ReCOver++ project: wrap up

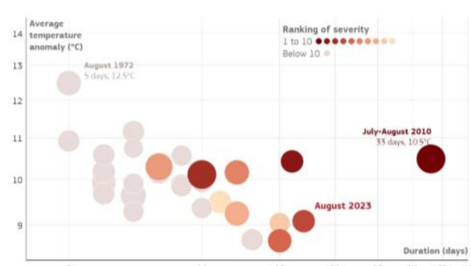
Improving resilience of buildings to overheating

Hilde Breesch (KU Leuven)

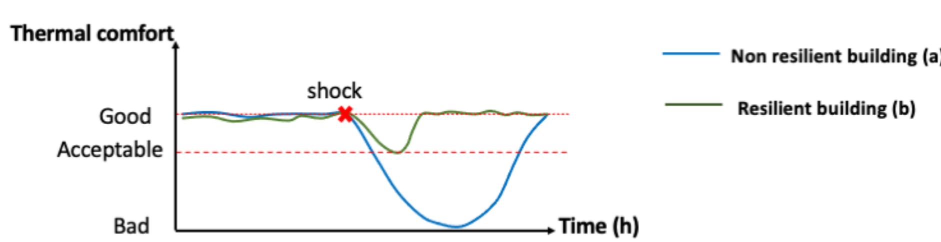
FLANDERS INNOVATION & ENTREPRENEURSHIP flux50 RENSON Creating healthy spaces ARCADIS archipelago ar-te KU LEUVEN UNIVERSITEIT GENT

Challenges

- More frequent and longer **heatwaves**
- Contempory buildings **vulnerable** to face extreme events or shocks
- Need to know how buildings **react to shocks**
  - Absorptivity: How long can building withstand shocks?
  - Recovery: How quickly can building get back to acceptable indoor conditions?
  - Severity: How severe is impact of shock?



Top 30 severe heatwaves Europe (1950 – 2023)



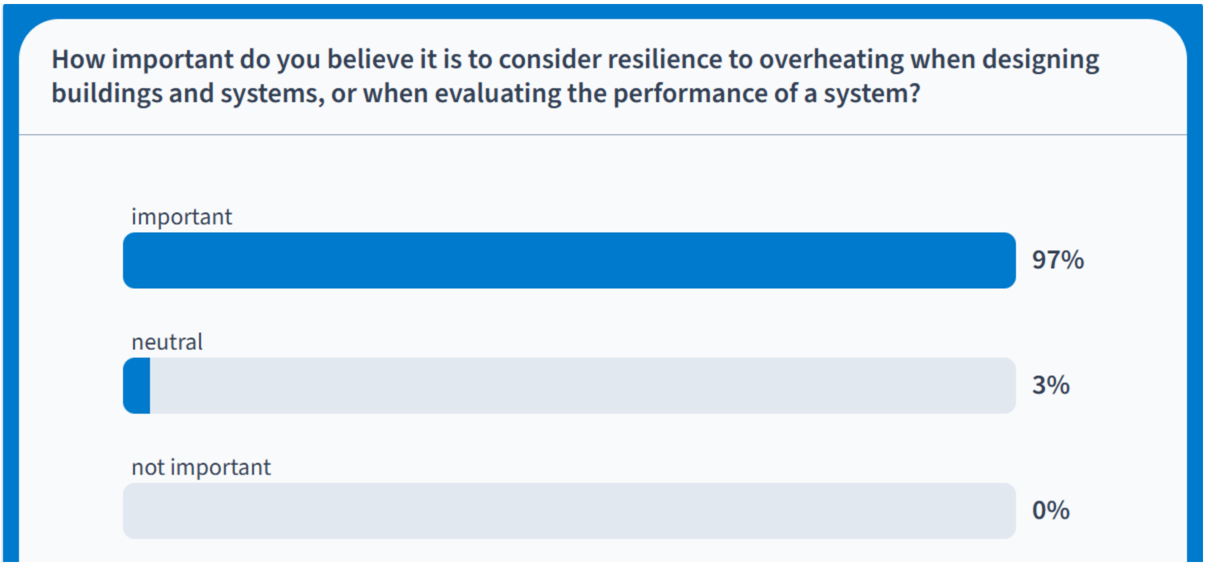
Challenges

- Understand how to design resilient buildings and HVAC systems and control
  - Unexpected events not included in daily design practice
  - No framework in building standards
  - Limited knowledge influencing building design parameters resilient buildings
- Need for resilience indicator
  - Explaining how buildings react to shocks
  - Communicable to stakeholders

Importance for industry

- ReCOver++ topical session AIVC-conference 2024
- 35 participants (20 from industry)
- Questions on resilience
  - How important do you believe it is to **consider resilience to overheating** when designing buildings and systems, or when evaluating the performance of a system?
  - Have you **previously considered resilience to overheating** in your professional practice or research?

Feedback: resilience



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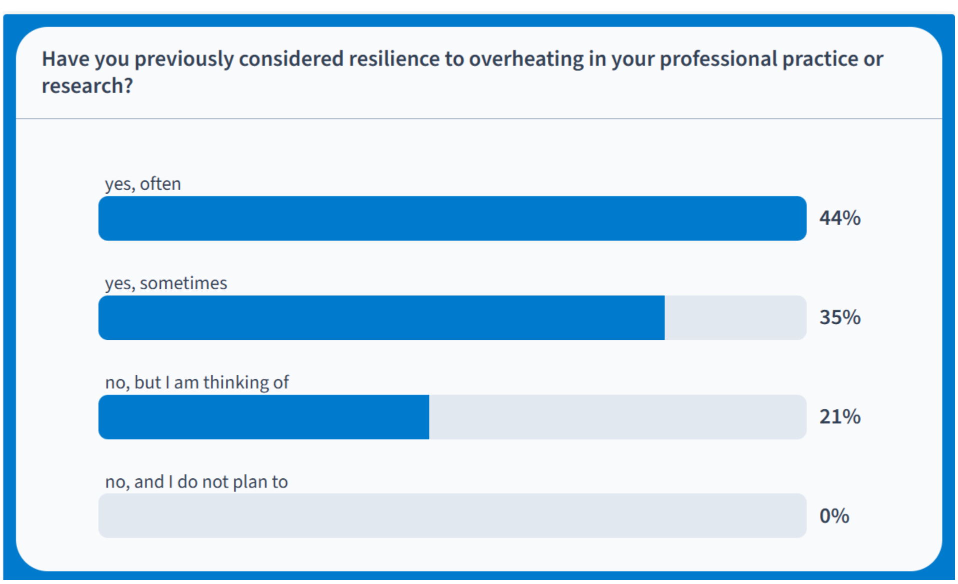
Feedback: resilience



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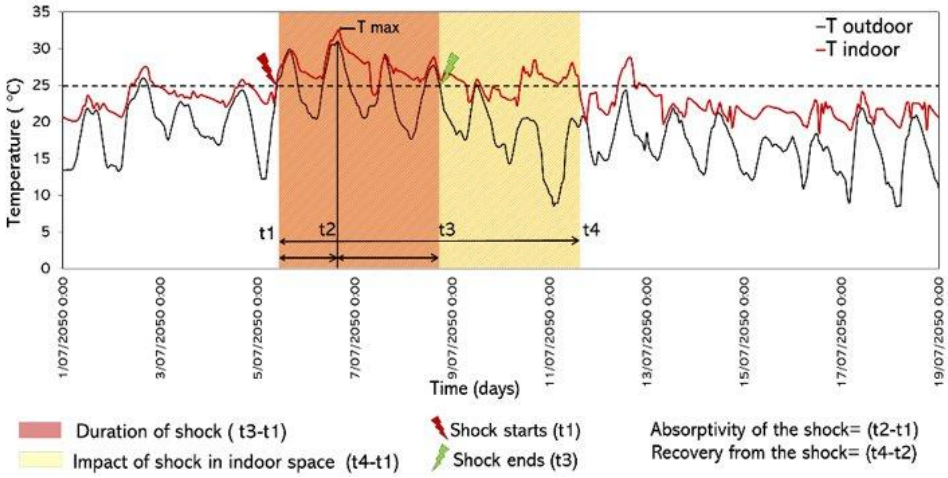
Overall aim ReCOver++

- improve resilience of buildings to overheating
- making resilience tangible & actionable concept for architects, engineering offices & manufacturers

Objectives ReCOver++

1. Quantify relevant **type of shocks**: severity & duration
2. Identify **influencing parameters** of building design, built environment and HVAC systems
3. Define new **resilience indicator**
   - Considering impacts of all relevant shocks
   - Reflecting aspects of resilience: absorptivity of shock, recovery, restoration & degree of impact on thermal comfort
4. Define resilience **scale**
5. Identify resilient **demonstrators** resilience <> costs

RO1 Defining the shocks

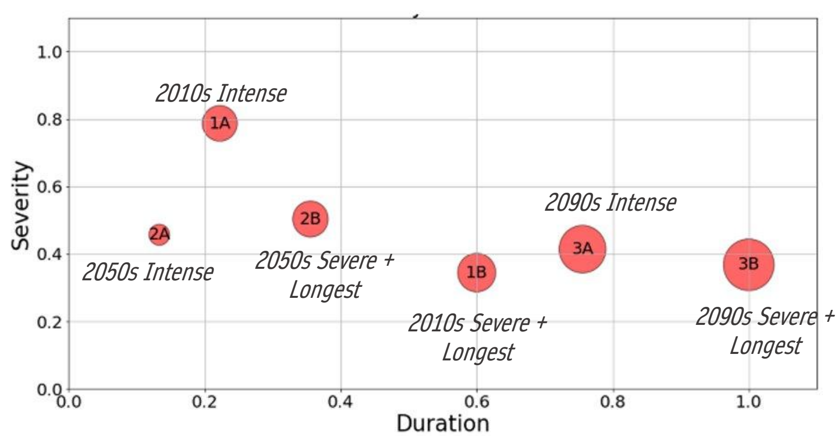


Degree of shock (doS) =

relative deviation of temperature x relative duration of the shock

RO1 Defining the shocks

- Focus on heatwaves

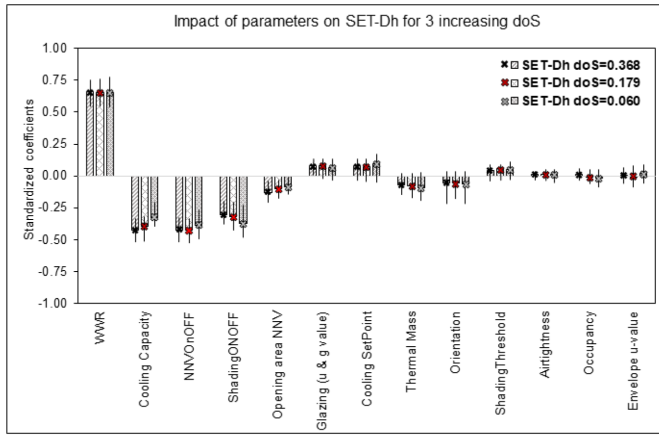


*Degree of shock (doS) for **6 extreme heatwaves** for Ghent between 2001-2010*

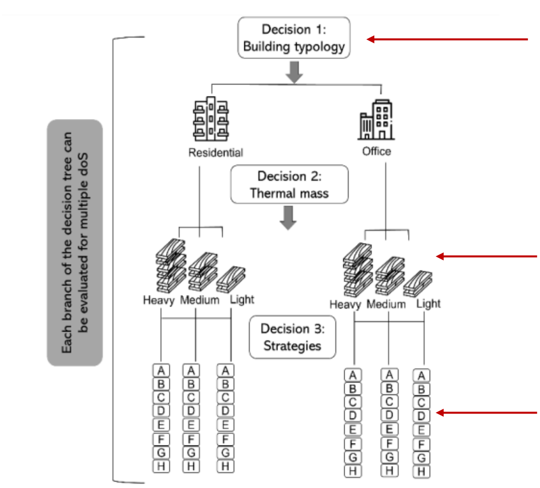
https://doi.org/10.1016/j.buildenv.2023.110152

RO2 Identifying most influential parameters

- Building and system design parameters
  - Building orientation
  - Thermal mass
  - Air-tightness (n_{50})
  - Window to wall ratio (WWR)
  - U-value external wall
  - U value glazing
  - Solar shading ON/OFF
  - Threshold for shading control
  - Natural night ventilation ON/OFF
  - Effective window opening area natural night ventilation
  - Cooling set point
  - Cooling capacity
  - Occupancy schedule



See: 10.1016/j.buildenv.2024.112031



Scenario	Shading	NNV	Active cooling
A	0	0	0
B	0	0	1
C	0	1	0
D	0	1	1
E	1	0	0
F	1	0	1
G	1	1	0
H	1	1	1

Type of building
-Occupant density
-Occupancy pattern
-Internal gains
-Ventilation rate

Thermal mass
-Heavy, medium, light

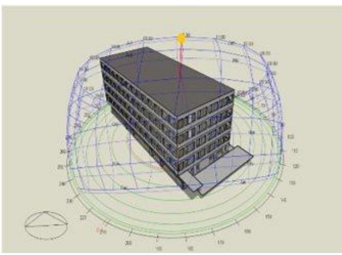
Strategies
-Shading
-Natural night ventilation
-Cooling

RO3 & 4 Resilience indicator & scale

RO5 Demonstrators

- Small office buildings

Residential building



ARCADIS

archipelago

RENSON
Creating healthy spaces

KU LEUVEN

A novel indicator to assess thermal resilience of buildings to overheating

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[2]Research Center En Aeronautique, Cenaero, Belgium
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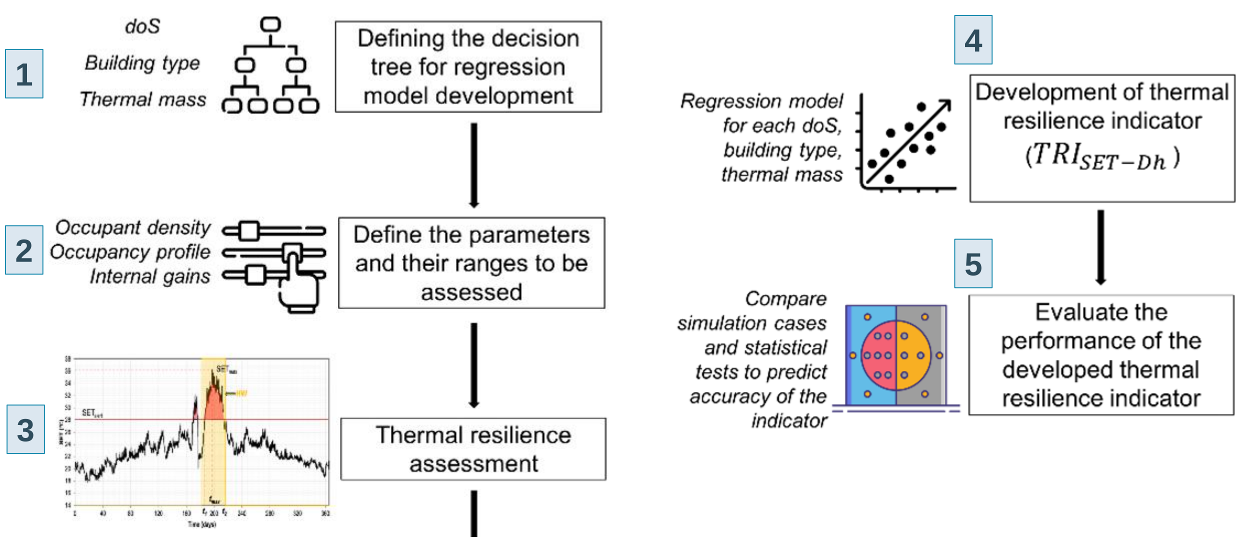
1

How was the indicator defined?



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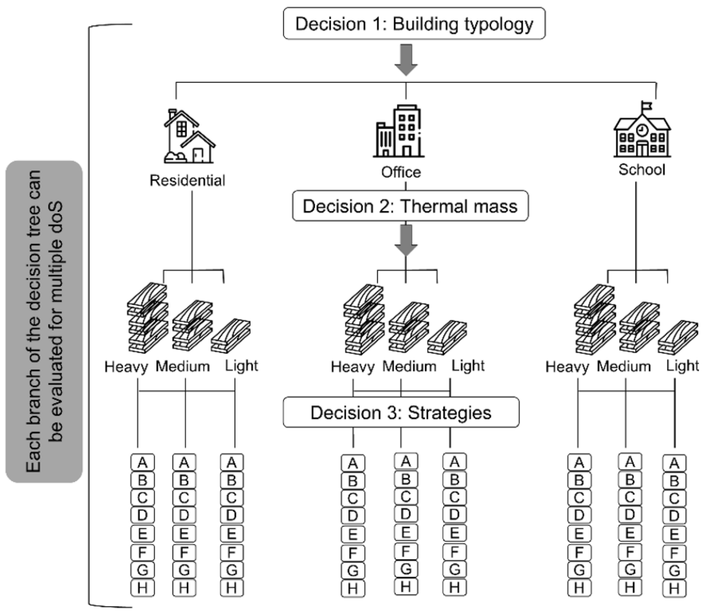
1 Decision tree

Defining the decision tree for regression model development



Cases	Shading	NNV	Active cooling
Case A	0	0	0
Case B	0	0	1
Case C	0	1	0
Case D	0	1	1
Case E	1	0	0
Case F	1	0	1
Case G	1	1	0
Case H	1	1	1

2 Parameters + ranges

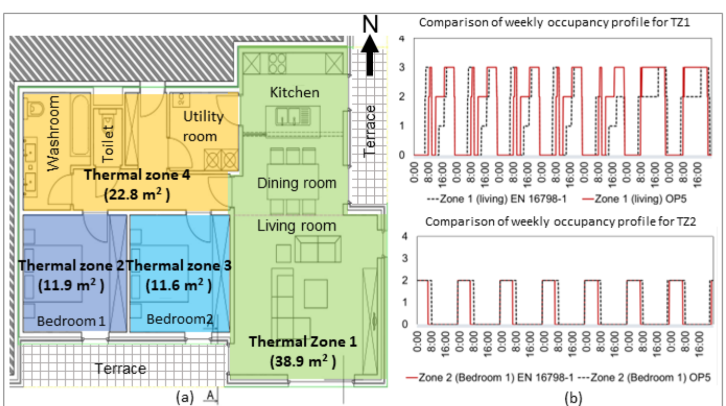
Category	Description/parameter	Range
Building parameters	Building Orientation (°)	0-360
	U-value of external wall (W/m².K)	0.10-0.30
	WWR (%)	25-80
	U-value (W/m².K) and associated g-value (-) of glazing	U-value (0.6-1.0) W/m².K g-value (0.4-0.6)
	Air tightness (ACH) n50 (1/h)	0.6-3
Solar shading	External shading Control (ShadingONOFF)	0-1
	Shading Threshold (W/m²)	100-300
Natural night ventilation	Effective window opening area (% of floor area)	1- 8
	Night Cooling control (NNVOnOFF)	0-1
Cooling system	Cooling set point (°C)	24 - 28
	Cooling capacity (W/m²)	0-40

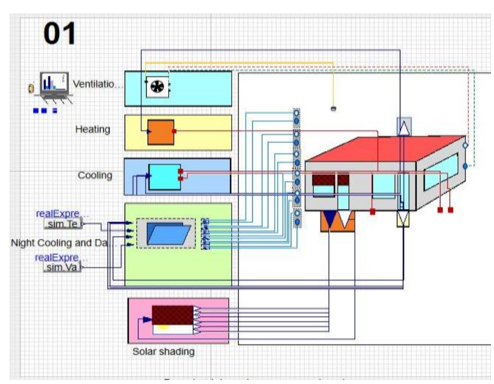
2 Parameters + ranges (continued)

Parameters		Office	Residential	School
Parameters that vary for each building typology	Occupant density (m²/pers)	10	28.3	5.4
	Occupancy profile	9h-18h Weekdays	24*7 (at least 1 occupant during daytime)	8h-17h Weekdays
	Ventilation rate (m³/h) per person	30-54	30	30-54
	Internal gains-appliances (W/m²)	12	3	8

3 Thermal resilience assessment

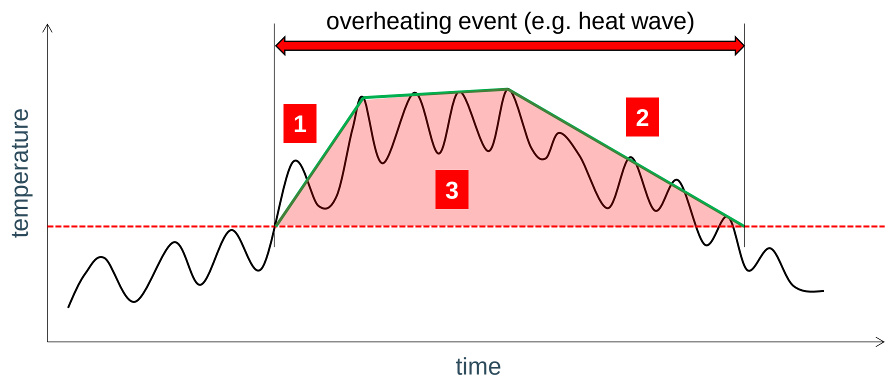
A model was developed for a Belgian reference apartment





3 Thermal resilience assessment

Resilience response on health = rate of change of temperature (absorption, recovery) + cumulative impact



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3 Thermal resilience assessment

Degree of Impact = standard effective temperature (SET) Degree-hours (SET-Dh)

What is SET?

"Temperature of imaginary environment at RH = 50%, v <0.1 m/s & total heat loss from the skin of imaginary occupant (1.0 MET & 0.6 clo) = person in actual environment, with actual clothing and activity level"

SET_{alert} = 28°C

Resilience class	SET-Dh range	Resilience rating
Class I	SET-Dh < (117 ± 30)	Best
Class II	(117 ± 30) < SET-Dh < (230 ± 42)	Good
Class III	SET-Dh > (230 ± 42)	Worse

Source: Laoudi et al. (2020)

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4 Multiple linear regression

Thermal resilience indicator ($TRI_{SET\text{-}Dh}$)

WWR 75% · Vent 9% · Glazing 6% · Walls 5% · Air-tightness 4% · Orientation 2%

Case A (without strategies: shading, night cooling, cooling)

$$TRI_{case\ A} = 37.05 - 0.01 \times Orientation + 3.66 \times WWR - 4.7 \times n_{50} - 75.79 \times U_{wall} + 36.12 \times U_{glazing} - 0.94 \times \dot{Q}_{vent}$$

Ranges: Orientation 0 – 4; WWR 91 – 293; n_{50} 3 – 14; U_{wall} 8 – 22; $U_{glazing}$ 21– 36; $\dot{Q}_{vent}$ 28 – 51

In newly-built buildings, where there is no availability of installing strategies, the first parameter to control is the WWR as it will have the most impact on overheating

4 Multiple linear regression

WWR 39% · Cooling 28% · Shading 16% · Glazing 5% · Vent 4% (rest lower than 3%)

Case H (with shading, night cooling, cooling)

$$TRI_{case\ H} = -63.90 + 0.01 \times Orientation + 1.38 \times WWR - 0.51 \times n_{50} + 0.15 \times Shading\ threshold - 2.70 \times A_{win,open} + 0.81 \times T_{set,cool} - 1.37 * Q_{cool} - 8.71 * U_{wall} + 24.62 * U_{glazing} - 0.27 \times \dot{Q}_{vent}$$

Ranges: Orientation 0 – 4; WWR 35 – 110; n_{50} 0.3 – 1.5; Shading threshold 15 – 45; $A_{win,open}$ 0 – 5; $T_{set,cool}$ 18 – 23; Q_{cool} 0 – 55; U_{wall} 1 – 3; $U_{glazing}$ 15 – 25; $\dot{Q}_{vent}$ 8 – 15

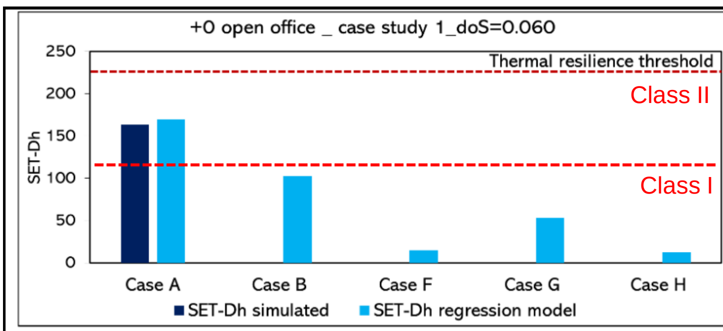
In newly-built buildings, where there is availability of installing strategies, the WWR is an important factor, but should be given as much importance as the system's cooling capacity and optimizing the deployment of shading

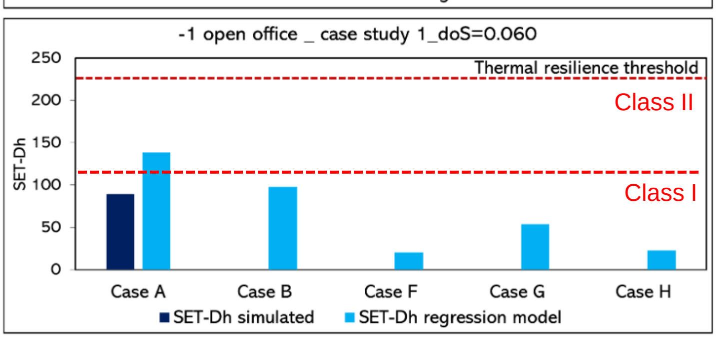
5 Testing indicator

Case studies in the ReCOver++ project:

- Office archipelago
- Office arcadis
- Renson Concept home

Comparison of Predicted $TRI_{SET\text{-}Dh}$ vs. Simulated SET-Dh





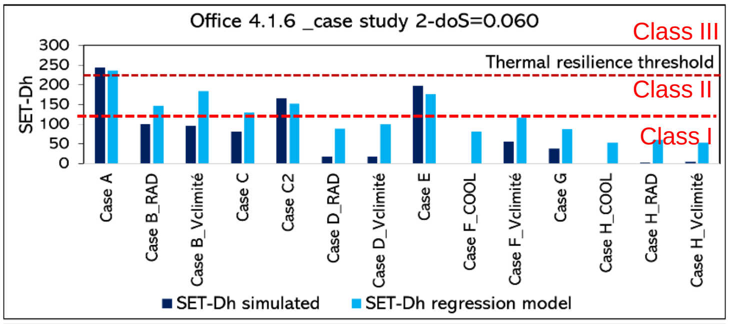
5 Testing indicator

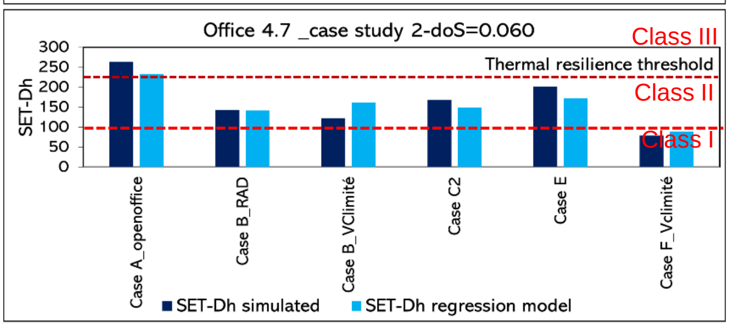
1) Office archipelago

Case A was correctly predicted as resilient Class II and Case B, F, G, H as Class I

Case A in the -1 open office was the exception

Cases	Shading	NNV	Active cooling
Case A	0	0	0
Case B	0	0	1
Case C	0	1	0
Case D	0	1	1
Case E	1	0	0
Case F	1	0	1
Case G	1	1	0
Case H	1	1	1



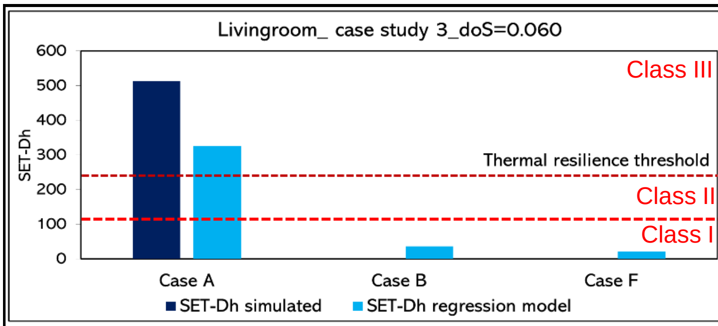


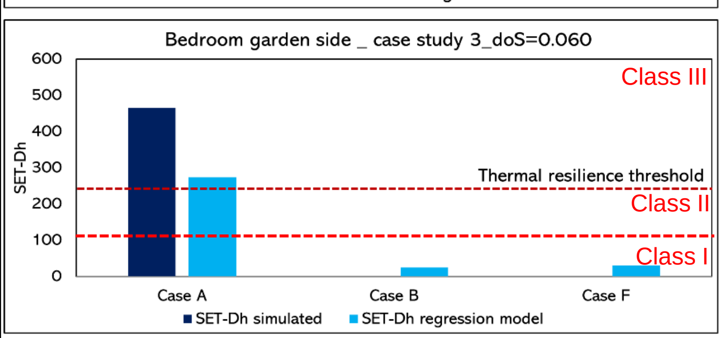
5 Testing indicator

2) Office arcadis

- Case A was correctly predicted as resilient Class III
- Case B predicted in Class II correctly **50%** of the time
- Case C predicted in Class II correctly **67%** of the time
- Case D **always** predicted in Class I correctly
- Case E **always** predicted in Class II correctly
- Case F to H **always** predicted in Class I correctly

Cases	Shading	NNV	Active cooling
Case A	0	0	0
Case B	0	0	1
Case C	0	1	0
Case D	0	1	1
Case E	1	0	0
Case F	1	0	1
Case G	1	1	0
Case H	1	1	1





5 Testing indicator

3) Renson Concept home

- Case A was **correctly** predicted as resilient Class III
- Case B **always** predicted in Class I correctly
- Case F **always** predicted in Class I correctly

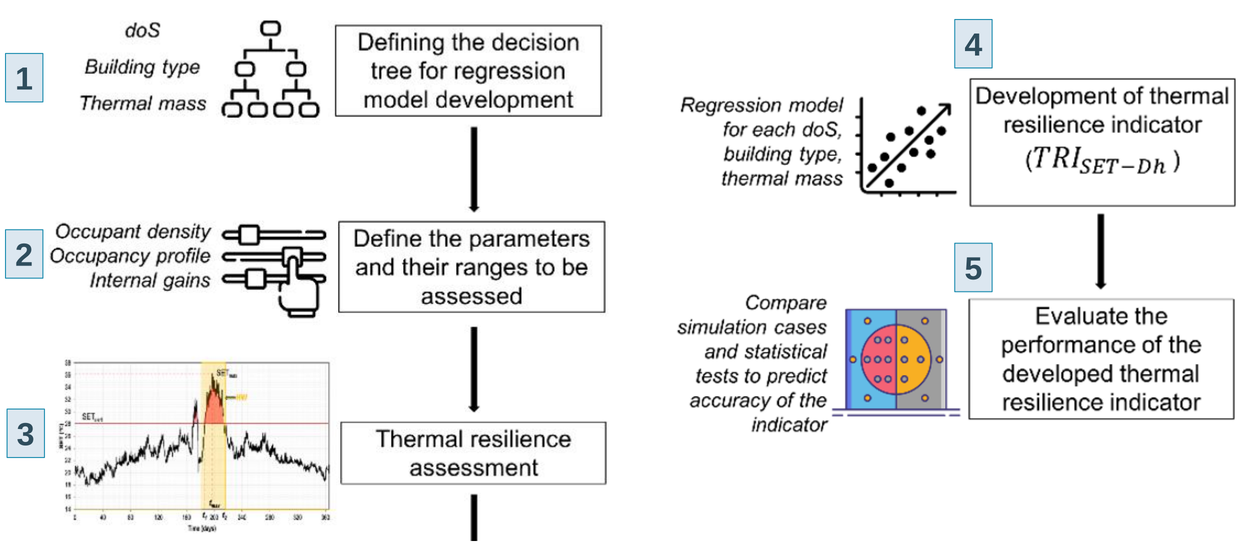
Cases	Shading	NNV	Active cooling
Case A	0	0	0
Case B	0	0	1
Case C	0	1	0
Case D	0	1	1
Case E	1	0	0
Case F	1	0	1
Case G	1	1	0
Case H	1	1	1

5 Testing indicator

Resilience class	SET-Dh range	Resilience rating	Prediction rate accuracy of indicator
Class I	SET-Dh < (117 ± 30)	Best	84%
Class II	(117 ± 30) < SET-Dh < (230 ± 42)	Good	100%
Class III	SET-Dh > (230 ± 42)	Worse	100%

16% should have been predicted Class I were predicted as Class II

Summary



Scope, limitations of the indicator and future directions

- Applicable to newly built buildings in Belgium & renovations with already acceptable insulation
- Applicable to heat-waves, should be tested for other disruptive events (power outages, excessive occupancy) and compared to more simulation cases
- More parameters can be tested for more specific design implications (thermal mass, shading parameters, cooling system parameters)
- Dose response and long-term is not considered
- Human behavioral and physiological adaptations are not considered
- Absorptivity and recovery rates should be considered in the future: more understanding is needed on human body's response to heat

References

- Laoudi et al. 2020: https://doi.org/10.1016/j.enbuild.2020.110360
- Annex 80 paper: simulation of different resilient strategies in different climates: https://doi.org/10.1016/j.buildenv.2025.112698
- Sensitivity analysis paper: https://doi.org/10.1016/j.buildenv.2024.112031
- Publication coming soon on the indicator!

Thank you

Resilience to overheating of buildings. How to design a resilient building?

archipelago

Joost Declercq, ir.architect – partner
archipelago architects (Belgium)

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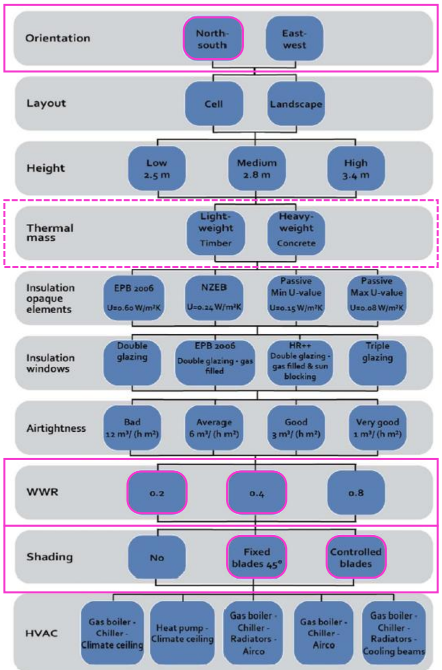


not include in the study: ventilative cooling

Delphine Ramon and Karen Allacker (2023), Optimizing building solutions in a changing climate: parameter-based analysis of embodied and operational environmental impacts, Environ. Res.: Infrastruct. Sustain. 3 045010

3

a designer's guideline

4

a designer’s guideline

window-to-wall ratio
shading
ventilative cooling
thermal mass

5

a designer’s guideline

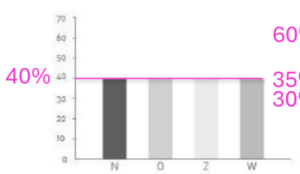
window-to-wall ratio
shading
ventilative cooling
thermal mass

6

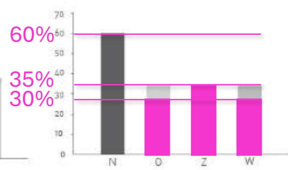
Sun- and daylight-harvesting

1. How much glazing do you need?

Mean solar radiation

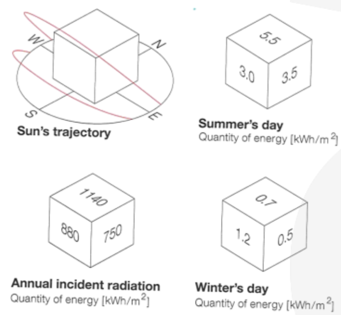


Window-to-Wall Ratio 'business as usual'



Window-to-Wall Ratio optimised

Source: European Passive Solar Handbook



Source: Birkhauser Energy Manual

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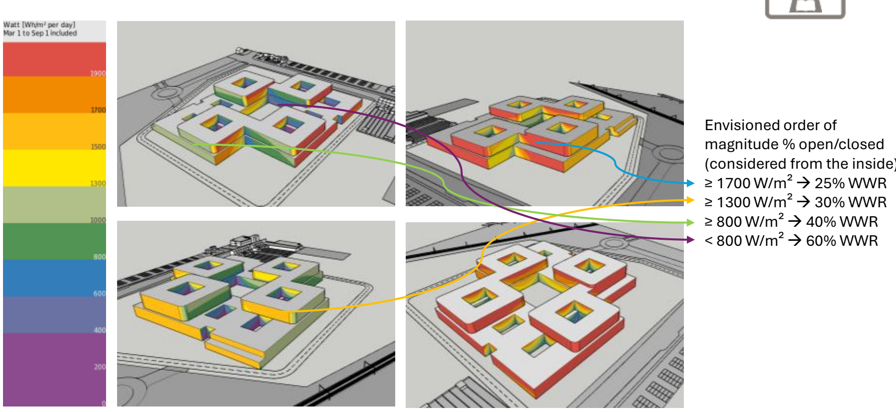
Sun- and daylight-harvesting

2. Positioning of windows and shading



Helora Hospitals | archipelago architects

What do these learn us?

Zones with high risk of overheating:
-> influence on the positioning of spaces
-> influence on the position of the windows
-> influence on the size of the windows
-> identifiction of zones in the facade with similar loads
-> anticipation on passive solarprotection strategies

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a designer's guide

window-to-wall ratio

shading

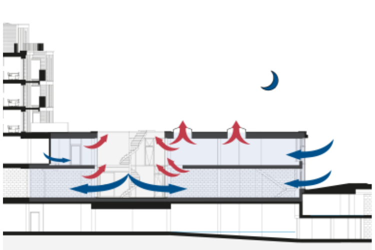
ventilative cooling

thermal mass

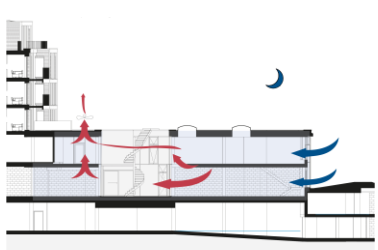
9

the VC concept

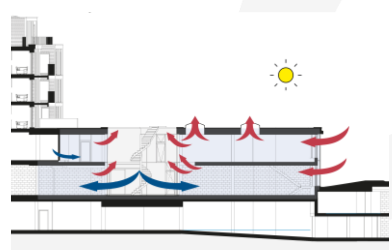
Natural Ventilative Cooling



Hybrid Ventilative Cooling



Natural hygienic ventilation



Joost Declercq et al. (2021), The feasibility of natural ventilative cooling in an office building in a Flemish urban context and the impact of climate change, Proceedings of Building Simulation 2021: 17th Conference of IBPSA; 2021; pp. 910 - 917

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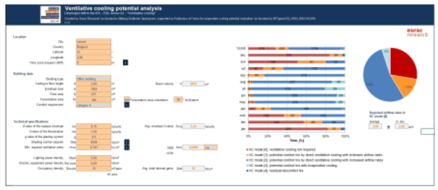
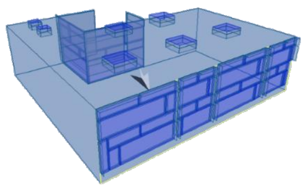
the design process

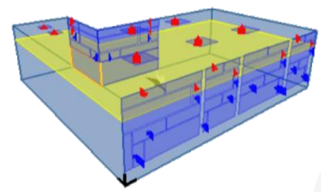
Feasibility NVC (Annex 62 VC-tool)

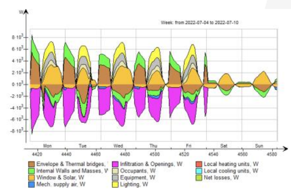
Early stage optimisation NVC (Dial+)

Concept verification (IDA ICE)



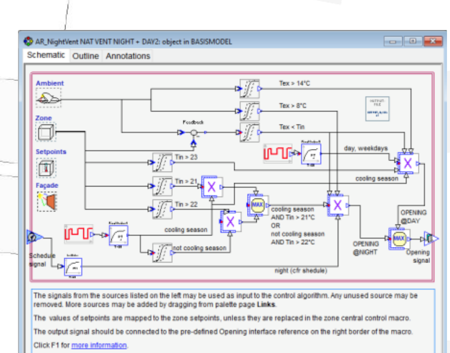




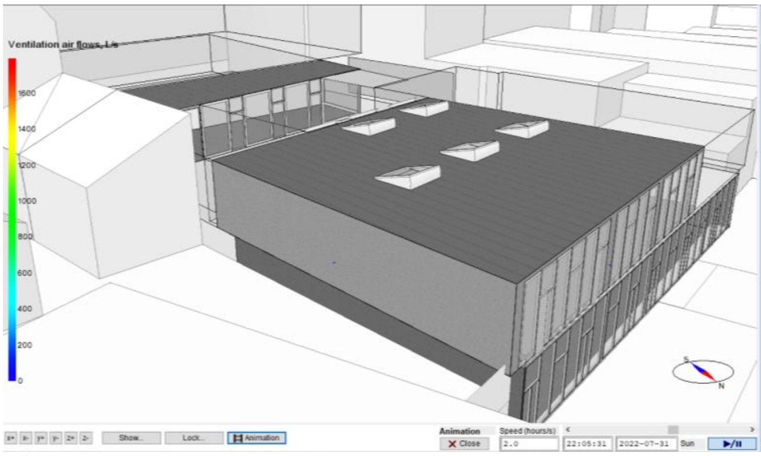


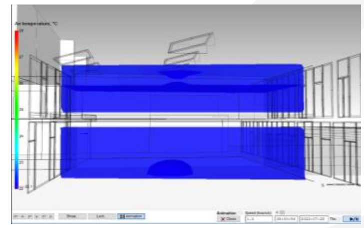
concept verification

IDA ICE



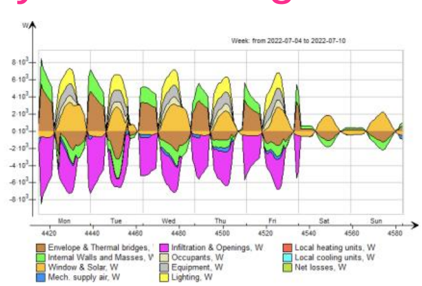
the hybrid cooling concept: NVC + MC

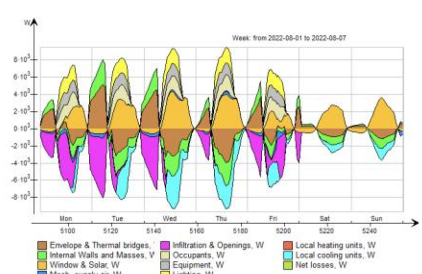




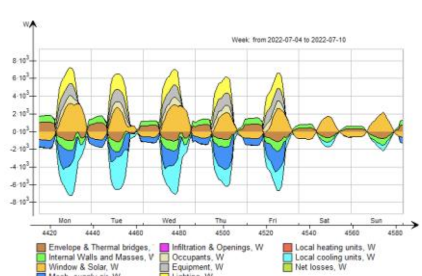
the hybrid cooling concept: NVC + MC

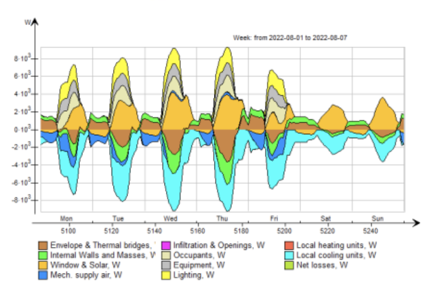
NVC + MC: Natural ventilative cooling + mechanical cooling





MC: Only Mechanical Cooling





concept verification

IDA ICE

6 scenario's:

(1) only mechanical cooling
(2) + dynamic shading
(3) + mechanical ventilative cooling (MVC)
(4) + thermal mass
(5) + natural ventilative cooling (NVC)
(6) + TABS

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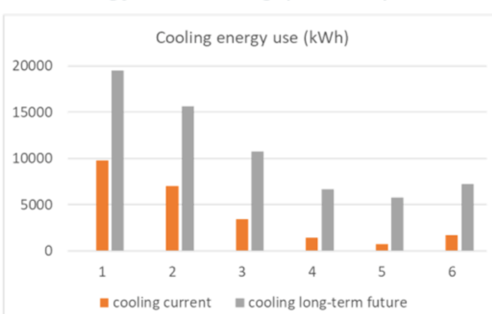
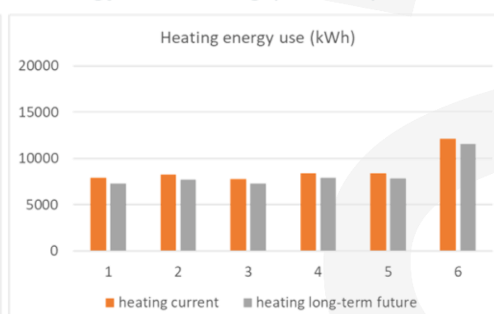
concept verification

(1) only mechanical cooling
(2) + dynamic shading
(3) + mechanical ventilative cooling (MVC)
(4) + thermal mass
(5) + natural ventilative cooling (NVC)
(6) + TABS

- Energy use cooling (3 zones)



- Energy use heating (3 zones)



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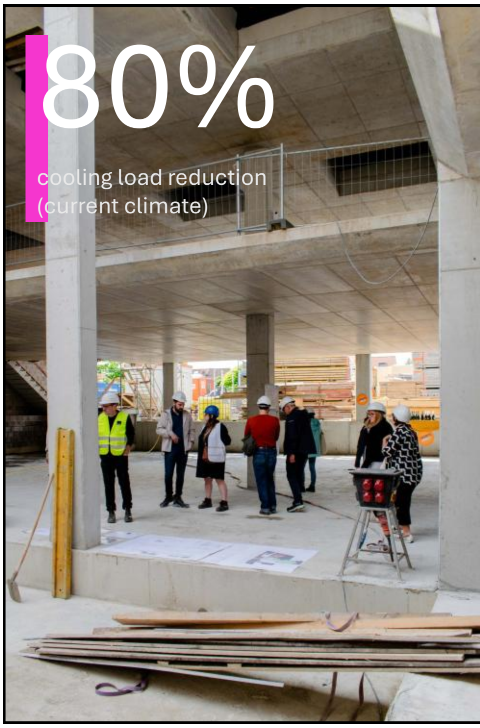
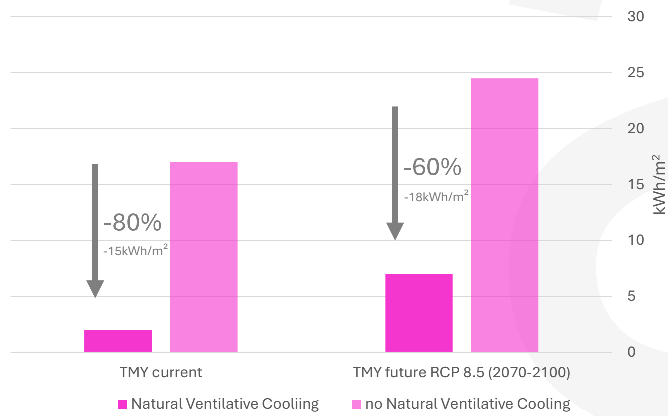


Mechanical cooling energy demand



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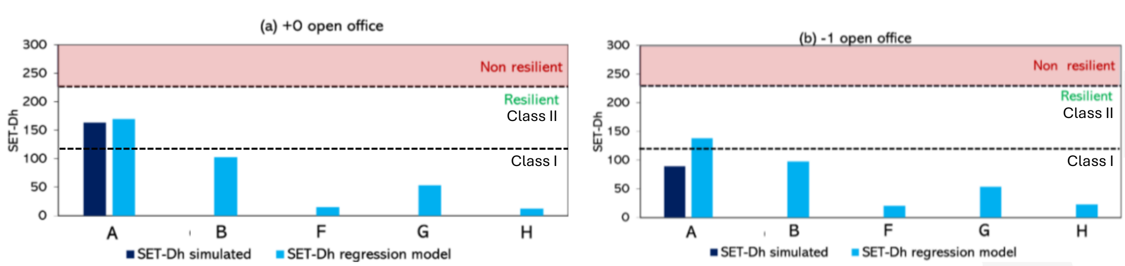
concept verification

Thermal resilience indicator

(A) no strategie
(B) dynamic shading
(F) cooling + shading
(G) shading + Natural Ventilative Cooling (NVC)
(H) cooling + shading + NVC



Source: Abantika Sengupta, KU Leuven

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a designers guide

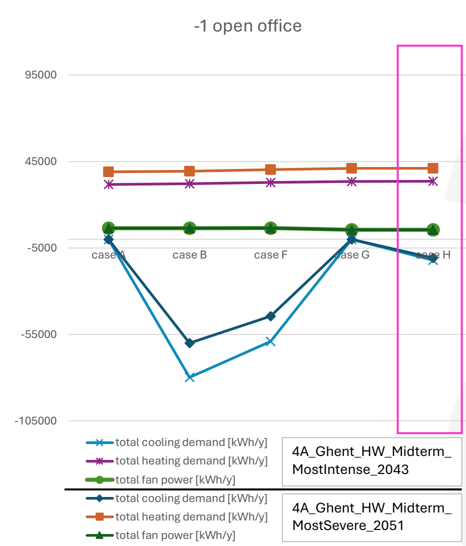
cost

investment - operational

19

cost

Energy demand on yearly base

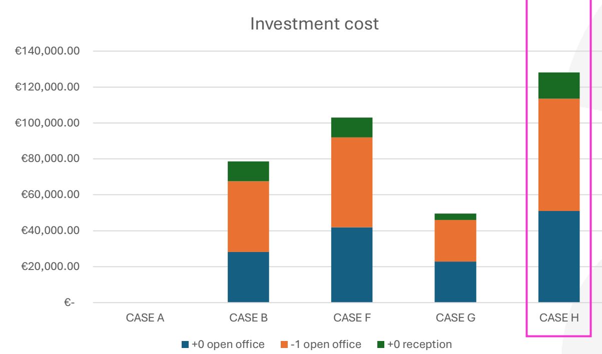


(A) no strategie
(B) cooling (30W/m^2)
(F) cooling + shading
(G) shading + Natural Ventilative Cooling (NVC)
(H) cooling + shading + NVC

20

cost

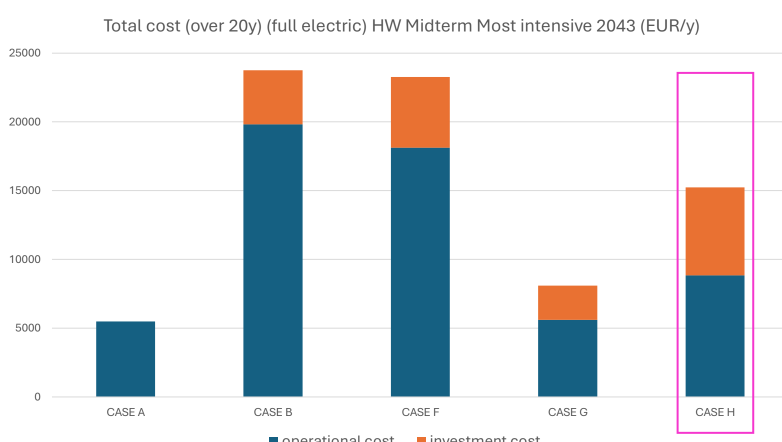
additional upfront investment cost



(A) no strategie
(B) cooling (30W/m^2)
(F) cooling + shading
(G) shading + Natural Ventilative Cooling (NVC)
(H) cooling + shading + NVC

cost

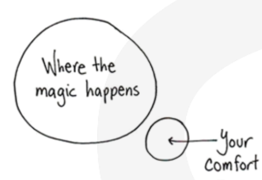
Total yearly cost (investment + operational) (all electric – COP 3 – lifespan 20y)



(A) no strategie
(B) cooling (30W/m^2)
(F) cooling + shading
(G) shading + Natural Ventilative Cooling (NVC)
(H) cooling + shading + NVC

How to build future proof?

1. Study the orientation and the solar exposure
2. Restrict the Window To Wall Ratio, depending on the solar exposure
3. Provide shading
4. Provide (natural) ventilative cooling
5. Use thermal mass
6. Use common sense (and fans…)



archipelago

corresponding author: jdeclercq@archipelago.be

ARCADIS

ReCOver++ project

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

Debora Resta, Bert Lemmens, Hilde Breesch, Abantika Sengupta, Douaa Al-assaad, Steven Delrue, Joost Declercq, and Marijke Steeman

AIVC Webinar

05 May 2025

May 05, 2025 **Debora Resta**

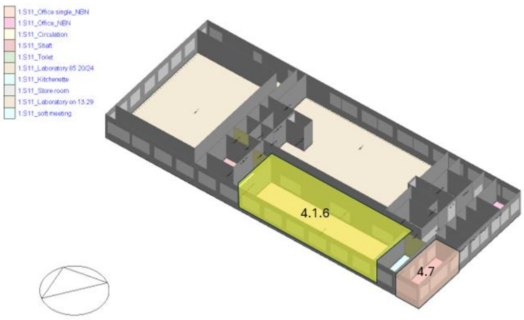
1

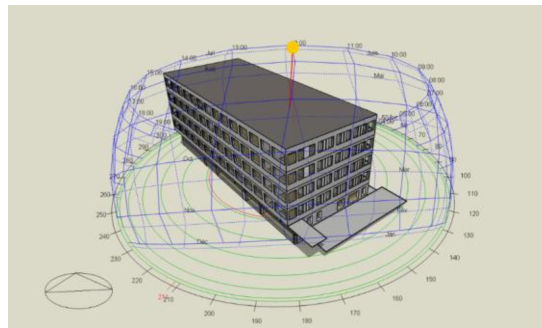
Question

What **cooling strategies** *(passive and active)* can enhance the **resilience performance** of the current building stock to overheating risks without compromising **energy performance**?

2

Demonstration Case





- New projet with Passive design
- According to Belgian and european legislation
- Schedule office according to EN 16798-1 : 2019

DesignBuilder

Software v7

Active cooling strategies

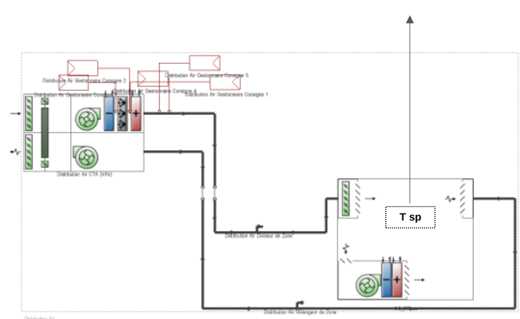
- **A/W Heat Pump**

  with **3 scenarios** :

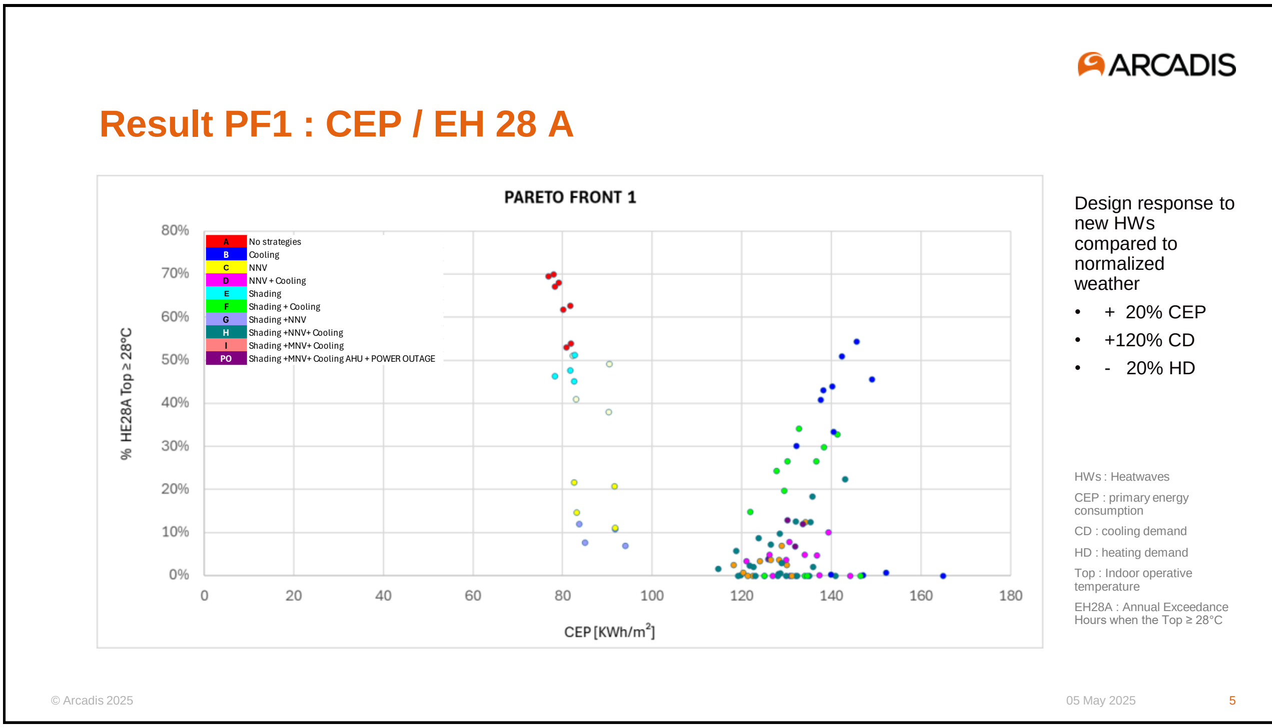
  1. Unlimited cooling power (Air Handling Unit + Fan coil)
  2. Limited cooling power
     a) precooling AHU
     b) precooling AHU + Local Fan coil

- **Variant** : MNC mechanical night cooling

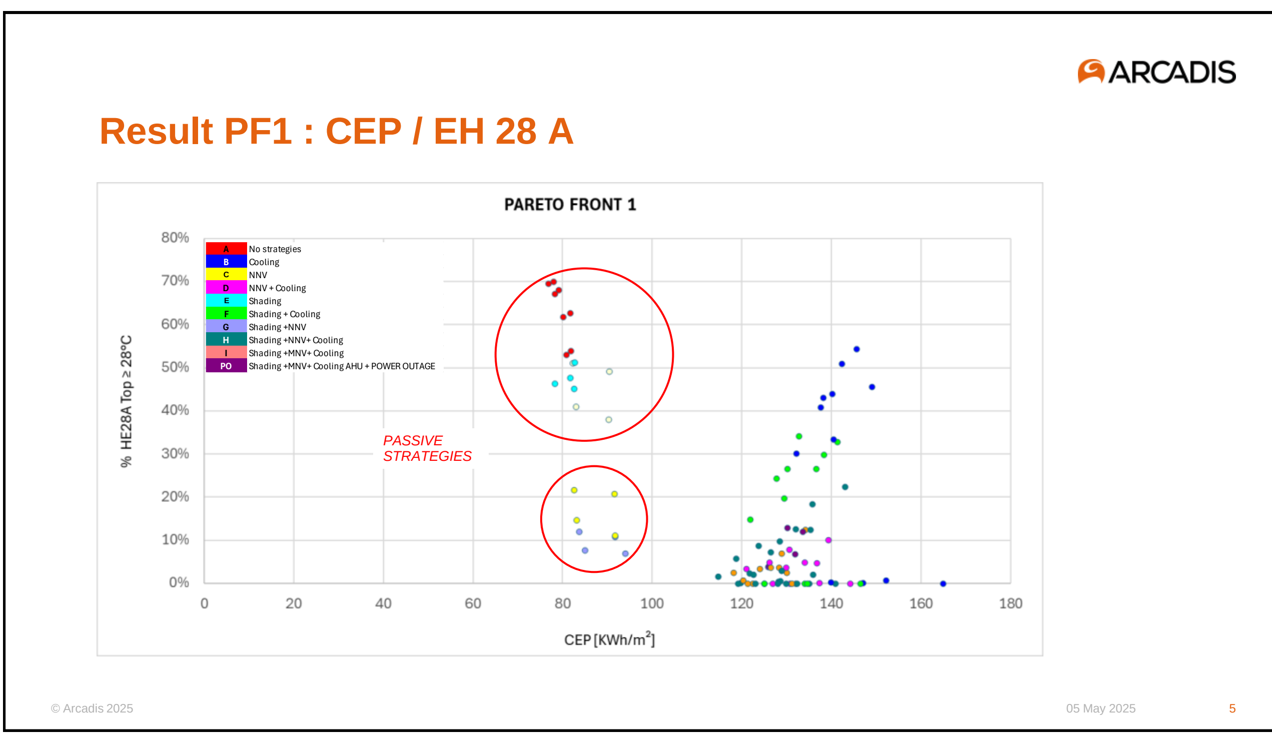
Parameter	Value
Heating set point temperature	21°C
Heating set back temperature	16°C
Cooling set point temperature	26°C
Cooling set back temperature	32°C



Autosize scenario DB:
(Unlimited cooling power)


ARCADIS
Result PF1 : CEP / EH 28 A
PARETO FRONT 1
A No strategies
B Cooling
C NNV
D NNV + Cooling
E Shading
F Shading + Cooling
G Shading +NNV
H Shading +NNV+ Cooling
I Shading +MNV+ Cooling
PO Shading +MNV+ Cooling AHU + POWER OUTAGE
% HE28A Top ≥ 28°C
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
20
40
60
80
100
120
140
160
180
CEP [KWh/m2]
Design response to new HWs compared to normalized weather
• + 20% CEP
• +120% CD
• - 20% HD
HWs : Heatwaves
CEP : primary energy consumption
CD : cooling demand
HD : heating demand
Top : Indoor operative temperature
EH28A : Annual Exceedance Hours when the Top ≥ 28°C
© Arcadis 2025
05 May 2025
5

5


ARCADIS
Result PF1 : CEP / EH 28 A
PARETO FRONT 1
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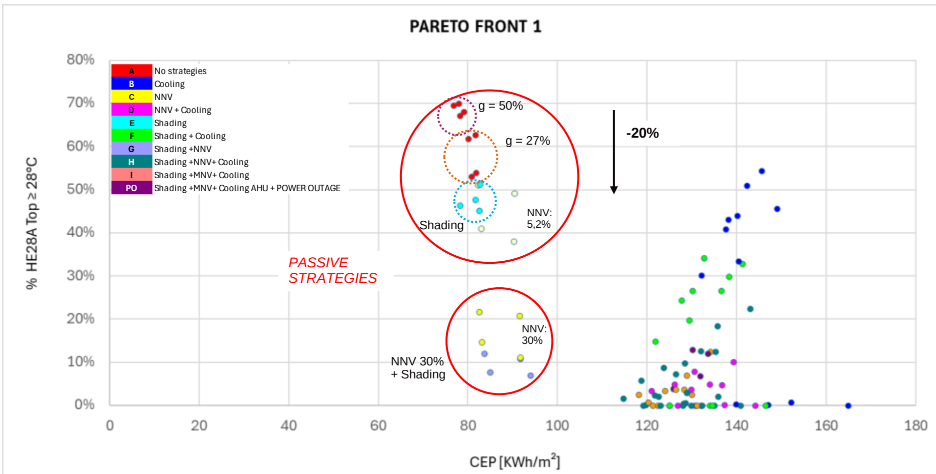
F Shading + Cooling
G Shading +NNV
H Shading +NNV+ Cooling
I Shading +MNV+ Cooling
PO Shading +MNV+ Cooling AHU + POWER OUTAGE
PASSIVE STRATEGIES
% HE28A Top ≥ 28°C
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
20
40
60
80
100
120
140
160
180
CEP [KWh/m2]
© Arcadis 2025
05 May 2025
5

6

Result PF1 : CEP / EH 28 A



05 May 2025

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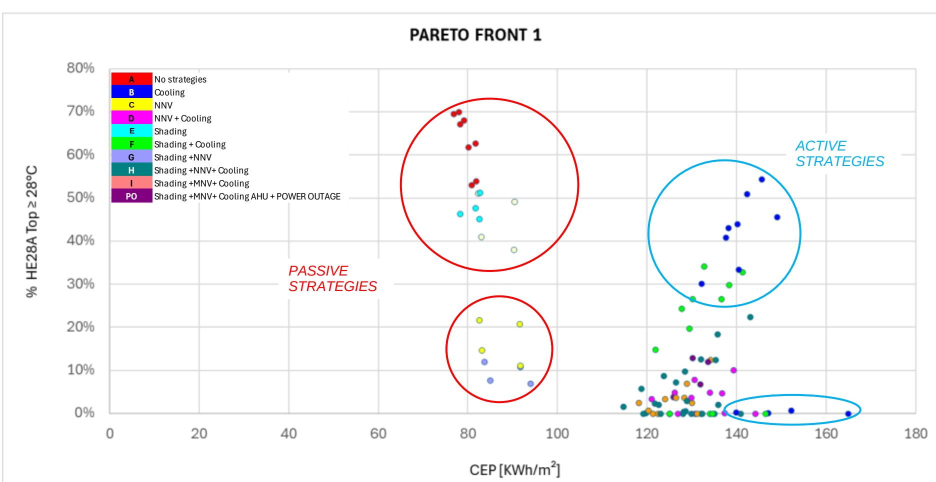
Result PF1 : CEP / EH 28 A



05 May 2025

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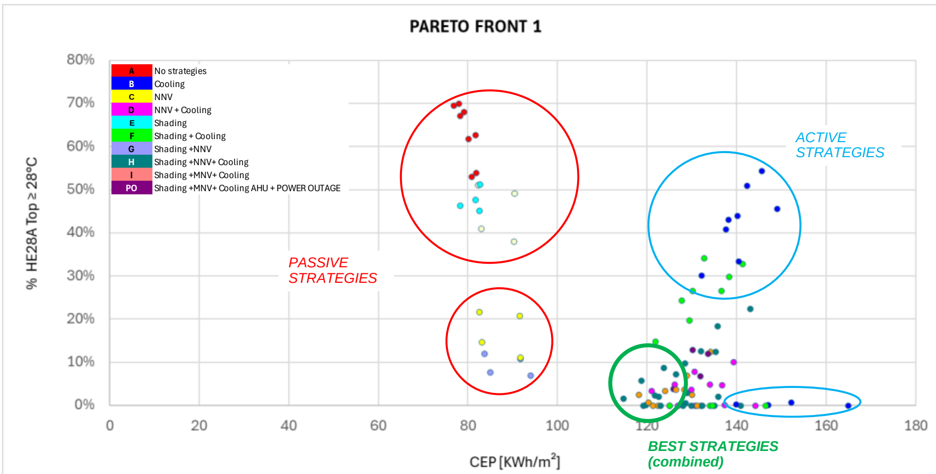
Result PF1 : CEP / EH 28 A



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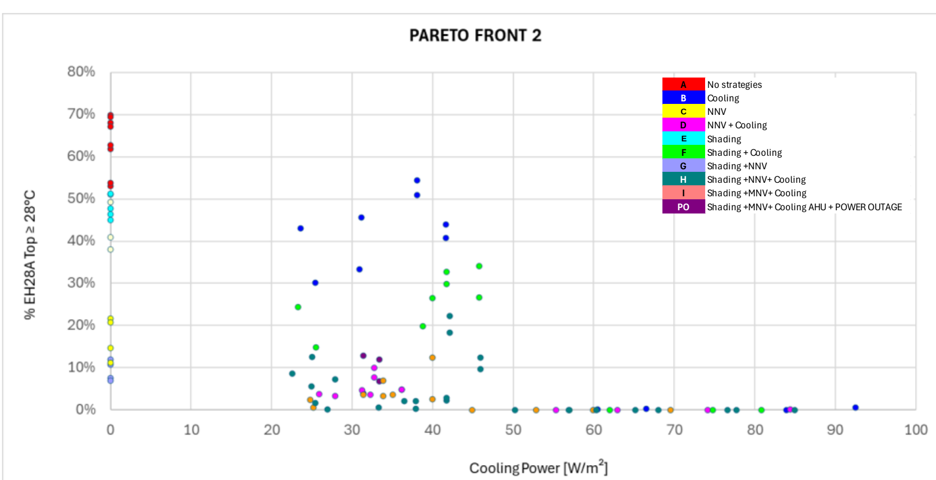
Result PF2 : CP / EH 28 A



Design response to new HWs* compared to normalized weather

- \+ 35% CP
- \- 18% HP

HWs : Heatwaves

CP : cooling power

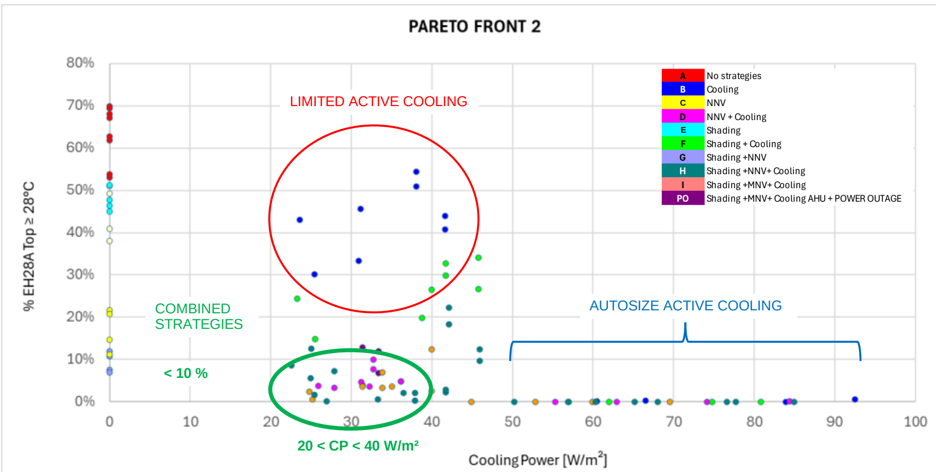
HP : heating power

Top : Indoor operative temperature

EH28A : Annual Exceedance Hours when the Top ≥ 28°C

ARCADIS

Result PF2 : CP / EH 28 A



11

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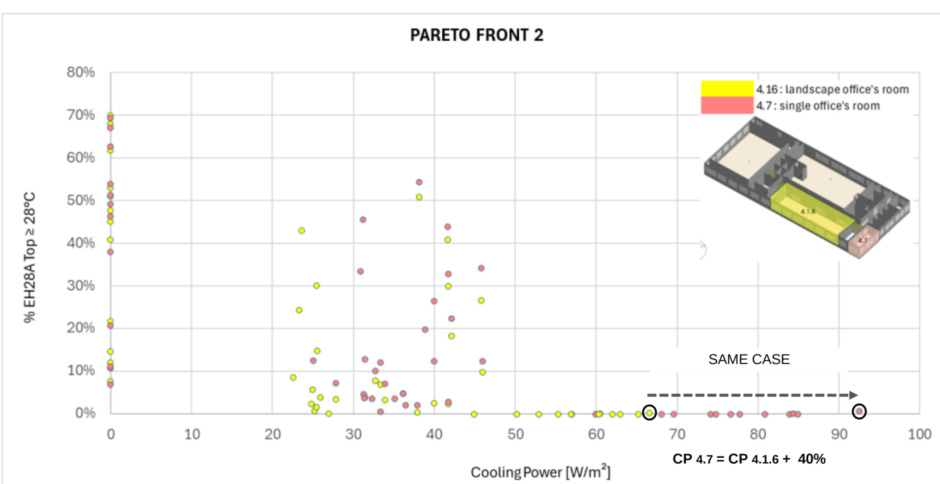
Result PF2 : CP / EH 28 A



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Question

What effects do different strategies
have on the **thermal resilience index**?

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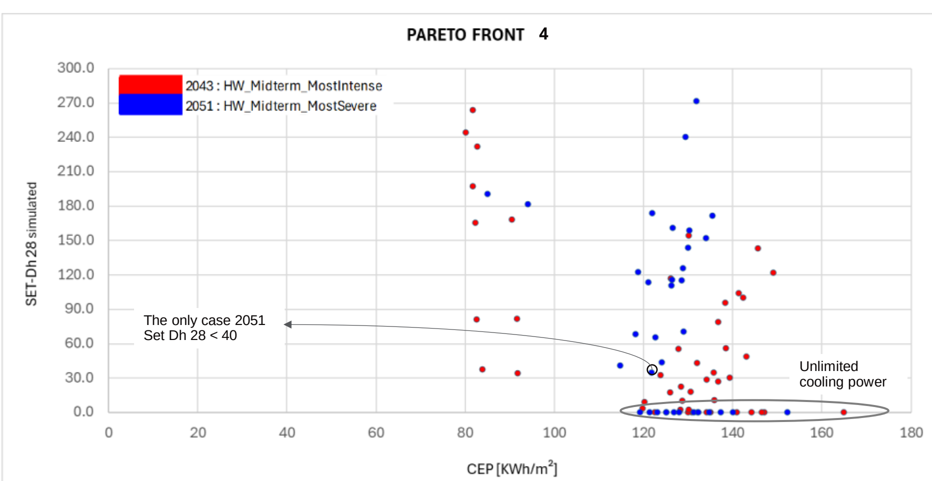
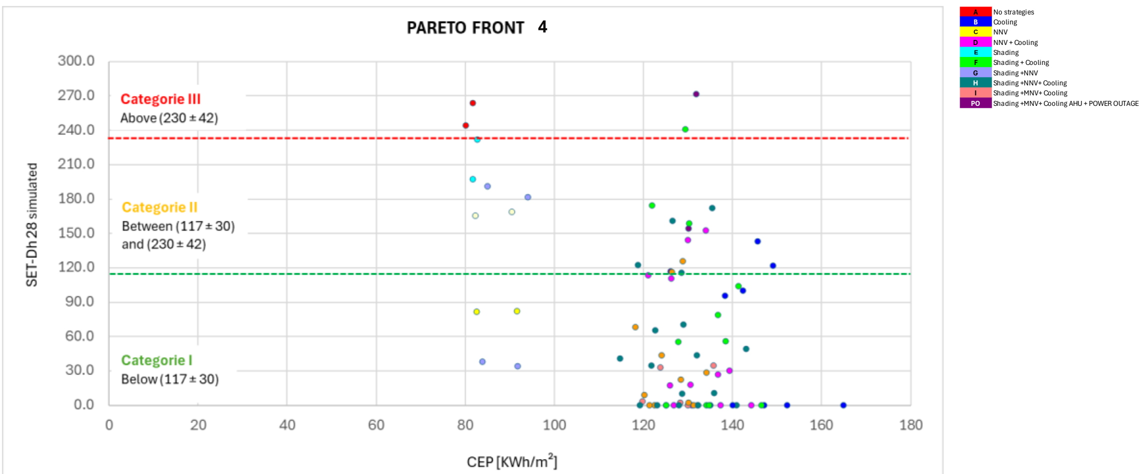
Thermal resilience index : SET-Dh 28



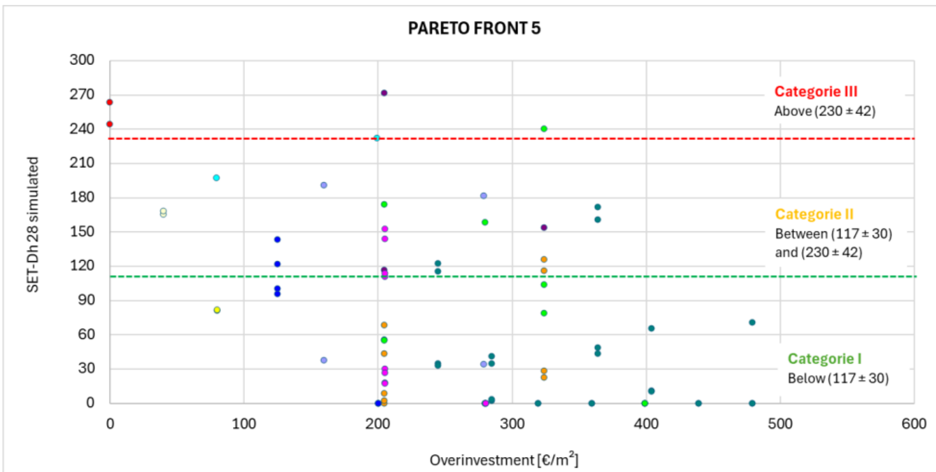
Thermal resilience index : SET-Dh 28



Appendix - Question

What is the **right price to pay today** to ensure comfort and resilience tomorrow?

Overinvestment

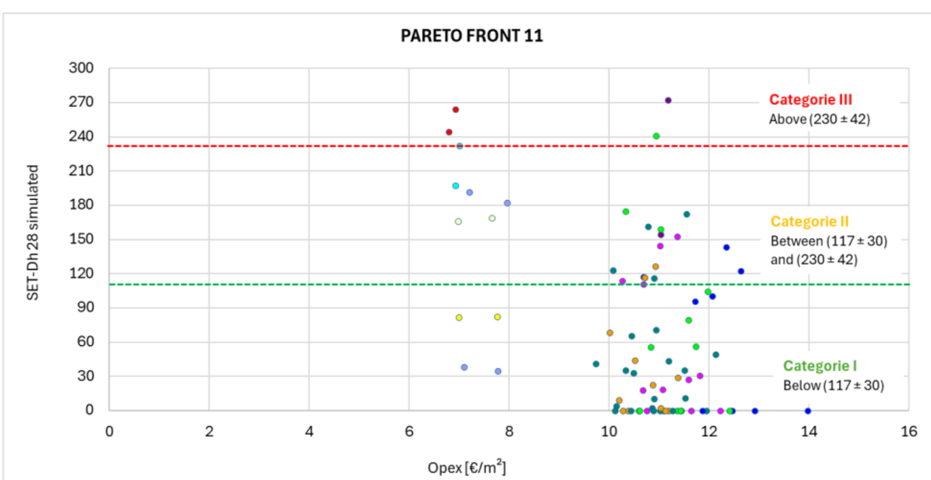


A	No strategies
B	Cooling
C	NNV
D	NNV + Cooling
E	Shading
F	Shading + Cooling
G	Shading +NNV
H	Shading +NNV+ Cooling
I	Shading +MNV+ Cooling
PO	Shading +MNV+ Cooling AHU + POWER OUTAGE

Important Notes:

- The **additional costs** for passive and active measures are **based on current conditions** but reflect future climate scenarios.
- **Exclusions:** These estimates do not account for inflation or Life Cycle Costs (LCC).
- **Preliminary forecast**: Figures are indicative and require further refinement

Opex



A	No strategies
B	Cooling
C	NNV
D	NNV + Cooling
E	Shading
F	Shading + Cooling
G	Shading +NNV
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PO	Shading +MNV+ Cooling AHU + POWER OUTAGE

Important Notes:

- **Costs** are **based on current conditions** but reflect future climate scenarios.
- **Exclusions:** These estimates do not account for inflation or Life Cycle Costs (LCC).
- **Preliminary forecast**: Figures are indicative and require further refinement

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Conclusion

According to the analysis:

- Ensuring comfort with HWs requires doubling the installed cooling capacity
- Implementing exterior solar shading is relevant for enhancing resilience
- Passive strategies alone are not sufficient to achieve good thermal comfort. **Combining passive strategies with active systems is essential**
- Cross natural ventilation allows to have the best comfort at lowest CEP but is not applicable everywhere
- Room and window sizes significantly influence heating and cooling demands
- A minimum additional investment of 200 €/m² is required to effectively mitigate overheating risks.

Notes:

- **Worst-case scenario** of offices facing south and southwest on the top floor
- 25 combinations x 2 HW weather data x 2 offices = **only 100 cases**
- The data set is limited and needs to be extended to other types
- **Preliminary Forecast**