Thermal Resilient Buildings: How to be Quantified?

A Novel Approach

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In general, buildings are designed based on a group of fixed assumptions and conditions in the design or renovation phases.

Building performance (including energy and comfort) can be affected by a wide range of foreseen and unforeseen changes during operation.
Buildings as facilities with significant investment costs should be able to react to these changes and maintain their performance and functionality.

Recently, attention is being paid to the concept of resilience, which involves "low probability high-impact scenarios".

Buildings as facilities with significant investment costs should be able to react to these changes and maintain their performance and functionality.

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The report of Intergovernmental Panel on Climate Change (IPCC) shows that the severity and frequency of extreme events, such as natural disasters, are expected to increase in the following years because of climate change.

A recent example is the record of low temperatures during the 2021 winter in Texas, US. The low temperatures were followed first by snow and then by the blackouts, leaving millions of people without access to electricity during the COVID-19 pandemic.

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Categories of disruptive events

Disruptive events

Natural disruptions

Meteorological
- Windstorms
- Snowstorms
- ...

Hydrological
- Floods
- ...

Geophysical
- Earthquake
- Volcano
- Landslides
- ...

Climatological
- Heat waves
- Cold waves
- ...

Biological
- Pandemic
- ...

Technological disruptions

General failure
- Power failure
- ...

Specific failure
- System failure
- ...

The building is defined to be resilient if it is able to prepare for, absorb, adapt to and recover from the disruptive event.

Resilient buildings

Multi-phase resilience curve associated to an event
First paper – cooling events

Quantify the thermal resilience of the building based on the deviation from target

- Developing a multi-phase test framework for building thermal resilience quantification,
- Quantifying the overall thermal resilience for multi-zone buildings,
- Labeling the building thermal resilience.

Multi-phase resilience curve

Initial state
- Operation based on the set point temperature before the disruption.

Phase I
- Between the initiation and the end of the disruptive event (decrease in the indoor operative temperature)

Phase II
- Starts after the end of the disruptive event and lasts until the building reaches to the same performance level in initial state. (Increase in the indoor operative temperature)

Final state
- Starts after the full recovery of the building (Operation based on the set point temperature).

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Resilience test framework

➢ In developing the test framework, Three factors should be considered:

- Type of the event
- The occurrence time
- Fixed duration event
- Same time duration for phase II
- The range of different performance levels

➢ The phase of the event
➢ The hazard level of the event
➢ The exposure time to the event

Calculation of WUMTP: weighted unmet thermal performance

- The application of two phases, three hazard levels and two exposure time sections results in 12 segments in the resilience test framework,
- Three penalty types are needed to be considered for each segment: phase penalty, hazard penalty, and exposure time penalty.

\[ W_{UMTP} = \sum_{i=1}^{12} S_i W_{P,i} W_{H,i} W_{E,i} \]

➢ \( S_i \): Area of segment i during occupancy hours
➢ \( W_{P,i} \): Phase penalty
➢ \( W_{H,i} \): Hazard penalty
➢ \( W_{E,i} \): Exposure time penalty

\[ W_{UMTP_{overall}} = \frac{\sum_{z=1}^{Z} W_{UMTP_z}}{\sum_{z=1}^{Z} A_z} \]

\[ IOD = \frac{\sum_{z=1}^{Z} S_{H(z)} (T_{MIN} - T_{MIN}) + T_{FLUX}}{\sum_{z=1}^{Z} S_{H(z)} T_{MIN}} \]

➢ \( z \): Building zone counter \( W_{P,i} \) : phase penalty
➢ \( Z \): Total number of zones
➢ \( A_z \): Area of each zone

The assigned values for each penalty are based on the logical assumptions that have been made by authors.
Resilience labelling

➢ In order to rate a building in a specific resilience class, the same approach as energy labelling is used.

\[ RCI = \frac{WUMTP_{overall,ref}}{WUMTP_{overall}} \]

Table 2

<table>
<thead>
<tr>
<th>Resilience class for buildings labelling.</th>
<th>Class A'</th>
<th>Class A</th>
<th>Class B</th>
<th>Class C</th>
<th>Class D</th>
<th>Class E</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCI</td>
<td>≥ 3.6</td>
<td>≥ 2.4</td>
<td>≥ 1.5</td>
<td>≥ 0.9</td>
<td>≥ 0.6</td>
<td></td>
</tr>
</tbody>
</table>

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Example of the results

Case study

Establishing the test framework for case study building: four-day test framework

➢ Four days power failure.
➢ During the four days with the highest heating demand (starting on 14 January).
➢ The duration of power failure was specified based on iterative simulations.
➢ Based on the literature 18 °C and 15 °C have been selected as the robustness and habitability thresholds for the living room.
➢ It has been assumed that easy exposure section will last one, two, and three hours in the uninhabitable, habitable, and acceptable levels.

Three performance thresholds for different zones of the case study building.

<table>
<thead>
<tr>
<th>Performance level</th>
<th>Zones</th>
<th>Living room</th>
<th>Bedroom</th>
<th>Bathroom</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{min} ) (°C)</td>
<td>21.5</td>
<td>18</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>( T_{max} ) (°C)</td>
<td>18</td>
<td>14.5</td>
<td>19.5</td>
<td></td>
</tr>
<tr>
<td>( T_{set} ) (°C)</td>
<td>15</td>
<td>11.5</td>
<td>16.5</td>
<td></td>
</tr>
</tbody>
</table>

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Example of the results
Results- Battery storage influence

➢ In the standard design, the implementation of the cost-effective battery postpones the power failure for 15 h (increase in the minimum temperature from 11 °C to 12 °C).
➢ The application of the cost-effective battery did not shift the resilience curve of the standard design out of the uninhabitable level.
➢ For the passive design, the application of the cost-effective battery leads to a 13-hour delay in the power failure, which increased the minimum experienced temperature from 15°C to 15.7°C.

Example of the results
Results- PV system influence

➢ In this case, the generated electricity by the PV systems was assumed to be directly used for heating during the power failure and it will not be used any more after the power connection.
➢ Only the electricity generation in the dark grey area was used by the building in the simulation.
➢ Both standard and passive designs faced peak temperatures on 15 January.
➢ The application of the PV system for the standard design increased the minimum experienced temperature from 11°C to 12.5°C, without moving the resilience curve from uninhabitable level.
➢ For the passive design, the minimum experienced temperature increased from 15°C to 16.5°C.
Example of the results
Quantification of WUMTP and resilience labeling

➢ The upgrade of the standard design to the passive design decreased the $W_{UMT_Poveral}$ by 80 degree-hours.
➢ If the building is less resilient, the improvements will be more significant.
➢ Adding the battery to the standard design does not changing the resilience class of the standard design.
➢ With the application of the PV systems, the resilience class of the standard design will be upgraded from class C to class B.
➢ Passive standards by itself is in resilience class A, and the application of the battery and PV systems moved the passive design to class A*.
➢ The maximum resilience class improvement occurred when the design changed from standard to passive equipped with PV panels.

Second paper – warm events

Topic: Resilience and Climate Change

The Impact of Building Retrofitting on Thermal Resilience against Power Failure: A Case of Air-conditioned House

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Keywords: Thermal resilient buildings, Building envelope retrofit, Building resilience labeling, Power failure

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### The Impact of Building Retrofitting on Thermal Resilience against Power Failure: A Case of Air-conditioned House

<table>
<thead>
<tr>
<th>Design</th>
<th>WUMTP,overall [Degree hours.m⁻²]</th>
<th>Improvement [Degree hours.m⁻²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IECC update</td>
<td>6.19</td>
<td>0.67 compared to existing</td>
</tr>
<tr>
<td>IECC + ASC</td>
<td>5.95</td>
<td>0.24 compared to IECC</td>
</tr>
<tr>
<td>IECC + EC</td>
<td>3.38</td>
<td>2.81 compared to IECC</td>
</tr>
<tr>
<td>IECC + PCM</td>
<td>2.93</td>
<td>3.26 compared to IECC</td>
</tr>
<tr>
<td>Passive house update</td>
<td>5.09</td>
<td>1.77 compared to existing</td>
</tr>
<tr>
<td>Passive house + ASC</td>
<td>5.03</td>
<td>0.06 compared to Passive house</td>
</tr>
<tr>
<td>Passive house + EC</td>
<td>3.12</td>
<td>1.98 compared to Passive house</td>
</tr>
<tr>
<td>Passive house + PCM</td>
<td>2.57</td>
<td>2.52 compared to Passive house</td>
</tr>
</tbody>
</table>

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