A study of the passive cooling potential in simulated building in Latvian climate conditions

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Abstract. In this paper authors point out that overheating in buildings during summer season is a major problem in moderate and cold climates, not only in warm climate zones. Mostly caused by solar heat gains, especially in buildings with large glazed areas overheating is a common problem in recently constructed low-energy buildings. At the same time, comfort demands are increasing. While heating loads can be decreased by improving the insulation of the building envelope, cooling loads are also affecting total energy demand. Passive cooling solutions allow reduction of heat gains, and thus reducing the cooling loads. There is a significant night cooling potential with low temperatures at night during summer in moderate and cold climates. Night cooling is based on cooling of buildings thermal mass during the night and heat accumulation during the day. This approach allows to provide thermal comfort, reducing cooling loads during the day. Authors investigate thermal comfort requirements and causes for discomfort. Passive cooling methods are described. The simulation modeling is carried out to analyze impact of constructions and building orientation on energy consumption for cooling using the IDA-ICE software. Main criteria for simulation analysis are energy consumption for cooling and thermal comfort.

1. Introduction

The comfort indoor air parameters are as follows: air temperature ranging from +20 to +24 °C, relative humidity between 40% and 60%, CO₂ level below 1000 ppm [2, 7]. However thermal comfort is defined by many factor [1, 6] and nowadays overheating become an actual problem in new well insulated buildings. As there is a constant exchange between outdoor and indoor environment through door and/or window openings, natural infiltration and other factors thermal comfort strongly depends on the climate conditions. The effect of climate conditions depends on building structural characteristics, orientation and location. Climate conditions influence the indoor thermal comfort via heat transfer through the building envelope, solar gains through glazing and openings, outdoor air infiltration through doors, windows etc. Recent national studies [13, 14] have evaluated different building structure in order to choose better materials for Latvian climates. These studies have shown importance of optimal proportion of materials thermal mass and thermal energy sources. This study focuses on passive nigh cooling application in Latvian climatic conditions. Nowadays passive methods for insuring necessary indoor air quality and thermal comfort become more and more popular [5].

However, thermal comfort is even more greatly influenced by numerous internal factors – internal heat gains from people, electrical equipment and lighting, heat insulation, glazing and shading, building
structure and function. In medium and long-term these factors are subject to various changes. Heat insulation is improved, occupant density increases and electrical equipment gets more efficient [3].

Study [17] investigates 16 new apartment buildings in terms of their compliance to thermal comfort requirements in summer season according to Estonian building codes. Investigated buildings are all different, built after 2009. Within this study temperature measurements in the apartments were being recorded from July 1 to August 31, 2014. In addition, the imitation modeling was carried out using IDA/ICE modeling software. Within this study the authors revealed that quite frequently temperature exceeded +30 °C. The maximum allowed 150 degree hours with the ambient temperature over +27 °C according to the relevant regulation [6] are exceeded with the ratio of occurrence of 94%, in one case reaching even 2110 °Ch. Modeling results show that in 13 out of 16 analyzed buildings the indoor conditions in summer do not meet the comfort requirements outlined in local building code “Minimum requirements for energy performance”. Very similar conclusions are drawn in study [18]. In this study, the authors compare summer thermal comfort conditions in apartment buildings in Estonia. The investigated buildings were constructed between 1960 and 2010. The temperature measurements were carried out in 100 apartments in 48 buildings. The newer buildings had a mechanical ventilation system, while the older buildings relied on natural ventilation measures. Interestingly, upon analyzing the results it was observed that overheating was not a case in older buildings, whereas the newer buildings were exposed to overheating in 13.7% cases mainly due to their increased glazed surface area. Work [4] in which the authors analyzed thermal comfort conditions in office buildings with large glazed areas in cold season.

Within the study the authors did temperature measurements along with carrying out a survey on occupant satisfaction with indoor environment. It was concluded that even in the cold season (October – April, according to the climate conditions in Baltic States) there is a high probability of overheating indoors. The key issues in buildings with large glazing surface area are linked to overheating that is initiated by direct solar gains and insufficient ventilation rates. The latter also leads to problems related to stuffy air. To avoid the overheating it is recommended to incorporate reflecting glass and/or use ventilated facades. The authors also emphasize the importance of carrying out a survey where occupants were asked to evaluate their level of satisfaction with the indoor environment. Another paper published by [8] was aimed at analyzing thermal comfort and overheating risks in low energy buildings during summer in Latvian climate conditions. The air temperature along with the relative humidity were measured. The results showed that there are overheating issues observed in low energy buildings even in relatively mild Latvian climate conditions. Indoor temperature in frequent occasions exceeded +30 °C even at relatively high ventilation rates. Based on the studies above it can be concluded that overheating is a great challenge even in mild climate conditions, and thus in Baltic States. Even in the cold season, which ranges from October through April and within which the building stock requires heating, the excessive indoor temperatures may occur. The overheating is especially common problem in buildings with large glazed facades throughout the year.

2. Passive cooling methods and Night cooling

By utilizing passive cooling methods it is possible to reduce the loads for cooling equipment in Central and North European countries. Passive cooling is predominantly linked to the building design approach that focuses on reducing heat gains and increasing heat extraction [8]. Indoor environment are affected by many parameters such as internal heat/moisture production as well as external [15,16]. In order to achieve that, it is necessary to reduce internal and external, that is, solar heat gains. Solar heat gains can be minimized through reasonably limiting glazing area and applying external shading elements. Internal heat gains are generated by people, electrical equipment, artificial lighting. Therefore, the use of energy efficient appliances in offices not only reduces the electricity consumption, but also considerably reduces cooling capacity and improve thermal comfort [13, 14]. However, it is worth to point out that internal heat gains are responsible only for minor portion of the total heat gains. Apart from reducing heat gains, passive cooling relies on natural heat transfer from building to surrounding air or to the ground. This is achieved with natural and mechanical ventilation systems. Through combining several
cooling methods, it is possible to obtain an efficient ventilation system. In hybrid cooling methods several passive or passive/active systems are combined. Using passive and active systems in combination, passive cooling system is used while natural heat extraction is sufficient. This approach enables to considerably reduce the energy consumption of the active cooling system.

In hybrid ventilation systems where mechanical and natural ventilation systems are combined, the specific ratio of each of both systems depends on the outdoor conditions. Night cooling offers the potential to minimize or even avoid the use of mechanical cooling and improve the internal conditions in naturally ventilated buildings. Night cooling uses the thermal mass of a building to absorb heat gains during the day, then this thermal mass is cooled at night. In buildings with sufficient thermal mass, utilization of the night cooling allows to reduce the max temperature for 2-3 °C. Night ventilation provides a possibility to reduce the use of mechanical cooling or to completely exclude the need for it in natural ventilation systems \[10\]. During the daytime heat gains are accumulated in the building’s thermal mass. When the outdoor air temperature is lower than the indoor air temperature, building’s overall temperature can be reduced using natural ventilation. The absorbed heat is transferred from the building mass the following night \[11\]. Passive night cooling systems operate primarily on natural ventilation basis. Cooled outdoor air transfers warm indoor air outdoors, cooling the building’s thermal mass. However, it should be noted, that natural ventilation is triggered by the wind and natural buoyancy that strongly depends on the building’s height. In active night cooling systems a fan is used to move the air. These systems provide a possibility for control to ensure the necessary air exchange as well as stop the cooling of the building, once the temperature reaches certain threshold. Night cooling is appropriate for regions where a relatively high difference between daytime and nighttime temperature is observed, with the night temperature being below 20 °C.

3. Methodology
Imitation modeling is a frequently used tool in engineering sciences for problem analysis and solving. Imitation model can be defined as an accurate real system representation in relation to a specific problem. Imitation model is a simplified version of real and existing systems.

To qualitatively evaluate and compare the impact of various passive cooling solutions on energy consumption for cooling and thermal comfort in different buildings, the imitation modeling technique provided by \textit{EQUA Simulation AB} was used. The software tool \textit{IDA Indoor Climate and Energy (IDA ICE)} enables to accurately model buildings, their internal systems and control equipment, allowing the designer to find an optimized correlation and match between the lowest energy consumption and highest occupant comfort. This software tool calculates building’s energy balance, taking into account climate conditions and alternating time intervals. Heat balance is calculated based on the user’s defined building geometry and construction, internal heat gains and HVAC settings \[9\].

The software tool uses climate data, that incorporates information on the air temperature, relative humidity, wind direction and velocity, as well as direct and diffuse solar radiation. The \textit{IDA-ICE} simulation enables to:

- Assess the overheating risks in buildings with acceptable heat insulation, large specific glazing area and natural ventilation system;
- Evaluate facades of different complexity;
- Simulate various HVAC control strategies.

The software tool takes into account the following criteria:

- Building’s thermal mass;
- Building’s construction materials and properties;
- Characteristics of the engineering and control systems.

Acquired results are then compared to the measured data.

The building model is a rectangular-shape one storey building with the largest facades oriented towards N and S, and with windows installed on S and SW facades (fig. 1). Outdoor climatic parameters were chosen from ASHRAE Fundamentals 2013.
Figure 1. Layout of the modeled building and climatic file.

The building geometry is described in the table below:

| Table 1. Geometry of the modeled building. |
|-------------------------------------------|
| Width                                      | 4.4 m |
| Length                                    | 5.1 m |
| Heated floor area                         | 20 m² |
| Ceiling height                            | 2.5 m |
| Volume                                    | 50 m³ |
| Building volume                           | 56 m³ |

**Windows**

| Width                                      | 3.6 x 2.1 m |
| Height                                    | 1.4 x 1.4 m |
| Area                                      | 5.04 x 2.94 m² |
| Windows/floor surface area ratio          | 40 %        |
| Windows/facade surface area ratio         | 46.5 %      |

To determine the cooling energy consumption and occupant thermal comfort in summer season, the period of May thru September is chosen for simulation. In the simulation model it is assumed that heating is not supplied.

To simulate the office environment the following assumptions were made:
- The room with floor area of 20m² is occupied by 4 people;
- The working day starts at 7:00 AM and ends at 6:00 PM with flexible lunch break (fig. 2.);
- No occupancy during the weekend;
- Occupant number is halved in July accounting for vacation.

Figure 2. Room occupancy during the weekdays.
The ventilation system was set up to ensure CO₂ level at 900ppm. The imitation model aims to determine the effect of the thermal mass used in the building on the energy consumption required for cooling. Three different types of external walls are compared (light, medium and heavy), keeping the floor and ceiling construction constant.

Different construction materials are used in each case, whereas the thickness of the heat insulation material in each case is chosen so that each of the modeled buildings have the same heat transfer coefficient. Constructions are compared in Table 2.

The heat transfer coefficient for external walls is selected according to Latvian Building Code LBN 002-15 “Heat Engineering for Buildings’ External Walls” [12]:
- Heat transfer coefficient $U_{RN}$ W/(m²·K) for public buildings – 0.20 k;
- Temperature factor $k$ for building located in Riga with internal rated temperature +21 °C – 0.86;
- Heat transfer coefficient $U = 0.172$ W/(m²·K).

### Table 2. A detailed description of the building.

| External wall (light) | $d$, m | $\lambda$, W/m·K | $\rho$, kg/m³ | $c$, J/kg·K | $U$, W/(m²·K) |
|-----------------------|--------|------------------|--------------|-------------|---------------|
| Drywall               | 0.026  | 0.22             | 970          | 1090        | 0.172         |
| Wooden frame + heat insulation | 0.026  | 0.052            | 92           | 2010        |               |
| Air gap               | 0.020  | 0.11             | 1.2          | 1006        |               |
| Wood                  | 0.025  | 0.14             | 500          | 2300        |               |

| External wall (medium) | $d$, m | $\lambda$, W/m·K | $\rho$, kg/m³ | $c$, J/kg·K | $U$, W/(m²·K) |
|------------------------|--------|------------------|--------------|-------------|---------------|
| Drywall                | 0.026  | 0.22             | 970          | 1090        | 0.172         |
| Light concrete         | 0.200  | 0.15             | 500          | 1050        |               |
| Mineral wool           | 0.106  | 0.037            | 20           | 750         |               |
| Light concrete         | 0.200  | 0.15             | 500          | 1050        |               |

| External wall (heavy)  | $d$, m | $\lambda$, W/m·K | $\rho$, kg/m³ | $c$, J/kg·K | $U$, W/(m²·K) |
|------------------------|--------|------------------|--------------|-------------|---------------|
| Drywall                | 0.026  | 0.22             | 970          | 1090        | 0.172         |
| Brick                  | 0.110  | 0.58             | 1500         | 840         |               |
| Mineral wool           | 0.190  | 0.037            | 20           | 750         |               |
| Brick                  | 0.110  | 0.58             | 1500         | 840         |               |

| Floor                  | $d$, m | $\lambda$, W/m·K | $\rho$, kg/m³ | $c$, J/kg·K | $U$, W/(m²·K) |
|------------------------|--------|------------------|--------------|-------------|---------------|
| Wood                   | 0.025  | 0.14             | 500          | 2300        |               |
| Mineral wool           | 0.100  | 0.037            | 20           | 750         |               |
| Medium density concrete| 0.200  | 1.42             | 2000         | 1000        | 0.3133        |

| Ceiling (roof)         | $d$, m | $\lambda$, W/m·K | $\rho$, kg/m³ | $c$, J/kg·K | $U$, W/(m²·K) |
|------------------------|--------|------------------|--------------|-------------|---------------|
| Roof material          | 0.020  | 0.58             | 1500         | 840         |               |
| Wooden frame + heat insulation | 0.020  | 0.044            | 56           | 1720        | 0.3943        |
| Drywall                | 0.026  | 0.22             | 970          | 1090        | 0.133         |

Floor $U$-value is calculated in accordance to LVS EN ISO 6946+A1, while the heat losses are calculated takin into account year fluctuation of soil temperatures which is fully in compliance with LVS EN ISO 13370 requirements. In that case estimated $U$-value for the floor is 0.20W/(m²·K) which is very close to LBN002-15 values. For such small case building normative $U$-value 0.15 W/(m²·K) will be difficult to reach to due low area/perimeter proportion. Ceiling $U$-value is assumed higher that normative requirements in order to highline importance of the solar gains in to get more clear difference of ventilation strategies.
4. Results
To determine the effect of the building’s thermal mass on the energy consumption for cooling, 3 simulation scenarios were defined in the simulation model. The 3 scenarios differ with the external wall construction (table 2), while other properties such as window placement, floor and ceiling/roof construction remain similar. The simulations are referred to after the external wall construction, that is, Light, Medium and Heavy. Heating supply is not active. The max indoor temperature is set to +24 °C.

The max CO₂ level is set to 900 ppm. Windows are not openable, mechanical ventilation system operates. The main criteria in determining the effect of the thermal mass on cooling requirement is kWh/m² equivalent. Energy consumption for cooling in summer season is shown in the below table.

Table 3. Energy consumption for cooling with non-openable windows in summer season in all 3 modeled scenarios: month by month, kWh/m².

| Scenario | Month | May | Jun | Jul | Aug | Sep | Total, kWh/m² |
|----------|-------|-----|-----|-----|-----|-----|--------------|
| Light    |       | 5.9 | 8.0 | 13.0| 12.0| 4.0 | 42.9         |
| Medium   |       | 5.0 | 7.3 | 12.0| 12.0| 3.4 | 39.7         |
| Heavy    |       | 4.8 | 7.1 | 12.0| 12.0| 3.2 | 39.1         |

The results of the modelled buildings in table 3 show that the light wall construction building (further in the text: w.c.b.) consumes the most amount of energy (858 kWh) for cooling, while the heavy w.c.b. g consumes the least amount of cooling energy (782 kWh). Medium w.c.b. consumes 794 kWh for cooling. The use of medium w.c.b. against the light w.c.b. provides 7,46% energy saving, while the use of heavy w.c.b against light w.c.b. gives 8,85% of energy saving. Based on these findings it can be inferred that more dense construction allows for better thermal accumulation during the day time, at the same time reducing the indoor air temperature, which in turn reduces the risk of overheating. The temperature readings in each case did not differ significantly, most probably because of the operation of the mechanical ventilation system in the IDA-ICE model.

Table 4. The comparison of heat gains and heat losses in the analyzed season with mechanical cooling, kWh.

| Scenario | Building envelope/ thermal bridges | Solar heat gains | Infiltration | Occupants | Electrical equipment | Mechanical Cooling |
|----------|-----------------------------------|-----------------|-------------|-----------|---------------------|--------------------|
| Light    | -634,40                           | 1118,80         | -279,10     | 263,50    | 82,90               | -565,90            |
| Medium   | -678,30                           | 1119,30         | -285,50     | 261,50    | 82,90               | -514,50            |
| Heavy    | -671,50                           | 1113,00         | -295,90     | 257,10    | 82,90               | -500,00            |

For the simulation, the preferred maximal set point was set up as 24°C. So, for the different types of constructions the indoor temperature fluctuation depends on thermal mass. For the light weight construction the indoor air temperature drop till 12 °C was observed due to constant airflow and insufficient rate of heat gains. According to the table 4, the solar gains account for the largest portion of total heat gains (76%), while the internal heat gains from occupants and electrical equipment are relatively small – 18% and 6% respectively. In all modeled scenarios, the largest amount of heat energy is transferred to the outdoors through the building envelope, and the specific ratio of heat transfer through the building envelope in each scenario is rather similar. This is due to the matching heat transfer coefficient. Temperature reduction with air exchange is most efficient in buildings with heave wall construction (20.2 %), while in medium and light w.c.b. this rate is 19.3% and 18.9% respectively. Cooling system consumed the most energy in light w.c.b. removing 565,90 kWh of heat energy. Medium and heavy w.c.b. utilized 514,50 and 500,00 kWh respectively. Therefore it can be inferred that light
w.c.b. have the greatest risk of overheating. The next model was run for the same three type of buildings, excluding the mechanical cooling system. It was defined that natural ventilation is used for cooling, exploiting night time cooling. It was defined that the opening of the windows is activated once the temperature exceed +24 °C.

**Table 5.** The comparison of heat gains and heat losses in the analyzed season w/o mechanical cooling, kWh/m².

| Scenario | Building envelope/thermal bridges | Solar heat gains | Infiltration | Occupants | Electrical equipment | Mechanical Cooling |
|----------|----------------------------------|-----------------|--------------|-----------|----------------------|--------------------|
| Light    | -793,80                          | 1050,30         | -605,40      | 252,70    | 82,60                | N/A                |
| Medium   | -813,50                          | 1064,50         | -598,60      | 251,30    | 82,70                | N/A                |
| Heavy    | -785,60                          | 1064,50         | -623,00      | 247,10    | 82,70                | N/A                |

Excluding the mechanical cooling system leads to the increased heat transfer through the wall construction and through the infiltration (naturally occurring air exchange). At the same time the model showed the considerably excessive amount of degree hours above the +25°C limit (Table 6).

**Table 6.** Amount of degree hours above the +25 °C limit.

| Scenario | 26°C | 27°C | 28°C | 29°C | 30°C | Total |
|----------|------|------|------|------|------|-------|
| Light    | 93   | 59   | 45   | 33   | 20   | 250   |
| Medium   | 87   | 59   | 44   | 31   | 19   | 240   |
| Heavy    | 90   | 65   | 48   | 34   | 20   | 257   |

**Conclusions**

Passive cooling is a building design approach to reduce daytime (mainly solar) heat gains and transfer the accumulated heat outdoors during the cooling hours (evening hours, nighttime). According to the IDA-ICE model results solar heat gains accounted for 76% of total heat gains, while internal heat gains accounted for the rest.

Based on the model, the largest energy used for cooling was observed in light wall construction building, while the heavy w.c.b. provided 8.85% energy saving on cooling capacity compared to light w.c.b.

Using the natural ventilation and night cooling did not satisfy the acceptable thermal comfort in modeled buildings, as the number of degree hours above the +25°C limit was exceeded in all three scenarios. It can be inferred that daytime natural ventilation combined with night time natural cooling will not ensure the acceptable thermal comfort for the occupants in the given conditions.

Nevertheless, it is worth noting that in Latvian climate conditions building designers and architects tend to place the largest windows particularly in the S faced façade to obtain more daylight and improving interior aesthetics, often disregarding the potential influence of solar heat gains. Investors, building developers and owners are also disregarding the importance of this challenge, leaving the users (building tenants) to compromised thermal conditions.
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