Analyzing natural ventilation and cooling potential in a communal space building in Belgium under future climate conditions

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ABSTRACT

Due to climate change, Western Europe is experiencing a surge in cooling demand, leading to higher summer temperatures accompanied by longer and stronger heat waves, thereby intensifying the toll on our buildings. This signals the need for architects to design buildings that take advantage of passive technics to provide thermal comfort. In recent years, natural ventilation has become a widely used method for reducing energy consumption and expenses. However, the utilization of natural ventilation can be restricted due to heatwaves and the impacts of climate change. To reduce the effects of these extreme conditions on the thermal comfort of the buildings, immediate guidance and decisions on architectural strategies are crucial. This study evaluated and compared the effectiveness of natural ventilation in current and future climate scenarios, particularly during extreme warm years.

The primary goal is to highlight the importance of increasing cross ventilation in order to reduce internal cooling loads during the summer months. The thermal performance of the building and the effect of natural ventilation was analyzed by the energy simulation tool '*IDA ICE*'. As a case study, we considered a cultural building with communal spaces located in Belgium.

According to our observation, indoor thermal comfort can be improved by determining an optimum set of input parameters such as the temperature setpoint, the discharge coefficient of the night ventilation, and the window operation behavior (opening and closing schedule).

The results of this study indicate that natural ventilation can substantially reduce overheating risks and cooling demand during a typical year both in current and future climate scenarios. However, it is important to keep in mind that during heatwaves, natural ventilation becomes less efficient and cannot guarantee full thermal comfort to all occupants.

KEYWORDS

Thermal comfort, cooling demand, climate change, heatwave

1 INTRODUCTION

The vast majority of people spend most of their time indoors and rely on mechanical heating, ventilation, and air conditioning (HVAC) systems to keep the indoor environment comfortable. (Luo M, et al. 2021). The International Energy Agency (IEA) has released a report indicating that emissions from air conditioning are one of the primary factors contributing to global warming (Marschall, et al. 2020; IEA: 2018). Consequently, In future architectural design, it will become increasingly important to reduce the use of mechanical cooling and air conditioning (Lomas, 2007; Chen, 2009).

In recent years, natural ventilation has become a widely used method for reducing energy consumption and reducing expenses. Natural ventilation systems have been estimated to save up to 60% of the energy required for ventilation and air conditioning in moderate climates (Elnagar et al. 2022).

While many studies have highlighted the benefits of natural ventilation, the actual application of natural ventilation can be affected by a variety of factors, making it challenging. A major challenge in integrating natural ventilation is that it creates uncertainty; as it relies on ever-changing weather conditions, the architectural layout of the building, as well as it entrusts the occupants with the task of regulating the indoor environment. However, the effectiveness of their behavior patterns cannot be guaranteed (Costanzo et al. 2019; Marschall et al. 2020). Moreover, the impact of the internal microclimate in complex spatial designs needs to be taken into account during the design phase. For example, many different spaces within a building can affect wind flow patterns, which may cause adverse consequences (Elnagar et al. 2022; Marschall et al. 2020). In general, sustainable design necessitates designers engaging with it at an early stage of the architectural design process and utilizing suitable metrics to simulate and visualize the performance of their proposals. However, even when buildings and their systems succeed in providing energy-efficient comfortable environments, they are often designed based on anticipated weather and operational conditions such as occupancy loads and solar heat gains, which may not always align with reality. Throughout the lifetime of buildings, they can be confronted with unexpected shocks and events, resulting in deviations from the originally intended comfort conditions and causing instances of over- or underheating.

Several studies indicate that the low-energy cooling strategies currently in use may become ineffective under long-term climate change, or in the event of an extreme event such as a heat wave or a power outage (Zhang et al. 2021). A report released by the Intergovernmental Panel on Climate Change (IPCC) in 2022 warns of the severity of climate change impacts and stresses the importance of adaptation and mitigation strategies (Sengupta et al. 2022).

With the continuation of global warming, building overheating is expected to increase. Summers that are warmer and more frequent heatwaves will lead to higher outdoor temperatures, which in turn will increase the risk of overheating inside buildings. There have been 18 warmest years in Europe over the last two decades, and extreme weather events are more frequent and intense than ever before (European Commission. 2018 ; Sengupta et al. 2023).

Despite the moderate climate in Belgium, buildings are subject to climate change and more frequent heatwaves, which increase overheating risk and cooling energy requirements (Jenkins et al. 2013; Sengupta et al. 2023). There are two essential aspects that must be considered in order to predict the building's thermal performance in the future: (1) an applicable energy simulation model that can accurately predict building performance and (2) high-quality future weather data (Ramon 2019).

Due to high occupant density, intermittent use, increased airtightness, and high glazing ratios, educational and cultural buildings, which represent a significant portion of the building stock, are responsible for high energy consumption. For this reason, in order to prevent any health risks associated with overheating in these types of buildings, it is important to evaluate and assess overheating separately from the buildings' energy efficiency. This paper aims to assess the thermal performance of a conference room with high occupant density, and presents preliminary findings regarding the influence of thermal mass and natural ventilation on the thermal comfort provided in a refurbished cultural building in Flanders (Belgium). To determine the effect of the aforementioned parameters on future energy performance, we analyzed the effects of current and future weather data for Typical Meteorological year (TMY) and Extreme Warm Year (EWY) in the building energy simulation.

Analyzing future climate change scenarios in simulations can be a useful approach to determining the optimal design of buildings based on their future thermal performance (Berger et al.2014; Andrić et al.2017). For this reason, the base case scenario was simulated with current weather data, and the results were compared to future weather files with no shock or power outage and EWY with heatwave scenarios.

2 METHODOLOGY

The thermal performance of the conference hall was assessed in this study using the IDA ICE v2.9.9 (EQUA) software (https://www.equa.se/en/ida-ice). As mentioned earlier, the case study building is a theoretical design of a conference hall in a cultural building located in Geel, Belgium (51°10′N 05°00′E). The floor area and the volume of the conference room are 320 m^2 and 5767.2 m^3 respectively. The conference hall has external insulation with a concrete external wall and concrete slab floor. Table 1 summarizes the thermal property of the building material.

Table 1: thermal property of the building envelope

Construction Package	U-value (W/m^2K)
External wall	0.13
Roof	0.15
Floor	0.15

Figure 1 shows IDA ICE model of the cultural building and conference hall. To accelerate the simulation process, the other zones of the cultural building were treated as adiabatic.

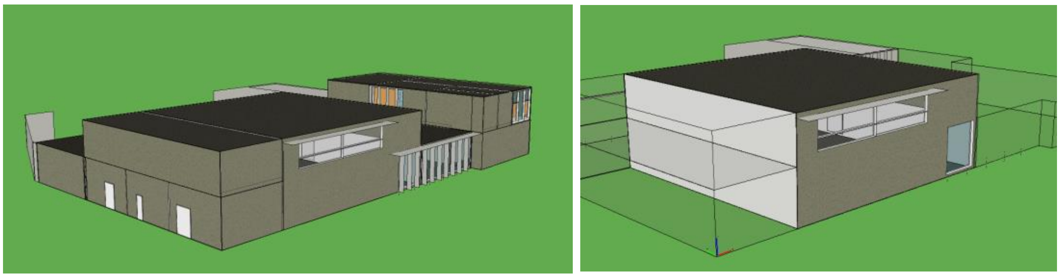

Figure 1: IDA ICE model (left : the cultural building, right: conference hall)

Windows are facing northeast and southwest and the area of each one is 24m^2. There are triple-glazed windows (U-value: 0.65 W/m^2K, g-value: 0.52).
There are external shadings, which are controlled automatically (shading is ON when the radiation on the windows is above 250W/m^2). In this study, the control strategy of natural ventilation is based on the indoor temperature, the temperature difference between indoor and outdoor temperatures, as well as the occupancy schedule for each scenario. Specifically, the natural ventilation system is activated from 7am to 6pm on working days when the indoor temperature is higher than 23 degrees Celsius and the outdoor temperature is higher than 14 degrees Celsius. During the night time, the ventilation system is activated if the interior temperature is higher than 21°C and the exterior temperature is lower than the interior and the exterior temperature is higher than 8°C.

The conference hall has a seating capacity of 170 individuals. It is utilized for three days each week, with a closure period from mid-July until the end of August. Figure 2 displays the occupancy schedule for one week.

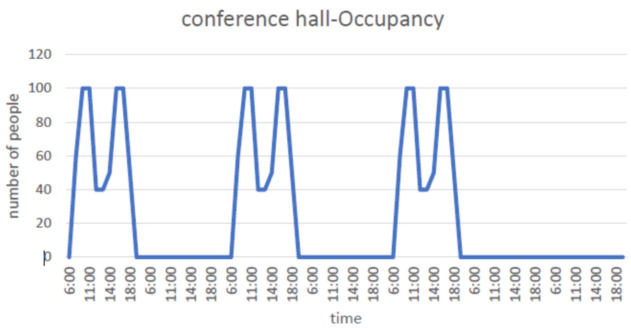

Figure 2: occupancy schedule

2.1 Weather data

Outdoor air quality is one of the most critical parameters in a natural ventilation strategy. It is necessary to conduct a qualitative assessment of the boundary conditions prior to proceeding with a quantitative approach. In this study, to determine whether the boundary conditions are suitable for natural ventilation, we conducted an analysis of the outdoor air quality and noise pollution (CIBSE, 2014). The Flanders Environment Agency (Vlaamse Milieu Maatschappij, VMM) monitors the outdoor air quality of Flanders and develops models to predict outdoor air quality. In general, air quality is improving. Except for Ozone, in almost all locations in Flanders, the European targets are met (VMM, 2018). Due to the property's location, near a forest and away from main traffic corridors, PM2,5, PM10, NO2, and Black Carbon concentrations are below European standards. Noise levels are deemed acceptable due to the location of the building which is situated in the middle of a green area.

The weather files typically used in building performance simulation software represent the weather data recorded for specific months in a given year. In this study, all simulations were conducted using two types of weather data, namely “Typical Meteorological year (TMY)” (Thevenard & Brunger 2002) and “extreme warm year (EWY)” (Nik 2016) for current and future climate data (Regional Climate Models (RCMs). The weather files are extracted for the recent past (1976-2004) and for an RCP 8.5 climate change scenario for the end of the 21st century (2070-2100). In Belgium, a climate model with a spatial resolution of 2,8 km is available through the CORDEX.BE project (Ramon 2021; Termonia P. et al. 2018). With a spatial resolution of 2,8 km, this model offers a better representation of extreme weather events and includes more local effects, such as urban heat islands, compared to RCMS with a spatial resolution of up to 10 km (Prein, A. F., et al. 2015), More information about the climate model can be found in Ramon et al. (2020)

3 RESULTS AND DISCUSSIONS

To evaluate the thermal performance of the conference hall, passive cooling strategies were applied, such as natural ventilation, shading, and thermal mass. Figure 3 presents the annual indoor and outdoor temperature distribution, as well as, thermal comfort in the conference hall for the base case (scenario1). These outcomes are derived from dynamic simulation conducted for the base case, taking into account the current weather data. The results demonstrate that indoor temperatures are mainly affected by occupancy, as evidenced by a decrease in operational temperature from mid-July to the conclusion of August.

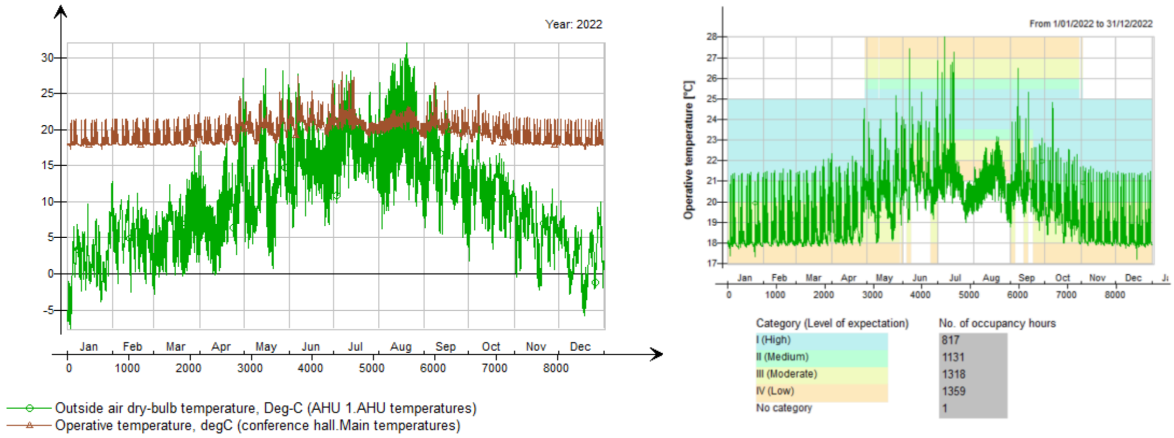

Figure 3: left: outside and operative temperature and right: thermal comfort

In order to demonstrate the impact of passive cooling strategies such as natural ventilation and thermal mass, a thermal dynamic simulation was conducted for 12 case studies. Each scenario is outlined and explained in Table 2.

Table 2: case study description

scenarios	Type of weather data	Passive cooling strategy	Thermal mass
Scenario 1	TMY current	Natural ventilation	high
Scenario 2	TMY current	Natural ventilation	low
Scenario 3	TMY current	No passive cooling	high
Scenario 4	TMY future	Natural ventilation	high
Scenario 5	TMY future	Natural ventilation	low
Scenario 6	TMY future	No passive cooling	high
Scenario 7	EWY Current	Natural ventilation	high
Scenario 8	EWY Current	Natural ventilation	low
Scenario 9	EWY Current	No passive cooling	high
Scenario 10	EWY future	Natural ventilation	high
Scenario 11	EWY future	Natural ventilation	low
Scenario 12	EWY future	No passive cooling	high

Figure 4 illustrates the annual occurrence of operative temperatures surpassing different thresholds (27°, 25°, and 30°) in the conference hall for the aforementioned scenarios. To highlight the impact of passive cooling figure 5 compares cooling demand for each case study. The frequency of annual operative temperature exceedances shows a significant contrast between scenarios without natural ventilation, whereas the variation is minimal when altering the thermal mass.

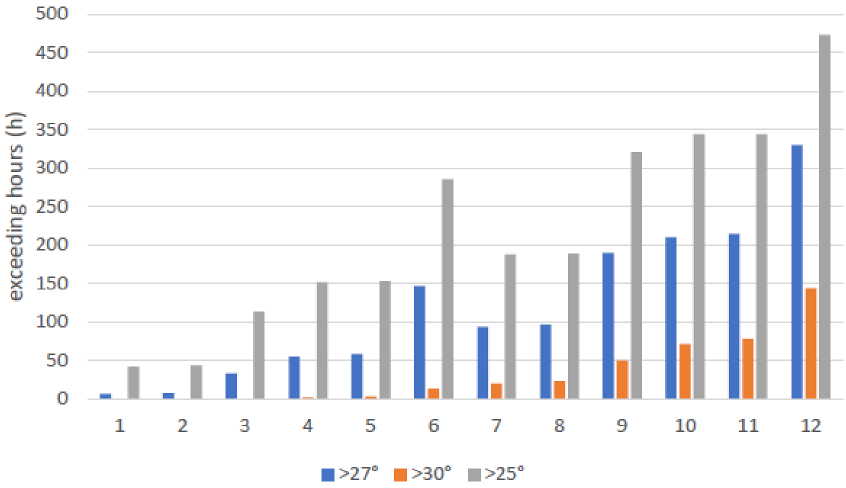

Figure 4: yearly exceedance of operative temperature

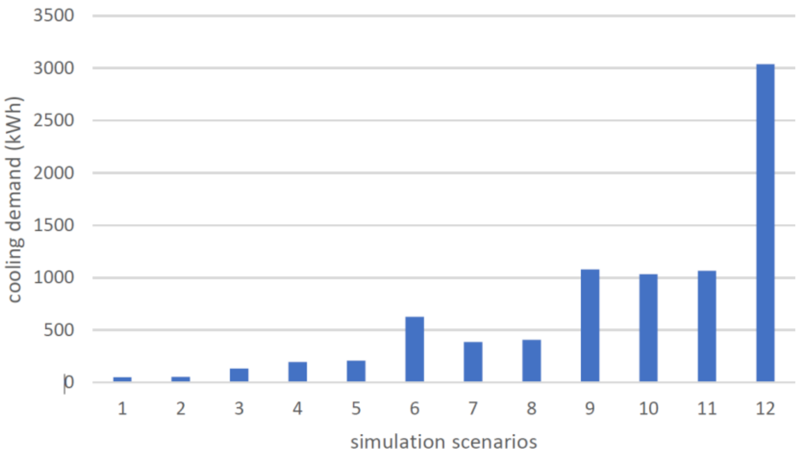

Figure 5: Annual cooling demand

This observation implies that, despite the challenges posed by rising temperatures due to global warming, natural ventilation remains a viable strategy for cooling indoor spaces. The graph depicted in Figure 4 emphasizes the reduction in indoor temperature resulting from the implementation of the natural ventilation strategy. However, future climate and heat waves will impose certain constraints on the utilization of night ventilation. Night ventilation effectively resets a building's thermal inertia by harnessing cooler outdoor air during nighttime hours to dissipate the heat accumulated within the building's walls throughout the day. However, the effects of global warming and extended duration of heatwaves are anticipated to diminish the potential of night ventilation, primarily due to the increasing temperatures during nighttime. As nights become warmer, the contrast between indoor and outdoor temperatures decreases, thereby reducing the effectiveness of night ventilation in dissipating heat. To address these challenges, alternative strategies and adaptations may be required. This could involve incorporating additional cooling methods, such as mechanical ventilation or air conditioning, to supplement natural ventilation during periods of reduced effectiveness. Additionally it is worth noting that a combination of natural ventilation and suitable thermal mass can result in an optimal indoor environment for thermal comfort.

4 CONCLUSION

This study examined the potential for passive cooling techniques, including natural ventilation and thermal mass, in a conference hall with a high occupancy rate located in Belgium. IDA ICE software was applied to analyze the thermal performance of the case studies. In this study, we assessed the impact of both natural ventilation and thermal mass on thermal comfort. Our findings clearly indicate that natural ventilation combined with thermal mass has a greater influence. According to the results of the study, Despite the difficulties presented by the increasing temperatures caused by global warming, natural ventilation continues to be a feasible approach for cooling indoor environments. In anticipated future climate scenarios, the inclusion of mechanical cooling becomes essential to achieve summer comfort under all circumstances. However, the potential energy savings achieved by combining mechanical cooling with natural ventilation are projected to be even greater compared to the present climate. This is due to the fact that the duration in which natural ventilation can effectively reduce the cooling load is expected to expand, thereby providing more opportunities for energy-efficient cooling.

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