Exploring the effect of different measures on thermal resilience: implications for design of HVAC systems and energy use

Debora Resta*[1], Bert Lemmens[1], Hilde Breesch[2], Abantika Sengupta[2], Douaa Al-assaad[2], Steven Delrue[3], Joost Declercq[4], and Marijke Steeman[5]

1 Arcadis
Markiesstraat 1 Rue du Marquis
B-1000 Brussels, Belgium
**Debora.Resta@arcadis.com*
Presenting author

2 KU Leuven
Faculty of Engineering Technology
Campus Ghent,
Gebroeders De Smetstraat 1
B-9000 Ghent, Belgium

3 Renson
Industriezone 2 Vijverdam -
Maalbeekstraat 10
B-8790 Waregem, Belgium

4 Archipelago
Woluwe Gate – 4th floor
Boulevard de la Woluwe 2
B-1150 Brussels, Belgium

5 UGent
Onderzoeksgroep Bouwfysica
Campus UFO
Sint-Pietersnieuwstraat 41
B-9000 Ghent, Belgium

SUMMARY

The commitment to improving the energy efficiency of buildings by 2030, with the goal of achieving carbon neutrality by 2050, has been triggered by environmental challenges and the increasing scarcity of energy resources. To this end, European countries are adopting stricter regulations on building energy consumption, as illustrated by the EPB system in Belgium.

Considering the increase in extreme weather events, the intensity and frequency of heatwaves in many regions of the world, it is essential that buildings are able to adapt to extreme events.

This study evaluates the energy and comfort thermal performance of an office building through energy simulations. The goal is to compare the effectiveness and impact of mechanical air conditioning systems with the implementation of passives strategies. This analysis aims to verify thermal comfort and energy consumption during expected future heatwaves.

KEYWORDS

Thermal resilience, Energy consumption, Heating and Cooling power, Future Heatwaves

INTRODUCTION

Over the past decade, there has been a growing emphasis on the thermal resilience of buildings and cooling strategies in various studies. For instance, Attia et al. [1] defines cooling resilience as the ability of the building system to maintain the initial design conditions when faced with disruptions such as heatwaves or power outages.

This study is part of a collaborative project with the objective of identifying a thermal resilience metric that can assess and enhance the resilience of buildings against overheating risks resulting

from climate change-related events (e.g., heatwaves) and operational failures (e.g., blackouts, cooling system malfunctions).
Within this report, we focus specifically on HVAC systems and their impact on building resilience. The analysis delves into how passive and active cooling techniques can assist an office building in mitigating the increasing internal overheating risks posed by mounting external thermal challenges in future climate scenarios.
Amid the backdrop of climate change, cooling strategies play a pivotal role in mitigating the surging impacts of overheating, contributing not only to human comfort but also to environmental sustainability.
In the following section, the methodology employed, and the demonstrative case are described. Section 2 presents the results. Section 3 wraps up the document.

This work has been supported by the Flanders Innovation and Entrepreneurship (VLAIO) in the flux 50 ICON-Project 'ReCOver++: Improving resilience of buildings to overheating.'

1 METHODOLOGY

The following table shows the research methodology of this article.

Table 1: Methodology

Methodology
Weather data: HW weather data based on CORDEX (RCP 8.5 scenario) for midterm 2043 and 2051
Building typology: Office building
Cooling strategies: - Solar shading - Natural Night cooling - Mechanical cooling - Free mechanical cooling
Performance evaluation: - CD and HD : Cooling demand and heating demand [kWh/m²] - HP and CP : Heating and Cooling power [W/m²] - CEP : Primary energy consumption [kWhep/m²] - GES : gas emission CO2 [tCO2] - Tair : Indoor air temperature - Top : Indoor operative temperature - EH28A : Annual Exceedance Hours when the Top ≥ 28°C - EH28HW : Exceedance Hours during Heatwaves Period when the Top ≥ 28°C

1.1 Simulation Program

In this document, to conduct the simulations, the software DesignBuilder 7.0.2.006 based on the simulation engine EnergyPlus Version 9.4.0.002 is used.

EnergyPlus is developed by the US Department of Energy (US DOE) as one of the twenty main building energy simulation programs to run the simulations. EnergyPlus contains an integrated thermal and mass balance module and a building system module.
The simulation results are then post-processed to calculate the results values.

1.2 Demonstration Case

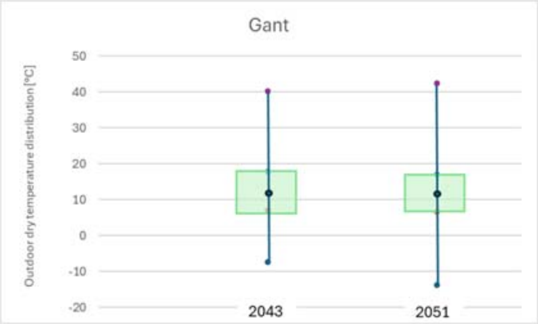
This section describes a demonstration case to compare the thermal performance to overheating due to climate change by simulating various passive and active cooling strategies and assessing the HVAC's impact on the building.

1.2.1 Weather data

The project, as described in the "case study" chapter, is located in Ghent.
Ghent University has provided two future meteorological scenarios for 2043 and 2051, corresponding to medium-term heatwaves with the highest intensity and severity, respectively. The table and figure below show the annual distribution of hourly outdoor air temperature for Scenario 2043 and 2051.

Table 2: Weather data

Outside temperature	**HW 2043**	**HW 2051**
Min	-7.4	-13.7
Percentile 25%	7.0	6.7
Median	11.8	11.5
Percentile 75%	17.8	17.1
Max	40.2	42.4
AWD[1]	11.33	13.29
CDH 18°	9.289	8.401



The two climates under consideration show a substantial increase in the maximum outdoor temperature of 6/8°C compared to current standardized climates and a doubling of cooling hours compared to 2024, and a decrease in heating hours by approximately 15%.

1.2.2 Case study

The case study is an office and laboratory building located in Ghent. It is a new project currently being studied by ARCADIS.
Here is an image of the 3D model and solar curve.

---

[1] The Ambient Warmness Degree AWD [◦C] metric is used to quantify the severity of outdoor thermal conditions by averaging the Cooling Degree hours (CDh) calculated for a base temperature (Tb) of 18 ◦C over the total number of building occupied hours.

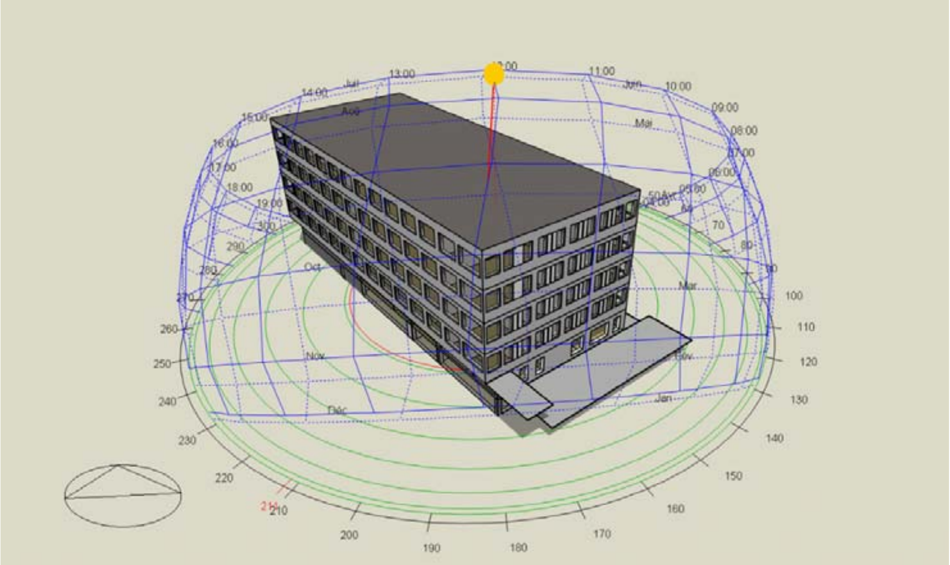


Figure 2: case study 3D model in Design Builder

The building envelope characteristics represent the values of new passive constructions (complying with EPB regulatory standards) and are summarized in Table 3.

The building envelope, geometry, as well as the orientation are the same as the building. For joint analysis with different partners, the occupancy densities and planning follow those of the EN 16798-1:2019 standard for an office environment.

It is also assumed that occupants wear generic winter clothes rated at 1 clo and summer clothes rated at 0.5 clo, with a sedentary metabolic activity rate of 123 W/person and an air speed of 0.1 m/s.

For this analysis, we focused on studying the two office rooms (4.1.6 and 4.7) that represent the worst scenario. They are positioned facing southwest and located under the roof.

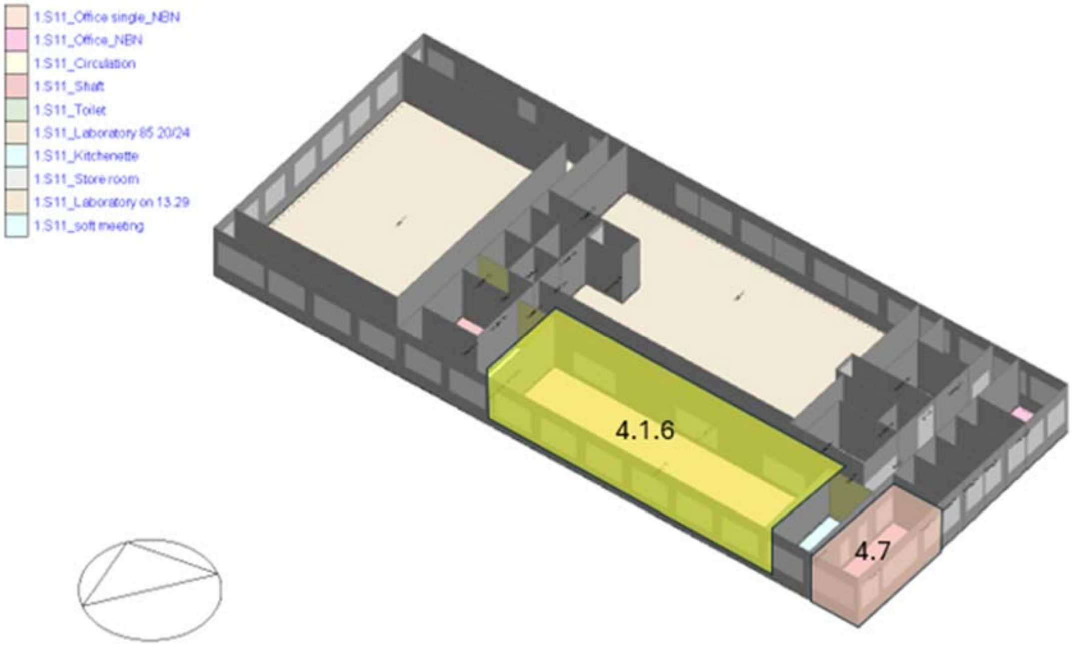


Figure 3: Last floor plan

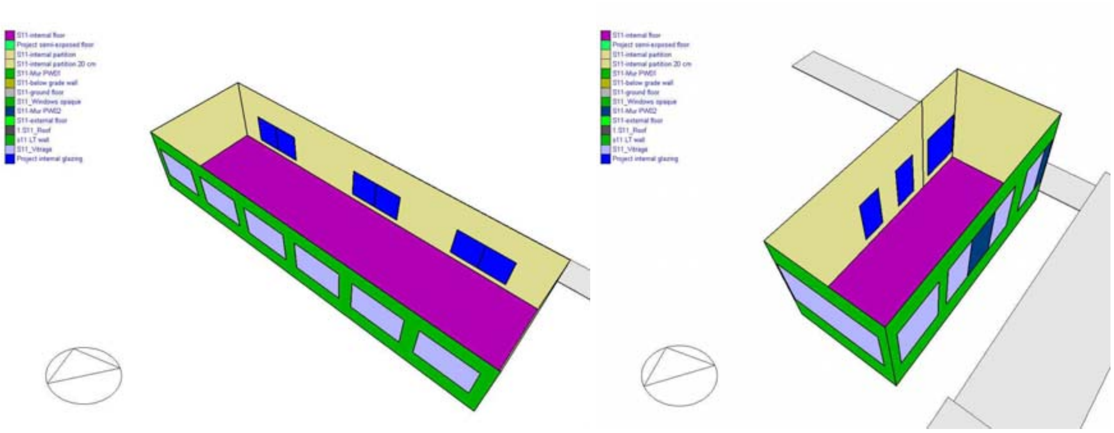


Figure 4: office's room 4.1.6 (left) and 4.7 (right)

Table 4: Orientation

Rooms	Orientation	WWR (windows to wall ratio)
4.7	227	37%
4.1.6	182	33%

1.2.3 Energy performance of walls assumption

1.2.3.1 Insulation

The table below shows all U-Value considered in the simulation:

Table 3: U-value

Code	Envelop	Description	U-value [W/m²K] Including bridges
R1	**Roof**	300 mm Concrete slabs with 50 mm of screed PUR insulation 230 mm Roofing bitumen sheet	0.12
S1	**Slab intermediate floor**	300 mm Concrete slabs with 50 mm of screed Finishing: Carpet	1.46
W1	**Walls above grade**	Fibrocement tiles Air gap Mineral wool 240 mm Concrete 200mm Mortar gypsum	0.15
W2	**Walls above grade**	Aluminium Air gap PUR 100mm Concrete 200mm Mortar gypsum	0.24
P1	**Partition**	Standard metal C stud partitions Acoustic Roll Plasterboard	0.4
EG	**Vertical Windows**	Aluminum frame with good thermal break Double glazed, low-e with 90% argon	Uw 1.8 Ug 1,1

			SHGCg 27,4% VTg 58,8%
IG	**Internal window**	Generic clear 3 mm Air 6 mm Generic clear 3 mm	Ug 3,3 SHGCg 76% VTg 81%

Table 4: average U-value

Rooms	U-value external wall
4.7	0.13
4.1.6	0.14

1.2.3.2 Thermal bridge

Attention will be paid to the compliance of constructive nodes. Indeed, the insulation will be continuous, whether it is implemented from the inside or the outside. Where possible, the insulation will be extended at the ends of the walls to extend the path of least thermal resistance.
Thermal bridges are currently fixed and represent an additional loss of 10% to the values mentioned below.

1.2.3.3 Airtightness

A good airtightness is required. For the simulation a value has been set equal to 1 Vol/h at 50 Pa.
(NB for variant natural ventilation by windows airtightness is autosize)

1.2.4 Internal gain

The values of lighting, fixtures, and occupancy schedules (Fig 5.) related to the building, following the EN 16798-1:2019 standard, include:

Table 4: Internal gain

Parameter	Value	Schedule
Occupancy	10 m^2/pers	7-18 h 5/7 day
Metabolic rate	123 W/pers	
Internal Equipment	12 W/m^2	7-18 h 5/7 day
Lighting	7 W/m^2	7-18 h 5/7 day
	500 lux	Daylight sensor
Ventilation fresh air	40 m^3/h	CO_2 detector

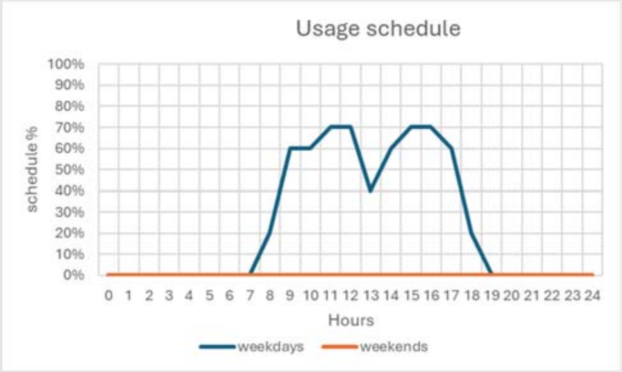


Figure 5: usage schedule

1.2.5 Temperature Setpoints

The temperature setpoints established in the different rooms are as follows:

Table 5: Set point

Parameter	Value
Heating set point temperature	21°C
Heating set back temperature	16°C
Cooling set point temperature	26°C
Cooling set back temperature	32°C

1.3 Strategies

The simulation has been carried out in a detailed way in Design builder.

1.3.1 No strategies

1.3.1.1 Baseline

The base case A does not present any active strategy.
The mechanical ventilation system includes a pre-heating battery to heat the incoming fresh air to 20°C. The zones are equipped with hot convector emitters capable of maintaining the winter setpoint temperature. An air heat pump powers the battery and convectors. The summer temperature is not controlled.

1.3.1.2 50

This scenario corresponds to case A where low-emissivity double glazing is substituted with clearer double glazing having a higher solar factor of 49.9% and a light transmission of 70%.

Table 6: U-value

Code	Envelop	Description	U-value [W/m²K] Including bridges
EG2	**Vertical Windows**	Aluminum frame with good thermal break Double glazed, with 90% argon	Uw 1.8 Ug 1,1 SHGCg 49,4% VTg 71,1%

1.3.2 Passive cooling strategies

1.3.2.1 NNV

Night Natural ventilation NNV for pre-cooling of the office's rooms during nighttime.
NNV is activated from 8:00 p.m. to 6:00 a.m., if all the following conditions are met simultaneously max air temperature exceed both the indoor set point of 24°C and the external temperature by min 2°C.

1. C : we have allowed all windows to be opened up to 30% of their surface
2. C2: we have allowed a limited number of windows to be opened corresponding to 5,2% of room's area

1.3.2.2 Shading

The screens on the southwest windows or both rooms were additionally provided with automatic store (when solar radiation > 250 W/m2). Store diffusing with solar reflectance 50% and transmittance 10%.
In this case the double glazing used is clearer with a solar factor of 49,4%.

1.3.3 Active Cooling Strategies

1.3.3.1 Cooling

In all cases, the Air Handling Unit (AHU) is equipped with additional features to maintain a relative humidity level between 40% and 60%.
Heating and cooling functions are carried out by a reversible heat pump (HP). This system can operate in both heating and cooling modes simultaneously. The Coefficient of Performance (COP) values are 3.3 and 3.2.

1.3.3.1.1 Autosize

In the Autosize scenario, cooling is enabled to maintain the inner air temperature at 26°C. The initial cooling strategy involves the Air Handling Unit (AHU) that provides fresh air within a temperature range from 20°C up to 26°C, based on outside temperature conditions. The FC fan coil unit covers the remaining cooling needs. AHU
In this scenario Cooling is exclusively allowed through the air precooled by AHU. Rooms are equipped by radiators.

1.3.3.1.2 Limited FC

In this variant the cooling power of the fan coil unit has been restricted.

1.3.3.2 MFC

Mechanical Free Cooling: This case is a combined the possibility for AHU to switch to free cooling mode when the outside temperature exceeds 15°C and the indoor temperature is above 24°C, with a maximum temperature difference of 2°C (limited to the maximum of Air flow per rooms).

1.3.3.2.1 PO Power Outage

A 24-hour power outage scenario was examined on the day of the most severe heatwave, specifically on July 1, 2043, and July 30, 2051.

1.3.4 Variant Combinations

The other cases are a combination of various variants. A table below summarizes all the combinations:

Table 7: Variants

OFFICE's ROOM (4.1.6 and 4.7)
A
• No strategies
B
• Cooling (AHU + FC) Autosize • Cooling (AHU + FC) Limited • Cooling (AHU)
C
• NNV
C2
• NNV
D
• NNV + Cooling (AHU + FC) Limited • NNV + Cooling (AHU) • NNV + Cooling (AHU + FC) Autosize
E
• Shading
F
• Shading + Cooling (AHU + FC) Limited • Shading + Cooling (AHU) • Shading +Cooling (AHU + FC) Autosize
G
• Shading +NNV
H
• Shading +NNV+ Cooling (AHU + FC) Limited • Shading +NNV+ Cooling (AHU) • Shading +NNV+ Cooling (AHU + FC) Autosize
H2
• Shading +NNV+ Cooling (AHU + FC) Limited • Shading +NNV+ Cooling (AHU) • Shading +NNV+ Cooling (AHU + FC) Autosize
I
• PO_Shading +MFC+ Cooling (AHU) • Shading +MFC+ Cooling (AHU + FC) Limited • Shading +MFC+ Cooling (AHU) • Shading +MFC+ Cooling (AHU + FC) Autosize

These 24 combinations were implemented for the entire building for the 2 HW weather data considered, by analyzing the two most problematic rooms, resulting in 100 cases.

1.4 Results

Several Pareto fronts have been established for the 100 cases:

- Pareto FRONT 1: CEP / EH28A
- Pareto FRONT 2: CP / EH28A
- Pareto FRONT 3: EH28A / EH28HW

These fronts allow for comparisons between the results of the present study.

In essence, a color highlighting of the points is used to emphasize the different variants (no strategies, passive cooling, and active cooling).

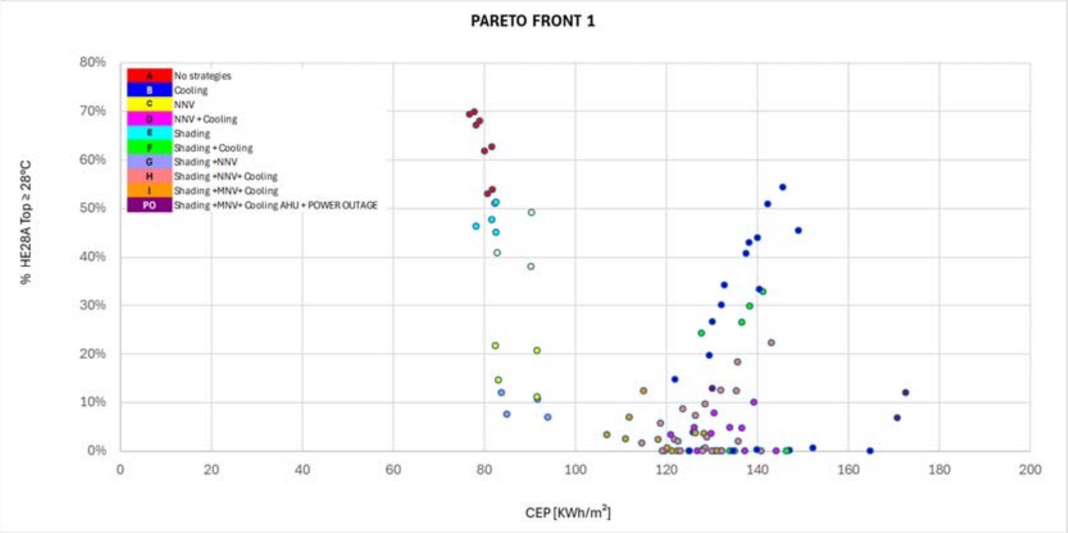


Figure 6: Pareto front 1

The image illustrates that without any strategy in place or with individual strategies such as shading, NNV with 5.2% of room's surface window opening, or limited cooling, there is a significant increase in hourly exceedances exceeding 40%.
Solutions with autosize active cooling achieve total comfort but with a substantial increase in consumption (blue point at 0% of HE28A).
The combination of controlled automatic external shading with intensive natural nighttime ventilation (opening all fixtures by 30%) allows for a reduction in consumption and comfort (<20% HE28A) in this weather scenario without resorting to HVAC systems. It must be pointed out that there is a significant amount of incoming air, which in normalized climates could lead to a reversal of needs with increased consumption.
The optimal solutions depicted by the orange points on the graph represent the combination of shading and active cooling with mechanical free cooling. These solutions maintain average consumption values from 100 to 120 kWh/m² and EH28A below 10%.
This combination provides an effective balance between energy efficiency and comfort, showcasing a sustainable approach to managing temperature control within the HW climat.

This graph highlights the importance of implementing effective combined strategies to efficiently manage and control the temperature levels within the given environment.

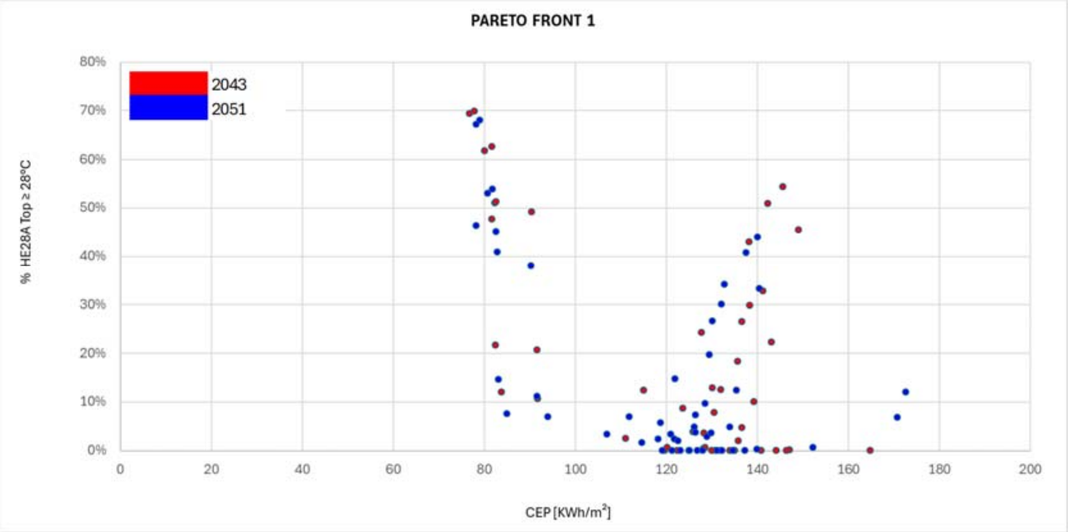


Figure 7: Pareto front 1 (HW in evidence)

This chart displays the Pareto front, with cases of HW 2043 represented in blue and HW 2051 in red.
Despite the higher peak temperatures in 2051, the weather conditions in 2043 exhibit a higher intensity, as reflected in the higher values of EH28A.

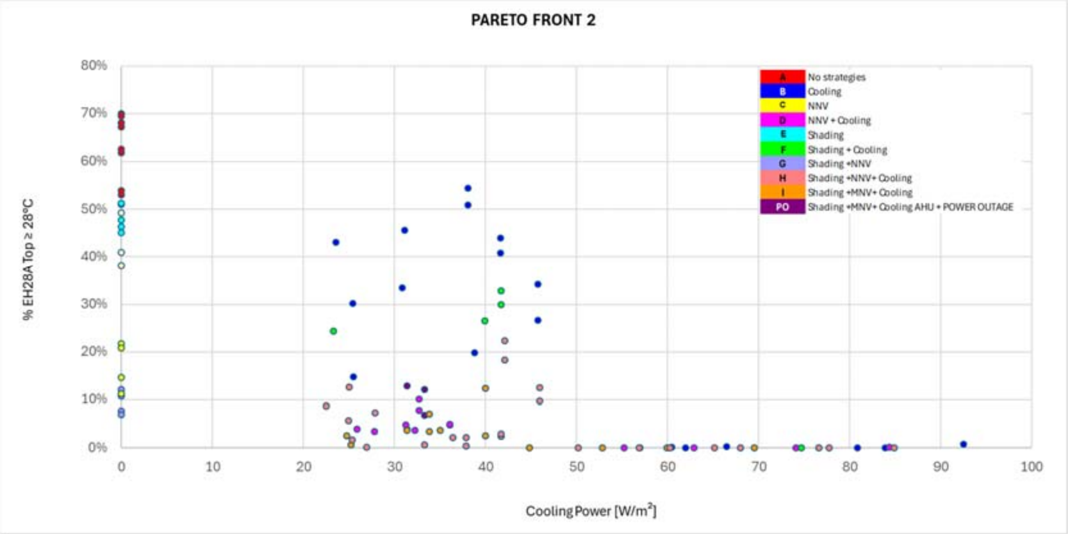


Figure 8: Pareto front 2

This image illustrates that for cooling powers exceeding 50 W/m², EH28A values are below 0. Within the range of 20 to 50 W/m², representing HVAC systems with lower power, EH values fluctuate between 0 and 60%. And for no cooling active strategy values fluctuate between 0 to 70%.
The graph emphasizes the importance of appropriately sizing the HVAC system and employing additional strategies to address increasingly hotter future climates.

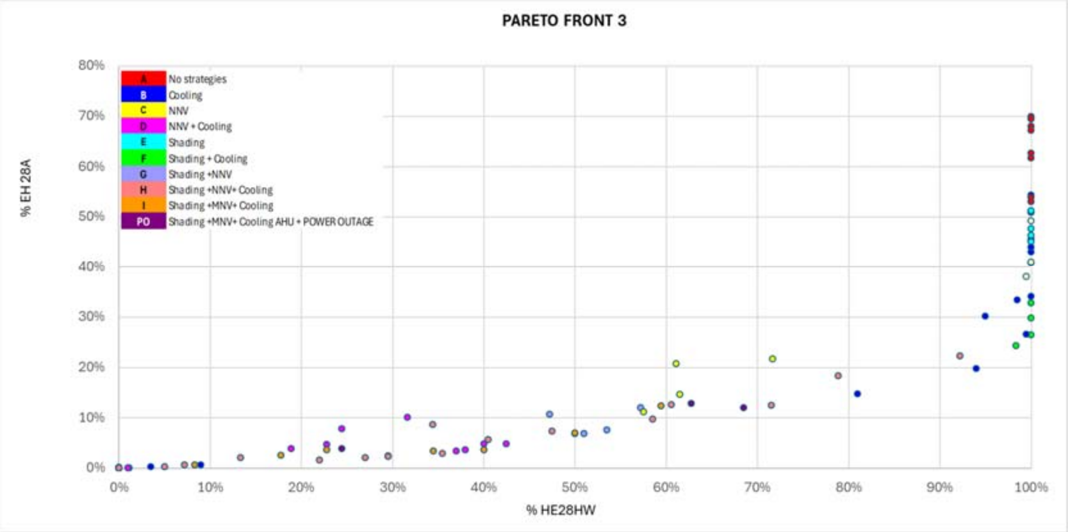


Figure 9: Pareto front 3

This graph showcases the correlation between annual excess hours and those specifically during the HW period. It effectively illustrates that any solutions surpassing an annual EH of 20% inevitably escalate to 100% during the hottest hours.
Optimal solutions corresponding to combined strategies with annual EH28A values below 20%, which equate to EH28HW values below 40%, typically involve a mix of energy-efficient HVAC systems and cooling passive strategy. By integrating these strategies judiciously, it is possible to maintain efficient thermal comfort levels while reducing energy consumption and environmental impact.

The table 8 provided includes various parameters related to different types of strategies (no strategies, passive cooling, and active cooling). Here is an explanation of each column in the table:

- Strategy: This column specifies the type of strategy being considered, such as "No Strategies," "Passive Cooling," and "Active Cooling” and combination between.
- HD Heat Demand: This column shows the average amount of heat required for each strategy.
- CD Cooling Demand: It presents the average cooling demand for each strategy.
- HP Heat Power: Indicates the maximum heat power required for each strategy.
- CP Cooling Power: Represents the maximum cooling power needed for each strategy.
- CEP Primary Energy Consumption: Displays the average annual primary energy consumption. CEP includes the consumption of auxiliaries (pumps), energy consumed by the heat pump, fan coil fan operation, air handling unit consumption, lighting consumption, and equipment consumption, as well as fan consumption for mechanical free cooling, motor consumption for window opening in cases of natural ventilation variations, and motor consumption for raising and lowering blinds for brightness control during shading.
- CO2 Emissions: Shows the average CO2 emissions, the source is electricity.
- Internal Air Temperature: Indicates the highest internal air temperature recorded for each strategy.
- Operative Air Temperature: Represents the highest operational air temperature observed for each strategy.
- %EW28A: represents the average number of hours in a year where the temperature exceeds 28°C. This parameter provides insight into how often the temperature rises above the

specified threshold throughout the year, indicating the frequency of high-temperature events. The annual occupancy hours is 2721 hours.

- EH28HW: specifically focuses on the average hours when the temperature exceeds 28°C during heatwave periods, corresponding to 200 hours for 2051 and 180 hours for 2043.

Each row in the table corresponds to a specific type of strategy, and the values provided under each column depict the characteristics or performance metrics associated with that particular strategy. The table serves as a reference for comparing and analyzing the outcomes of the study based on the different strategies employed.

Table 8: Results for groups of variants

Strategies	HD [kWh/m²]	CD [kWh/m²]	HP [W/m²]	CP [W/m²]	CEP [kWhep/m²]	GES [tCO2]	Temperature air int max	Temperature operative max	% EH28A	% EH28HW
No strategies	7.5	0.0	39.3	0.0	79.6	1.0	51.8	52.0	63%	100%
Cooling (AHU + FC) Autosize	14.6	55.0	48.9	92.5	151.1	1.8	26.1	28.2	0%	3%
Cooling (AHU + FC) Limited	15.7	23.7	48.9	31.2	140.0	1.7	34.1	34.9	38%	98%
Cooling (AHU)	18.8	19.6	38.0	41.7	141.4	1.7	35.7	36.5	48%	100%
NNV	11.0	0.0	40.1	0.0	86.9	1.0	37.9	37.6	31%	81%
NNV +Cooling (AHU + FC) Autosize	15.7	29.0	49.0	84.4	134.8	1.6	26.5	28.1	0%	0%
NNV + Cooling (AHU + FC) Limited	15.1	15.7	49.0	32.3	128.4	1.6	30.6	31.1	4%	29%
NNV + Cooling (AHU)	17.9	16.6	34.3	36.1	132.5	1.6	31.1	31.4	7%	35%
Shading	9.6	0.0	40.0	0.0	81.3	1.0	40.0	39.8	48%	100%
Shading +Cooling (AHU + FC) Autosize	16.3	39.7	47.7	80.9	135.1	1.6	26.0	27.7	0%	0%
Shading + Cooling (AHU + FC) Limited	16.4	20.2	47.7	40.0	129.0	1.6	31.5	32.3	21%	93%
Shading + Cooling (AHU)	20.3	20.7	38.0	45.8	135.7	1.7	33.4	34.1	31%	100%
Shading +NNV	12.7	0.0	40.1	0.0	88.6	1.1	32.7	32.0	9%	52%
Shading +NNV+Cooling (AHU + FC) Autosize	17.3	24.9	51.3	84.9	129.2	1.6	26.0	27.5	0%	0%
Shading +NNV+ Cooling (AHU + FC) Limited	16.2	13.5	51.3	36.5	123.4	1.5	30.6	31.0	5%	30%
Shading +NNV+ Cooling (AHU)	20.4	19.0	34.9	46.0	132.2	1.6	31.3	31.9	9%	48%
Shading +MFC+Cooling (AHU + FC) Autosize	15.7	22.9	49.8	69.6	126.8	1.5	26.0	27.6	0%	0%

Shading +MFC+ Cooling (AHU + FC) Limited	14.2	15.3	36.8	35.1	124.3	1.5	29.0	29.3	2%	16%
Shading +MFC+ Cooling (AHU)	17.0	15.6	49.8	40.0	115.0	1.4	31.1	31.5	5%	39%
PO_Shading +MFC+ Cooling (AHU)	16.6	16.1	38.0	33.4	150.0	1.9	34.7	34.7	9%	51%

Analyzing the table, it can be inferred that to achieve a comfortable operational temperature, the cooling power needs to be doubled compared to the restricted fan coil scenario “Cooling (AHU + FC) Limited”, leading to a light increase in energy consumption of 7%.

In situations with limited cooling capacity, the hours exceeding 28°C account for an average of 40% of total occupancy hours. These findings highlight that the current system design, without proper planning and incorporation of passive cooling methods, fails to meet the needs of the increasingly severe future climates.

We can notice from the table that passive solutions alone don’t reduce overheating hours without reaching acceptable comfort levels.

When examining a power outage scenario, configured as a comprehensive strategy utilizing a fusion of air-cooling AHU and free cooling alongside shading elements, it becomes evident that while the power demand for heating and cooling decreases, consumption rises by 23% to address the elevation in internal temperature and restore equilibrium. The surge in durations surpassing 28°C accounts for a 13% increment during the heating season and a 4% rise annually.

For completeness, all data related to the years, rooms, and variations are included in the tables below.

Table 9: Results for year and room

cases	HD [kWh/m²]	CD [kWh/m²]	HP [W/m²]	CP [W/m²]	CEP [kWhep/m²]	GES [tCO2]	Temperature air int max	Temperature operative max	% EH28A	% EH28HW
2043	**14.8**	**17.7**	**46.4**	**83.9**	**121.7**	**1.5**	**49.8**	**50.1**	**19%**	**48%**
4.7	**18.0**	**19.1**	**46.4**	**83.9**	**125.6**	**0.5**	**49.8**	**50.1**	**20%**	**51%**
A	8.1	0.0	31.7	0.0	79.3	0.3	49.8	50.1	66%	100%
B	18.5	39.1	36.2	83.9	153.2	0.7	34.6	35.4	33%	67%
C	14.6	0.0	40.0	0.0	91.6	0.4	31.8	31.4	21%	61%
D	19.7	22.9	46.4	74.1	140.1	0.6	29.7	29.9	5%	18%
E	10.9	0.0	31.9	0.0	82.7	0.4	38.6	38.3	51%	100%
F	20.0	30.5	36.9	74.7	141.5	0.6	32.7	33.3	20%	67%
G	16.2	0.0	40.0	0.0	91.8	0.4	31.0	30.4	11%	47%
H	21.2	18.4	46.4	68.1	133.2	0.6	28.9	29.0	1%	7%
I	18.9	19.8	36.8	59.9	126.4	0.5	32.6	32.6	7%	36%
C2	13.6	0.0	40.0	0.0	90.4	0.4	35.6	35.5	49%	100%
H2	21.8	22.1	43.9	76.6	138.7	0.6	30.5	30.7	12%	51%
4.1.6	**11.5**	**16.4**	**20.8**	**60.5**	**117.9**	**2.4**	**48.6**	**48.9**	**18%**	**46%**
A	6.0	0.0	12.4	0.0	79.1	1.6	48.6	48.9	66%	100%
B	13.3	31.0	13.2	60.5	142.6	2.9	33.0	33.9	31%	67%
C	7.1	0.0	15.9	0.0	82.5	1.7	32.1	31.8	22%	72%
D	12.1	20.6	18.8	55.3	129.1	2.7	29.3	29.7	4%	14%
E	6.9	0.0	15.3	0.0	81.8	1.7	37.1	36.5	48%	100%
F	13.7	24.7	14.4	57.0	133.4	2.7	30.5	31.1	18%	66%

G	7.8	0.0	19.4	0.0	83.8	1.7	31.1	30.2	12%	57%
H	12.6	17.3	20.5	50.2	124.3	2.6	28.3	28.3	0%	2%
I	12.6	16.8	14.4	44.9	120.0	2.5	31.3	31.3	2%	13%
C2	7.0	0.0	15.9	0.0	82.3	1.7	35.7	35.6	51%	100%
H2	13.7	20.3	20.8	56.9	129.8	2.7	29.7	29.8	9%	38%
2051	**15.9**	**16.3**	**51.3**	**92.5**	**119.2**	**1.5**	**51.8**	**52.0**	**16%**	**51%**
4.7	**19.6**	**17.3**	**51.3**	**92.5**	**122.5**	**0.5**	**51.8**	**52.0**	**16%**	**53%**
A	9.2	0.0	39.3	0.0	80.0	0.3	51.8	52.0	60%	100%
B	20.0	33.0	48.9	92.5	144.3	0.6	35.7	36.5	26%	69%
C	15.9	0.0	40.1	0.0	91.7	0.4	33.9	33.7	11%	58%
D	20.7	19.6	49.0	84.4	133.8	0.6	31.1	31.4	3%	27%
E	12.9	0.0	40.0	0.0	78.2	0.3	40.0	39.8	46%	100%
F	22.5	28.7	47.7	80.9	132.3	0.6	33.4	34.1	18%	65%
G	18.1	0.0	40.1	0.0	94.0	0.4	32.4	31.9	7%	51%
H	23.1	17.3	51.1	77.7	126.6	0.5	29.9	30.0	2%	21%
I	20.3	17.9	49.8	69.6	135.6	0.6	34.7	34.7	6%	40%
C2	14.6	0.0	40.1	0.0	90.3	0.4	37.8	37.6	38%	100%
H2	23.5	21.3	51.3	84.9	131.4	0.6	31.3	31.9	7%	40%
4.1.6	**12.1**	**15.3**	**24.4**	**66.5**	**115.9**	**2.4**	**49.7**	**49.9**	**15%**	**49%**
A	6.5	0.0	20.7	0.0	79.9	1.6	49.7	49.9	61%	100%
B	13.7	27.8	21.3	66.5	136.6	2.8	33.4	34.3	24%	66%
C	7.6	0.0	20.8	0.0	83.1	1.7	34.5	34.2	15%	62%
D	12.3	18.6	21.5	63.0	124.7	2.6	30.6	31.2	3%	26%
E	7.8	0.0	23.4	0.0	82.6	1.7	38.4	37.8	45%	100%
F	14.6	23.7	22.8	62.0	125.8	2.6	31.1	31.8	14%	60%
G	8.6	0.0	23.1	0.0	85.0	1.7	32.7	32.0	8%	54%
H	13.4	16.5	24.3	60.3	118.6	2.4	29.2	29.3	1%	17%
I	13.1	15.6	24.2	52.9	129.4	2.7	33.6	33.6	3%	29%
C2	7.5	0.0	20.8	0.0	82.9	1.7	37.9	37.6	41%	100%
H2	14.6	19.8	24.4	65.2	123.5	2.5	30.4	30.9	5%	33%

2 CONCLUSION

In this article, a generic framework based on simulations has been developed to evaluate the impact of cooling strategies, especially the size of HVAC systems, on overheating due to climate change and future heatwaves.

The results demonstrate that:

- A system designed to combat high outdoor temperatures leads to a doubling of installed power and a significant increase in consumption.
- Restricting the installed cooling power is essential to decrease consumption but is not enough to tackle future climates.
- A blend of passive strategies such as external shading or night ventilation in conjunction with active systems is vital to uphold occupant comfort, managing consumption, and consequently, CO2 emissions.
- All of these considerations are relevant even in the event of power outage.
- The dimensions of rooms and openings proportionally impact the outcomes. Section 4.7 exhibits higher internal temperatures and increased consumption due to larger openings.

3 REFERENCES

In the text, references that are cited in a reference list should mention the author's surname and the year of publication. Example:

Attia et al. (2021), Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. *Energy & Buildings 239 (2021) 110869*

Crowe, K. (1974). *A History of the Original Peoples of Northern Canada.* Montreal: McGill/Queen's University Press for the Arctic Insitute of North America.

Zaslow, M. (1988). The Northward Expansion of Canada. *The Journal of Canada, 2*(3), 216-222.