Thermal Resilient Buildings: How to be Quantified?

A Novel Approach

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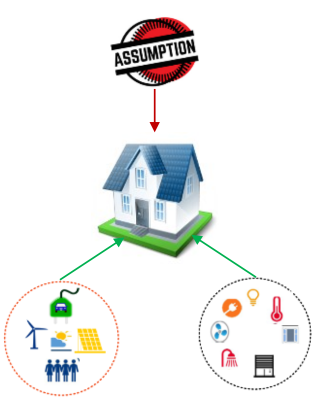
Building Design with no Disruptive Events

Standard



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.

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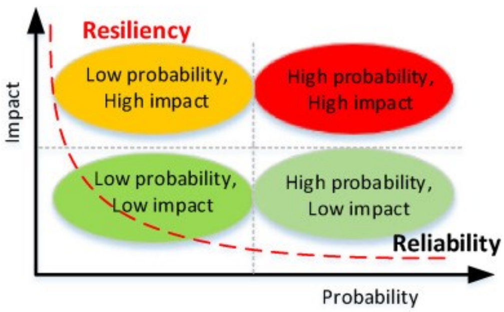
Building Design with Disruptive Events

New thinking



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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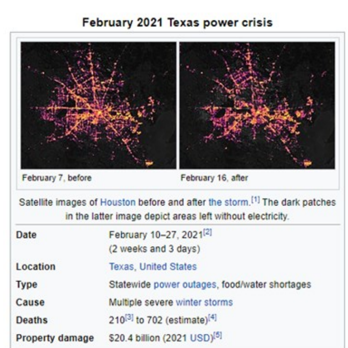
Extreme Event – Higher frequency

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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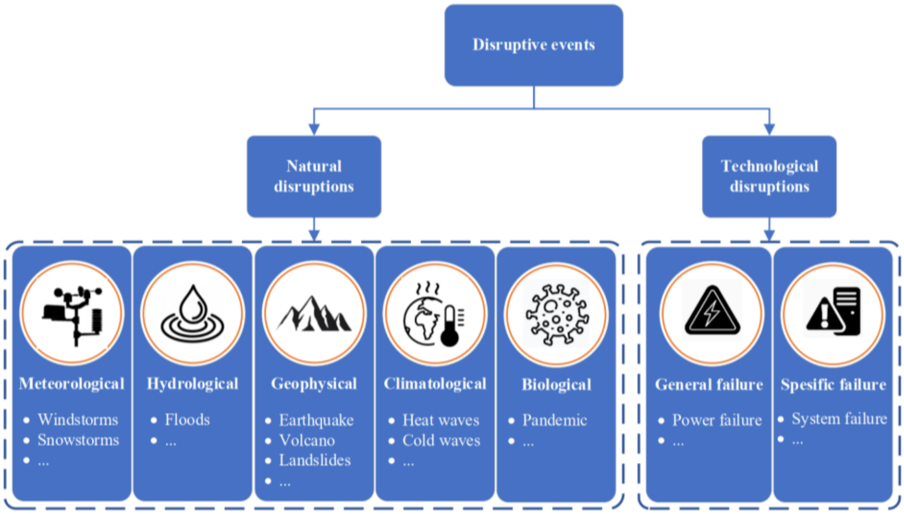
Categories of disruptive events



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Resilient buildings

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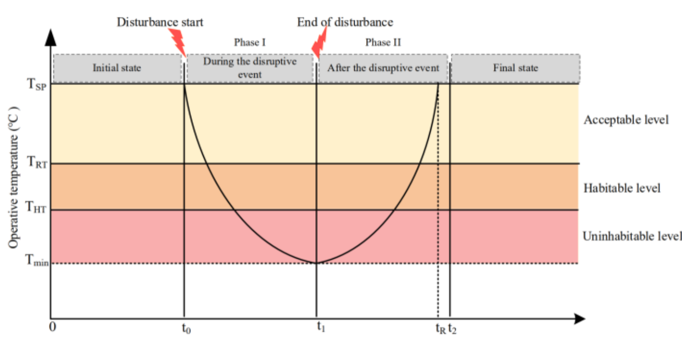
The building is defined to be resilient if it is able **to prepare for**, **absorb**, **adapt to** and **recover from** the disruptive event.



Multi-phase resilience curve associated to an event

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First paper – cooling events


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Thermal resilient buildings: How to be quantified? A novel benchmarking framework and labelling metric

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Battery storage

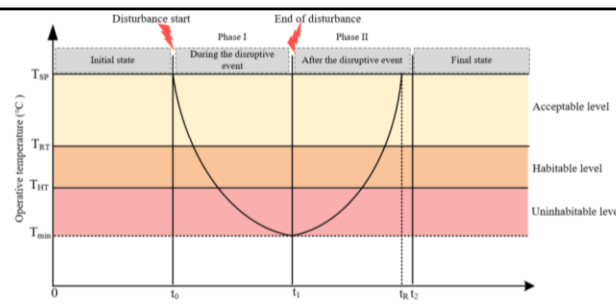
ABSTRACT

The resilient building design has become necessary within the increasing frequency and intensity of extreme disruptive events associated with climate change. Since thermal comfort is one of the main requirements of occupants, evaluating building resilience from a thermal perspective during and after disruptive events is necessary. Most of the existing thermal resilience metrics focus on thermal performance only during disruptive events. Building designers are still seeking metrics that can capture thermal resilience in both phases (i.e. during and after the disruptive events). This paper introduces a novel benchmarking framework and a multi-phase metric for thermal resilience quantification. The metric evaluates thermal resilience concerning building characteristics (i.e. building envelope and systems) and occupancy. It penalises for thermal performance deviations from the targets based on the phase, the hazard level , and the exposure time of the event. The introduced methodology is validated by quantifying the thermal resilient performance of six building designs against a four-day power failure as a disruptive event. The six designs represent minimum and passive building requirements with and without batteries or photovoltaics as resilience enhancement strategies. For the considered case study, upgrading the building from the minimum to the passive design has a huge impact (71%) on resilience improvement against power failure in winter. The application of the battery and PVs can improve the thermal resilience of the two designs in the range of 19%–27% and 44%–60%, respectively. Findings can provide a useful reference for building designers to benchmark the building's thermal resilience and constitute resilience enhancement measures.

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).

T_{SP}
the set target (the setpoint temperature), which is needed for the desired performance of the building

T_{RT}
the performance robustness threshold. Any performance less than T_{RT} will not be robust.

T_{HT}
the habitability threshold for the occupant. Passing this threshold shows that the building has been failed in providing the minimum required comfort condition for building's occupant.

T_{min}
the minimum performance level caused by the disruptive event.

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Resilience test framework

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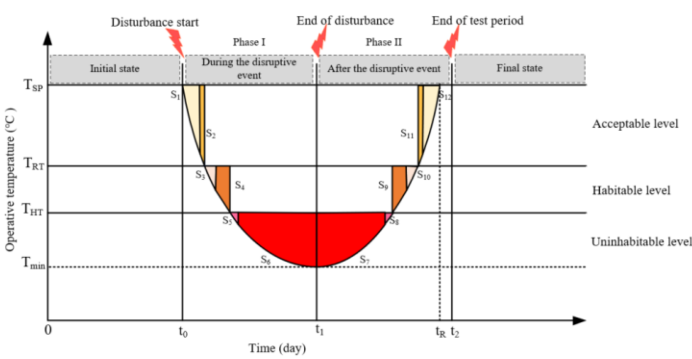
- In developing the test framework, Three factors should be considered:

▪ 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**

Associated penalties for different segments inside the resilience test framework.

Segment	Penalties		
	Phase penalty (W_P)	Hazard penalty (W_H)	Exposure time penalty (W_E)
S1	0.6	0.1	2
S2	0.6	0.1	8
S3	0.6	0.2	10
S4	0.6	0.2	20
S5	0.6	0.7	20
S6	0.6	0.7	40
S7	0.4	0.7	40
S8	0.4	0.7	20
S9	0.4	0.2	20
S10	0.4	0.2	10
S11	0.4	0.1	8
S12	0.4	0.1	2

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

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Calculation of WUMTP: weighted unmet thermal performance

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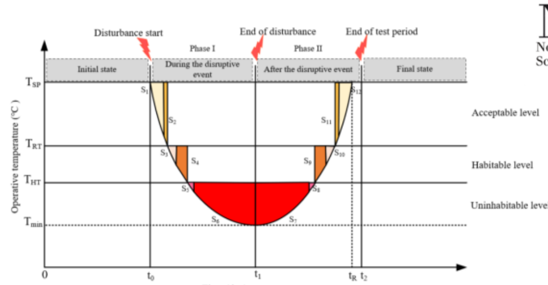
- The application of **two** phases, **three** hazard levels and **two** exposure time sections results in 12 segments in the resilience test framework,
- Three penalty types are needed to be considered for each segment: phase penalty, hazard penalty, and exposure time penalty.

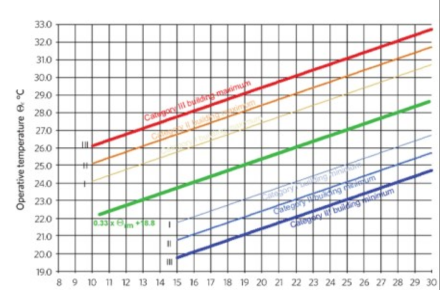
$$WUMTP = \sum_{i=1}^{12} S_i \, W_{P,i} \, W_{H,i} \, W_{E,i}$$



- 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

$$WUMTPA_{overall} = \frac{\sum_{Z=1}^{Z} WUMTP_z}{\sum_{z=1}^{Z} A_z} \qquad IOD = \frac{\sum_{Z=1}^{Z} \sum_{i=1}^{N_O(Z)} [(T_{fr,i,z} - TL_{comf,i,z})^{+} . t_{i,z}]}{\sum_{Z=1}^{Z} \sum_{i=1}^{N_O(Z)} t_{i,z}}$$

- z: Building zone counter $W_{P,i}$: phase penalty
- Z: Total number of zones
- A_z : Area of each zone



Resilience labelling

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

Table 2
Resilience classes for buildings labelling.

<3.6	RCI		Class A+
<2.4	RCI	≤ 3.6	Class A
<1.5	RCI	≤ 2.4	Class B
<0.9	RCI	≤ 1.5	Class C
<0.6	RCI	≤ 0.9	Class E
	RCI	≤ 0.6	Class F

$$RCI = \frac{WUMTPA_{overall,ref}}{WUMTPA_{overall}}$$

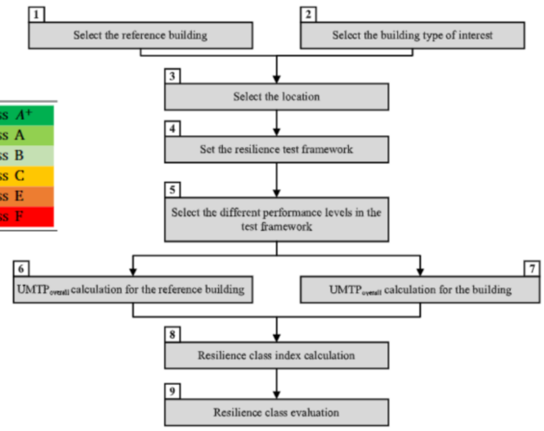


Fig. 4. Steps to implement re

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Example of the results

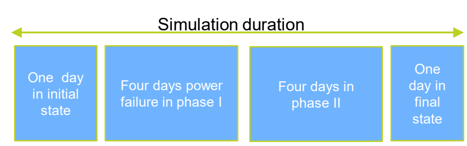
Case study

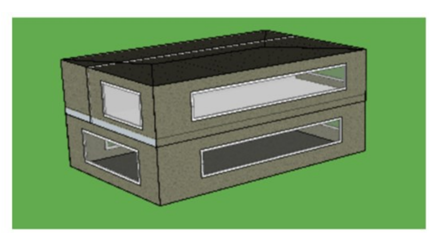
Establishing the test framework for case study building: four-day test framework

- 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, hibitable, and acceptable levels.

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

Performance level	Zones		
	Living room	Bedroom	Bathroom
T_{SP} (°C)	21.5	18	23
T_{SP} (°C)	18	14.5	19.5
T_{SP} (°C)	15	11.5	16.5





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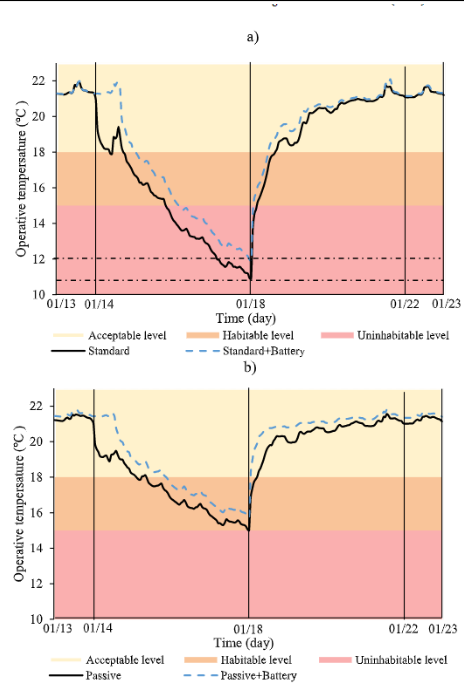
Example of the results

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.



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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.

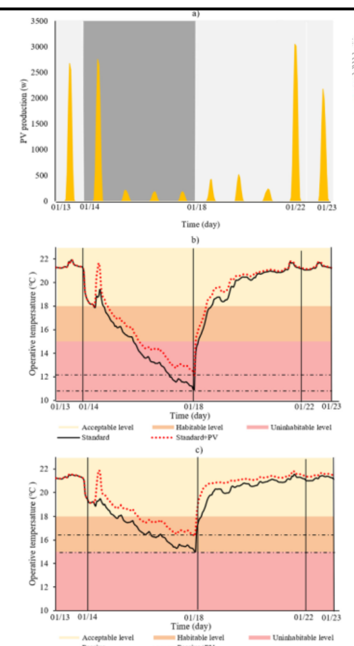

Fig. 8. (a) PV production during test days, (b) Influence of the PV system on the standard design, (c) Influence of the PV system on the passive design.

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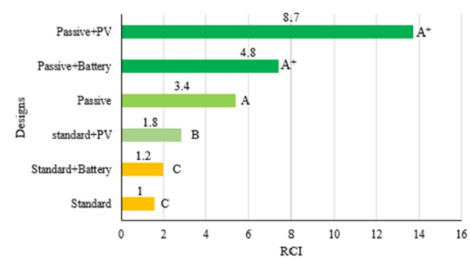
Example of the results

Quantification of WUMTP and resilience labeling

- The upgrade of the standard design to the passive design decreased the $WUMTP_{overall}$ 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.

Table 7
Calculated $WUMTP_{overall}$ for the six designs of the case study building.

Num	Design	WUMTP (Degree hours)	Improvement (Degree hours)
1	Standard	113	–
2	Standard+Battery	91	22 (compared to standard)
3	Standard+PV	63	50 (compared to standard)
4	Passive	33	–
5	Passive+Battery	24	9 (compared to passive)
6	Passive+PV	13	20 (compared to passive)



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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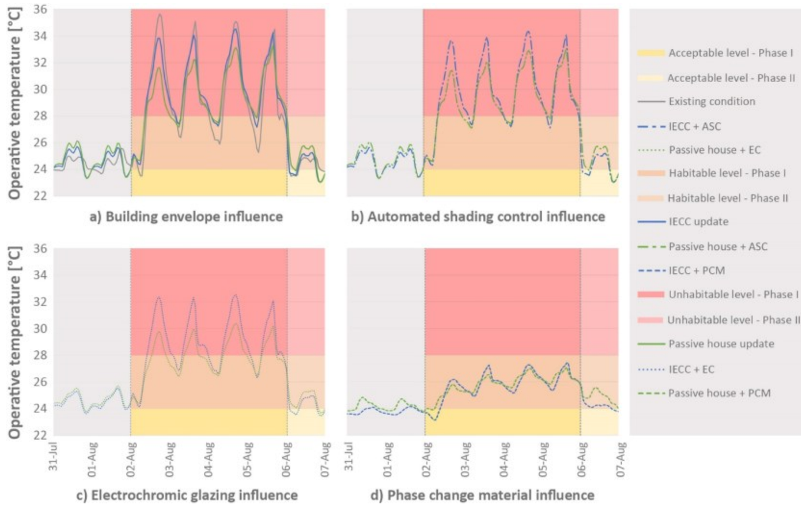

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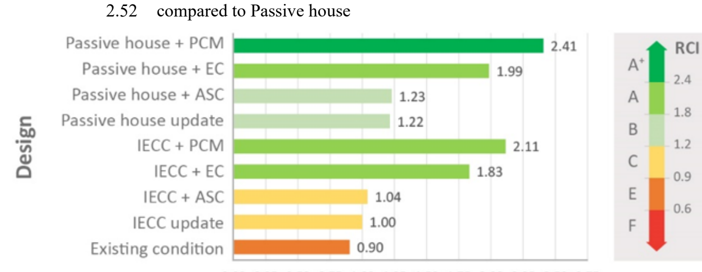
Design	$WUMTP_{overall}$ [Degree hours.m^{-2}]	Improvement [Degree hours.m^{-2}]	
IECC update	6.19	0.67	compared to existing
IECC + ASC	5.95	0.24	compared to IECC
IECC + EC	3.38	2.81	compared to IECC
IECC + PCM	2.93	3.26	compared to IECC
Passive house update	5.09	1.77	compared to existing
Passive house + ASC	5.03	0.06	compared to Passive house
Passive house + EC	3.12	1.98	compared to Passive house
Passive house + PCM	2.57	2.52	compared to Passive house



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Thank You!

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