Cooling Demand Reduction Approaches in a Nearly Zero Energy Building for Future City District in Central-Sweden

Sana Sayadi¹, Jan Akander¹, Abolfazl Hayati¹, Mathias Cehlin¹
¹Department of Building Engineering, Energy Systems and Sustainability Science, Faculty of Engineering and Sustainable Development, University of Gävle, 801 76 Gävle, Sweden

Abstract
The increase in population and living standards, as well as global warming and heatwaves due to climate change, have created a challenge to meet the cooling demand in buildings. In this study, the cooling requirement for a multifamily building through simulations in a future city district in central-Sweden was determined. Different air supply set point strategies, window to floor ratio and building rotations were employed to minimize the cooling requirements. The building was modelled so as to meet the Nearly Zero Energy Building (NZEB) requirements. Window to floor ratio of 10% with a piecewise proportional controller for supply temperature was depicted as appropriate for the building. A 45° rotation of the building increased the cooling demand. The cooling demand of the building increased by employing the extreme climate condition, as a representative for future climate, with factors 3.8 and 6.4 for cooling set points 25°C and 27°C for window to floor ratio 10%. This implies the need for a resilient building to withstand future climate conditions. The requirement to update the climate files was also used for decision making in the design process and building regulation.

Key Innovations
- New Swedish building regulations may imply low energy use but high exceedance hours in the future.
- Evaluating the influence of window to floor ratio and building rotation on cooling demand for typical and extreme summer climate conditions.
- Use of typical climate condition and an extreme summer climate condition

Practical Implications
The need to increase the resilience of buildings, and the requirement to update the weather datasets used for designing and defining building regulations, according to buildings’ future demand given that the present buildings in Sweden do not presently include cooling facilities.

Introduction
One-third of the world’s total energy use is due to the building sector; the amount of energy use for a building can be calculated from the building envelope, equipment, outdoor climate conditions, and the occupants (Cui et al. 2017). This trend continues to grow with the increase in population, urbanization and comfort level with more time spent indoors (Pérez-Lombard et al. 2008). An increase in energy use leads to an increase in carbon emissions. With the ongoing climate changes, more extreme weather events are experienced and the building sector appears to be more vulnerable to these changes (Yau et al., 2013). These extreme events are expected to affect building energy use. Using currently available sources of energy to face the climate implications for buildings endangers future energy security (Jing et al., 2014).

Buildings that are optimized from an energy use perspective, must be made more resilient, especially to future climate changes. During recent years, heatwaves have been the reason for certain heat-related deaths. A study conducted on heatwave-related mortality in Sweden depicted that heatwaves increase mortality and coronary heart disease mortality in particular by approximately 10% and 15% respectively (Oudin Åström et al., 2020). A study conducted in France revealed thousands of excess deaths (Vandentorren et al., 2006). Certain causes were reported as the main reasons such as high temperatures on the top floors.

Studies have been conducted to evaluate the importance of climate change and the use of future climate files on the annual energy use of buildings. Santamouris (2016) investigated the future cooling energy use of a building by implementing three scenarios based on parameters such as future climate, population increase, etc. and an average cooling demand was calculated for the future scenario. A study (Petersen, 2020) considered Typical Meteorological Year (TMY) weather files from historic data and three future climate scenarios (the 2020s, 2050s and 2080s) for a Danish office building. It was concluded that by employing the future climate scenarios, cooling demand increases and to have resilient buildings that would withstand future climate changes, it is better not to rely on historic data for building simulations.

To have a detailed assessment of the resilience of buildings and their performance in the long term, an insight into extreme climate is needed (Ramon et al., 2019). Different weather datasets were investigated for building simulations on a Flemish office building by Ramon et al. (2019), who reported the best combination of weather datasets to estimate the energy need of the resilient building.

The use of an “analogue scenario” has been introduced by (Belcher et al. 2005; Petersen 2020). In this method, the weather data of the studied building location that is expected to adopt the same behaviour as that of future
climate condition could be chosen to study the effect of extreme climate on a building’s energy performance.

One way of optimizing the amount of energy used is by applying an optimal supply temperature strategy. Wang et al. (2012) established a steady-state energy consumption model for AHU under the economizer cycle. Optimal supply flow and air temperature concerning outside temperature are obtained through an analytical optimization model. A control sequence was developed to meet the optimal supply airflow or supply air temperature to minimize the energy cost (Wang et al., 2012).

Therefore, implementing new approaches to reduce energy requirements in buildings to pave the path for energy transition to sustainable energy is an area of interest. With the ongoing climate changes, present buildings may not withstand future heatwaves and extreme climate conditions, therefore new regulations are required to increase the resilience of the buildings in future climate conditions. Given that current Swedish residential buildings are not equipped with any cooling units at all, this study aims to analyse and minimize the cooling requirement for a multifamily building through simulations in a new city district in central Sweden. The simulations were carried out with IDA - Indoor Climate and Environment (IDA-ICE) software version 4.8. Buildings must meet the Nearly Zero Energy Building (NZEB) requirements enforced within Swedish building regulations by implementing optimum building and window specifications.

The characteristics of the model building are aligned with Key Performance Indices (KPIs) which are based on the proposed list from IEA Annex 80: Resilient cooling of buildings. Reduction of heat load, reducing cooling requirement and exceedance hours (number of hours the building exceeds its comfort range during summer period (Bakhitiari et al., 2020; Nicol, 2013)).

**Methodology**

A future multifamily building in central-Sweden has been modelled. The plan of the building is shown in Figure 1. The building model consists of four floors with floor to ceiling height of 2.7 meters. Each apartment’s floor area is 77 m² and the total floor area is 1414 m². Different parameters such as equipment, lighting, window U-value and its shading factor were implemented based on the Swedish building regulations (Boverket, 2020; Sveby, 2012) to meet the NZEB requirements. Table 1 presents the efficiencies of the AHU and the heating/cooling set point s. The AHU is a constant air volume system that is equipped with heat recovery. In each zone, an ideal heater (EQUA, n.d.) also is implemented in order to evaluate the cooling load of the building during the cooling season. Ideal heaters could be considered as standalone heaters (EQUA, n.d.). Ideal coolers also were implemented in order to evaluate the cooling load of the building during the cooling season. Based on the regulation, a Primary Energy number (EP_{PET}), that describes the energy performance of the building based on its primary energy use has been defined. In order for the building to be considered an NZEB, EP_{PET} < 75 kWh/m²·A_{comp·year} should be satisfied. A_{comp} stands for the heated area (more than 10°C) in the building.

![Figure 1: Scheme of the building model's geometry. (a) The plan of the building (dimensions are in meters). (b) Modelled building in IDA-Indoor Climate and Energy (IDA-ICE)](image)

<p>| Table 1: Input parameters for the model building |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind profile</td>
<td>Urban</td>
</tr>
<tr>
<td>Heating set point</td>
<td>21°C (Boverket, 2020)</td>
</tr>
<tr>
<td>Cooling set points</td>
<td>Air temperature 25°C, 27°C</td>
</tr>
<tr>
<td>AHU specific fan power</td>
<td>0.75 kW/(m³/s)</td>
</tr>
<tr>
<td>Heat exchanger efficiency (air to air heat exchanger)</td>
<td>0.85</td>
</tr>
</tbody>
</table>

The insulation material used in the building envelope is based on the latest material available on the market which leads to heavy inertia with an average U-value 0.21 W/ (m²·K). The U-values for external walls and roof are 0.1 and 0.06 W/ (m²·K) respectively. External floor and internal floors have U-values of 0.11 and 1.8 W/ (m²·K) respectively. Glazing material used for the fenestration system also is based on regulations from Forum for Energy Efficient Buildings (FEBY) (2018). The glazing U-value and solar heat gain coefficient correspond to 0.8 W/ (m²·K) and 0.4 respectively. Total window U-value is 0.92 W/ (m²·K). Internal blinds with a solar gain multiplier of 0.65 were employed which are controlled by the solar radiation level in order to reduce solar heat gain. If the radiation level exceeds 100 W/m², the blinds would be drawn to cover the window. This value is chosen based on the global setting that is implemented in IDA-ICE (EQUA, n.d.). Surrounding buildings have been considered, 20 m from the model building in every orientation. Window to floor ratio of 10% is put into practice for the building model. The windows are set to be closed all the time in order to evaluate the cooling demand of the building without employing any cooling techniques. The supply and exhaust airflow of the system are 0.35 and 0.37 L/ (s·m²) respectively (Sveby, 2012).
Each apartment is defined as one zone in the model. The total sensible heat emitted in each zone is defined based on (Westin, 2019) and is set to be 1927 kWh/ year per apartment. This amount corresponds to household electricity.

In order to investigate the effect of different supply temperature strategies, window properties and orientations, three different case studies have been defined in the following subsections. For each case, different parameters have been evaluated; the exceedance hour is defined as the total hours that the building exceeds the comfort range (Nicol 2013; Bakhtiari et al. 2020). In this study, the number of hours, exceeding operative temperature 27°C during a complete year, are considered in exceedance hour evaluation. Cooling degree-hours (CDH) is defined as the sum of the difference between room air temperature and a base temperature on an hourly basis, which is calculated using equation (1):

$$ CDH = \sum_{j=1}^{N} (T_j - T_b)^+ $$  

Where $N$ is the number of hours in a given period, $T_b$ and $T_j$ are the base temperature and hourly mean room temperature respectively. The “$+$” superscript indicates that only positive values are considered in summation (Simson et al. 2015). The CDH is calculated over the summertime period (1st July-31st August). The base temperature is taken as $T_b= 25 \, ^\circ C$ as well as $T_b= 27 \, ^\circ C$.

**Case 1: Investigation of different mechanical ventilation strategies:**

In this case, different control schemes for the supply air temperature and their effect on the indoor conditions were investigated. Window to floor ratio was 10%. A constant supply temperature of 16°C was first considered. Correspondingly the AHU supply air temperature is always 16°C until the ambient temperature reaches 16°C. From that point onwards, the supply temperature would be the same as the ambient temperature.

The alternate mechanical ventilation strategy studied, was a piecewise proportional controller for the supply air temperature. Different combinations of supply temperature were examined in order to find the scheme that helps to reduce the exhaust air temperature and the exceedance hours in the zone which consequently reduces the cooling load. Figure 2 depicts the chosen supply air temperature scheme. Based on this strategy, when the ambient temperature is below 8°C, the supply air temperature is 16°C. The supply air temperature gradually decreases by the ambient temperature increase, until the ambient temperature reaches 16°C. Since no cooling coils are defined in the system, the AHU does not supply cooled air streams to the zones. When the ambient temperature is above 16°C, AHU supplies the same temperature as the ambient temperature.

**Case 2: Window to floor ratio change**

Initially, the window to floor ratio employed in the study was 10%, which is the minimum ratio allowed to meet the daylight requirements in Swedish building regulations (Boverket, 2018).

In order to study the effect of different window sizes, different window to floor ratios of 15% and 20% were considered by employing the chosen supply strategy from Case 1, which is the piecewise proportional controller for the supply air temperature. The maximum window to floor ratio (20%) was chosen based on the previous Swedish building regulation (Boverkets, 1988).

**Case 3: Rotation of the building**

The building was then rotated 45° in order to investigate the effect on the interior conditions. Later the building was rotated 90° and the simulations were carried out for this orientation as well.

**Case 4: Extreme summer climate condition**

The climate file used throughout the procedure has been the climate file based on the 30 years of data (years 1981-2010) from the Swedish Meteorological and Hydrological institution (SMHI, n.d.) to create a typical year climate file. In this case, the extreme climate file for 2018 was used as a representative of the future climate condition. The extreme climate of 2018 was recorded to have the warmest summer with longer heatwaves (Wilcke et al., 2020). In this case, the effect of the same window to floor ratios (10-15% and 20%) and building rotation (45° and 90°) on cooling demand and the exceedance hours were investigated. Finally, a combination with the least cooling demand and exceedance hours is selected.

**Results**

After running the simulations for all the cases, the results are shown below. The typical year climate file has been used for the Base case, Case 1, Case 2 and Case 3. The extreme climate of 2018 has been employed for the last case (Case 4: extreme summer climate condition).

**Case 1 (Base case):**

Figure 3, shows the duration curve for the following temperatures: ambient, supply, exhaust air, operative for the worst zone (zones on the fourth floor), and best zones (first-floor zones) for two different supply air temperature schemes. Figure 3a shows the duration curve when constant supply temperature was employed and Figure 3b shows the duration curve for a piecewise controller
scheme for supply air temperature. The worst zones have the highest operative temperatures and the best zones have the lowest operative temperatures. The rest of the zones are considered average zones.

The lines A, B and C shown in Figure 3, represent the heating and cooling set points. Line A shows where the exhaust air temperature (grey dotted line) exceeds 21°C. From this point onwards, the building does not require heating. Lines B and C depict where the exhaust air temperature exceeds the cooling set points of 25°C and 27°C respectively. Exhaust air exceedance hours are calculated from these three lines onwards. Exhaust air exceedance hour represents the number of hours in a year in which the exhaust air temperature rises above the mentioned cooling set point.

As it can be seen in Figure 3a, the heating set point (21°C) has been maintained for about 4300 hours during a year. In this case, CDH corresponds to 1379°Ch and 274°Ch for base temperatures of 25°C and 27°C respectively.

As mentioned in Table 1, two cooling set points were considered in the study. The second vertical line B indicates the exhaust air exceeding the cooling set point 25°C and the third line C, represents the exhaust air exceeding cooling set point 27°C. From these latter mentioned lines onwards, the building is in need of cooling. The cooling demands of the building for these two set points are 1.8 and 0.62 kWh/m² respectively for 25°C and 27°C cooling set point.

The operative temperature in the worst zone is more than AHU’s exhaust air temperature for nearly 4400 hours during the year due to the solar gain absorbed by the interior surfaces and windows (glazing) which increases the operative temperature. Exceedance hours correspond to 700 hours in worst zone and 350 hours in average zones in a year. Figure 3b, shows the duration diagram by implementing the piecewise controller with control strategy, depicted in Figure 2. The exhaust temperature is maintained at 21°C for about 4600 hours and rises above 21°C after this duration (line A). The new supply strategy has been able to delay the rise in exhaust air temperature, consequently leading to better indoor conditions for a longer time.

Figure 3: Duration diagram for base case, for the following temperatures: ambient, supply, exhaust air, operative. (a) Constant supply temperature (16°C). (b) Piecewise controller schedule.
Line B represents the exhaust air temperature rising above the first cooling set point (25°C) at 8000th hours and line C represents the exhaust air temperature rising above the second cooling set point (27°C) at late 8000th hours. The exceedance hours in the worst zone are 440 hours and in an average zone are 260 hours. CDH is 1011°Ch and 163°Ch for base temperatures 25°C and 27°C respectively during the considered period (1st July- 31st August). These factors indicate the effectiveness of the new supply strategy. Therefore piecewise controller is implemented for further case studies in this research. The cooling demands for the cooling set points of 25°C and 27 °C are 1.33 and 0.43 kWh/m² respectively. The model building should meet the NZEB requirements by satisfying the primary energy number, $P_{PET}$. $P_{PET}$ is 43.4 and 44 kWh/ m² respectively for constant supply temperature and controlled supply scheme. Both the obtained values are smaller than 75 kWh/ m² (Boverket, 2020). Therefore the model building satisfies the NZEB requirements. It should be noted that no cooling energy was considered in obtaining the $P_{PET}$ values since residential buildings in Sweden are not normally equipped with cooling units. However, $P_{PET}$ remains relatively the same when adding an ideal cooling unit with a cooling set point of 27°C. $P_{PET}$ corresponds to 44.6 and 45 kWh/ m² for constant supply temperature and controlled supply scheme respectively when a cooling unit with a cooling set point 25°C was employed.

**Case 2:**

Table 2 reports the exceedance hours (number of hours the operative temperature is above 27°C), the cooling degree hours (room air temperature above base temperatures 25°C and 27°C), exhaust air temperature exceedance hours (number of hours the exhaust air temperature is above cooling set point s) and the cooling demand for the given set point s of 25 °C and 27°C. Results for window to floor ratio of 10% also are presented for better comparison between the cases. Piecewise controller scheme for the supply temperature was employed for all the studied window to floor ratios. The maximum exhaust air temperature for window to floor ratio 10% is 29°C. By increasing this ratio to 15%, the maximum exhaust air temperature rises to 30.8°C. This indicates the increase in operative temperature as well. The operative temperature in the worst zones (zones on the 4th floor, especially facing south) increase by 2°C compared to the window to floor ratio 10%. The operative temperature in the best zones increases by 1°C.

The same terms could be applied for window to floor ratio of 20%. The maximum exhaust air temperature, in this case, is 31.9°C and the operative temperature in the worst zones increases by 4°C compared to the case with window to floor ratio of 10%.

**Table 2: Exceedance hours, exhaust air temperature exceedance hours, the cooling degree hours and the cooling demand for the studied window to floor ratios when employing a typical year.**

<table>
<thead>
<tr>
<th>Window to floor ratio</th>
<th>Operative temperature above 27°C in average zones</th>
<th>Operative temperature above 27°C in worst zone</th>
<th>Exhaust air temperature above 25°C (Cooling set point)</th>
<th>Exhaust air temperature above 27°C (Cooling set point)</th>
<th>CDH (°Ch)</th>
<th>Cooling Demand (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>260</td>
<td>610</td>
<td>800</td>
<td>200</td>
<td>1011</td>
<td>163</td>
</tr>
<tr>
<td>15%</td>
<td>610</td>
<td>1050</td>
<td>1100</td>
<td>470</td>
<td>1810</td>
<td>583</td>
</tr>
<tr>
<td>20%</td>
<td>870</td>
<td>1310</td>
<td>1400</td>
<td>700</td>
<td>2348</td>
<td>973</td>
</tr>
</tbody>
</table>

**Figure 4: Solar irradiation on the building at 12:00, 15th July. (a) 45° rotation. (b) 90° rotation**

As depicted in Table 2, by increasing the window to floor ratio, the cooling demand of the building also increases as can be seen from the CDH values reported. It could be concluded that window to floor ratio of 10% with the piecewise controller for the supply temperature is an appropriate combination among the studied cases.

**Case 3:**

Rotation of the building has no significant effect on exhaust air and operative temperatures. The exhaust air temperature remains relatively the same (maximum exhaust air temperatures are 28.6°C for the base case, 29.2°C when rotated 45° and 28.9° when rotated 90°). The same applies to the operative temperatures.

Table 3 shows the exceedance hours, CDH and cooling demand of the building for two cooling set points during
a year for 45° and 90° rotation of the building. As can be seen from Table 3, the cooling demand of the building increases when rotated 45° compared to the building due south and 90° rotation. Solar heat gain absorbed by the building increases in case of 45° rotation, therefore the cooling requirement of the building also increases. Figure 4 shows the building on 15th July, at 12:00. Figure 4a and 4b depict 45° and 90° rotation respectively.

Table 3: CDH and exceedance hours and cooling requirements for Case 3, typical year

<table>
<thead>
<tr>
<th>Rotation</th>
<th>CDH (°Ch)</th>
<th>Exceedance hours</th>
<th>Cooling demand (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{\text{b}}=25$</td>
<td>$T_{\text{b}}=27$</td>
<td>Average zones</td>
</tr>
<tr>
<td>45°</td>
<td>1096</td>
<td>200</td>
<td>350</td>
</tr>
<tr>
<td>90°</td>
<td>965</td>
<td>143</td>
<td>260</td>
</tr>
</tbody>
</table>

**Extreme climate condition:**

Table 4 depicts the exceedance hours (number of hours the operative temperature is above 27°C), the cooling degree hours (room air temperature above base temperatures 25°C and 27°C), exhaust air temperature exceedance hours (number of hours the exhaust air temperature is above cooling set point s) and the cooling demand for the given set point s of 25 °C and 27°C after employing the 2018 climate file. Piecewise controller scheme for the supply temperature was employed for the simulations. By comparing the obtained results (Table 4) to the presented result in Table 2, an increase in the cooling requirement of the prototype building could be seen. Table 5 shows the relative changes in cooling demand for both set points, comparing window to floor ratios 15% and 20% to window to floor ratio 10%. The exhaust air temperature shows a rise of almost 3°C compared to Case 2 (maximum exhaust air temperatures are 32.3°C, 33.8°C and 34.8° for window to floor ratios 10%, 15% and 20% respectively). This implies the need for change in the current cooling technique (passive cooling) for future buildings, as presently buildings in Sweden are not equipped with any cooling systems. These temperature changes show the importance of the weather dataset that should be used to update building regulations and to evaluate the resilience of buildings. The climate file that was used in the previous sections, was based on 30 years of historic data (years 1981-2010).

Table 5 shows the relative changes in exceedance hours for each of the studied climates. The exceedance hours for each window to floor ratios of 15 and 20% are compared to the window to floor ratio of 10% of their respective climate. As can be seen from the results in Table 6, the relative rise in exceedance hours when employing an extreme climate, does not change as that of the average year climate which is due to the low value for window to floor ratio 10% for average climate condition.

Table 6 presents the exceedance hours, CDH and cooling demand of the building for the given base temperatures and the cooling set point s after rotating the building 45° and 90° for building with window to floor ratio of 10%. Window to floor ratio of 10% was chosen since the cooling demand was the least among the other ratios, as could be seen from Table 4. Results depicted in Table 6 indicate small relative changes for the extreme climate condition.

Figure 5 shows the duration diagram when the extreme climate of 2018 was chosen as a representative for the future climate. Based on the results from the previous cases, building from the base case, with piecewise controller scheme for the supply temperature was chosen as the final and best combination for this case. From Figure 5 it could be concluded that more hours of cooling are required, as lines B and C have shifted to the left, meaning the extreme climate has affected the cooling requirements of the building. The cooling demand of the building with a cooling setpoint of 25°C and 27°C is 5.01 and 2.76 kWh/m² respectively. Since the cooling demand has increased compared to the normal year with a factor of 3.8 and 6.4 respectively for the latter mentioned set points. Maximum exhaust air temperature would in this case be 32°C. Apart from the increase in exhaust air temperature, the operative temperature for both worst and best zones have increased by 2°C in comparison.
were considered to calculate this value. The extreme climate condition has adversely affected the cooling demand of the building.

### Discussion

Today, the energy criterias for fulfilment of the Swedish building regulations are based on a typical year, where the criteria is based on energy use of the building. Moreover, it is a primary energy number which is based on weighted values depending on the sources of energy that the building uses.

Traditionally, building regulations and standards have focused on heating requirement and set minimum indoor temperature limits during the winter season. In view of future climate changes, both winters and summer will be warmer. In recent building regulations, energy for cooling has been imposed as part of the total energy requirement (Pet).

This paper focuses on cooling demand of a prototype building, given that Sweden has a limited tradition of passive cooling strategies for residences. In this situation, problems may arise for a residential building that fulfils today’s NZEB in the future. The typical climate prescribed to be used in simulations, to check that fulfils energy requirements, indicates minor cooling requirement and fairly low exceedance hours. The values presented in this paper would imply “let’s build as usual – no active cooling systems in residences.” However, the extreme climate indicates that increase in cooling requirement is substantial in comparison to the typical climate. Without a cooling system, the exceedance hours cannot be neglected. The typical climate cannot be used for design purposes (as concluded by Petersen (2020), and questioned if new building’s energy performance should at all be based on past years recordings).

### Conclusion

The effect of window to floor ratio, building rotation and different supply schemes on the cooling requirement of a prototype NZEB was investigated. The cooling requirement of the building was evaluated by calculating CDH value. By employing a piecewise controller, to control the supply temperature, CDH decreased 27% and 40% for base temperatures of 25°C and 27°C respectively, compared to constant air temperature supply. The cooling demand of the building also decreased 26% and 30% for 25°C and 27°C cooling setpoints respectively. Window to floor ratio of 10% showed the least cooling demand.

### Table 4: Exceedance hours, exhaust air temperature exceedance hours, the cooling degree hours and the cooling demand for the studied window to floor ratios when employing an extreme climate.

<table>
<thead>
<tr>
<th>Window to floor ratio</th>
<th>Exceedance hours</th>
<th>Exhaust air temperature exceedance hours</th>
<th>CDH (°Ch)</th>
<th>Cooling Demand (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operative temperature above 27°C in average zones</td>
<td>Exhaust air temperature above 25°C (Cooling setpoint)</td>
<td>T₀=25</td>
<td>T₀=27</td>
</tr>
<tr>
<td>10%</td>
<td>1220</td>
<td>2000</td>
<td>1050</td>
<td>2008 925</td>
</tr>
<tr>
<td>15%</td>
<td>1840</td>
<td>2500</td>
<td>1600</td>
<td>2525 1301</td>
</tr>
<tr>
<td>20%</td>
<td>2100</td>
<td>2600</td>
<td>1960</td>
<td>2904 1591</td>
</tr>
</tbody>
</table>

### Table 5: Rise in exceedance hours in average and the worst zone for each climate condition when compared to window to floor ratio 10%

<table>
<thead>
<tr>
<th>Climate</th>
<th>Window to floor ratio</th>
<th>Multiplying factors when compared to window to floor ratio 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average zones</td>
</tr>
<tr>
<td>Average year climate</td>
<td>15%</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>2.9</td>
</tr>
<tr>
<td>Extreme year climate</td>
<td>15%</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>1.9</td>
</tr>
</tbody>
</table>

### Table 6: CDH and exceedance hours and cooling requirements for building rotation when employing the extreme climate

<table>
<thead>
<tr>
<th>Rotation</th>
<th>CDH (°Ch)</th>
<th>Exceedance hours</th>
<th>Cooling demand (kWh/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>T₀=25</td>
<td>T₀=27</td>
<td>Cooling setpoint 25°C</td>
</tr>
<tr>
<td>45°</td>
<td>2089</td>
<td>978</td>
<td>1314</td>
</tr>
<tr>
<td>90°</td>
<td>1981</td>
<td>904</td>
<td>1226</td>
</tr>
</tbody>
</table>

To the base case with the same supply temperature scheme. The exceedence hours for the worst zone corresponds to 1660 hours and in average zones 1220 hours which shows an increase compared to the reported result for the base case with the same control scheme. The CDH was reported 2534°Ch and 1346°Ch for base temperatures of 25°C and 27°C respectively. PEPE values for cooling set points of 25°C and 27°C were 46.1 and 44.5 kWh/ m² respectively. The PEPE value was considered throughout a complete year. Heating, cooling and facility electricity were considered to calculate this value. The extreme climate condition has adversely affected the cooling demand of the building.
45° rotation of the building increased cooling demand by 8% and 3% for cooling setpoints 25°C and 27°C respectively, compared to building with no rotation. A 90° rotation did not have a significant effect on the cooling demand.

By employing extreme climate condition weather data (the year 2018), cooling demand and CDH increased for all the studied cases. By employing window to floor ratio of 10% with the schematic supply temperature for the prototype building, the CDH values increased 2.5 and 8 times the typical climate condition for base temperatures of 25°C and 27°C respectively. The cooling demand of the building also increased 3.8 and 6.4 times the typical climate for cooling set point 25°C and 27°C respectively. These changes indicate the need for increasing the resilience of the buildings and requirements to update the historic weather datasets used to design building regulations.

References


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