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A novel indicator to assess thermal resilience of buildings to overheating

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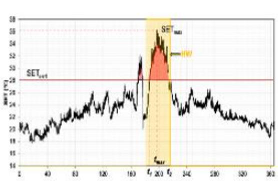
How was the indicator defined?

1 *doS* / *Building type* / *Thermal mass* → Defining the decision tree for regression model development

2 *Occupant density* / *Occupancy profile* / *Internal gains* → Define the parameters and their ranges to be assessed

3 Thermal resilience assessment



4 *Regression model for each doS, building type, thermal mass* → Development of thermal resilience indicator (TRI_{SET-Dh})

5 *Compare simulation cases and statistical tests to predict accuracy of the indicator* → Evaluate the performance of the developed thermal resilience indicator

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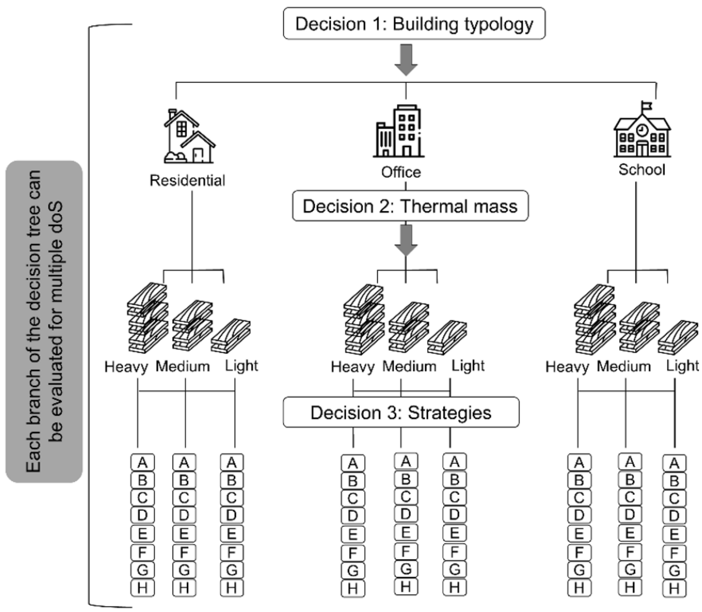
1 Decision tree

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

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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

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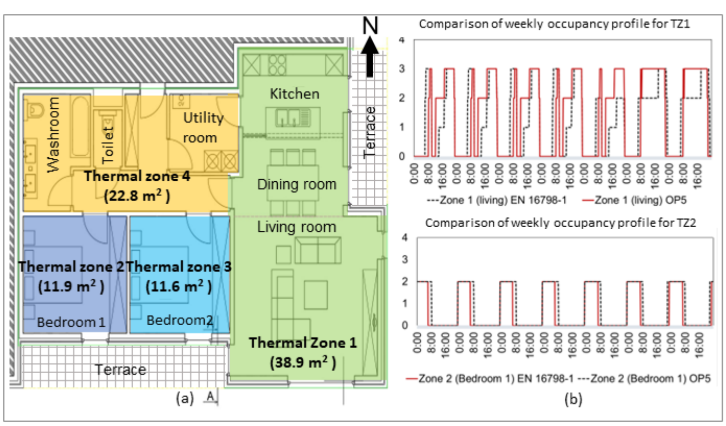
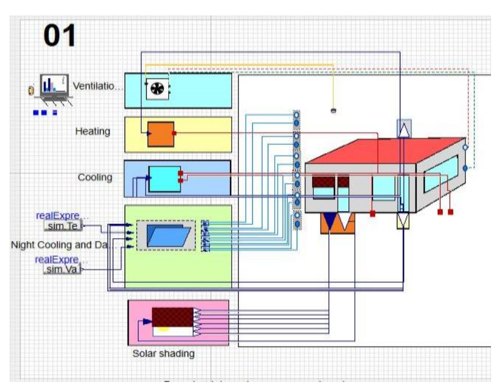
2 Parameters + ranges (continued)

Parameters		Office	Residential	School
Parameters that vary for each building typology	Occupant density (m^2/pers)	10	28.3	5.4
	Occupancy profile	9h-18h Weekdays	24*7 (at least 1 occupant during daytime)	8h-17h Weekdays
	Ventilation rate (m^3/h) per person	30-54	30	30-54
	Internal gains-appliances (W/m^2)	12	3	8

3 Thermal resilience assessment

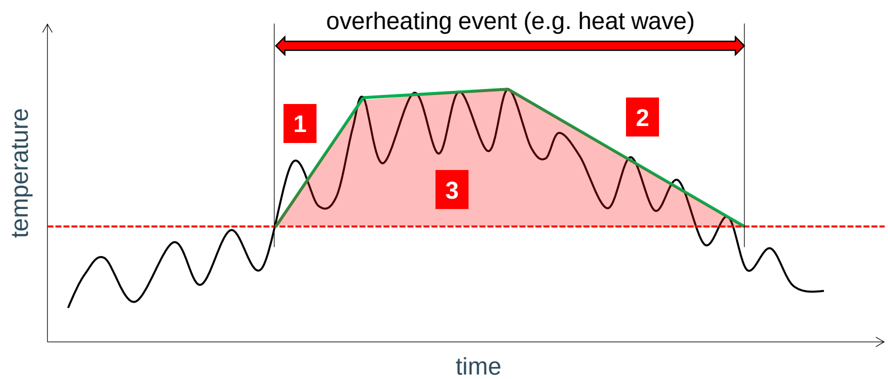
A model was developed for a Belgian reference apartment





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)

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

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)

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

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

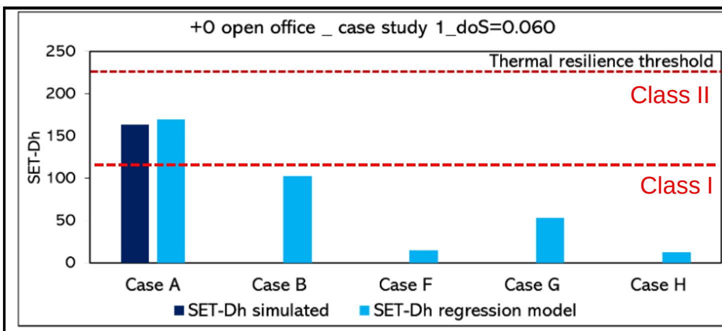
5 Testing indicator

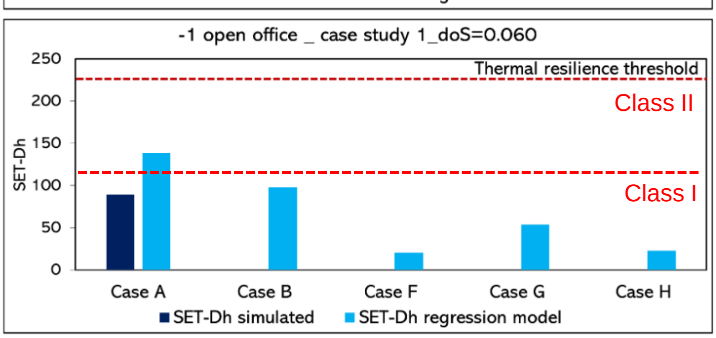
Case studies in the ReCOver++ project:

- 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

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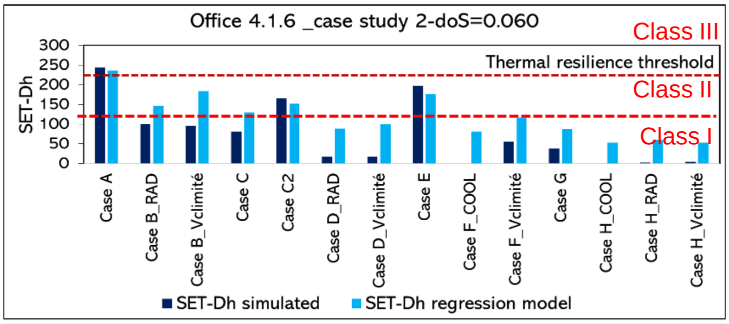

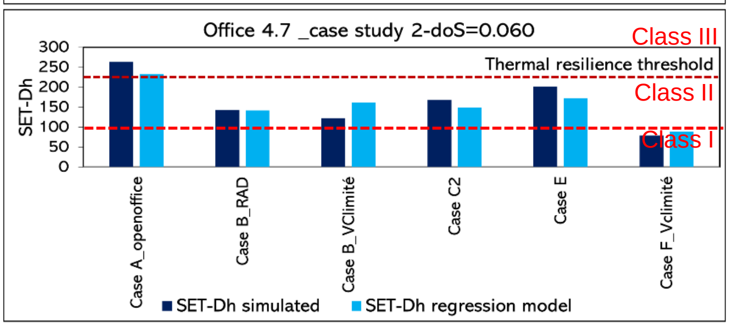

5 Testing indicator

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

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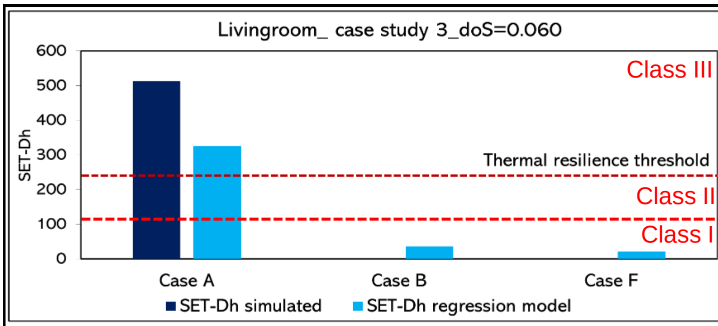

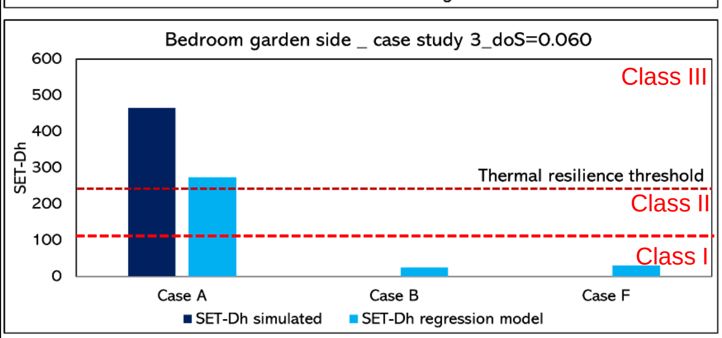

5 Testing indicator

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
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Case D	0	1	1
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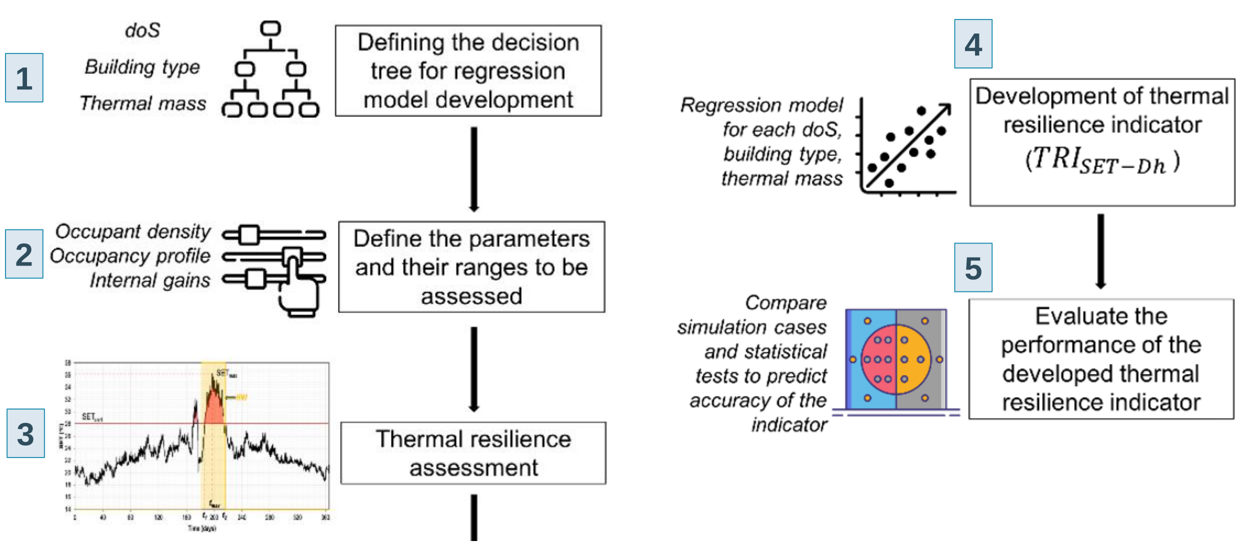
Case F	1	0	1
Case G	1	1	0
Case H	1	1	1

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!

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Thank you