KU LEUVEN

Assessment framework: thermal & IAQ resilience of buildings & systems

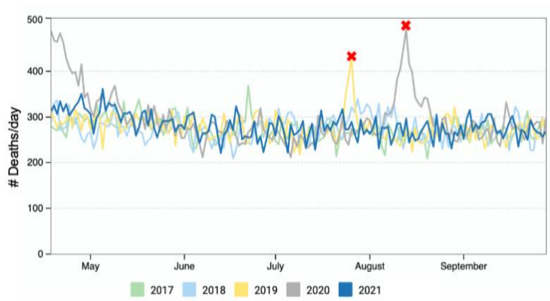
Hilde Breesch, Douaa Al Assaad, Abantika Sengupta
Department of Civil Engineering
Building Physics and Sustainable Design

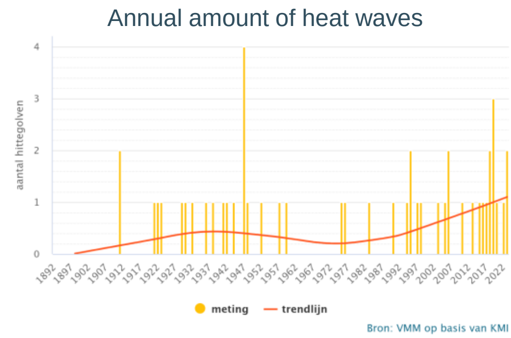
1

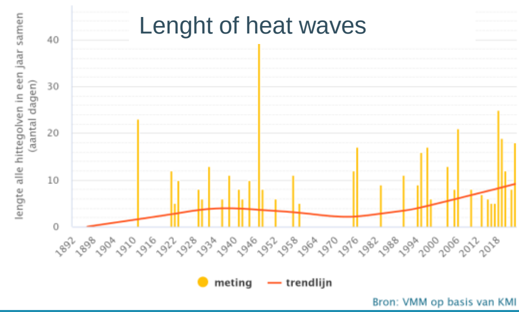
2

Challenges

- Heat waves
  - Increasing frequency and severity
  - Health impact
    - Heat stress
    - Mortality rate





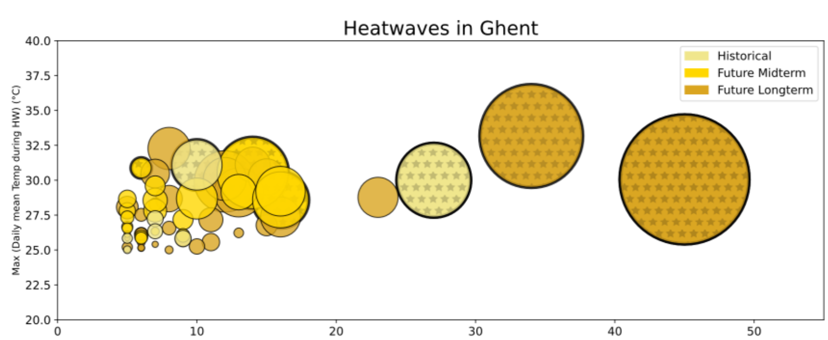


Mortality in Belgium in 2017-2021 (Source: Statbel.fgov.be)

Amount & Length of heat waves in Belgium to 2023 (Source: RMI)

Challenges

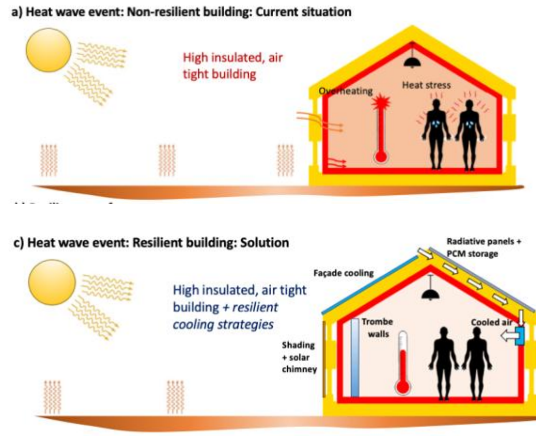
- Contempory buildings & systems vulnerable to face **disruptive events or shocks**
  - Shock = inevitable event occurring inside/outside building, or affect HVAC systems
  - Type of shocks
    - Heat waves
    - Power outages
    - Wild fires
    - …



Current and future heat waves in Belgium

Challenges

- Building's reaction to shocks
  - **Severity**: How severe is the impact of the shock on IEQ?
  - **Absorptivity**: How long can a building withstand shocks?
  - **Recovery**: How quickly can a building get back to acceptable indoor conditions?
- Need for assessment framework

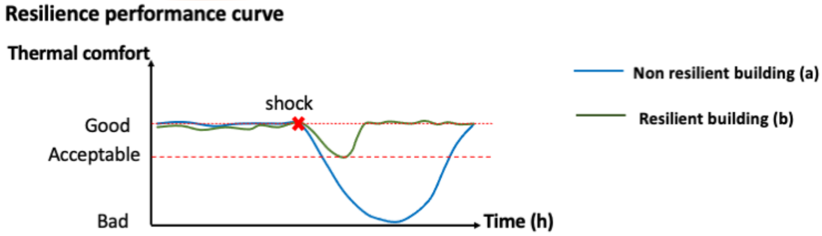


KU LEUVEN

What is resilience?

- Resilience
  - Building's ability to withstand to shocks & reduce impact on indoor environment
  - Characterized by absorptivity, recovery and severity
  - Different aspects
    - Thermal resilience
    - IAQ resilience

b) Resilience performance curve



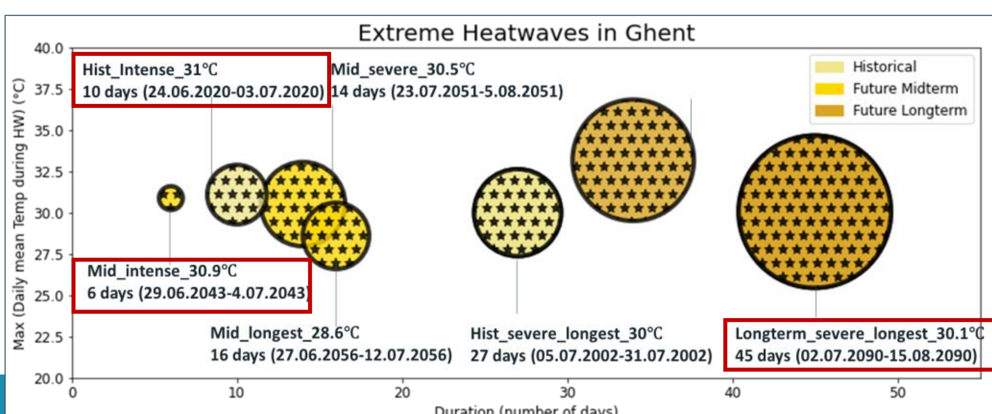
KU LEUVEN

Thermal resilience performance of buildings to overheating

PhD Abantika Sengupta

Disruptive events

- Selection of heat waves
  - Historical <> future midterm <> future longterm
  - Most intense <> severe <> longest



Quantification of disruptive events: degree of shock (doS)

- External shocks (ES)
- System shocks (SS)

$$doS = \underbrace{\frac{T_{shock} - T_{ref}}{T_{ref}}}_{Severity} \times \underbrace{\frac{t_{shock}}{t_{ref}}}_{Duration}$$

$$doES = \underbrace{\frac{T_{oa,avg,ES} - T_{oa,avg,TMY}}{T_{oa\ avg,TMY}}}_{Severity} \times \underbrace{\frac{t_{shock}}{t_{shock\_max}}}_{Duration}$$

$$doSS = \underbrace{\frac{T_{sa,avg\_shock} - T_{sa,avg\_op}}{T_{saavg\_op}}}_{Severity} \times \underbrace{\frac{t_{shock}}{t_{op}}}_{Duration}$$

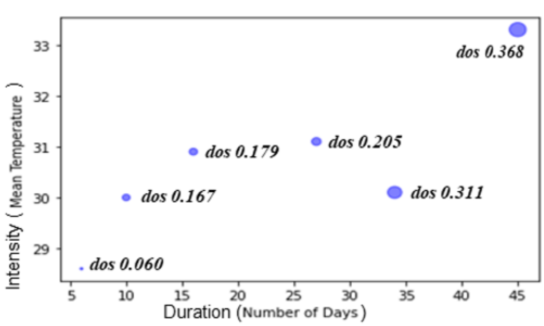
Severity= deviation from normal operation *Duration of shock normalized*

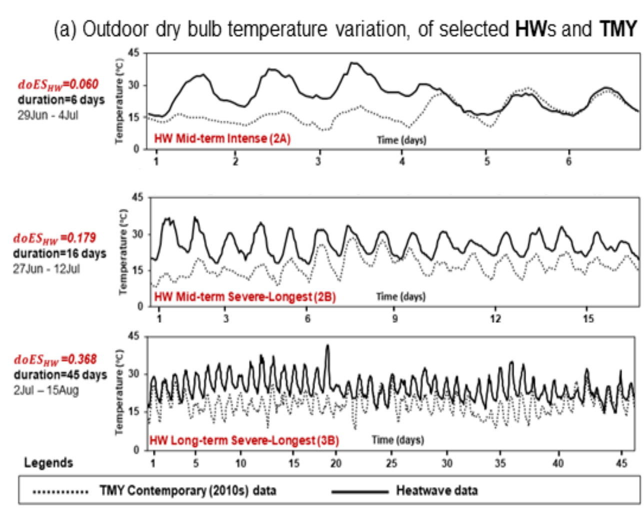
https://doi.org/10.1016/j.buildenv.2023.110152

KU LEUVEN

Quantification of disruptive events: degree of shock (doS)

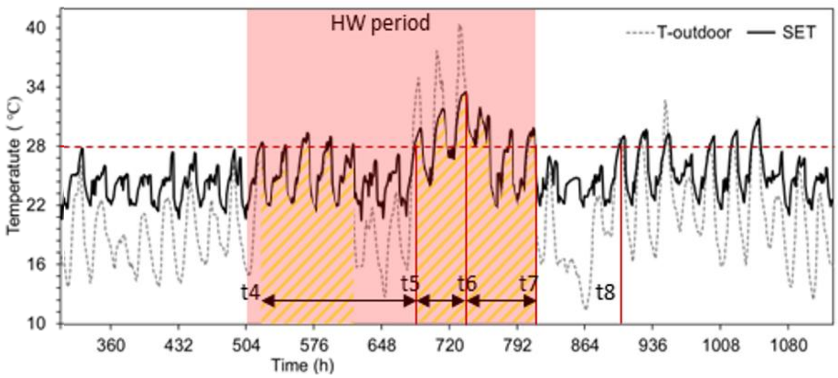
- Heat waves (BE)





KU LEUVEN

Resilience performance aspects



Absorptivity

Recovery

Degree of impact

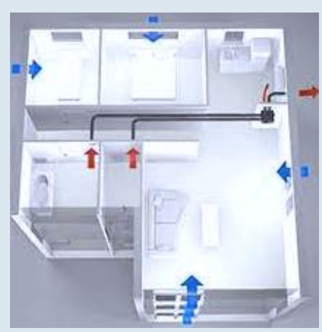
t4 = SET 28°C threshold violation before the peak SET is reached

t5-t6= Abs time during Heatwave
t6-t7= Rec time during Heatwave
t8 = SET 28°C threshold violation after the Heatwave is over

KU LEUVEN

Indoor air Quality (IAQ) resilience performance of ventilation - Quantitative assessment framework

Post-doc Douaa Al-Assaad



https://flux50smartventproject.weebly.com/

https://doi.org/10.1016/j.buildenv.2023.110669

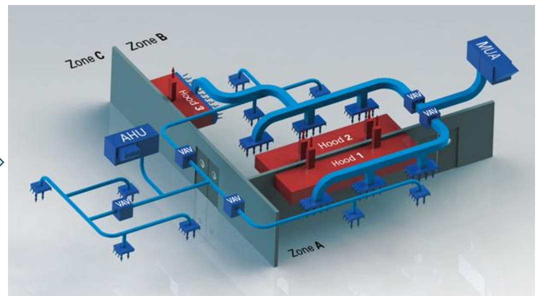
KU LEUVEN

Introduction | Resilience score | Case study | Conclusions

What is IAQ resilience performance?

Expected indoor/outdoor conditions

Good breathable air quality
Energy efficient



Unexpected disturbance Or "shock"

Reduced system performance: Indoor space shifts drastically from its **IAQ design conditions**

(-) Accumulation of contaminants

(-) Acute exposure during short duration

System needs to be resilient ←

Introduction | Resilience score | Case study | Conclusions

Disruptive Events

Mechanical disruptions

Partial or complete disruption in the operation of the ventilation system (e.g., fan failure, power outages, fouling filters)

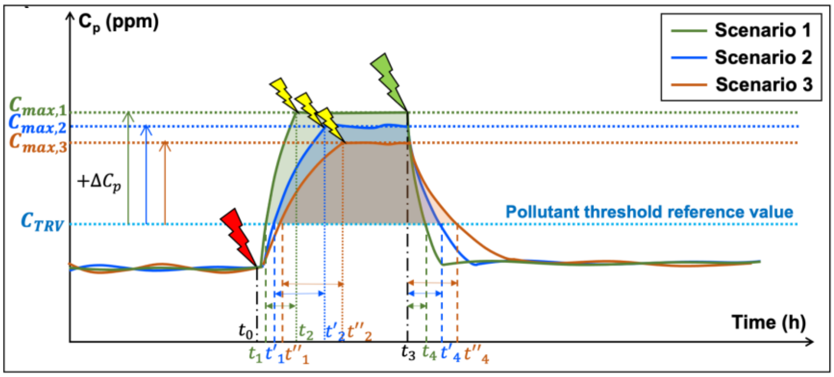
Internal disruptions

Occurs inside the space due to excessive indoor pollution event (e.g.,excess occupants beyond capacity of AHU)

External disruptions

Occurs outside the building envelope due to excessive outdoor pollution (e.g., outdoor fire, traffic jams)

Resilience performance aspects



- Absorptivity
- Recovery
- Degree of impact

Quantification of disruptive events: the degree of shock (doS)

Mechanical disruptions

$$doMS = \underbrace{\frac{\dot{Q}_{a,r}-\dot{Q}_a}{\dot{Q}_{a,r}}}_{Severity} \times \underbrace{\frac{t_s}{t_{occ}}}_{Duration}$$

degree of mechanical shock (**doMS**)

Internal disruptions

$$doIS_s = \underbrace{\frac{ER_s-ER_{s,exp}}{ER_{s,exp}}}_{Severity} \times \underbrace{\frac{t_s}{t_{occ}}}_{Duration}$$

degree of internal shock (**doIS**)

External disruptions

$$doOS_s = \underbrace{\frac{C_{s,oa}-C_{s,oa\,exp}}{C_{s,oa\,exp}}}_{Severity} \times \underbrace{\frac{t_s}{t_{occ}}}_{Duration}$$

degree of outdoor shock (**doOS**)

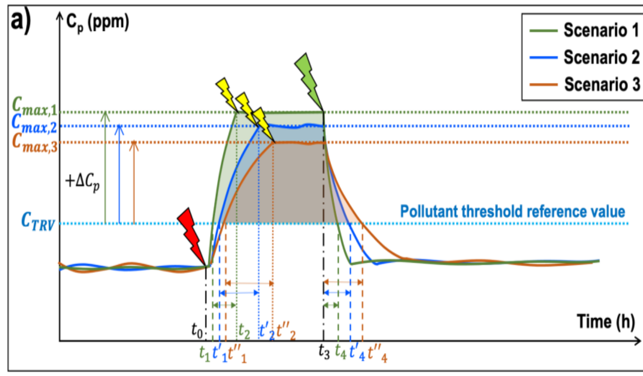
Quantification of resilience aspects

Absorptivity $\varepsilon_{abs} = \frac{\Delta t_{abs}}{t_{occ}}$

Slower absorptivity time is desired

Recovery $\varepsilon_{rec} = 1 - \frac{\Delta t_{rec}}{t_{occ}}$

Faster recovery time is desired

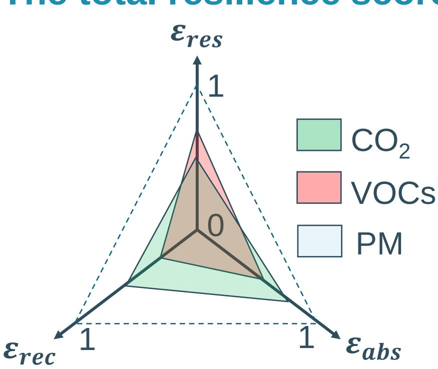


Resilience effectiveness

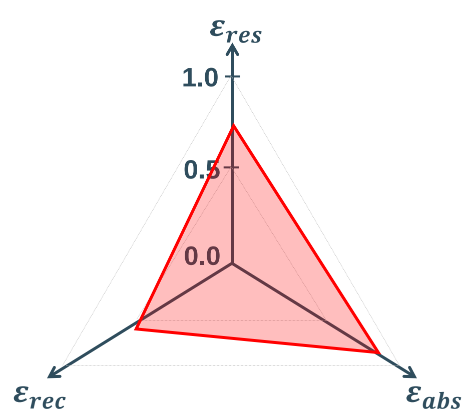
$$\varepsilon_{res} = \frac{ppm.hours_{ref} - ppm.hours_{system\ under\ shock}}{ppm.hours_{ref} - ppm.hours_{system\ normal\ operation}}$$

Higher effectiveness desired

The total resilience score



Σ



$$RS_{zone} = \frac{5}{13}\left(RS_{CO_2} + \sum \omega_i RS_i\right)$$

i = 1 to N (number of Hazardous air pollutants) **0 < RS < 1**

The total resilience score: Determining the weighting factors

Qualitative approach

Carcinogenic
Mutagenic
Reprotoxic effects
Endocrine disruptions

1 (High evidence)
to
5 (No evidence)

VOCs (Formaldehydes, acrolein, aldehydes usually found in classrooms) rank as CMRE2/ PM fine and coarse rank as CMRE1

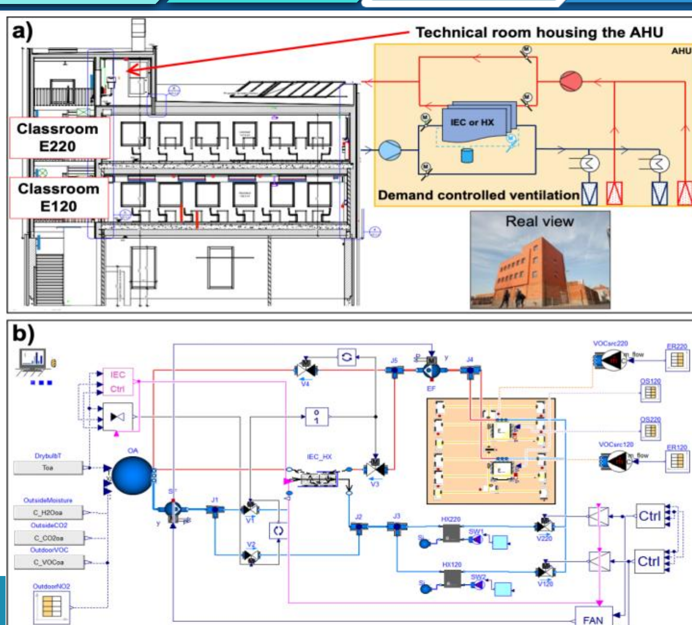
Quantitative approach: HQ: Hazard Quotient

$$HQ = \frac{Mean\ exposure\ concentration}{TRV\ (threshold\ values)}$$

$$\mathrm{HQ}_{\mathrm{mean}} \text{ or } \mathrm{HQ}_{P95} > 1$$

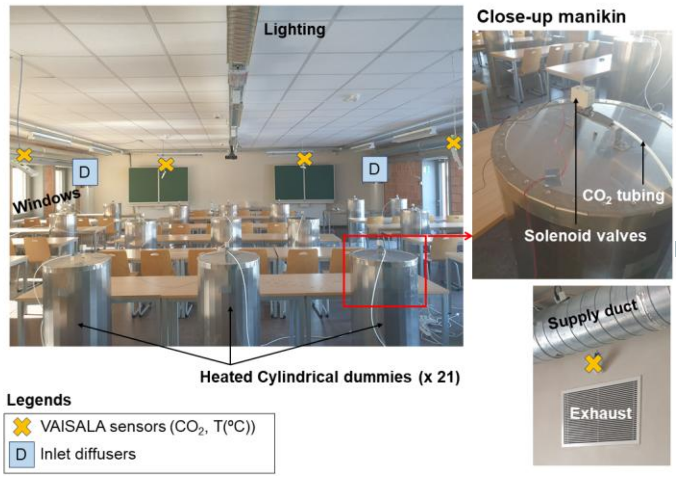
19 Sérafin, Guillaume, Patrice Blondeau, and Corinne Mandin. "Indoor air pollutant health prioritization in office buildings." *Indoor Air* 31.3 (2021): 646-659.

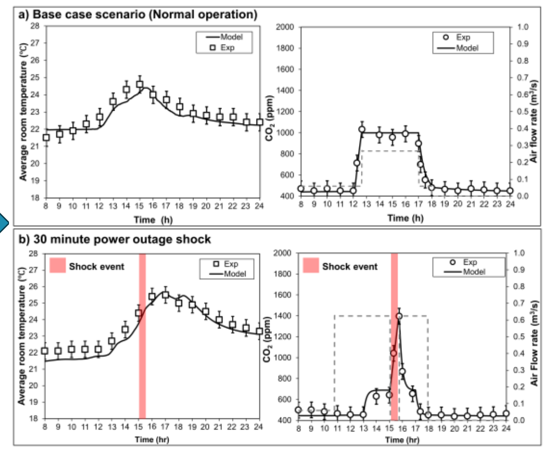
Case study



Model in Modelica, Dymola

Case study validation under normal and shock scenarios



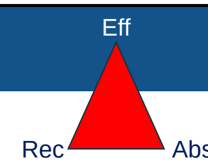


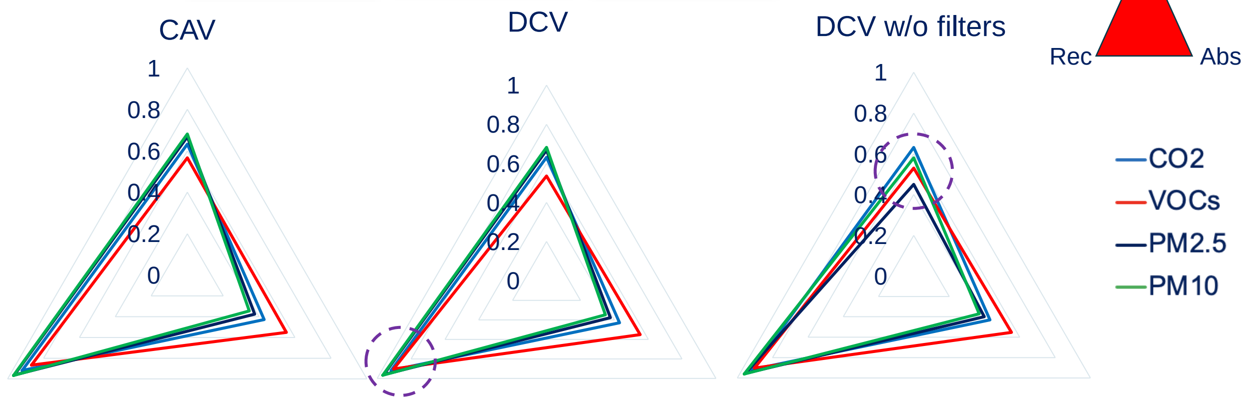
Scenarios

Demand controlled balanced mechanical ventilation (DCV)
Constant air volume system (CAV)
DCV without filters

Mechanical shock (doMS: 0 to 1)
Internal shock (doIS: 0 to 1)
Outdoor shock (doOS: 0 to 1)

Contaminants: CO_2, VOCs, $PM_{2.5}$, PM_{10}





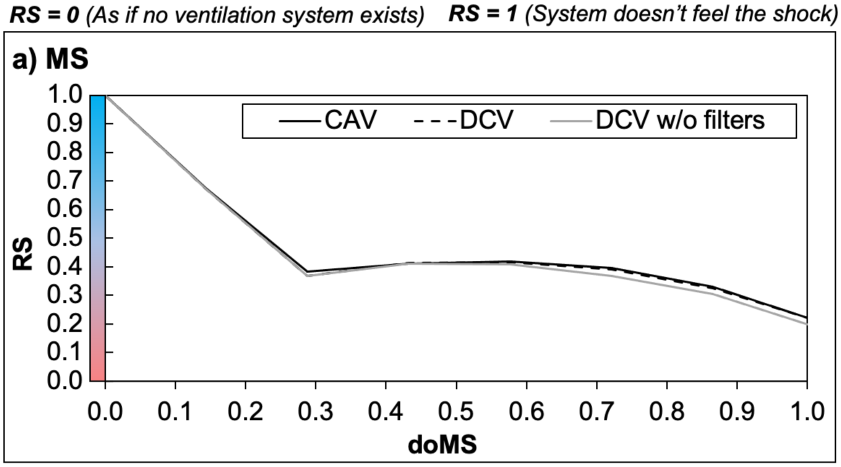
CO_2 : Same res. Effectiveness but CAV has slower gradual absorbtivity and faster recovery

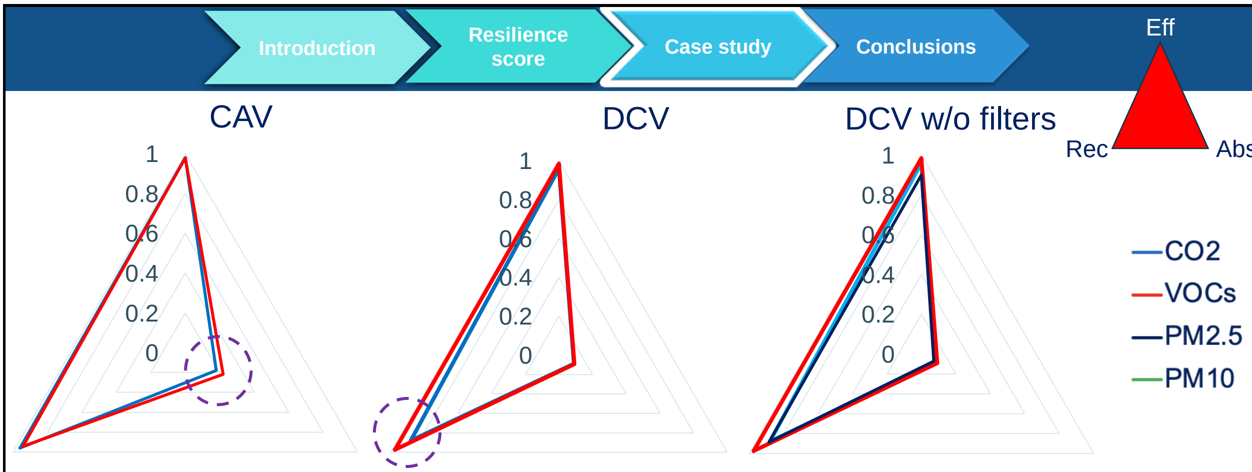
VOCs: Same Absorptivity but DCV has better recovery and CAV has better effectiveness

PM: Same Absorbtivity, Recovery and Effectiveness. DCV w/o filters has significantly lower effectiveness

Resilience score (RS): Mechanical shock (MS)

RS = 0 *(As if no ventilation system exists)* ***RS = 1*** *(System doesn't feel the shock)*





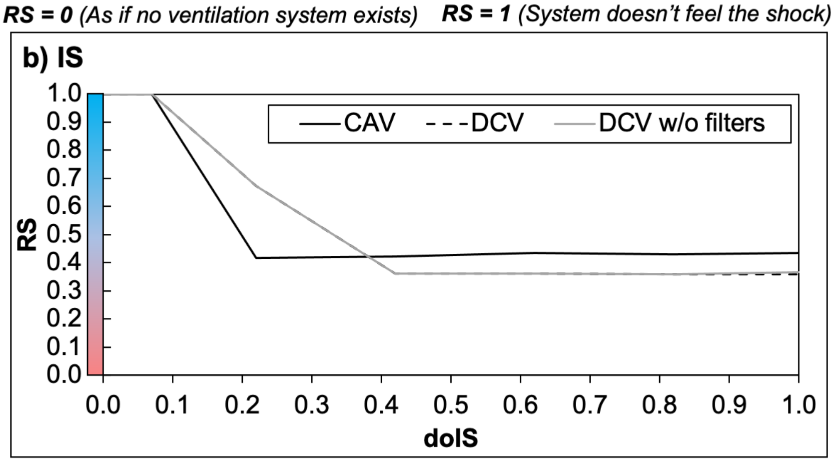
CO_2 : Same Effectiveness, but CAV has slower gradual absorbtivity and faster recovery

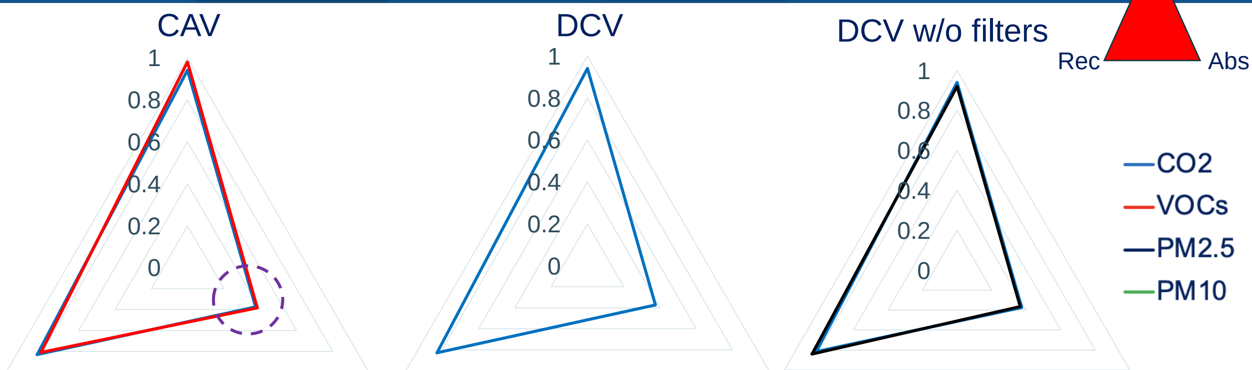
VOCs: Same Effectiveness (very high in both), CAV has significantly slower absorptivity, DCV has slightly faster recovery

PM: Only challenged at high shock intensities and for the case of DCV w/o filters

Resilience score (RS): Indoor shock (IS)

RS = 0 *(As if no ventilation system exists)* ***RS = 1*** *(System doesn't feel the shock)*





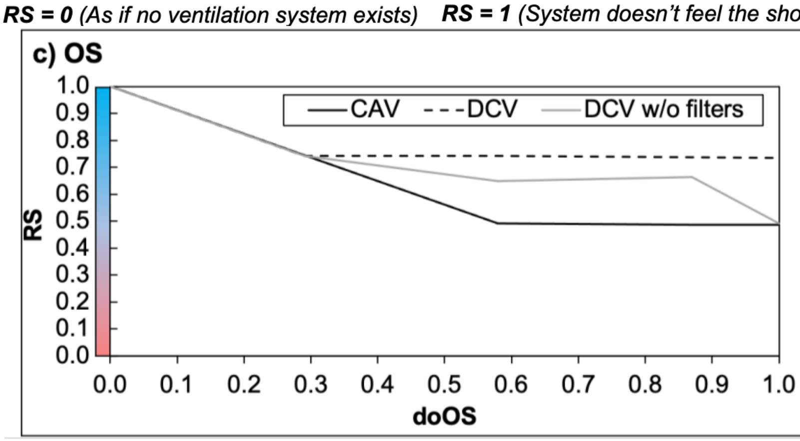
CO_2 : Same Effectiveness, but CAV has slower gradual absorbtivity and faster recovery

VOCs: DCV wasn't challenged for VOCs

PM: Only challenged at mid-shock intensities and for the case of DCV w/o filters

Resilience score (RS): Outdoor shock (OS)

RS = 0 *(As if no ventilation system exists)* ***RS = 1*** *(System doesn't feel the shock)*



Conclusions

- **Resilience score** for **IAQ resilience** assessment was developed
- **Smart** vs **Conventional** ventilation **IAQ resilience** during **disruptive events**:
  - Mechanical shocks: Smart **=** Conventional
  - Internal shocks: Smart **<** Conventional
  - Outdoor shocks: Smart **>** Conventional
- **Filters**: No pronounced effect in the case of Mechanical and Internal shocks but more so in Outdoor shocks
- Framework should be tested for more case studies (residential, offices) and more systems (mechanical extract, natural ventilation, personalized systems, other smart control strategies, etc.)

To conclude

Summary

- Resilience = answer how buildings react to shocks
  - Thermal resilience to overheating
  - IAQ resilience
- Resilience aspects
  - Shocks: defined + quantified
  - Indicator & score: defined for IAQ resilience
  - Most influential parameters: thermal resilience
- Next steps
  - Indicator & score thermal resilience
  - Upscaling: other building typologies & climates
  - Combined thermal & IAQ resilience

KU LEUVEN