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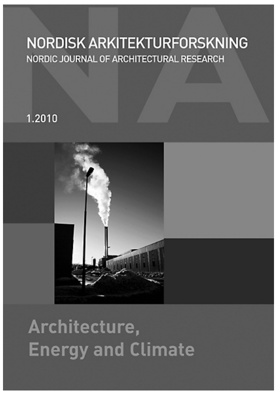

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TOPIC: ARCHITECTURE, ENERGY AND CLIMATE

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BOKANMELDELSER

Building for climate change – meeting the design challenges of the 21st century

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Berit Time and Anne Grete Hestnes

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TOPIC: ARCHITECTURE, ENERGY AND CLIMATE

Abstract:

This paper addresses the dual challenge of designing sustainable low-energy buildings while still providing thermal comfort under warmer summer conditions produced by anthropogenic climate change—a key challenge for building designers in the 21st century.
These issues are evaluated by predictions of thermal comfort performance under a climate change scenario. Climate conditions independent of building types were studied in order to get an overview of the potential for passive cooling of low energy buildings in Norway. Three sets of future climate data were used as future weather data scenarios (2020, 2050, and 2080) that form the basis for evaluating the future thermal comfort performance of such buildings. These were taken as the basis for future climate change development and compared with respect to summer comfort conditions. Results show that future climate change predictions will increase cooling degree days. Thus, thermal comfort criteria during summer months are becoming more important when designing energy efficient buildings. It was therefore important to evaluate the potential of thermal comfort and related overheating problems in future summer periods that might even extend it to autumn and spring seasons.
A climate responsive building design should assist the design strategies and try to exploit climatic conditions. The cold climate of Norway provides a number of strategies to ensure thermal comfort by passive means.

Keywords:
Climate analysis, design strategies,
future temperature predictions, thermal comfort

Introduction

This paper addresses the dual challenge of designing sustainable low-energy buildings while still providing thermal comfort under warmer summer conditions produced by anthropogenic climate change – a key challenge for building designers in the 21st century.

Even in heating dominated climates like Norway more stringent building envelope requirements to reduce heat losses during the heating period lead to the use of cooling equipment that uses additional energy. Especially in buildings with high internal loads like commercial buildings, this can easily lead to high energy use in the operation of those buildings.

Climate change predictions for Norway forecast an increase in outside temperature and precipitation (Lisø et al. 2003). This has the potential to increase the use of cooling equipment even more. A recent study tried to estimate energy implications of predicted climate change (Haase and Andresen 2009). Figure 1 shows the calculated results in energy demand of a typical office building in Oslo today. It can be seen that the total energy use for equipment, lighting, cooling and heating decreases by 7% by 2050 and by 9% by 2100 compared with today's figures. While heating energy use is reduced by 16 kWh/(m^{2}a) until 2100, an increase in cooling energy use by 5 kWh/(m^{2}a) is predicted based on average climate change predictions. However, these predictions were based on monthly average outdoor temperatures and do not take other factors such as humidity, solar radiation or wind speed into consideration. The variations in annual average outdoor temperatures that exist in Norway today can lead to a wider spread in the predicted energy use.

A study of passive cooling by night-time ventilation has shown a high potential especially for North Europe (Artmann et al. 2007). However, implications of predicted climate change have not been evaluated.

Further, thermal comfort has not been evaluated. It is important to evaluate the potential of thermal comfort and related overheating problems in future summer periods that might even extend into autumn and spring seasons. Implications of predicted climate change and an increase in annual mean temperature should also be taken into consideration.

Method

These issues are evaluated by predictions of thermal comfort performance under a climate change scenario. Climate conditions independent of building types were studied in order to get an overview of the potential for passive cooling of low energy buildings in Norway. Four sets of climate data were used as future weather data scenarios (2011 until 2100).

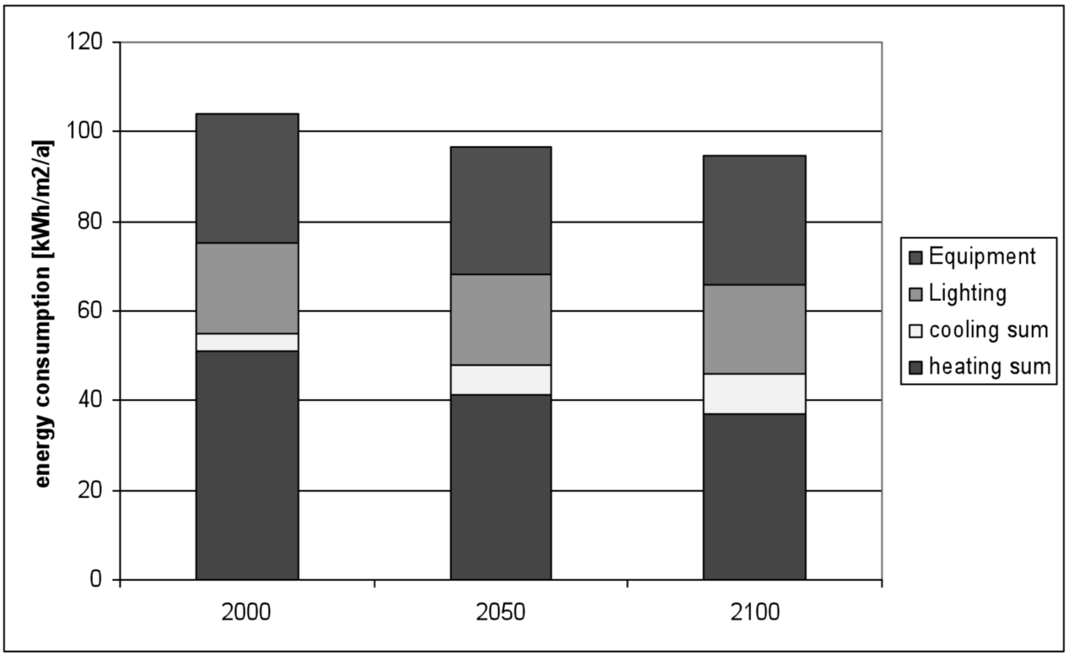


Fig. 1:
Annual energy use for Oslo (Haase and Andresen 2009)

These form the basis for evaluating the future thermal comfort performance of such buildings.

The scenarios have been derived from climate model runs at the Hadley Centre. The Hadley Centre's Regional Climate Model (HadCM3 RMC) has been run and dynamically downscaled for one of the four global emissions profiles (A2), developed by the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic and Swart 2000; Pachauri et al. 2008). This predicts a global average change in temperature in the 2080s of 3.3 C and a CO_2 concentration in the atmosphere of 715ppm.

Using 30 year time-slices is consistent with standard meteorological practice for defining a region's climate. The time-slices are therefore produced by taking the mean climate for periods conventionally defined (baseline 1961–1990) as the

- 2020s (2011–2040),
- 2050s (2041–2070) and
- 2080s (2071–2100).

Based on the A2 output Belcher et al. have developed a methodology for transforming IWEC weather files into climate change weather years (Belcher et al. 2005). Hourly weather data for the present-day climate is adjusted with the monthly climate change prediction values of the scenario datasets. This methodology is termed 'morphing' due to the fact that data of existing weather sites is 'morphed' into climate change weather data. The basic underlying methodology for weather file 'morphing' is described in Jentsch et al. (Jentsch et al. 2008).

Weather data analysis

For the purpose of energy performance predictions, the climate is determined by the amount of solar radiation, mean outside temperature and humidity that a building is exposed to. The climate influences the amount of energy that is used for heating and cooling and lighting. In this study it is assumed that the building is well shaded, minimizing the influence of solar radiation. Solar excess is the amount of solar energy that is not wanted in the building. It is in the same order of magnitude for all climates used in this study. The new Norwegian standard for calculating energy use in buildings is based on Oslo weather data for code compliance (TEK 2007).

A weather data analysis was carried out. Weather data of the six different locations were taken and the cooling degree hours and days (CDD), the heating degree hours and days (HDD) and the solar excess hours and days (SED) for each month were calculated. A degree hour is the difference in temperature above or below the reference temperature during the course of one hour and can be calculated if hourly temperature data are available. Summing up the degree hours from one day gives a daily degree hour value. Next, the daily degree hours of the month are summed up to obtain monthly degree hours. Dividing monthly degree hours value by 24 delivers degree-days for the specific month.

$$CDD = \sum (T_m - T_b) \qquad (1)$$

$$HDD = \sum (T_b - T_m) \qquad (2)$$

with

T_b = base temperature (26°C for cooling and 18°C for heating)

T_m = average of maximum and minimum temperatures

Table 1:
Degree days and annual average outdoor temperature (Tavg) for different scenarios (ASHRAE 2001)

location	Latitude	HDD	CDD	SED	Tavg	ΔT compared to Oslo	Oslo climate in
Bergen	60.2	3878	17	589	6.9		
Oslo	59.9	4085	27	750	5.7		
Trondheim	63.4	4379	18	951	5.7		
Gardemoen	60.0	5085	13	936	3.7		
Tromso	69.4	5339	0	635	2.9		
Karasjok	69.2	7346	5	710	-2.6		
Oslo-2020	59.9	3725	49	758	7.7	2.0	2011-2040
Oslo-2050	59.9	3325	79	759	9.0	3.3	2041-2070
Oslo-2080	59.9	2844	146	750	10.6	4.9	2071-2100

Finally, the solar excess degree hours were calculated. The surface temperature is called the sol-air temperature: and can be described as the equivalent outdoor temperature that will cause the same rate of heat flow at the surface and the same temperature distribution through the material as the current outdoor air temperature, the solar gains on the surface and the net radiation exchange between the surface and its environment. Solar excess degree hours are the amount of degree hours where the sol-air temperature exceeds the outside air temperature. The sol-air temperature is defined as:

$$T_S = T_O + dT_e \qquad (3)$$

$$dT_e = (G * a_W * R_{SO}) \qquad (4)$$

= sol-air excess temperature (K),
with
T_S = Sol-air temperature (°C),
T_O = Outside air temperature (°C),
G = total incident solar radiation (W/m²),
a_W = solar absorptance of wall (0-1)
R_{SO} = outside air-film resistance.

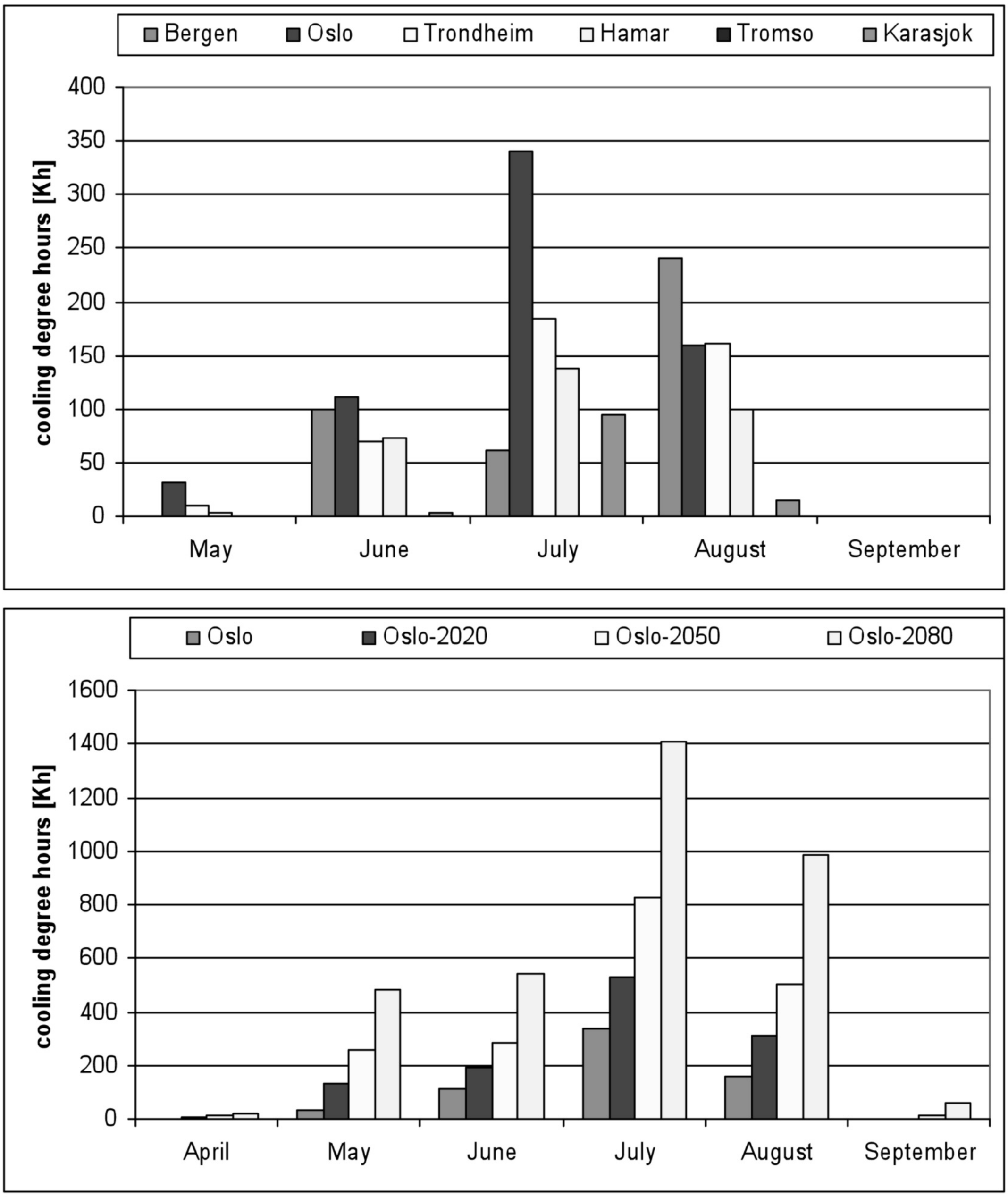


Fig. 2:
Cooling degree days in Norway (Enova 2007) present and future
*Notes: * Gardemoen weather data was used for Hamar.*

Solar excess degree hours are causing an excess cooling load on the building due to incident solar radiation in the overheating period (summer) but can be beneficial in periods with a need for auxiliary heating (winter). This calculation uses a formula based on latitude and the ratio of vertical to horizontal surfaces in a 'standard' building, as well as the following assumptions (Szokolay c1988.):

- All windows are fully shaded in the overheating period.
- A well designed building with north-south orientation and an aspect ratio (long axis over short axis) of 1.4.
- Negligible solar radiation on north and south walls in the overheating period as the sun is near its zenith and a well-designed building will provide adequate eaves/shading.
- A horizontal roof surface.
- An assumed absorptance of $a_r = 0.3$ for roofs and $a_W = 0.52$ for the east and west walls, with surface film conductances of $h_r = 22$ W/m²K and $h_W = 18$ W/m²K ($R_{so} = 1/h$).

Table 1 summarizes the resulting mean annual temperatures, heating (HDD), cooling (CDD) and solar excess (SED) degree days for the different scenarios.

Figure 2 gives Cooling degree days for the different locations in Norway. It can be seen that Oslo has most cooling degree days, and July is the month with the largest amount of cooling degree days (340). There are no cooling degree days in Tromsø.

Thermal Comfort

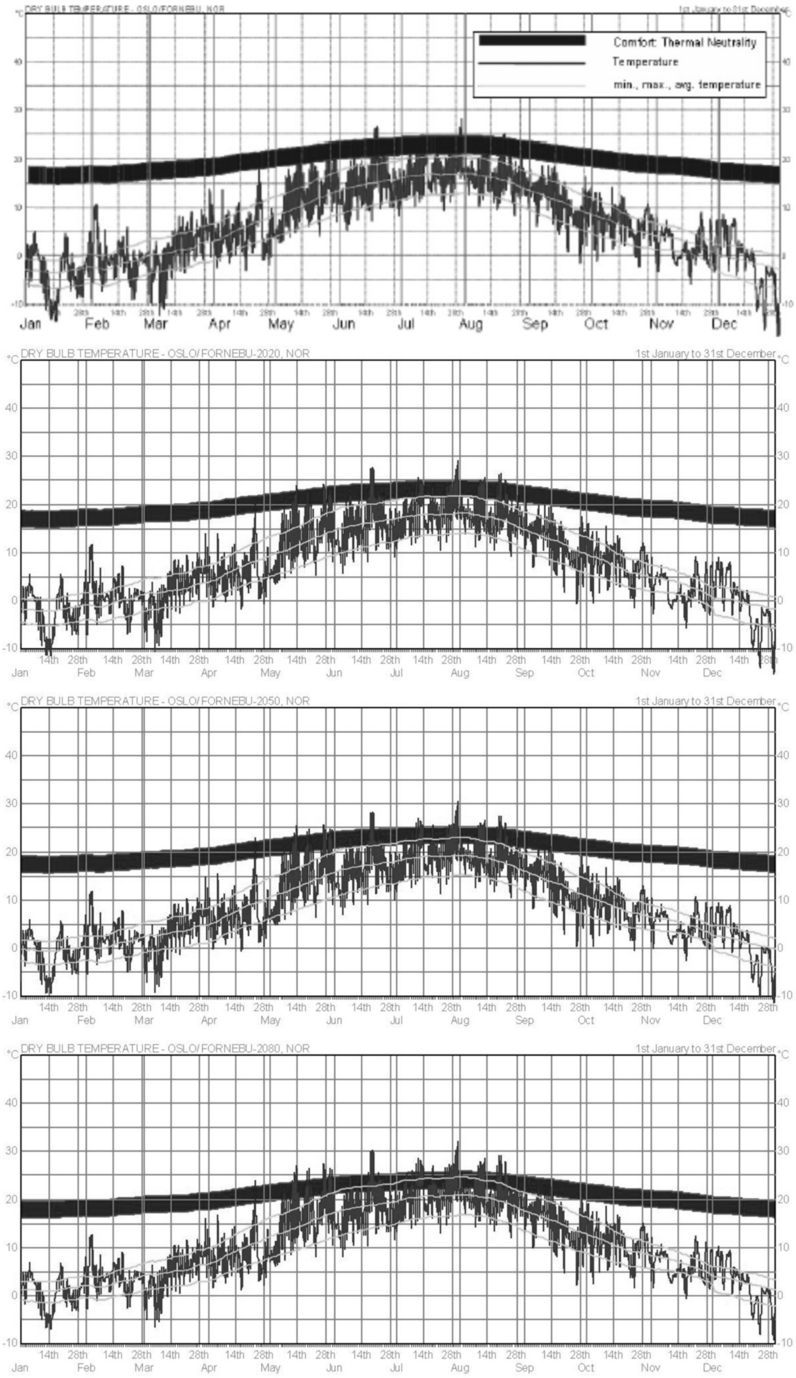
Thermal comfort was calculated followed by an analysis of the potential of different passive design strategies. The adaptive model based on a neutral temperature approach was chosen as described by Auliciems (Auliciems 2002).

$$T_n = 17{,}6 + 0{,}31\, T_{ave} \qquad (5)$$

with

T_n (Thermal Neutrality) = the air temperature at which, on average, a large sample of people would feel neither hot nor cold.

T_{ave} = outdoor daily average dry bulb temperature (DBT)



The Thermal Neutrality with the range of +-1.75K is shown in Fig. 3 for Oslo, 2020, 2050, and 2080 as a dark band. Per definition T_{ave} will always be lower than T_n ,according to Eq. (5), but the instantaneous dry bulb temperature (DBT) shows some peaks during summer. In order to visualize the influence of humidity, T_n can also be plotted in the psychrometric chart and is shown in Fig. 4 as the base comfort zone.

Fig. 3:
Thermal Neutrality for Oslo 2020, 2050, and 2080

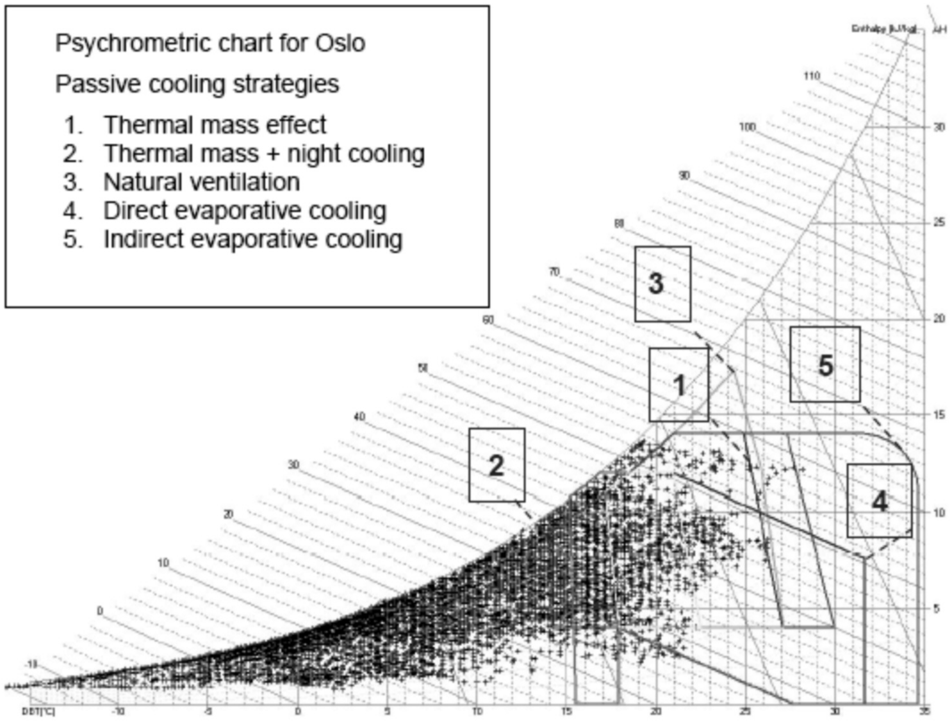


Fig. 4:
Different Strategies for Improving Thermal Comfort for Oslo

The method used for estimating the potential of different passive strategies was based on Szokolay (Szokolay 1987). He established six strategies for improving thermal comfort and evaluated their potential. It can be seen in Figure 4 that each strategy results in comfort improvement effects.

These effects are based on a fundamental set of assumptions laid out by Olgyay and Szokolay (Olgyay c1963.; Szokolay c1988.) and extend the area of the comfort zone. It is therefore possible to determine the effectiveness of different passive design strategies by comparing the number of data points inside the base comfort area and the extended area resulting in percentages of thermal comfort potential. It should be noted that the base comfort zone relates to the Thermal Neutrality discussed above (Fig.3).

Figure 4 gives an overview of five different passive cooling design strategies for Oslo and their possible impacts on thermal comfort in a psychrometric chart. All calculations are based on assumptions as to the moderating effects of passive systems within a building. It is assumed that the techniques used are of good efficiency (η=0.7) with adequate thermal insulation used when required. The potential of Natural ventilation was estimated for an increase in air movement of 1 m/s in the building (Szokolay 1987).

Results

The results of the different strategies were analyzed for the different locations in Norway as well as the future climate scenarios for Oslo (2020, 2050, and 2080). It can be seen from Fig. 4 that a rise in outdoor temperature will still be within the limits of passive cooling strategies. Here, especially the use of thermal mass has a very high potential, followed by natural ventilation. Fig. 5 shows the thermal comfort potential for Oslo for the five different cooling strategies. It should be noted that passive heating strategies were not fully explored in this study. However, it can be seen that remaining thermal comfort potential (until 100%) is due to cold outdoor air, whereas the warm outdoor air is within the extended (due to thermal mass and natural ventilation respectively) thermal comfort zone.

Fig. 6 summarizes the thermal comfort potential for the use of thermal mass while Fig. 7 shows the results for Natural ventilation for the different climates in Norway.
The potential varies over the year. In order to evaluate its usefulness as a passive cooling strategy focus should be on the months with cooling degree days (May to Sept).

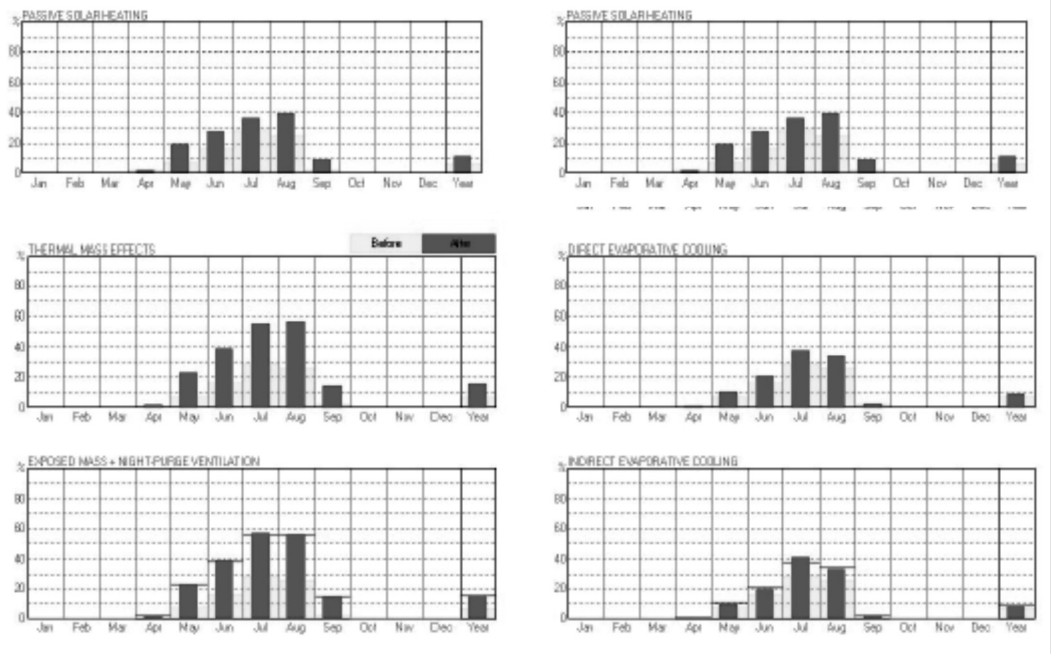


Fig. 5:
Monthly Thermal Comfort (yellow columns) and potential (red columns) for Oslo

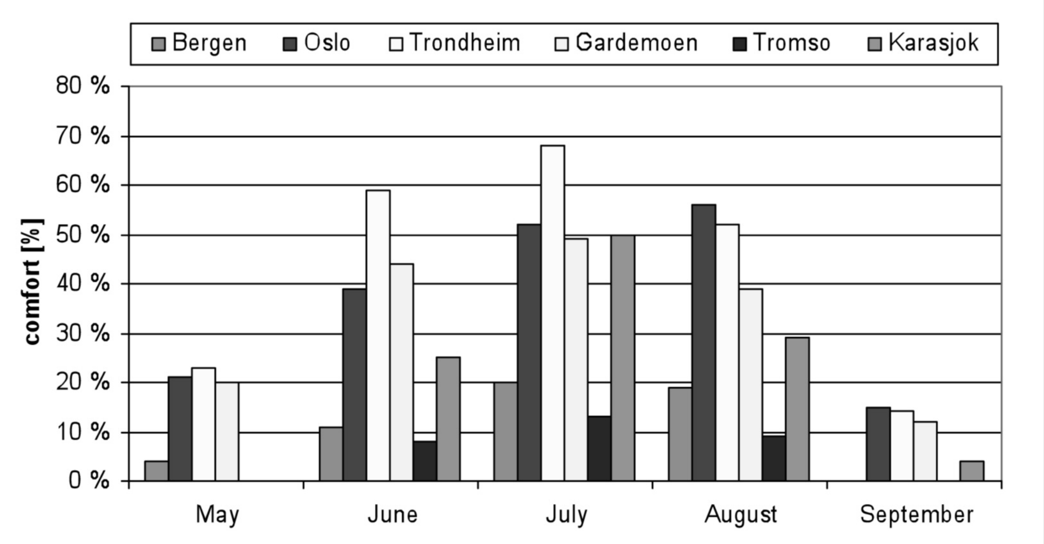


Fig. 6:
*Monthly Thermal Comfort potential for the use of Thermal Mass in Norway (for the locations listed in Table 1), Notes: * Gardemoen Weather Data was used for Hamar*

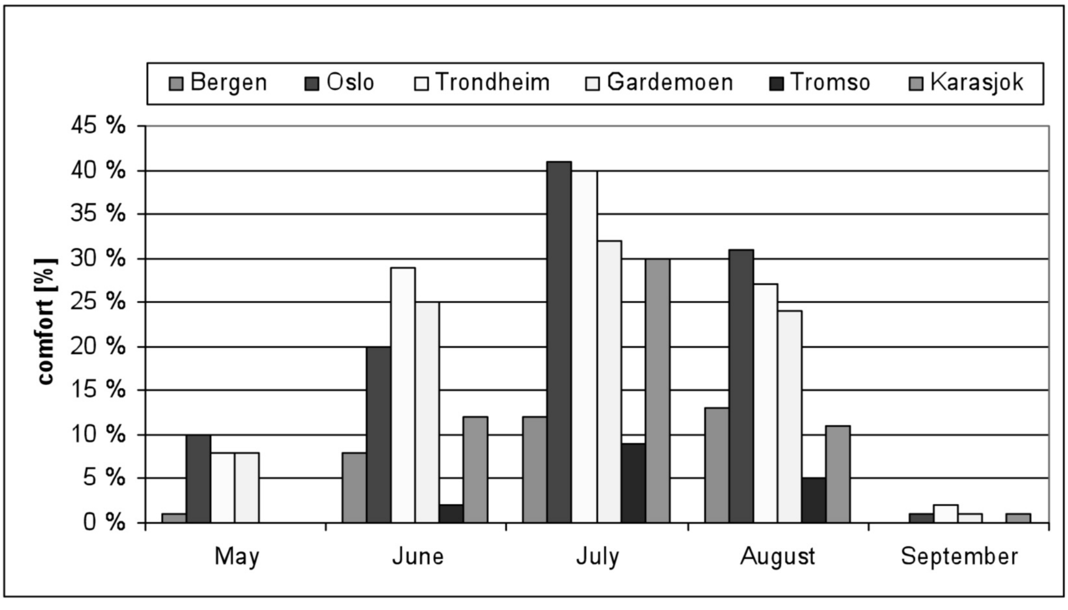


Fig. 7:
*Monthly Thermal Comfort potential for the use of Natural Ventilation in Norway (for the locations listed in Table 1), Notes: * Gardemoen Weather Data Was Used For Hamar.*

Fig. 8 summarizes the thermal comfort potential for the use of thermal mass while Fig. 9 shows the results for Natural ventilation for climates that might be prevalent in Norway in the future.

The potential varies over the year. In order to evaluate its usefulness as a passive cooling strategy focus should be on the months with cooling degree days (May to Sept).

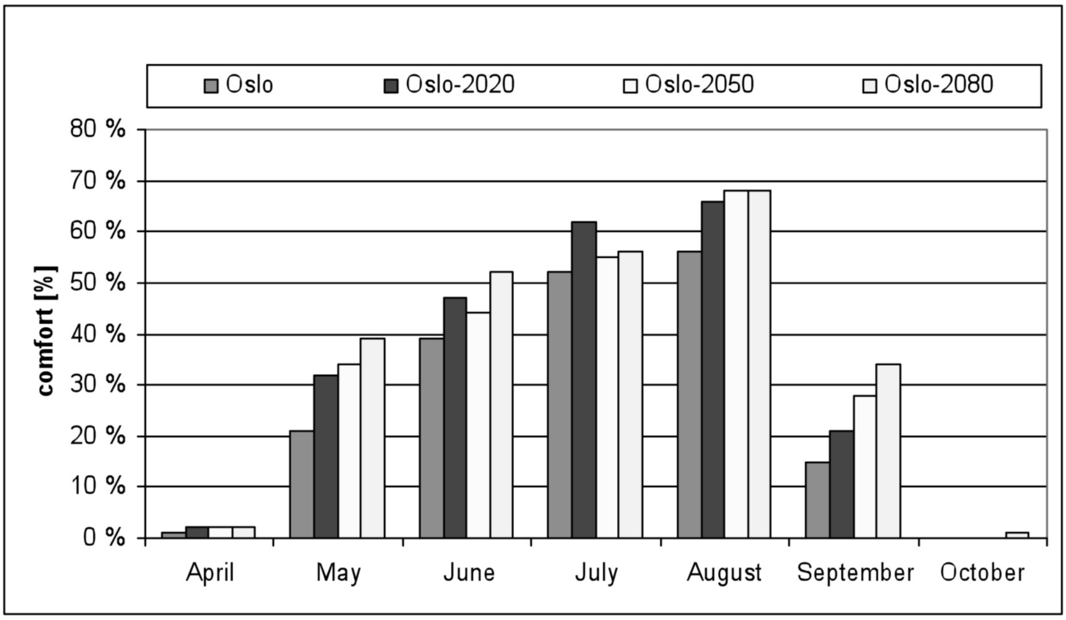


Fig. 8:
Monthly Thermal Comfort potential for the use of Thermal Mass in (for Oslo)

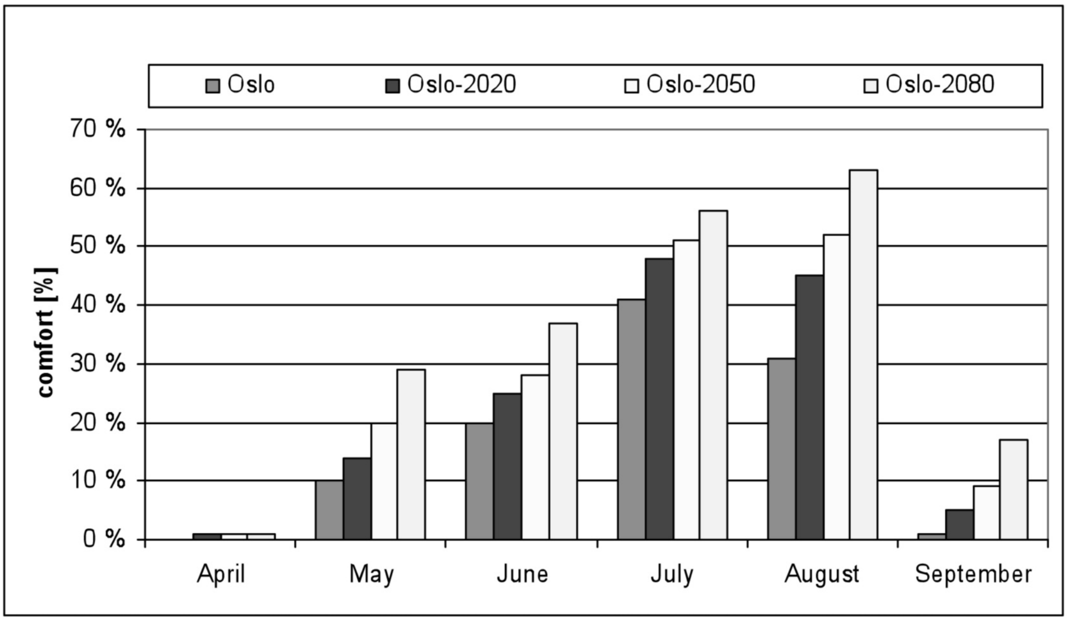


Fig. 9:
Monthly Thermal Comfort potential for the use of Natural Ventilation (for Oslo)

Conclusions and recommendations

Results show that predicted future climate change will reduce energy use in Norwegian buildings. However, thermal comfort during summer months is becoming more important when designing energy efficient buildings. Thus it was important to evaluate the potential of thermal comfort and related overheating problems in future summer periods that might even extend it to autumn and spring seasons.

The results of the weather data analysis show that there is a significant potential for improvements in thermal comfort, especially in the summer months. This can help to design comfortable buildings with climate responsive building components.

The cold climate of Norway requires different passive strategies to ensure thermal comfort.

The projected temperature rise over the next 100 years indicates an increase in cooling degree days. The thermal comfort analysis shows that thermal mass and natural ventilation are appropriate strategies to passively cool buildings in Norway.

The use of thermal mass has a good potential. The results show that in particular in the warmest summer months (July and August) the potential for achieving thermal comfort is around 50%. With a predicted increase in temperature over the next 100 years, the thermal comfort potential of these strategies increases up to 68%. The design of climate responsive building envelopes should take this into consideration.
It means a shift in the design paradigm away from focusing on reducing heat losses towards focusing on the integration of passive cooling strategies. It is therefore recommended to use the following three steps:
1 Prevent
2 Modulate
3 Utilize

Prevent

The first and most important strategy, which should be the focus already in the first phase of the planning, is to prevent or minimize the chance that excess heat occurs in the building at all. The measures to prevent overheating can be summarized as:

- Micro-climate and environmental design
- Solar control, window orientation
- Building design and organization
- Thermal insulation and solar absorption of opaque structures
- Internal load control
- Influence user behavior

Modulate

The second strategy is to modulate the heat surplus by moving the heat energy in the time domain by utilizing thermal mass. Excess heat is stored in the building materials with high thermal mass, such as in a concrete wall and then released by venting it out at night. In principle two measures are possible:

- Utilization of thermal mass
- Night cooling combined with thermal mass

Utilize

The third strategy is to use heat sinks to store the excess heat energy and ideally reuse it elsewhere (in the building) or at another time (day – night shift). To utilize heat gains this way the following measures can be applied:

- Comfort-ventilation (replace the warm air with colder air)
- Geothermal Cooling (culvert in the ground)
- Evaporative cooling
- Radiant cooling

In order to achieve drastic reductions in the energy use in new buildings the development of new construction solutions, new types of building envelopes, and development of new building materials is needed. It will also require some monetary investment, most effectively in the application of more holistic building concepts. But it is money well spent since energy savings remain relatively stable over the expected life time of new constructions.

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