KU LEUVEN GENT

AIVC Workshop "Climate Change, Ventilation and Resilience", Madrid, 2026

Power outage profiles generation to assess thermal and indoor air quality resilience

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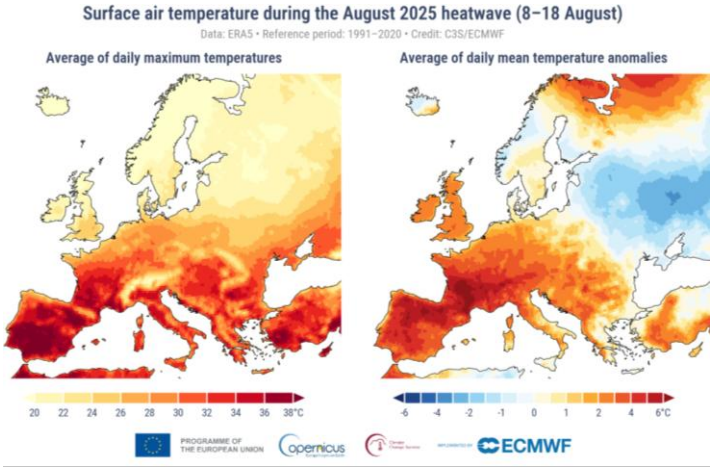
BACKGROUND

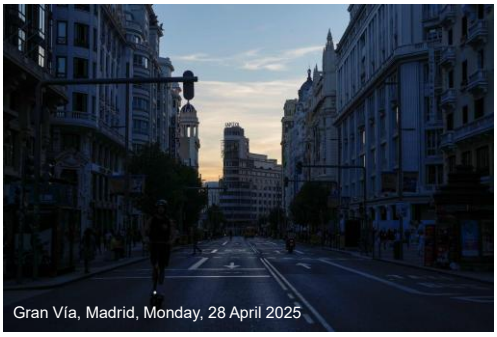


Heatwaves(HW) in Europe have become more frequent and intense：

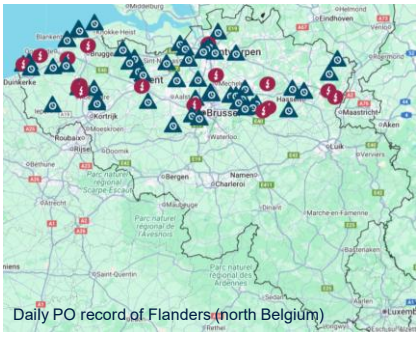
- Europe came across multiple HW events from **April** to **September** 2025.
- Maximum temperature in both Portugal and Spain broke **46 °C** [1].
- The 2025 European heatwaves caused over **24,000** heat-related deaths [2].

[1]https://www.theguardian.com/environment/2025/jun/30/spain-records-highs-of-46c-and-france-under-alert-as-europe-swelters-in-heatwave
[2]https://www.euronews.com/2025/09/17/silent-killer-climate-change-led-to-16500-more-heat-deaths-in-europe-this-summer-study-say

BACKGROUND



Gran Vía, Madrid, Monday, 28 April 2025



Daily PO record of Flanders (north Belgium)

- AC adoption in Europe is estimated to rise from 20% today to **35%** by 2030 [1], with total units expected to more than **double** by 2050 [2]. Over **40%** of households have AC in Spain [3].
- PO is more frequent and more chanllenging than expected. Belgium is estimated to have over **3,000** individual PO events last summer based on PO data provided by local grid operator

[1] https://energy-efficient-products.ec.europa.eu/product-list/air-conditioners-and-comfort-fans_en
[2] https://www.iea.org/reports/the-future-of-cooling
[3] https://www.idealista.com/en/news/property-for-sale-in-spain/2024/07/30/818081-41-of-the-housing-stock-in-spain-has-air-conditioning

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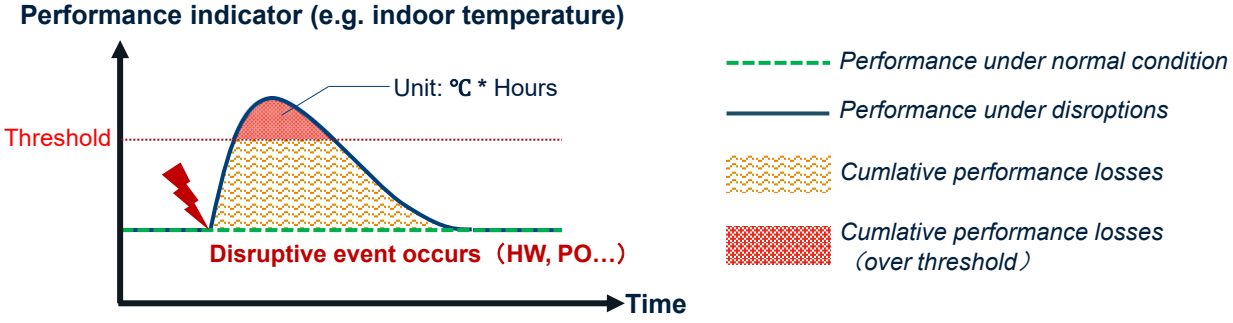
BACKGROUND

In general, **resilience** refers to a system's capacity to absorb disturbances, sustain its critical functions under stress, and recover efficiently from disruption with acceptable losses in performance, time, cost, and risk.



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GAP & AIM

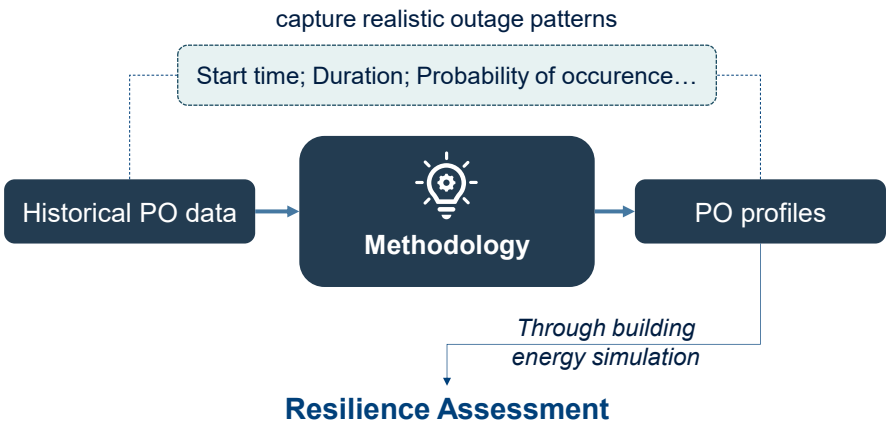
- **There is no methodology to quantify PO events in current studies.**
  e.g. some studies on resilience:
  - Sheng et al. [1] assumed the PO to have the **exact start and end time** as the extreme weather (duration: over **multiple days**）
  - Sengupta et al. [2] assumed a **24-hour** PO to occur on the exact **hottest day.**
  - Al-Assaad et al. [3] assumed a **1-hour** PO during HW refering to historical PO data.
  - …

Worst cast scenario lack of data-basis;
Limited use of the PO data(lack of probaility estimation)

[1]M. Sheng, M. Reiner, K. Sun, and T. Hong, Assessing thermal resilience of an assisted living facility during heat waves and cold snaps with power outages
[2] A. Sengupta et al. Evaluation of thermal resilience to overheating for an educational building in future heatwave scenarios.
[3] D. Al Assaad et al. Demand-controlled ventilation in educational buildings: Energy efficient but is it resilient

GAP & AIM

- **AIM:** To develop a methodology that generates PO profiles from historical data.



METHODOLOGY

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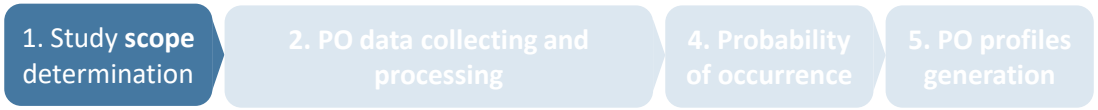
METHODOLOGY



Target building

The building that we would like to study its resilience under POs

The “scope ”is geographical area covering the target building, referred to as the **spatial boundary** (**SB**)

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METHODOLOGY

1. Study scope determination | 2. PO data collecting and processing | 4. Probability of occurrence | 5. PO profiles generation

Target building

Spatial boundary(SB)

Extreme example: the SB include **only** the Target building

SB is too small :

Local PO data is more representative for the target building. However, require **more data in temporal dimension** to create the profiles.

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METHODOLOGY

1. Study scope determination | 2. PO data collecting and processing | 4. Probability of occurrence | 5. PO profiles generation

Target building

Spatial boundary(SB)

PO occurs in another city

SB is too big :

Local PO data has higher variety in spatial distribution and is **less representative for target building.**

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METHODOLOGY

1. Study scope determination → 2. PO data collecting and processing → 4. Probability of occurrence → 5. PO profiles generation

Target building

Spatial boundary(SB)

Rule of Thumb：Same grid, no bigger than one administrative region

SB should :

be set at an appropriate size to **represent the local situation** around the target building, also comply with the **data availability**.

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METHODOLOGY

1. Study scope determination → **2. PO data collecting and processing** → 4. Probability of occurrence → 5. PO profiles generation

Example of the PO dataset

Start date (yyyy-mm-dd)	Start time (hh-mm)	Duration (hours)	Impact users ($n_{impacted\ users}$)	Location
2024-06-17	08:30	2.5	1,500	xx street…
2024-06-18	07:45	3.2	4,800	xx street…
…	…	…	…	…

Within ***SB*** or not ?

- Remove the entries occurs outside the SB

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METHODOLOGY

1. Study scope determination → **2. PO data collecting and processing** → **4. Probability of occurrence** → 5. PO profiles generation

Example of the PO dataset

Start date (yyyy-mm-dd)	Start time (hh-mm)	Duration (hours)	Impact users ($n_{impacted\ users}$)	P_{PO}
2024-06-17	08:30	2.5	1,500	**0.005**
2024-06-18	07:45	3.2	4,800	**0.016**
…	…	…	…	**…**

*e.g. There are **300,000** electricity users inside SB; a single PO impacted **1,500** users; we can assume there is a probability of **1,500/300,000 = 0.005**, that this PO impact the target building*

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METHODOLOGY

1. Study scope determination → **2. PO data collecting and processing** → **4. Probability of occurrence** → **5. PO profiles generation**

*PO profile generation through **Monte Carlo Sampling** (MCS)*

Start date	Start time	Duration	Impact users	P_{PO}	$Rand$	$\leq P_{PO}$?
				0.005	**0.241**	**FALSE**
				0.016	**0.012**	**TRUE**
				…	**…**	

- A column of **random** rational numbers between 0 and 1 is generated;
- If the $Rand \leq P_{PO}$, this PO is considered **to occurs and affect the target building**
- All the PO entries labeled "**TRUE**" are selected to combine a "***Profile***"

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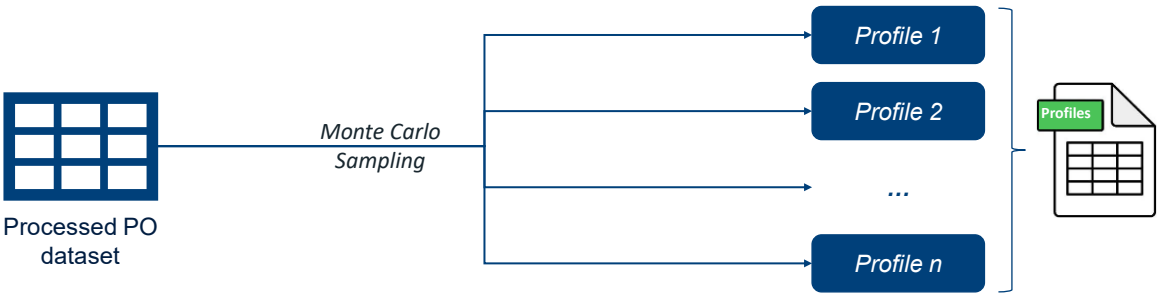
METHODOLOGY

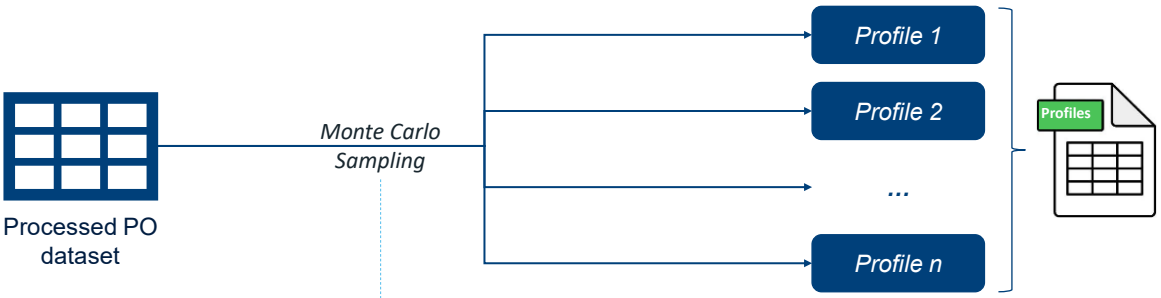
Profiles may contain no PO at all. (Blank profile)



PO dataset:
- Atucal collected historical PO records;
- **One timeline only**;
- The timeline records all POs within SB.

PO profiles:
- Generated based on PO dataset;
- Each profile is an **individual possible scenario**, with an **individual timeline**.
- In each profile, the timeline only contains the PO that impact the **Target building**

METHODOLOGY



When to stop ?

Consider the computational cost (not only for MCS, but also for Building Simulation)

CASE STUDY

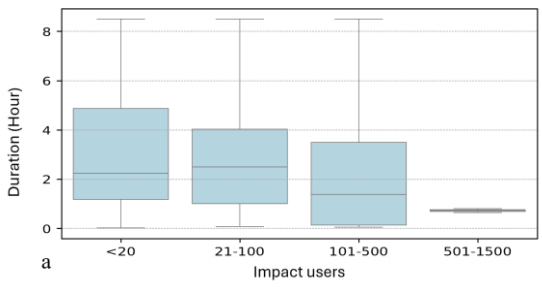
Ghent, capital city of the East Flanders, Belgium

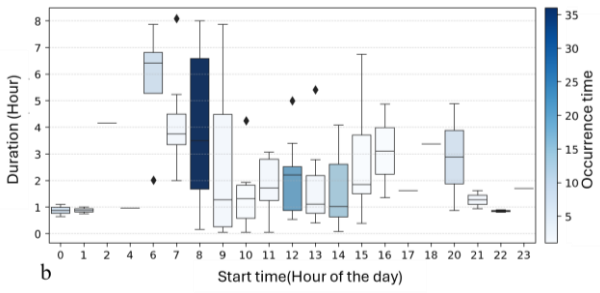
Lecture room in KU Leuven, Ghent campus

- **Fluvius** is the sole grid network operator in Ghent, holding a 100% market share (legal monopoly in Flanders).
- **Fluvius** provides daily updated PO data.

CASE STUDY

- PO **dataset** is manually collected from **Fluvius** on daily basis (on going)
- Data from **June 2024 to October 2024** is used to generate the PO profiles

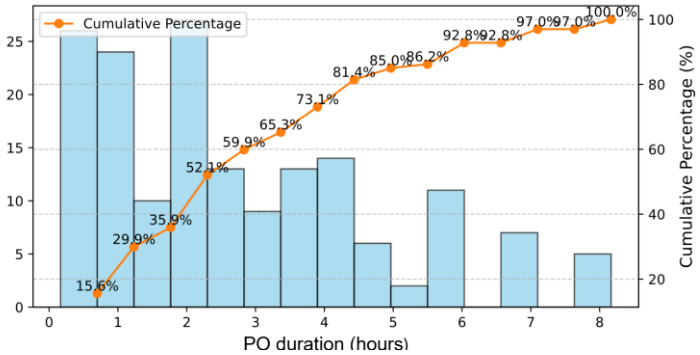




Collected historical PO data distribution on (a) Duration and Impact users, (b) Duration and start time

CASE STUDY

- 2,000 prifles were generated, 200 of them contain at least one PO.
- 163 profiles were chosen for these POs overlaps the HVAC schedule.

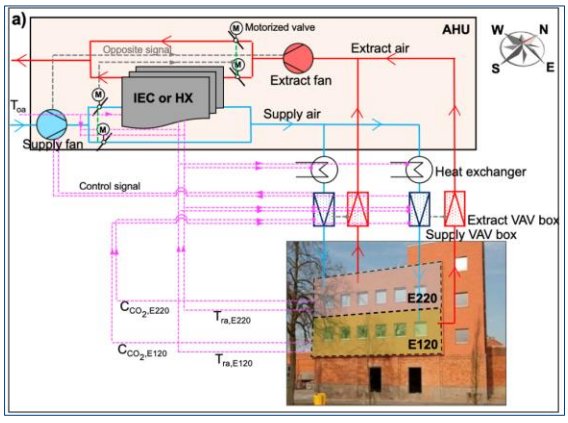


Histogram of the selected PO profiles (total 163)

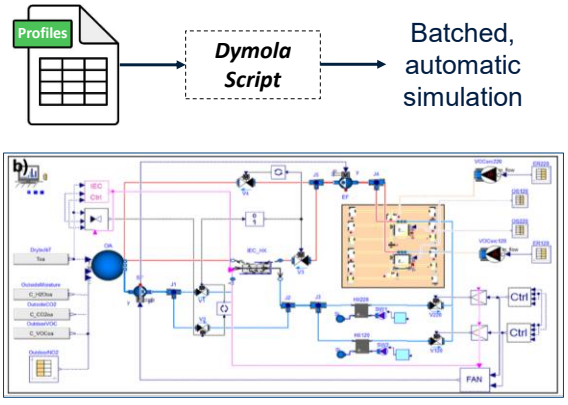
- POs with duration **less than 3 hours** takes up **60%**;
- POs with duration **less than 6 hours** takes up **92%**;
- PO that last **over 8 hours** is **extremely rare** based on the collected data.

CASE STUDY

- The dymola model is validated by previous works [1].



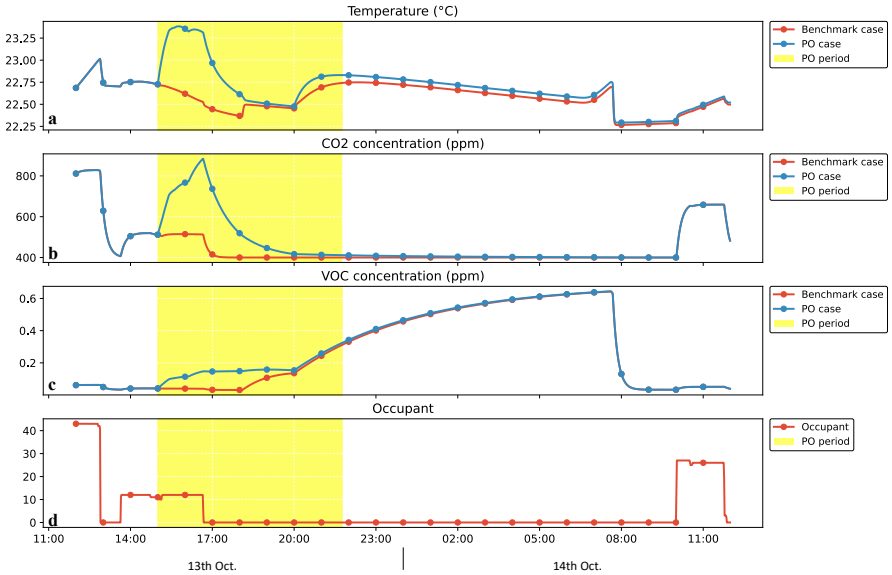
Schematic of the test lecture room building consisting of classrooms E120, **E220** and the associated AHU



Associated Dymola model for the case study

[1] A. Sengupta, D. A. Assaad, J. B. Bastero, M. Steeman, and H. Breesch, "Impact of heatwaves and system shocks on a nearly zero energy educational building: Is it resilient to overheating?,"

RESULT



Sample outputs of building performance simulation (Dymola) in terms of (**a**) Operative Temperature (**b**) CO_2 concentration (**c**) VOC concentration and (**d**) Occupants

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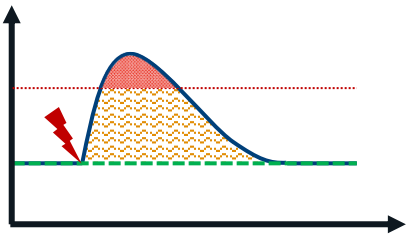
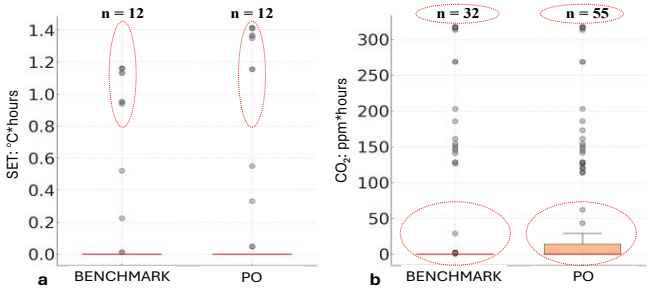
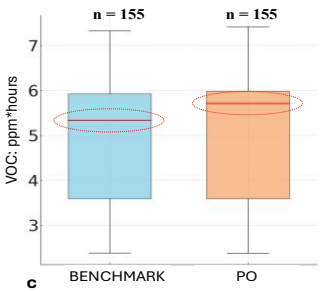
RESULT





Threshold:
SET: 26.7 °C
CO_2 : 950 ppm
VOCs: 0.049 ppm



Distribution of the 163 simulation runs (bench+PO) in terms of

Cumlative performance losses(over threshold)

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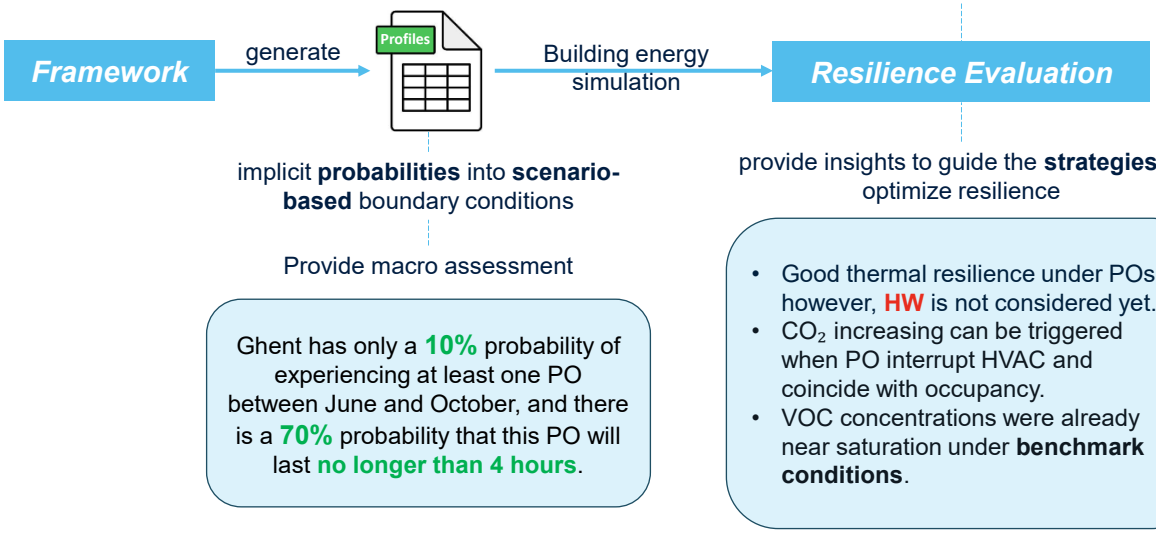
DISCUSSION

- The overall PO risk for this case study is extremely **Low**: only **8%** (June-October).
- IAQ resilience differs in terms of KPI:
  - CO_2 concentration is highly sensitive to PO **timing and duration**: significant rising occurs only when outages are long enough and overlap with occupancy.
  - For VOC, PO acts as a systematic amplifying factor, highlighing the limited effectiveness of ventilation and the need to prioritize **source control**.
- Strong thermal resilience under PO alone, however the **combined impact of HW and PO** still need further research.

CONCLUSION



CONCLUSION

Limitations

- Data acquisition challenge
- How to set Spatial Boundary
- Uncertainty in MCS

Future work

- To include external factors
- To refine and optimize the methodology
- To apply this framework under PO+HW

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