How to design a resilient building? Lessons learnt from an architectural view

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SUMMARY

The EIA EBC Annex 80 Resilient Cooling program has focused on bringing together and extending the knowledge on the resilience of buildings to overheating (Holzer, 2024). In the context of the Annex 80 Resilient Cooling program a research project, Recover++, has been setup to define a new resilience indicator, based on the properties and behaviour of real-world building projects under extreme climatological condition and shocks, as heatwaves under current and future weather conditions. These extreme weather conditions will become a reality for the building stock in the near future. The real impact will depend upon the RCP-scenario. As the mean life expectance of buildings in Europe is between 50 and 60 years, the building stock, which is being designed and built now, will be exposed to these future weather conditions, during its lifespan. And, as the main architectural design features such as the building envelope and the spatial concepts, are less prone to change during the lifetime of a building, it's relevant to take the impact of these future weather conditions in account, in the architectural design and conception of new buildings. Future weather conditions to which buildings will be exposed, can be both represented by Typical Meteorological Years (TMY), by Extreme Warm and Extreme Cold Years (EWY and ECY), and by weather data which include extreme events as heatwaves (Machard, 2024).
Up until now the impact of the architectural building features under future weather conditions have mainly been evaluated under typical future weather conditions (TMY, EWY and ECY) (Declercq, 2021, Machard, 2021, Ramon, 2023). These studies have suggested architectural strategies to reduce operational energy use for cooling under future climate conditions (Declercq, 2021 and Machard, 2021) and to reduce the embodied impacts over the full life cycle (Ramon, 2023). In this paper, parameters related to the architectural building properties have been explored which have an impact on the resilience of buildings under extreme weather conditions with shocks, such as heatwaves.
In this context two real-life buildings of different typology, from which one is under construction and the second one is due for construction, have been modelled and simulated under future weather conditions, including future weather conditions with shocks. Several architectural building features such as thermal mass, natural ventilative cooling strategies and different mechanical cooling strategies have been analysed.
The conclusions of (Machard, 2021 and Ramon, 2023) have been challenged towards the criteria of resilience to overheating. The case studies have confirmed that the main architectural drivers, influencing the resilience to overheating under extreme conditions, are the glazing ratio, the presence of shading, the thermal mass and the natural ventilative cooling. The design of one of the case studies was evaluated under typical future weather conditions (TMY 2070-2100 under RCP 8,5) (Declercq, 2021). This research has confirmed that the architectural design strategies, which were adopted to reduce the operational energy use for cooling under current and future climate conditions, also result in a high resilience to overheating of the building.

KEYWORDS

Resilient Cooling; Overheating; Future Weather; Climate Change; Climate Responsive Design

1 INTRODUCTION

Climate change will result in higher stress on the built environment and higher efforts to guarantee a stabile indoor climate, which is comfortable and healthy for its occupants. In most regions guaranteeing summer comfort will become more challenging and, in most cases, will increase the operational energy demand for cooling (Ramon, 2020). As the mean expected life spans of a building in the European context reaches from 50 to 60 years (Allacker, 2010), it is important to take these future conditions in consideration when designing new or refurbishing existing buildings.
Up until recent the impact of climate change upon summer comfort in buildings has mainly been studied from the perspective of changing energy demands. In this context, future weather data for Typical Meteorological Years (TMY) has been used. To inform current practise of climate responsive design towards future weather conditions, several studies have focused on the impact of the architectural building features, such as thermal mass, glazing ratio, air tightness, insulation level, natural ventilative cooling strategies, … (Declercq, 2021, Machard, 2021 and Khosravi, 2023) and on the life cycle environmental impact (Ramon, 2023). Only recently also the behaviour of buildings under the new extremes induced by climate change is being studied. In this context, the EIA EBC Annex 80 Resilient Cooling program focuses on bringing together and extending the knowledge on the resilience of buildings to overheating (Holzer, 2024). In this paper the impact on indoor thermal comfort and energy use of extreme shocks, such as heatwaves and power outages, is evaluated.

This paper focuses on the double question, based upon real life case studies of two non-residential buildings:

- What is the impact of climate responsive design strategies on the resilience of buildings to overheating?
- To what extent can lessons learned from assessments under typical future climate weather data inform design strategies for improved resilience to overheating of buildings?

2 METHODOLOGY

2.1 The cases

Two non-residential buildings have been selected. Both are real life architectural projects whereof one is under construction and the second is due for construction. The data are acquired from the architectural office, archipelago architects (BE).
The first case consists of a low-tech duplex inner-city office building encompassing 940m^2 offices and architectural design studios in the city of Leuven (BE), designed by archipelago architects for their own use. The building design is orientated towards minimizing the need of operational energy and technical installations, through a set of climate responsive design strategies as automated natural ventilative cooling, exposed thermal mass, active shading and an equilibrated glazing ratio. The design team has made extensive use of thermal dynamic simulations during the design process to optimise the building design. The building, its design process and its performance under future TMY is extensively described in (Declercq, 2021 and Khosravi, 2024).
The second case is a freestanding community building on the outskirts of the city of Geel (BE). This project is an extensive refurbishment of an existing auditorium building, which is extended with a foyer and meeting and leisure spaces. This project also uses climate responsive design strategies as natural ventilative cooling and passive and active shading strategies. Thermal mass is to a lesser extent present, as the new foyer has a lightweight roof.

The existing auditorium only has accessible thermal mass in its walls, as the ceiling is closed with acoustical panels. The second case and its performance under future TMY is described in (Khosravi, 2023).

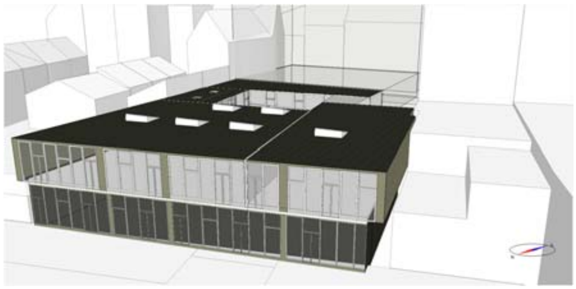

Figure 1: Case 1- IDA ICE model, viewed from the north-west facade

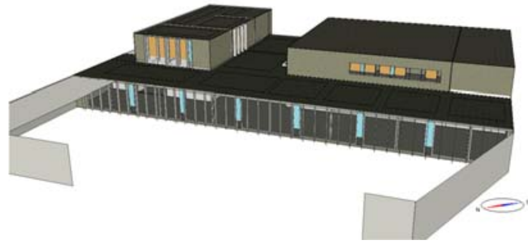

Figure 2: Case 2- IDA ICE model, viewed from the north-west facade

2.2 The resilience assessment

The two case studies have been modelled in the Building Energy Simulation software package IDA ICE v5.0 as a multi-zone model. In the simulation, different sets of TMY and heatwave data files have been used: one corresponding to the “historical severe heat wave,” spanning 25 days from July 6th to July 31st, and the other representing the “long-term severe heat wave,” lasting for 45 days from July 2nd to August 15th. For comparison reasons, weather data for the city of Brussels (BE) have been used in both cases. The weather datasets have been elaborated in the context of IEA EBC Annex 80 (Machard et al., 2024). The methodology has been aligned to (Zhang et al., 2021).

The resilience was assessed in the most relevant zones in the two buildings (see figure 3 and 4) through a dynamic simulation with an adaptive timestep, with a maximum of five minutes. The following resilience KPIs were assessed for the selected zones: Indoor Overheating Degree (IOD) and Overheating Escalation Factor (OEF) (Stern et al, 2024).

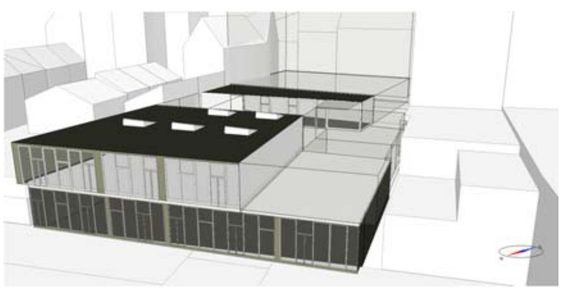

Figure 3: Case 1- zones evaluated: landscape office - 1 and 0, entrance lobby

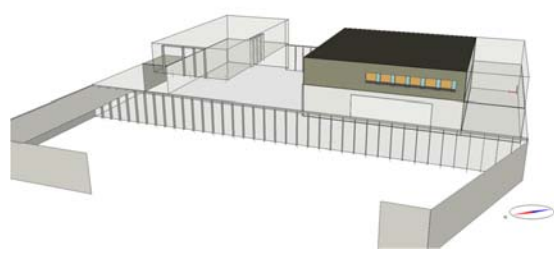

Figure 4: Case 2- zone evaluated: auditorium

For the first case six scenarios (Table 1) and for the second case three scenarios (Table 2) have been evaluated.

Table 1 Case 1 – scenarios studied for landscape office -1 and 0, entrance lobby

Scenario	Automated shading	Mechanical ventilative cooling 24/7	Natural ventilative cooling 24/7	Thermal mass	Mechanical heating and cooling devices (zone level)
1	no	no	no	light	radiant panel
2	yes	no	no	light	radiant panel
3	yes	yes	no	light	radiant panel
4	yes	no	yes	light	radiant panel
5	yes	no	yes	heavy	radiant panel
6	yes	no	yes	heavy	TABS

Table 2 Case 2 – scenarios studied for the auditorium

Scenario	Automated shading	Mechanical ventilative cooling 24/7	Natural ventilative cooling 24/7	Thermal mass	Mechanical heating and cooling devices (zone level)
1	yes	yes	yes	light	fan coil
2	yes	yes	yes	heavy	fan coil
3	yes	yes	no	heavy	fan coil

3 MAIN FINDINGS

3.1 Evaluation of the resilience indicators

The results of calculation of the Overheating Escalation factor (OEF) and the Indoor Overheating Degree (IOD) under Historical Heatwave and under long-term future heatwave for the six scenarios of case 1 are shown in Figure 6. All scenarios have been simulated with and without mechanical cooling. For the second case similar results were found.

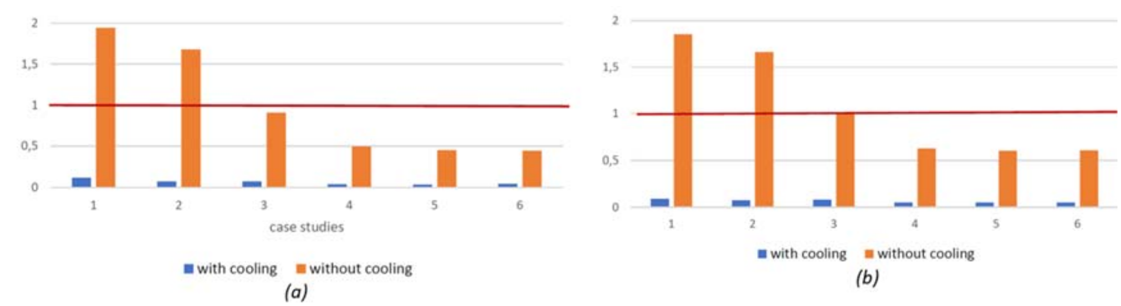

Figure 6: *Case 1 (a) Overheating Escalation Factor (historical HW), (b) Overheating Escalation Factor (long-term future HW)*

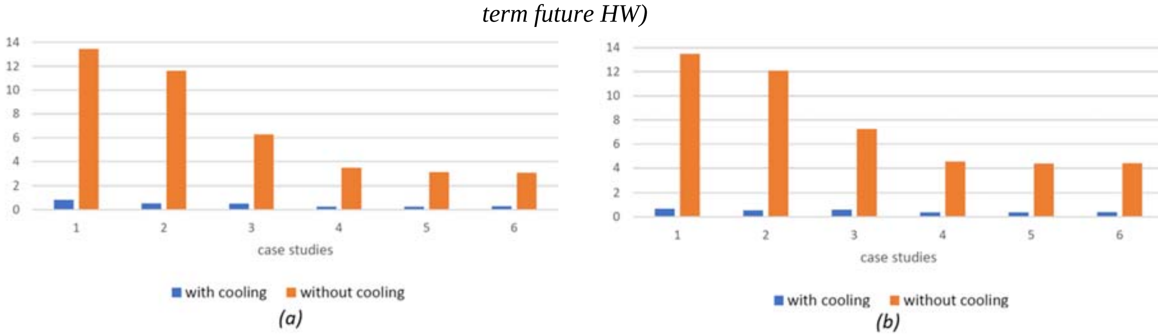

Figure 7: *Case 1 (a) Indoor Overheating Degree (historical HW), (b) Indoor Overheating Degree (long-term future HW)*

In both cases the effect of the climate responsive design strategies on the resilience indicator is clear. For case 1 the combination of shading with a ventilative cooling strategy, whether natural or mechanical results in an OEF < 1. An OEF greater than 1 means that indoor thermal conditions get worse when compared to outdoor stress. An OEF lower than 1 means that the dwelling can suppress some of the outdoor thermal stress (REHVA Task Force, 2024). The combination with a natural ventilative strategy results in an OEF < 0,5, which shows that this concept is even more robust. The impact of thermal mass is less significant. The results are similar under historical (Figure 6a and 7a) and future heatwave conditions (Figure 6b and 7b).

4 DISCUSSION

(Machard, 2021) has identified thermal mass, free-cooling, a high-albedo, and a reduced glazing percentage as main strategies to reduce the cooling load under future climate conditions. (Ramon, 2024) evaluated the whole life cycle environmental impact under future climate conditions. She identified characteristics related to windows, with Window-To-Wall ratio as the most important and solar shading as one of the most important strategies. The main orientation of the windows also had a significant influence, with north-south orientated windows as more favorable than east-west. Thermal mass in combination with night cooling was considered in certain scenarios as a favorable strategy.

(Declercq, 2021) and (Khosravi, 2023) have identified similar strategies for the two case studies as favorable to reduce the energy use for cooling, both under current and under future climate conditions.

The resilience indicators OEF and IOD show a similar behavior. Shading and ventilative cooling prove to be good strategies to improve the resilience to overheating. The impact of thermal mass is less visible. The reason could be twofold. In first instance the high nocturnal ventilation rates reduce already significantly the risk to overheating. In second instance the resilience assessment is being performed with weather data with heatwaves of significant duration. During long heatwaves the thermal mass can get saturated. When the heatwave ends, the building needs more time to cool down and to regain its comfort status.

5 CONCLUSION

Climate Responsive Design strategies, such as reducing the glazing ratio, providing shading, and adopting ventilative cooling strategies, with or without thermal mass, appear to be relevant strategies to reduce the energy demand for cooling, both under current and future typical meteorological year, and to improve the resilience to overheating under extreme weather conditions with shocks, such as heatwaves.

In current research, only a few cases are assessed. A more profound research could bring further insights. In these case studies some parameters have not been varied, such as the window-to-wall ratio and the overall orientation of the building. Also assessing the impact of these parameters on the resilience to overheating of a building can be an important added value to gain more insight and to further develop climate responsive design strategies, which make the building stock more robust towards the resilience of overheating.

The insights gained are already valuable to inform future building design. The impact of these building design related parameters on the resilience is significant. With the future climate challenges in mind it is worth considering the extent to which these design strategies should be applied to reach a more resilient building stock. That both reduces the energy demand for cooling and has greater resilience to shocks.

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