were changed in 1991; since then crop damage has also been compensated (MMM, 2003).

Flooding in Finland has been less severe than in the rest of Europe. This may result from lower precipitation, but also from regulation and flood protection activity that has been carried out in recent decades. Serious problems seem to occur within unregulated, unprepared watersheds.

For the protection of communities against flooding, local assistance to determine safe levels for flooding is needed. These values should be included in local plans and building codes for consideration. Determining these levels requires contributions by experienced specialists.

4.3.2. Heavy storm rainfall in late July 2004

In the last week of July 2004, an intensive storm system moved over the capital region and further over Lahti and the western side of North Savo to Kajaani (Figure 5). Daily precipitation in some areas exceeded 100 mm/d. The rain caused severe flooding within the minor water courses of southern Finland, and damage and disturbance to buildings, water services and roads.

The immediate damage estimated for Helsinki, Vantaa and Riihimäki was about 2700 k€, and the damage to the road network in the zone from Uusimaa to Northern Savo about 800 k€. These cost estimates included neither cost caused by the interruptions of using the facilities nor secondary or long-term costs (value reduction, shorter life period, higher maintenance)

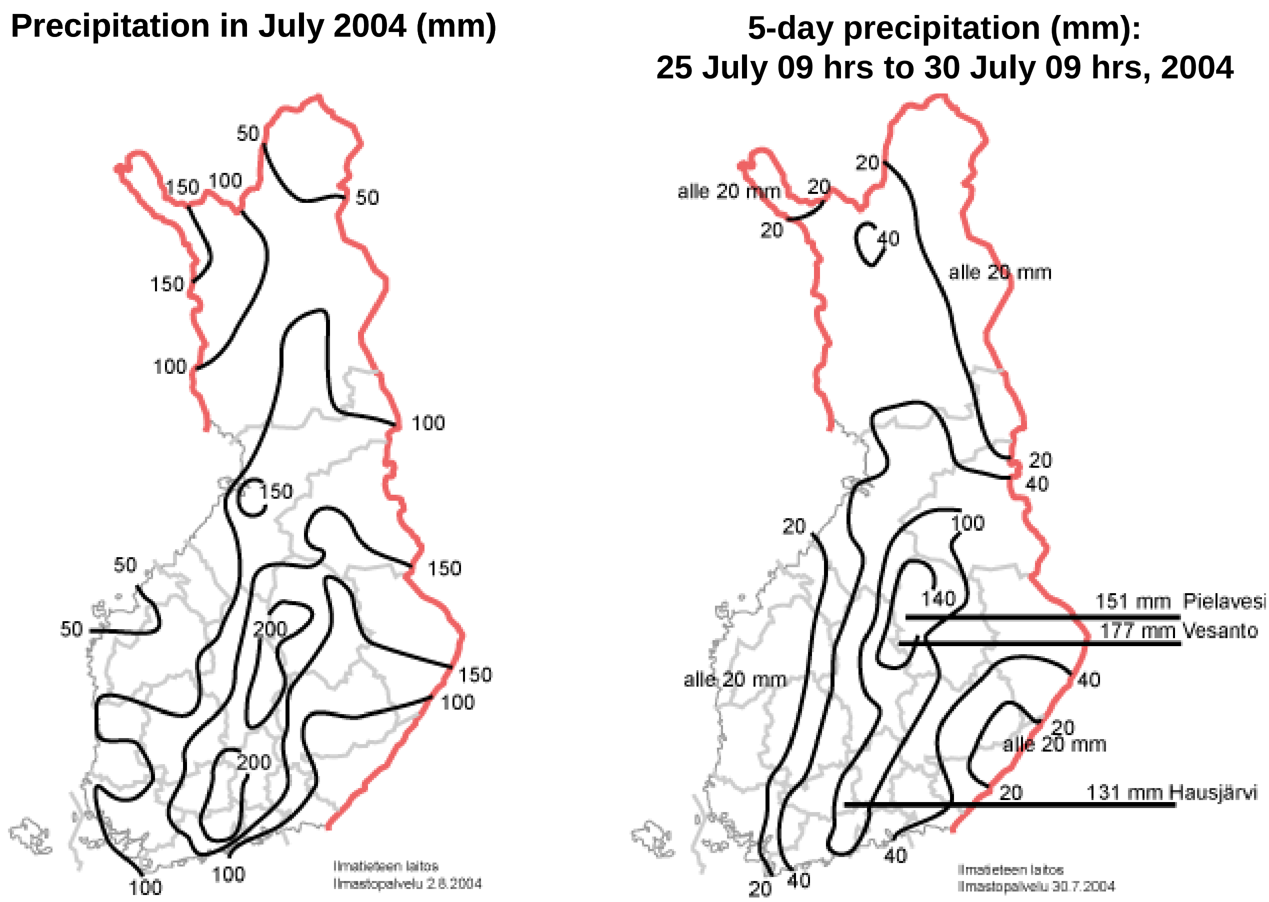

Figure 5. Monthly precipitation in July 2004 (left) and estimated 5-day rainfall intensity during 25-30 July 2004 (right). Alle 20 mm means less than 20 mm (Source: Finnish Meteorological Institute).

4.3.3. Heavy storm rainfall in early August 2004

In the first week of August 2004, heavy storm rainfall occurred in the region of Vöyri and Oravainen in eastern Bothnia, reaching from Kyrönjoki to Pietarsaari. Precipitation was more than 100 mm/d. Damage was centred within the watershed of the Vöyrijoki-river. This river was unregulated, seldom flooding, and its flood protection level was technically essentially lower than in the nearby watersheds of Kyrönjoki and Lapuanjoki rivers, where, despite the heavy rain, no damage was mentioned in the media.

The rains caused heavy flooding within the watershed of the river Vöyrinjoki and damage to buildings and roads. Estimated, immediate damage cost was for buildings about 1000 k€ and for roads about 200 k€.

Rainfall with an intensity of more than 100mm/d occurred statistically somewhere in Finland as an average once in 3 years during the latest observation period of 30 years (Solantie, 2004).

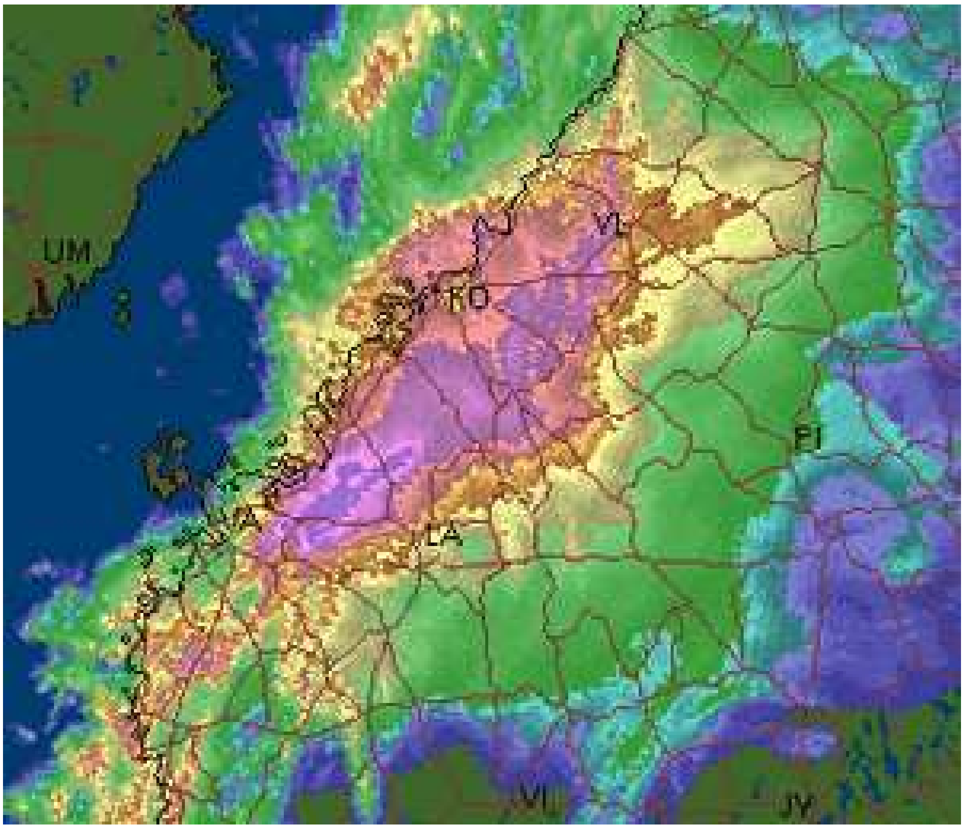

Figure 6 Radar image of cumulative 12-hour rainfall from afternoon 3.8.2004 to morning 4.8.2005. Lilac zone shows the most intense rainfall with Oravainen at its centre (Source: Finnish Meteorological Institute).

4.3.4. Urban flooding in Vaasa, 31 July 2003 (Lonka and Raivio, 2003)

Heavy rain occurred in the Vaasa region on 31 July 2003. Between 20 and 100mm of precipitation was estimated to have fallen in a day (H. Myllys, Finnish Meteorological Institute, personal communication, 2003). This estimate was based on radar interpretation. According to reported precipitation measurements, the precipitation at Vaasa automatic weather station was about 25mm. The rain fell in a couple of hours, and it could be classified as a storm rainfall.

Damage resulted mainly from flooding, as rainwater inundated streets and surfaces, in places rising to street-level floors and cellars. At some sites, water led from roofs through rainwater outlets, caused leakage damage because of open joints. Most of the damage to private property was shown to result from malfunctioning devices or construction. The flooding damage in Vaasa totalled some 130 000€, consisting of damage to private and municipal buildings and private enterprises.

The rain was evaluated as extreme compared to long-term rainfall statistics. The response of the surface in terms of flooding depends on the functional level of the drainage system (drainage capacity), which should be capable of preventing harmful flooding under the design rainfall. Besides the dimensions of the pipeline, flooding may be caused by intakes of wells, and surface flow conditions (length of flow route, inclinations etc.). Normally in street pavement design, only the dimension of the storm sewer is determined.

The standard design of street drainage is based on a maximum storm rain in 10 minutes, occurring once in 2 years. According to the design chart, this rain is about 7mm/10min, meaning an hourly value of 42mm as a steady rain of the same intensity. The estimated storm rain in Vaasa was at the same magnitude or smaller.

The recommendations arising from this event included:

- Occurrence of extreme, local storms and rains should be investigated especially considering cities located at the seashore
- The design codes of foundation drainage and storm sewers of real estates and structures should be updated
- Public information and counselling should be strengthened
- Cooperation of various authorities should be coordinated.
- Codes of action should be created for alarm centres
- Interaction between water services and municipal technicians should be strengthened
- Buildings and real estate should be guided to plan their preparations against flooding damage
- Citizens should be informed about the risks of urban flooding

5. Adaptation of design principles and risk levels to the changed damage risk

5.1. Principle of optimized standard design

Standard design is normally based on a commonly approved risk level. The severity of this level is usually considered on a qualitative basis combining a number of factors: risk to life, risk for property, risk for functioning, extent of impact.

One of the key factors is the relation between the impact and damage. Damage can be described as costs, or material or human losses. Cost information is only reliable if it is based on adequate and detailed inventory and analysis.

Adaptation to climate change impacts means basically three aspects:

- impacts without preparation, under today's conditions
- impacts after proactive adaptation measures in the current built environment (repair option)
- change of current design and construction practice (new building option)

5.2. Adaptation to climate change impacts

5.2.1. Communities

Current situation

The current situation in communities emphasises sustainable development, a good environment and life-cycle based construction. Communities are planned to maintain sustainable, environmentally healthy and natural resource efficient development, with some consideration also given to the mitigation of climate change.

Buildings and infrastructure are planned and designed, in principle, considering local, prevailing environmental conditions. Buildings have been designed considering climatic stresses such as extreme temperature, rainfall, drainage, wind loadings and soil conditions for a long service life, and with proper maintenance potentially continuous use.

Impacts of climatic events on the current built environment can be controlled with reactive, adaptive measures, and a range of different actions to minimize harmful effects on the environment. The consideration of adaptation measures is important in the planning of current urban areas, and the necessary measures can be carried out through detailed planning and construction and repair projects.

Adaptation to climate change

Improvement of consideration of climate change impacts, and natural conditions in general, may require a revision of regional and land use planning principles. More accurate design of storm drainage systems is required, in particular, including local handling of precipitation using infiltration and storage, and planning reserve zones for storage basins. One important question is the improvement of storm drainage and sewage nets and facilities considering intensified storm rains and resulting groundwater rise. In communities, a specific study on the conditions and risks as well as reported damage is recommended. Risks should also be mapped and investigated for planned new sites.

For the investigations and mapping, practical guidelines and examples are needed both for investigation procedures as well as for the application in planning. The new procedures may be more generally fruitful for planning, because they emphasise the consideration of natural conditions.

The introduction of climate change aspects as risks in the planning, repair, design and maintenance of municipal service nets for energy, water, sewage supplies and waste management may require the development and testing of new approaches.

5.2.2. Buildings and construction

Adaptation in building construction

Adaptation can be considered in the structural design of new buildings to provide solutions that fulfil the demands and criteria of the building site and region. It is then possible to consider the future repair and renovation needs. For prevailing construction, in repair projects climate-based risks and adaptation measures should be considered to maintain the service level of the building or facility in the future.

Buildings and structures

Adaptation in the building sector follows mainly the same principles as in communities, but applied on a limited property. In prevailing real estate, the problems may be recognized as problems or damage experienced in extreme weather conditions (rain, wind, flood, snow/ice), but the improvement options may be limited. In the design and construction of new buildings, the changed design criteria can be applied.

Improvement of drainage within a property, to meet new storm rain standards, depends on the standard of the environment. Locally the situation can be improved using local infiltration and storage possibilities.

Temperature rise in buildings during warm summers can be relieved using local air conditioning (heat pumps) that may be cooled in foundations or the ground. Heat pumps can then be utilized for heating in the cold season.

The air-tightness of buildings can be influenced in the building design. The need for improvement of current buildings may be studied on the basis of energy and maintenance inspections. The durability of surface materials against increased and more densely occurring moisture stress may require more maintenance and service.

The sustainable use of buildings requires that maintenance and repair be continuous. For this, procedures, tools and devices are and should be developed. There is a pressing need for new, correct and effective methods to be applied for inspection, monitoring and repair.

The change and renewal of building stock is very slow. Thus the adaptation of buildings to the new conditions is a challenge, and the time span for climate change may be shorter than the cycle of conventional renovation and reconstruction.

5.3. Life-cycle assessment

In the current design, the lifetime of buildings is assumed to be 40-100 years. There are few examples where buildings need to be demolished, unless they are in an irreparable shape. It is more normal for buildings to be repaired or modernized for the next lifecycle. In the design of buildings, a long-term use and the need for easy and practical renovation should be considered.

Advanced methods for rehabilitation after flood damage should be developed. If a flood risk is seen, measures to limit the damage and even prevent it, should be carried out.

6. Research approaches concerning impacts and adaptation to climate change

6.1. Communities

Studies of climate change impacts on the functioning of communities, considering aspects of land-use planning and regulation, have hitherto not been conducted in Finland. It is especially important to investigate regional and local impacts of climate change. Some potential adaptation measures are listed in Table 3, based on expert judgement.

Table 3. Summary of potential adaptation measures in land use and community planning (MMM, 2005).

		Proactive	Reactive
Public	Administration and planning	• Considered in the long-term planning • A specific evaluation of vulnerable sites, considering flood risk, drainage needs, possible storm winds, etc.	• Improvement of current communities against flooding, storms • Need for improvement of storm water drainage
	Research	• Flood risk areas • Methods for investigations of local impacts and adaptation measures	• Implementation of design methods for storm water drainage
	Normative	• Reform needs of legislation and regulations • Recommendations on different planning levels	
Private		• Improvement of storm water drainage	• Improvement of storm water drainage

6.2. Buildings

According to a literature survey, research activity concerning climate change impacts and adaptation for building and community planning has until recently been very low. In a study on buildings, construction and infrastructure by VTT Building and Transport ”Climate change impacts in the built environment” (Ala-Outinen et al., 2004) some illustrations of the potential impacts of climate change were presented. Topics for further research were also identified that are required to get a comprehensive general view of the issue, to provide generalized impact results and to develop proposals for generalized adaptation measures.

In the ongoing research project “Exceptional natural phenomena and the built environment in a changing climate” in the Environmental Cluster Research Programme, some methods have been developed to reliably analyse infrequently occurring natural phenomena, with a focus on buildings and construction.

The renovation need of storm water drainage in urban areas should be investigated as well as the possibilities to apply infiltration and delay reservoirs. Observations of rainfall intensity should be increased from the current 4-5 communities to cover about 50 sites. Groundwater observations should also be widened. Some other possible adaptation measures are listed in Table 4.

Table 4 Summary of a possible set of adaptive measures for climate change in construction (MMM, 2005).

		Proactive	Reactive
Public	Administration and planning	• Climate change is included in long-term planning and design on the building sector	
	Research	• Flooding risks • Improvement in storm rain drainage applying also storage and percolation • Changes in normative wind speeds for current buildings and new construction • Inspection of current buildings	• Technical-economical damage inventories and investigations • Development of investigation and design methods
	Technical development	• Guidelines for the design of storm rain drainage	• Repair technology of damaged buildings after storms • Diverse repair measures
	Normative regulations	• Checking and improving design standards, and regulations • Local recommendations according to climatic conditions	
Private		• Various improvement measures	• Various repair measures

7. Discussion, conclusions and recommendations

7.1. General

Adaptation can be seen as risk assessment considering:

- *Contingency (emergency) planning and reservation*. This means planning for protection and rescue of lives and property under a sudden, specific climatic event (flood, storm, wind etc.)

- *Structural provision to limit and prevent damage in existing buildings and infrastructure.* The damage can be reduced and even mitigated, if proactive measures have been planned and taken into use (e.g. improvements in urban drainage, temporary and constant flood control, etc.)
- *Improving design criteria for new construction* (design wind speeds, flood levels, etc.)
- *Implementation in urban planning* (consideration of adaptation needs in planning and re-planning of urban areas and technical facilities)
- *Improving the building regulations* (changing the design criteria and recommendations considering the projected climate change, etc.)
- *Emergency investigations and planning of important technical services* (clean water, sewage treatment, waste management, industries handling hazardous materials etc.)

All of this requires a better knowledge basis consisting of reliable statistics on the occurrence of significant climate parameters. The processes leading to damage should be investigated to identify the basic mechanisms and critical details that should be improved. The costs of damage should be related to the costs of improvement in damage cases, to get an idea of optimum solutions.

Warning systems should be considered for critical climatic parameters, to enable early and proper preparation for prevention. Adaptation to climate change resembles protection planning against acute hazards such as fire, earthquake, tsunami and storm.

7.2. Research needs

New knowledge is needed to develop and maintain sustainable communities in a changing climate. The main body responsible for the built environment and communities is the municipality. Thus, the development and implementation of practical measures should be carried out together with the local municipality.

The following research will be needed to improve the capability for adaptation:

Basic knowledge

- *Determination of weather statistics*. These include available climatic data on critical parameters as well as estimates of future changes in extreme values and probability of occurrence
- *Development of efficient methods for the inventory and monitoring of terrain conditions and vulnerability over large areas*. These are needed for evaluating the response and vulnerability of natural terrain and built areas at a large scale.
- *Development of early warning systems for critical weather events.* These systems facilitate early, proactive and appropriate preparation and resemble normal contingency planning against sudden accidents like fire, explosion, earthquake, etc.

Damage investigations

- *Documentation and physico-economical analysis of damage processes in actual cases of damage.* The processes leading to damage should be investigated and documented to recognise the basic mechanisms involved and possible avoidance measures. Comparing damage costs and possible improvement costs, the concept of optimum solutions can be studied.
- *Development of preventive measures for acute hazards.* To limit flooding, efficient protective materials, structures and equipment suitable for temporary use should be developed. Also a protection strategy (emergency planning, operational planning) should be developed.
- *Development of repair and rehabilitation methods for damaged buildings and structures.* Efficient and reliable methods for physical investigations of wetted structures as well as technology for repair and rehabilitation.

Building technology

- *Development of sustainable solutions for design and construction of buildings and infrastructure.* The design of buildings should be studied to examine effects of enhanced wind loads, stronger horizontal rains, and increasing moisture loadings from the ground. The efficiency of drainage around buildings and their foundations should be improved to minimise flood damage.
- *Improvement of building regulation concerning climate-induced hazards.* Current regulations and recommendations should be checked to account for possible climate change impacts on buildings and other structures in the built environment.

Community planning

- *Development of methods for planning a sustainable urban environment.* Consideration of natural conditions requires testing and implementation of efficient methods for analysis and description of natural conditions. This kind of knowledge is needed, for example, in mapping of flood risks and regional drainage planning and design. Planning tools for a safe environment can be developed applying the method of prototype planning.
- *Development of guidelines for city planning*

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Title of publication	CLIMATE CHANGE AND RISKS TO THE BUILT ENVIRONMENT	
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Abstract	The vulnerability of the built environment to climate change impacts is likely to be manifest in a higher occurrence of extreme weather events, which increases the risk of damage and costs. Most weather-related impacts should be taken into account in normal design and construction practices. Damage is caused if a weather-based impact exceeds the design level, and this can increase dramatically with a rising impact level. Events in recent years have shown that Finnish society is not properly prepared for the effects of extreme weather. In order to prepare for such events, the investigation and documentation of previous damage occurrences is important. Investigations should cover, besides damage costs, the prevailing weather conditions and resulting damage, including the damage process, mapping of damaged objects and evaluation of the technical causes for building failure. On the basis of these investigations, protection measures can be implemented and longer-term measures introduced for adapting communities to withstand climate change impacts. The research needed to improve the capability for adaptation includes basic knowledge (e.g. determination of past and future climate information, development of efficient methods for the inventory and monitoring of terrain conditions and vulnerability over large areas, and development of early warning systems for critical weather events), damage investigations (e.g. documentation and physico-economical analysis of damage processes, development of preventive measures for acute hazards, and development of repair and rehabilitation methods for damaged buildings and structures), building technology (e.g. development of sustainable solutions for design and construction of buildings and infrastructure, and improvement of building regulations concerning climate-induced hazards) and community planning (e.g. development of methods).	
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Tiivistelmä	Rakennetun ympäristön haavoittuvuus ilmastonmuutoksen vaikutuksille tullee esiin ääri-ilmiöiden lisääntymisen myötä. Pääosa säähän liittyvistä vaikutuksista tulisi ottaa huomioon tavanomaisen suunnittelun ja rakentamisen puitteissa. Vahinkoja syntyy, jos ilmastoperäinen vaikutus ylittää mitoitustason. Tällaiset tilanteet voivat lisääntyä selvästi kasvavien ilmastovaikutusten takia. Viime vuosina on voitu havaita, ettei suomalainen yhteiskunta ole valmistautunut riittävästi sään ääri-ilmiöihin. Ääri-ilmiöiden varautumisen kannalta tapahtuneiden vahinkojen tutkimukset ja dokumentointi ovat tärkeitä. Tutkimusten tulisi kattaa paitsi aiheutuneet kustannukset, vahinkoihin johtaneet sääolosuhteet ja syntyneet vahingot, mukaan lukien vahinkoprosessin eteneminen, vahingoittuneiden kohteiden kartoitus ja vahinkojen teknisten ym. syiden selvittäminen. Dokumentoidun tiedon perusteella on mahdollista arvioida suojelutoimenpiteitä sekä pysyvämpiä toimenpiteitä yhdyskuntien sopeuttamiseksi kestämään voimakkaampia ilmastonmuutoksen vaikutuksia. Seuraavia tutkimuksia tarvitaan sopeutumiskyvyn parantamiseksi: perustiedot (esim. kriittisten ilmastotekijäin havaintotilastojen käsittely ja tulevien ääriarvojen suuruuden ja toistuvuuden estimointi, inventointi- ja monitorointimenetelmien kehittäminen, varoitusjärjestelmien kehittäminen kriittisiä ilmastotapahtumia varten); vahinkojen selvittäminen (vahinkotapahtuminen dokumentointi sekä vahinkoprosessien fyysinen ja taloudellinen analysointi, suojelumenetelmien kehittäminen äkillisiä onnettomuuksia vastaan, korjaus- ja kunnostusmenetelmien kehittäminen vahingoittuneille rakennuksille ja rakenteille); rakennusteknologia (kestävien ratkaisujen kehittäminen rakennusten ja rakennetun ympäristön suunnittelua ja rakentamista varten, rakennusmääräysten parantaminen); ja yhdyskuntasuunnittelu (menetelmien kehittäminen kestävän kaupunkiympäristön suunnittelua varten, kaavoitusohjeiden kehittäminen)	
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The vulnerability of the built environment to climate change impacts is likely to be manifest in a higher occurrence of extreme weather events, which increases the risk of damage and costs. Most weather-related impacts should be taken into account in normal design and construction practices. However, flooding events in recent years have shown that Finnish society is not properly prepared for the effects of extreme weather that exceed these design criteria. Research needed to improve the capability for adaptation includes: collection of basic knowledge on climate, terrain and other factors influencing physical vulnerability, documentation and analysis of damage processes, development of preventive measures for acute hazards, development of repair and rehabilitation methods for damaged buildings and structures, progress in building technology and development of guidelines for community planning.

Rakennetun ympäristön haavoittuvuus ilmastonmuutoksen vaikutuksille voi tulla esille ääri-ilmiöiden lisääntymisen myötä, jolloin myös vahinkojen ja kustannusten riskit kasvavat. Pääosa säähän liittyvistä vaikutuksista tulisi ottaa huomioon tavanomaisessa suunnittelussa ja rakentamisessa. Viime vuosien tulvat ovat kuitenkin osoittaneet, että suomalainen yhteiskunta ei ole rittävän valmistautunut vaikutuksiin, jotka ylittävät nykyisen mitoitustason. Sopeutumiskyvyn parantamiseksi tarvitaan tietoa ilmastosta, maapohjasta ja muista fyysiseen haavoittuvuuteen liittyvistä tekijöistä, tapahtuneiden vahinkojen dokumentointia ja analysointia, varoitusjärjestelmien sekä korjaus- ja kunnostusmenetelmien kehittämistä, rakentamisteknologian edistämistä sekä kaavoitusohjeiden uudistamista.

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