IEA EBC Annex 80 - Resilient Cooling

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On behalf of Operating Agent Peter Holzer
Institute of Building Research & Innovation
Vienna, Austria

Federal Ministry Republic of Austria
Climate Action, Environment, Energy, Mobility, Innovation and Technology

10/05/2022

IEA EBC Annex 80

Series of webinars in cooperation with AIVC & venticool

1. **Indicators to assess resilience of cooling in buildings** [May 10, 15:00-16:15 CEST]
2. Future weather data and heatwaves [May 31, 16:00-17:15 CEST]
3. Examples of resilient cooling solutions [September 13, 15:00-16:15 CEST]
4. Case studies and policy recommendations [September 20, 15:00-16:15 CEST]

Today‘s Programm

Programme (Brussels time)

15:00	**Introduction to Annex 80, AIVC & venticool** Peter Holzer, OA EBC Annex 80, Institute of Building Research & Innovation, AT
15:05	**Definitions of resilient cooling of buildings & overview of indicators to assess resilience** Peter Holzer, OA EBC Annex 80, Institute of Building Research & Innovation, AT
15:25	**Thermal resilient buildings: How to be quantified? A novel benchmarking framework and labelling metric** Mohamed Hamdy, Associate Professor, NTNU, NO
15:40	**Example of indicators and application to vulnerable buildings** Abdelaziz Laouadi, NRC, CA
15:55	**Questions and answers**
16:15	**End of the webinar**

IEA EBC Annex 80

EBC Energy in Buildings and Communities Programme

Part 1: Introduction to Annex 80 and State of the Project

Part 2: Definitions of resilient cooling of buildings & overview of indicators to assess resilience

IEA EBC Annex 80

- **Participants**

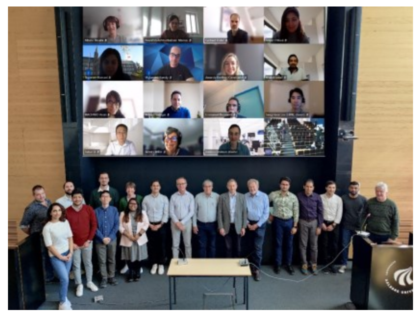
  36 institutions from 16 countries (Americas, Europe, Asia, Australia)

- **Guests** (not part of EBC yet)

  Mexico, **José Roberto Garcia Chavez**, Metropolitan Autonomous University Mexico City

  India, **Rajan Rawal**, CEPT University, CARBSE

1. Preparation Phase (1 year)
   June 2018 – June 2019
2. Working Phase (3 years)
   June 2019 – June 2022
3. Reporting Phase (1 year)
   June 2022 – June 2023



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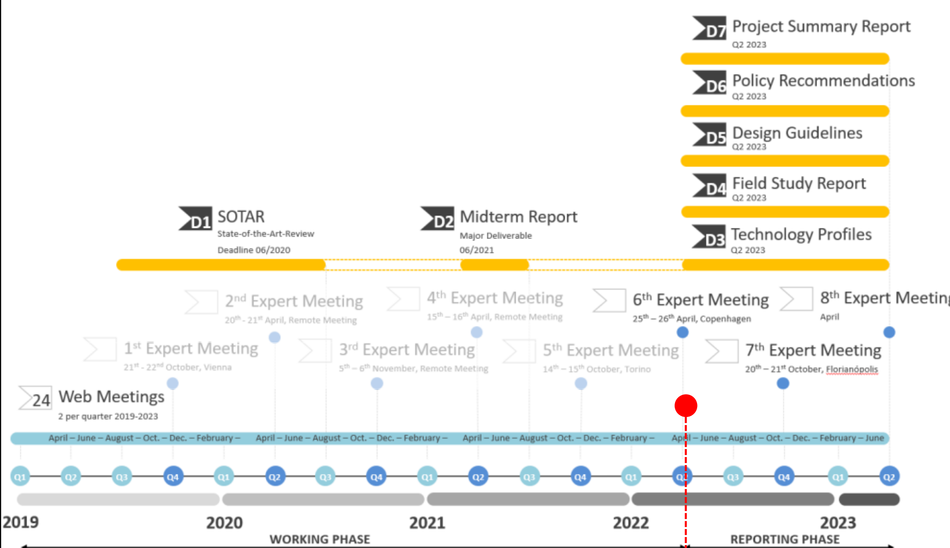
Annex 80 Roadmap



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Annex 80 Objectives

"Support a transition to an environment
*where **affordable low energy** and **low carbon** cooling systems*
are the mainstream and preferred solutions
for cooling and overheating issues in buildings."

A Assess benefits, potentials and performance indicators.
Provide guidance on design, performance calculation and system integration.

B Research towards implementation of emerging technologies.
Extend boundaries of existing solutions.

C Evaluate the real performance of resilient cooling solutions.

D Develop recommendations for policy actions.

Annex Subtasks

The Annex is structured in four subtasks:

A Fundamentals

B Solutions

C Field Studies

D Policy Actions

Subtask A – Fundamentals

Objectives:

- Definition of Resilient Cooling in terms of buildings
- Definition of Key Performance Indicators
- Composition of Resilient Cooling Design and Operation Guidelines (deliverable)

Definition of Resilient Cooling

"Affordable low energy and low carbon cooling solutions, strengthening the ability of individuals and communities to withstand and prevent the thermal - and other - **impacts of changes in global and local climates."**

Groups of Technologies

a. **Reduce heat loads to people and indoor environments**
b. **Remove sensible heat from indoor environments**
c. **Enhance personal comfort apart from space cooling**
d. **Remove latent heat from indoor environments**

Technology Review - Subtask B

A. Reduce heat load to indoor environments and people indoor
   1. **Advanced solar shading/advanced glazing technologies**
   2. **Advanced cool materials**
   3. **Green roofs, roof pond, green facades, ventilated roofs and ventilated facades**
   4. Thermal mass utilization including, PCM and off-peak ice storage
B. Remove sensible heat from indoor environments
   1. **Ventilative cooling**
   2. **Adiabatic/evaporative cooling**
   3. Compression refrigeration
   4. **Absorption refrigeration, including desiccant cooling**
   5. **Natural heat sinks, such as ground water, borehole heat exchangers, ground labyrinths, earth tubes, sky radiative cooling,**
   6. **High temperature cooling system: Radiant cooling, chill beam**
C. Enhance personal comfort apart from space cooling
   1. Comfort ventilation (elevated air movement)
   2. **Micro-cooling and personal comfort control**
D. Remove latent heat from indoor environments
   1. High performance dehumidification including desiccant humidification

Subtask B - Solutions

Objectives:

- Assessment of technologies in future weather scenarios
- Extension of range of resilient cooling systems
- Derivation of rules for successful implementation
- Composition of Technology Profile Sheets (deliverable)

Subtask C – Field Studies

Objectives:

- Analysis and evaluation of implemented Resilient Cooling Technologies
- Identification of barriers and performance gap examination
- Composition of Field Studies Report (deliverable)

Subtask C – Field Studies

			Building Type										Project type		1. Reduce external heat gain				2. Removing heat from indoor environments						3. Remo	4. Increasing personal comfort apart from space		5. Other
			sidential	ces	olesale and retail trade	els & guest houses	staurants	sery home	spitals	ucational buildings	rts facilities	ers	vbuilding	ovation	Advanced solar shading	Cool materials	Advanced glazing technologies	Double skin Facades / Ventilated ades	Ventilative cooling as regards night h ventilation	Thermal mass utilization, including PCM l off-peak ice storages	Adiabatic cooling	High performance compression chillers, including split and multiple split and VRV s	High performance absorption chillers, uding desiccant cooling	Natural heat sinks, such as ground water and soil, borehole heat hangers and others	Desiccant dehumidification	Ventilative cooling as regards comfort tilation	Micro-cooling / Personal comfort control	Micro-cooling / Personal comfort control
1	e7	AT								Y			Y						Y									
2	e7	AT	Y										Y						Y					Y				
3	e7	AT									Y		Y						Y	Y				Y				
4	KU Leuven aug	BE	Y										Y				?							Y				
5	KU Leuven	BE								Y			Y						Y	Y	Y							
6	Thomas More (218m2)	BE	Y														Y							Y	Y			Geothermal
7	Thomas More (264m2)	BE	Y											Y			Y				Y			Y				Geothermal
8	Hunan University	CN										Y		Y	Y		Y		Y							Y		
9	Hunan University	CN	Y										Y													Y		
10	Hunan University	CN	Y										Y													Y		
11	Hunan University	CN	Y										Y													Y		
12	Brunel University	EN				Y								Y		Y	Y			Y						Y		
13	Concordia University	CA								Y				Y					Y									
14	Concordia University (6100m2)	CA								Y				Y					Y									
15	Concordia University	CA							Y					Y					Y							Y		
16	Concordia University	CA							Y					Y														heat recovery
17	University of Gävle	SE		Y										Y					Y							Y		
18	ENEA	IT		Y										Y	Y		Y		Y									
19	Gebze Technical University	TR																					Y					

Subtask D – Policy Actions

Objectives:

- Support implementation and mainstreaming of Resilient Cooling Technologies
- Develop recommendations for regulatory policies (labelling programmes, building regulations, standards and compliance requirements)
- Report on recommendations for legislation and standards (deliverable)

Subtask D – Policy Actions

November 2020 – April 2021
Policy collection

May 2021 - April 22
Policy review & comparison

May 2022 – August 2022
Recommendations

September 2022 – June 2023
Write-up

Annex 80 Deliverables

D1	State-of-the-Art-Report	▪ Research community and associates ▪ Real Estate developers ▪ Urban planning experts ▪ Policy makers	OA, STA, STB, STC, STD
D2	Midterm Report	▪ Research community and associates ▪ IEA and EBC Programme	OA, STA, STB, STC, STD
D3	**Technology Profiles**	▪ Building component developers and manufacturers ▪ Architects and design agencies ▪ Engineering offices and consultants	STB
D4	**Field Studies**	▪ Building component developers and manufacturers ▪ Architects and design agencies ▪ Engineering offices and consultants ▪ Real Estate developers	STC
D5	**Design and Operation Guidelines**	▪ Architects and design agencies ▪ Engineering offices and consultants ▪ Real Estate developers	STA, STB, STC
D6	**Recommendations for policy actions, legislation and standards**	▪ Policy makers ▪ Legal interest groups ▪ Experts involved in building energy performance standards and regulation	STD
D7	**Project Summary Report**	▪ Research community and associates ▪ IEA and EBC Programme ▪ Real Estate developers ▪ Policy makers	OA, STA, STB, STC, STD

Annex 80 Publications

1. "**Developing an understanding of resilient cooling**: a socio-technical approach City and Environment Interactions" (Wendy Miller et al; published in Elsevier City and Environment 2021) https://doi.org/10.1016/j.cacint.2021.100065
2. "**Resilient cooling of buildings to protect against heat waves and power outages**: key concepts and definition" (Shady Attia et al; published in Energy and Buildings 2021) https://doi.org/10.1016/j.enbuild.2021.110869
3. "**Resilient cooling strategies - a critical review and qualitative assessment**" (Chen Zhang et al; published in Energy and Buildings 2021) https://doi.org/10.1016/j.enbuild.2021.111312
4. Report of Thermal Conditions Task Group "**Framework to evaluate the resilience of different cooling technologies**" (Shady Attia et al; published) http://dx.doi.org/10.13140/RG.2.2.33998.59208




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IEA EBC Annex 80

EBC
Energy in Buildings and Communities Programme

Part 2: Definitions of Resilient Cooling of Buildings & Overview of Indicators to assess Resilience

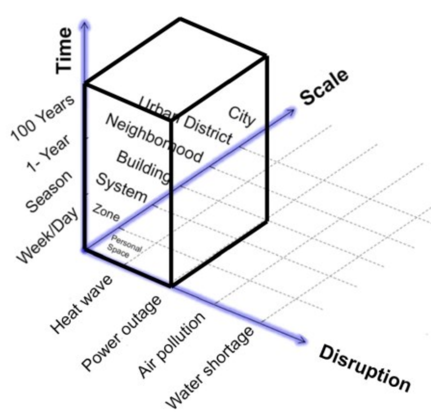
Wendy Miller et al, Developing an understanding of resilient cooling: a socio-technical approa
City and Environment Interactions, City and Environment, 2021

Attia et al, Resilient cooling of buildings to protect against heat waves and power outages: Ke
concepts and definition, Energy Buildings, 2021

Identifying the Boundaries

We limited the definition to:

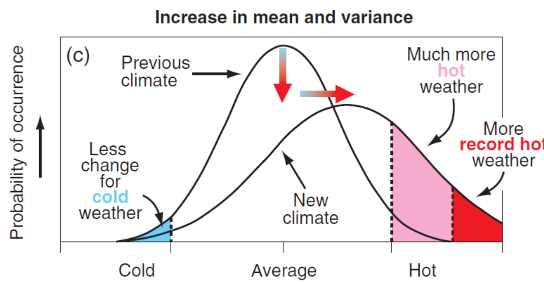
- **building scale**
- **heat waves**
- **power outages**



Source: Attia et al, Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition, Energy Buildings, 2021

Background

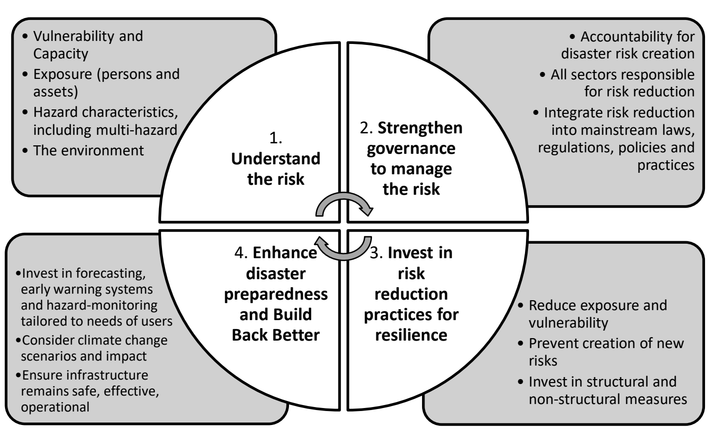
Why Resilience?



- **longer and more intense heatwaves**
- **risk of power outages**

Source: (IPCC). Climate Change 2001: The scientific basis. Contribution of Working Group I

Sendai Framework for Disaster Risk Reduction



Process for "temperature hazard" management based on Sendai Framework for Disaster Risk Reduction

Source: United Nations. Sendai Framework for Disaster Risk Reduction 2015-2030. Geneva 2015

Definition of Resilient Cooling Characteristics and Risk Factors

Resiliency Characteristics	Vulnerability	Resistance	Robustness	Recoverability
Resilient Cooling Characteristics	Overheating Exposure Risk	Overheating Exposure Severity	Overheating Exposure Adjustment	Overheating Exposure Recovery
Risk Factors	Climate Change Scenarios Heat wave events Power Outages Urban Heat Island Load Change (occupancy, solar or other thermal loads)	Building Design (glazed area, thermal mass, …) Cooling Technology Characteristics Level of Energy Autonomy	Occupant Adaptability Potential Occupant/System Interaction Potential Building Adaptability Potential (thermal safety zones,…) Smart Readiness Level (System Adaptation) Emergency Control Possibility Energy System Back-Up Availability	Building Design Cooling Technology Characteristics Learning Ability of Building, Systems and Occupants

Source: Attia et al, Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition, Energy Buildings, 2021

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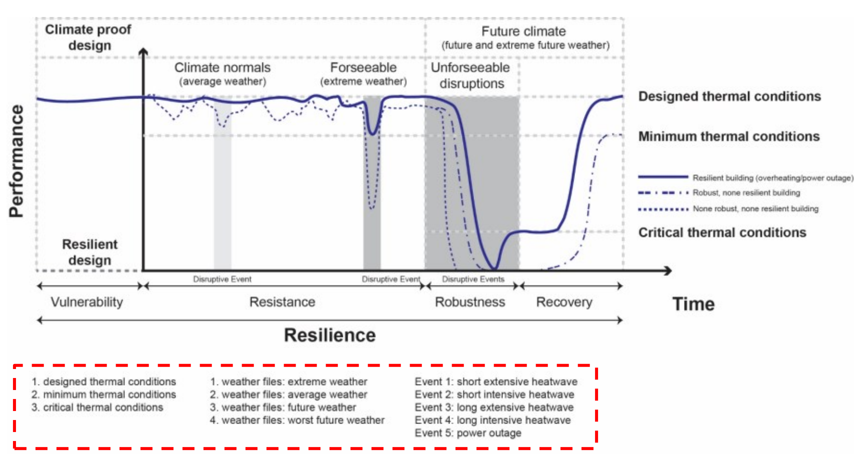
Definition of Resilient Cooling of Buildings



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Important Parameters for Resilience Assessment

1. **Thermal Conditions**: designed, minimum, critical
2. **Weather**: average, extreme, future, extreme future
3. **Disruptive Events**: heat wave, power outage

1. Thermal Conditions

- **ISO 17772 P1-2**
  (PPD, PMV and adaptive Model)
- Limitation of the thermal comfort model
  -> ASHRAE 55
  -> EN 15251

Table 3.3 Acceptability classes in ASHRAE 55

ASHRAE 55 class	Scope	PPD (%)	Fanger PMV	Adaptive ΔT_{op} (K)
90%	To be used when a higher standard of thermal comfort is desired	≤10	$-0.5 \leq PMV \leq +0.5$	±2.5
80%	To be used for typical applications and when other information is not available	≤20	$-0.85 \leq PMV \leq +0.85$	±3.5

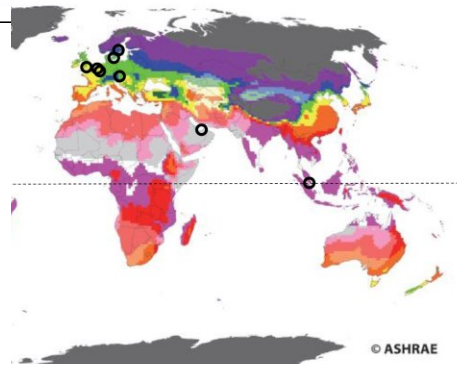
Table 3.4 Thermal comfort categories and acceptability ranges according to EN 15251

EN 15251 category	Description	Fanger		Adaptive
		PPD (%)	PMV	ΔT_{op} (K)
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile people with special requirements like handicapped, sick, very young children and elderly persons	≤6	$-0.2 \leq PMV \leq +0.2$	±2
II	Normal level of expectation and should be used for new buildings and renovations	≤10	$-0.5 \leq PMV \leq +0.5$	±3
III	An acceptable, moderate level of expectation and may be used for existing buildings	≤15	$-0.7 \leq PMV \leq +0.7$	±4
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year	>15	$PMV < -0.7$ and $PMV > 0.7$	

2. Future Weather

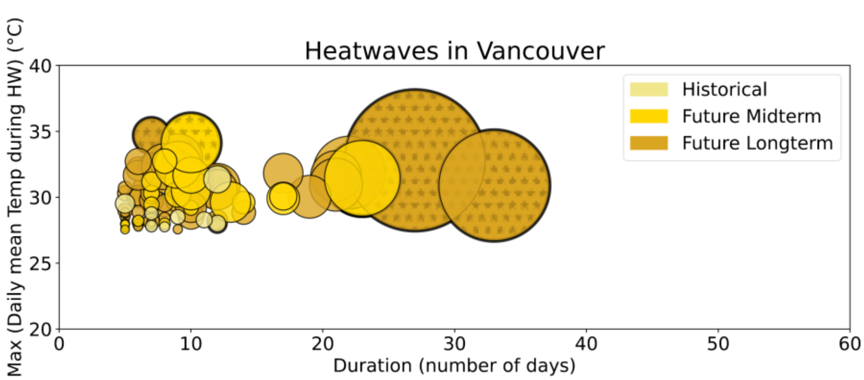
1. At least **one city for climate zones** considering the ASHRAE classification
2. Cities with **high population and growth**
3. Cities in **different continents** with preference for **cities of the Annex 80 participants**

CLIMATE ZONE	City	Country	Continent
0A	Singapore	Singapore	Asia
0B	Abu Dhabi	UAE	Asia
1A	Guayaquil	Ecuador	South America
2A	Rome	Italy	Europe
2A	Sao Paulo	Brazil	South America
2B	Cairo	Egypt	Africa
3A	Buenos Aires		South America
3B	Teheran	Iran	Asia
3B	Los Angeles	California	North America
4A	Paris	France	Europe
4A	London	UK	Europe
4A	Gent	Belgium	Europe
4A	Brussels	Belgium	Europe
4B	Xian	China	Asia
4C	Vancouver	Canada	North America
5A	Toronto	Canada	North America
5A	Copenhaguen	Denmark	Europe
5A	Vienna	Austria	Europe
6A	Montreal	Canada	North America
6A	Stockholm	Sweden	Europe



➢ **Webinar 2 of this series**

3. Heatwaves



Categories of KPIs

a. IEQ / Thermal Comfort Metrics
   - comfort, thermal safety, indoor overheating degree …

b. Energy Metrics
   - energy use, power demand, carbon emissions, …

c. HVAC and Grid Metrics
   - SEER, SCOP, recovery time…

d. Specific KPIs, relevant to specific cooling technologies

Conclusions

– Any definition of resilience must be based on the **identification of a specific shock or disruption.**

– Designer must specify and distinguish, the **resistance and robustness conditions against heat waves and power outage events**.

– Resilient cooling design is an **urgent requirement for future proof buildings**.

– **Building operation systems and building management systems will play a significant role** in applying the adaptation strategies and risk mitigation plans in collaboration with buildings users.

– **Resilience is a process**, and its criteria should be addressed **integrating user experience during shocks is essential to increase the emergency learnability and feed the preparedness loop.**

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Thermal Resilient Buildings: How to be Quantified?

A Novel Approach

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A strategic leader with the center Green2050 and a member in our innovation committee
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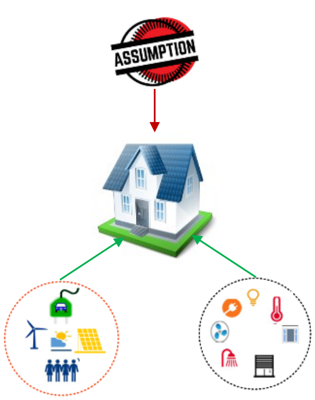
Building Design with no Disruptive Events

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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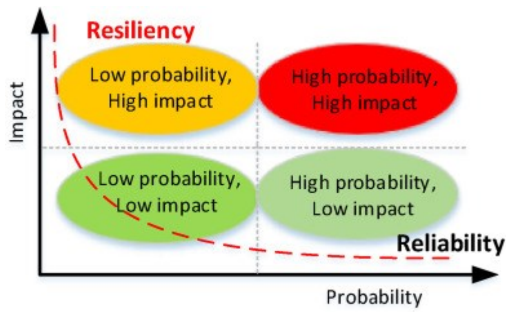
Building Design with Disruptive Events

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.


ENERGY & ENVIRONMENT

Texas Winter Storm Death Toll Goes Up To 210, Including 43 Deaths In Harris County

Harris County leads the state in freeze-related deaths.


Report: More than 456.5K Claims Filed in Texas After Winter Storm

September 24, 2021

A recently released report from the state's insurance department shows more claims and higher average claim costs resulting from the severe and prolonged winter storm that enveloped Texas in mid-February than were previously reported.

In the report released Sept. 1, the Texas Department of Insurance detailed property/casualty claims data from Winter Storm Uri, which blanketed the state with sub-freezing temperatures, ice and snow from Feb. 11 through Feb. 19, 2021.


February 2021 Texas power crisis

February 7, before | February 16, after

Satellite images of Houston before and after the storm.[1] The dark patches in the latter image depict areas left without electricity.

Date	February 10–27, 2021[2] (2 weeks and 3 days)
Location	Texas, United States
Type	Statewide power outages, food/water shortages
Cause	Multiple severe winter storms
Deaths	210[3] to 702 (estimate)[4]
Property damage	$20.4 billion (2021 USD)[5]

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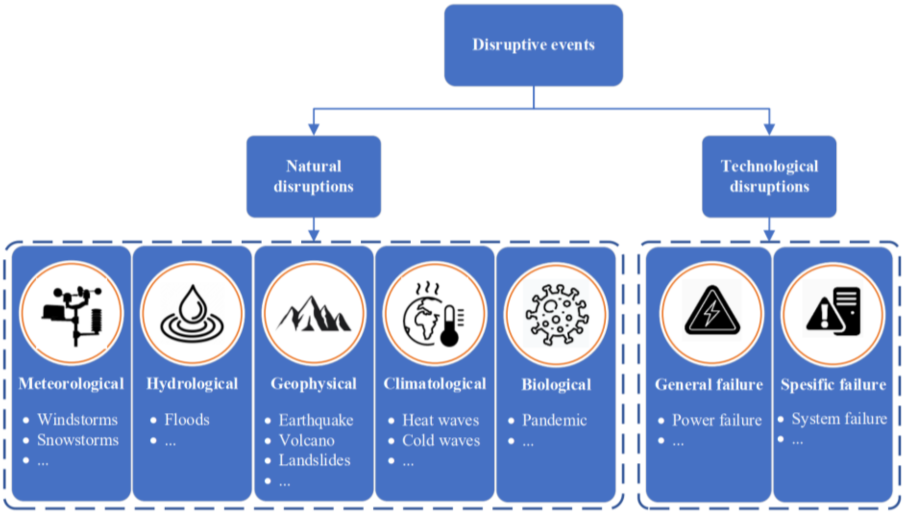
Categories of disruptive events



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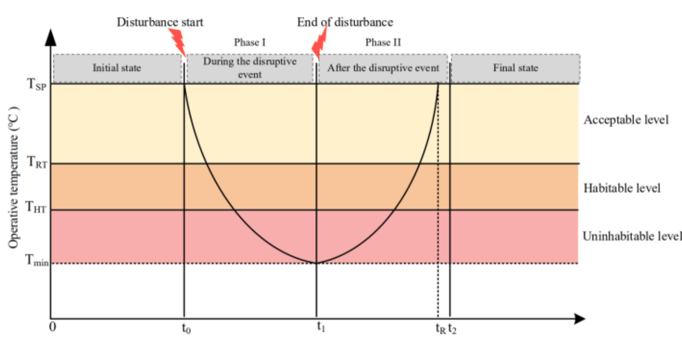
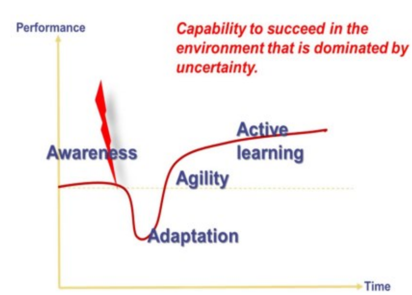
Resilient buildings

NTNU
Norwegian University of Science and Technology

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



Mohamed Hamdy Ph.D. MSc. Eng.

First paper – cooling events

Building and Environment 201 (2021) 108022

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

ELSEVIER

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

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ARTICLE INFO

Keywords:
Thermal resilient buildings
Multi-phase resilience metric
Building resilience labelling
Resilience test framework
Power failure
Battery storage

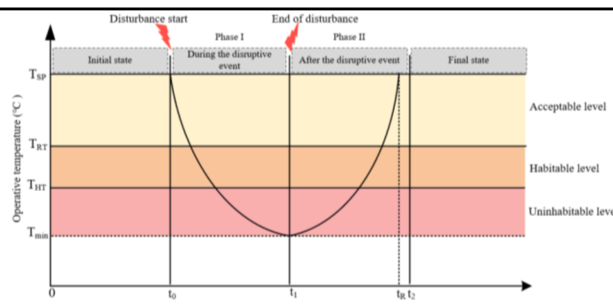
ABSTRACT

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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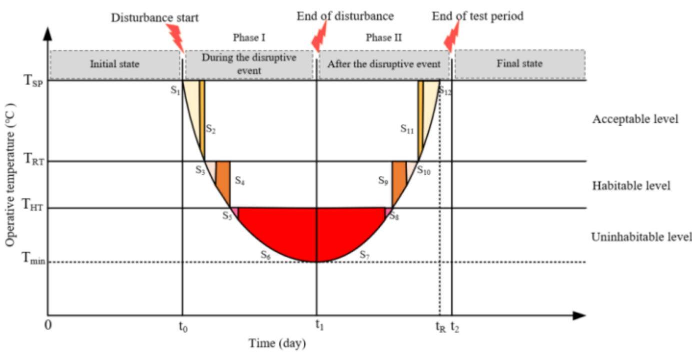
NTNU

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**

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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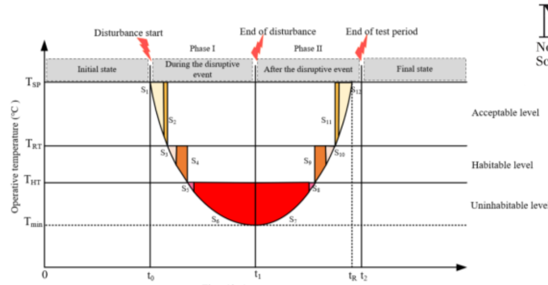
AVC venticool EBC

NTNU

Calculation of WUMTP: weighted unmet thermal performance

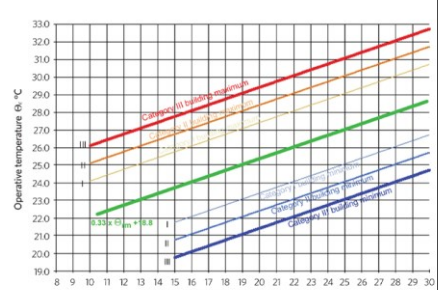
- The application of **two** phases, **three** hazard levels and **two** exposure time sections results in 12 segments in the resilience test framework,
- Three penalty types are needed to be considered for each segment: phase penalty, hazard penalty, and exposure time penalty.

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



- 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

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- 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

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

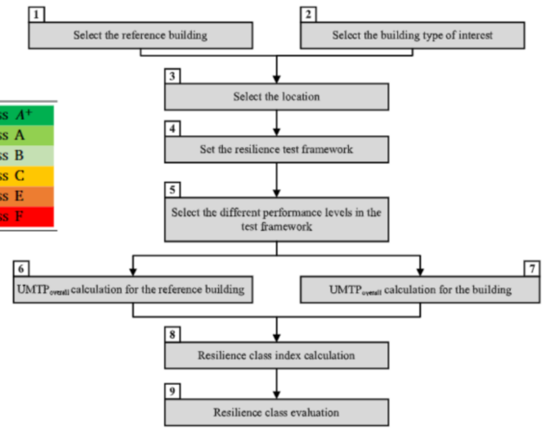

Fig. 4. Steps to implement re

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Example of the results
Case study

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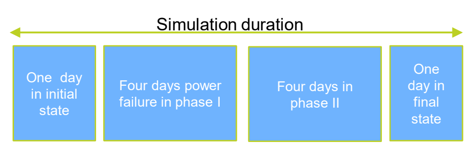
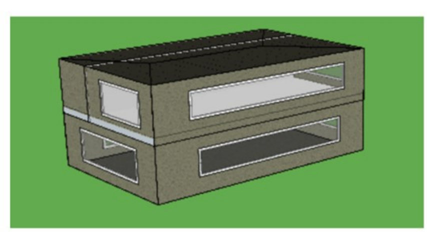
Establishing the test framework for case study building: four-day test framework

- 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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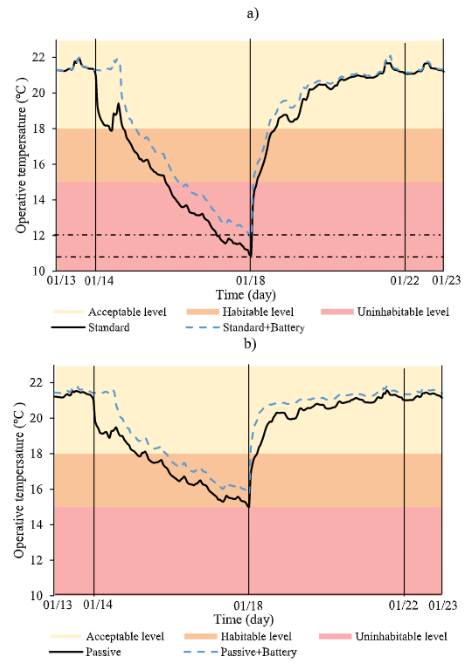
Example of the results

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.

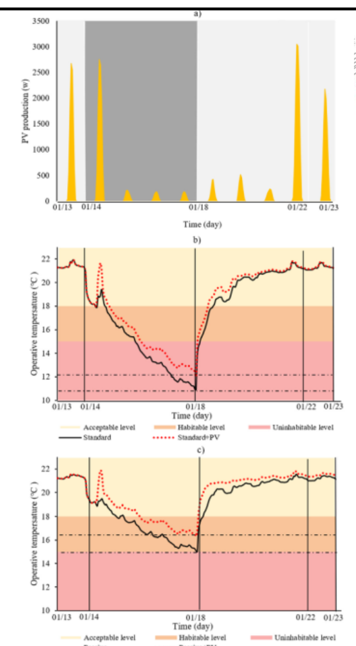

Fig. 8. (a) PV production during test days, (b) Influence of the PV system on the standard design, (c) Influence of the PV system on the passive design.

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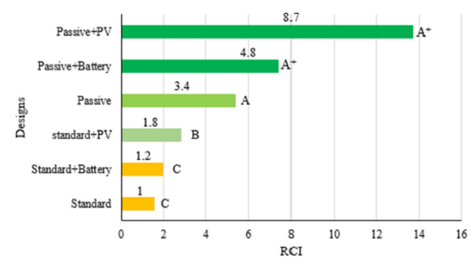
Example of the results

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

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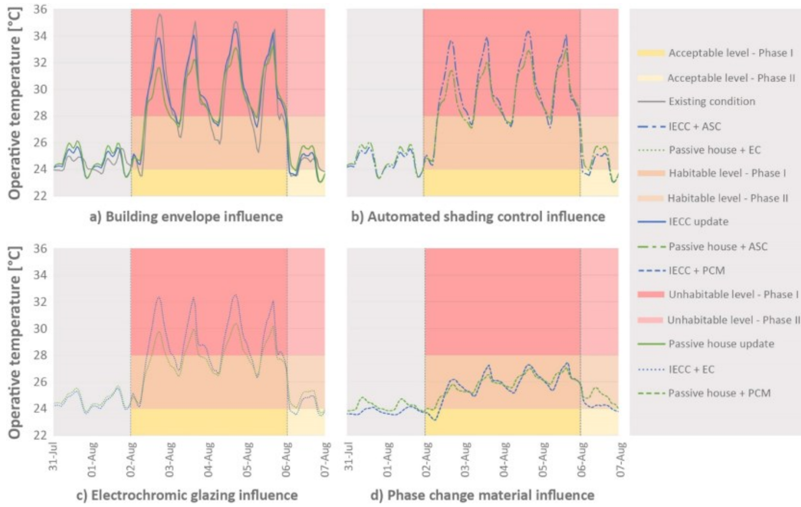

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The Impact of Building Retrofitting on Thermal Resilience against Power Failure: A Case of Air-conditioned House

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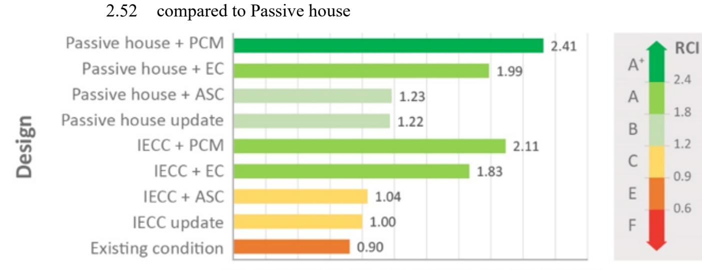
Design	$WUMTP_{overall}$ [Degree hours.m^{-2}]	Improvement [Degree hours.m^{-2}]	
IECC update	6.19	0.67	compared to existing
IECC + ASC	5.95	0.24	compared to IECC
IECC + EC	3.38	2.81	compared to IECC
IECC + PCM	2.93	3.26	compared to IECC
Passive house update	5.09	1.77	compared to existing
Passive house + 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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Example and application of indicators to evaluate overheating in vulnerable buildings

Aziz Laouadi, PhD, MASHRAE
Senior research officer
NRC Construction Research Centre
Ottawa, Ontario, Canada

Annex 80, Venticool & AIVC webinar:
Indicators to Assess Resilience of Cooling in Buildings
May 10, 2022

National Research Council Canada | Conseil national de recherches Canada

Canada

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Contents

1. Introduction
2. Overview of metrics related to overheating
3. Proposed metric for overheating
4. Application to selected vulnerable buildings
5. Conclusion

2

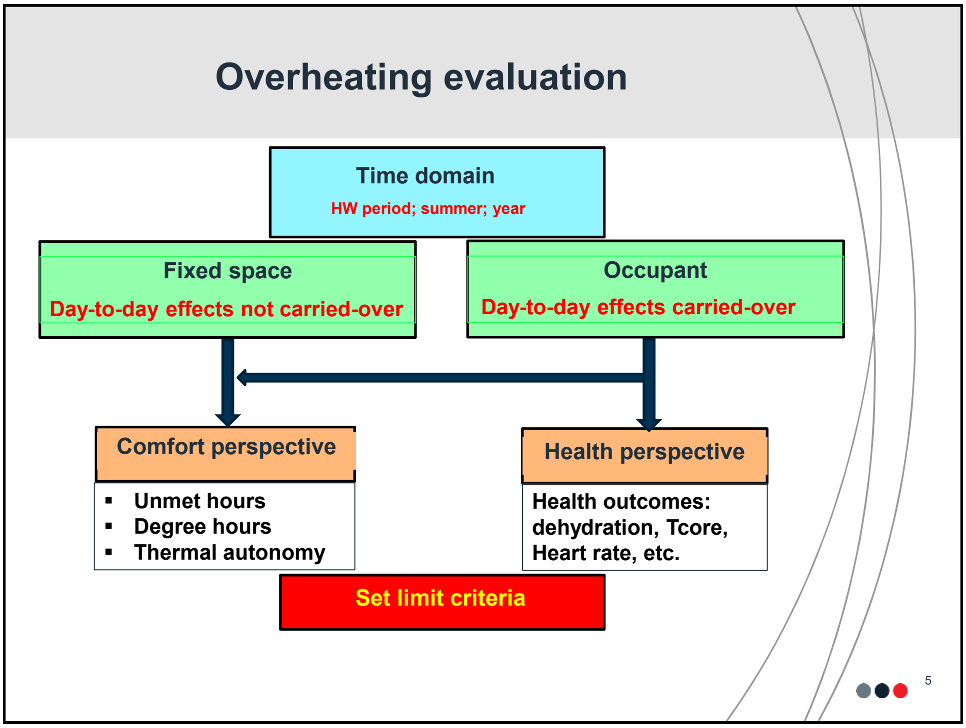
Introduction

- Overheating is a hazard to public health/wellbeing
- Caused high toll on population (mortality) in various places in the world:
  - Global deaths: 489,000/year (2000-2020)
  - Recent 2021 Heat Home in BC/Canada: 815 deaths
- Overheating found in all types of buildings:
  - Free-running (non air-conditioned) buildings
  - Mixed mode buildings (combination of naturally ventilated and air-conditioned spaces)
  - Power outages or HVAC failures during heat wave periods (disruptive events)

Overview of metrics related to overheating

Definition of overheating event: a thermal event that results in thermal discomfort and heat stress to building occupants

Overheating	
Thermal comfort metrics ▪ Set comfort threshold values for different types of buildings and occupants ▪ Sleep comfort	**Heat stress metrics** ▪ Set thermal limits to avoid any heat-related health injury ▪ Need physiological models of human body

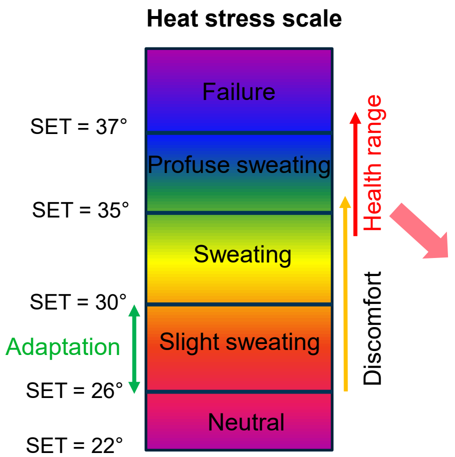


Metrics for heat stress

- There are over 100 metrics
- Most popular indices → Table

Index	Application
Standard Effective Temperature (SET): ASHRAE 55	indoor; outdoor
Universal Thermal Climate Index (UTCI)	outdoor
Physiologically Equivalent Temperature (PET)	outdoor
Predicted Heat Strain (PHS) : ISO 7933	indoor; outdoor
Wet-Bulb Globe Temperature (WBGT) : ISO 7243; NIOSH	indoor; outdoor
Perceived Temperature (PT): German weather services	outdoor
Humidex (H) : Canadian weather services	outdoor (indoor)
Heat Index (HI) : NOAA weather services (USA)	outdoor (indoor)

SET scale & heat-related health effects



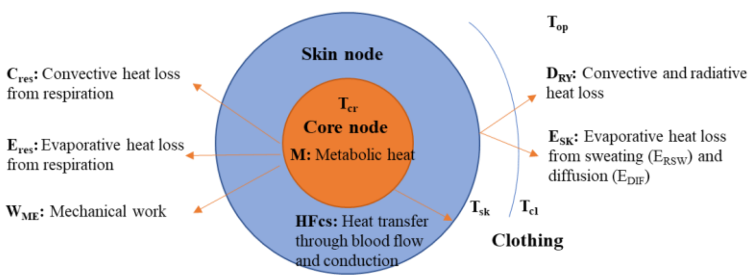
Heat-related health effects
(for healthy young adults) *

Core temperature (°C)	Health condition
> 44	Brain death certain
41 – 44	Heat stroke
39 – 41	Heat exhaustion
38 - 39	Heat cramps; Heat syncope
36 - 38	Normal

*Pisacane et al. Use of Thermoregulatory Models to Enhance Space Shuttle and Space Station Operations and Review of Human Thermoregulatory Control. NASA 1-17; 2007.

Physiological models of a human body

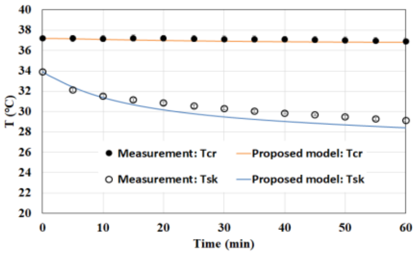
- Developed two-node models for*:
  - Average young adults
  - Average older adults (> 65 years)

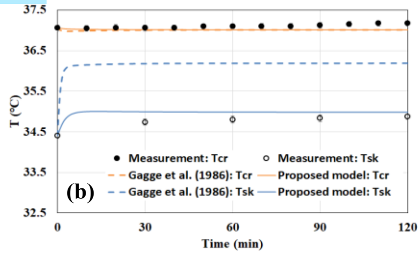


* DOI:10.1016/j.enbuild.2021.111235 & DOI:10.1007/s12273-022-0890-3

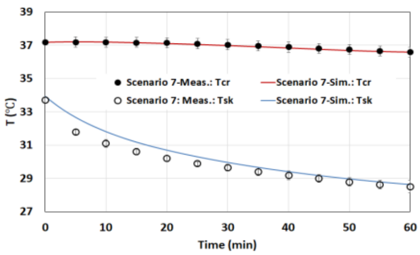
Model validation

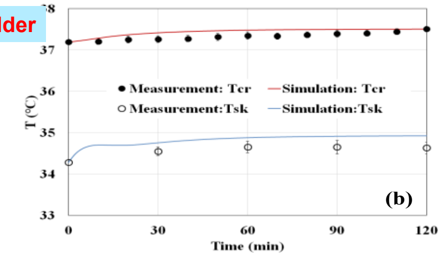
Cold: 17°C & RH 45% | **Young** | **Hot/humid: 36.5°C & RH 60%**





Older



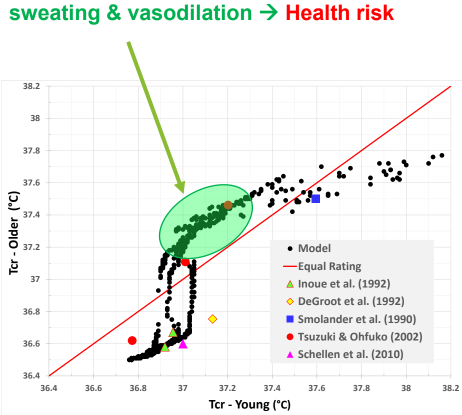


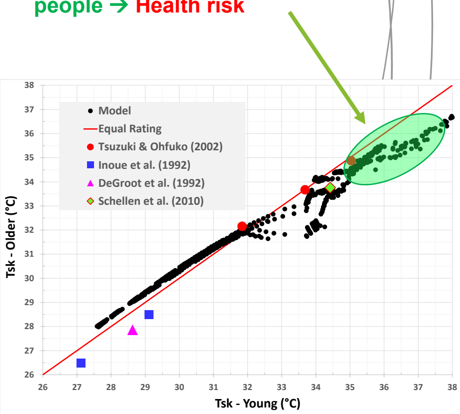
Heat stress for older people under typical indoor conditions

Older people with 30% lower metabolic heat than young adults

Less sensitivity to heat due to delayed sweating & vasodilation → Health risk

Avoid fan ventilation for older people → Health risk





Thermal comfort metrics

- **Global indices**
  - **Predicted Mean Vote (PMV) for air-conditioned buildings**
  - **Adaptive thermal comfort for free-running or naturally ventilated buildings**
  - **Adaptive thermal comfort for mixed mode (MM) buildings**
- **Limitations**
  - **Comfort for older people**
  - **Comfort for sleeping environments**

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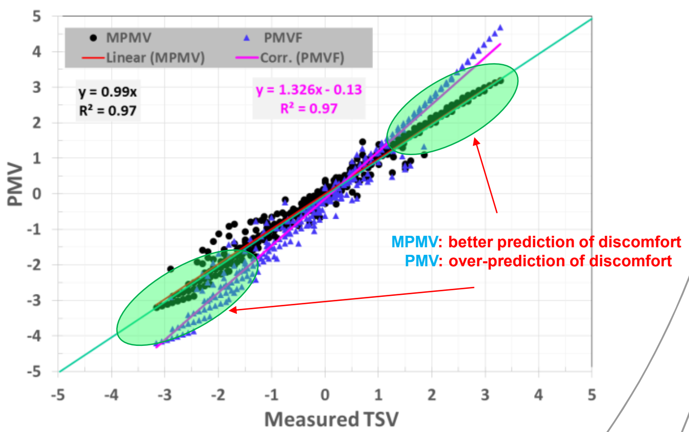
New PMV index

- **Metabolic-based PMV index (MPMV)**
  - **Covers comfort for young and older people**
  - **Comfort for sleeping environments**



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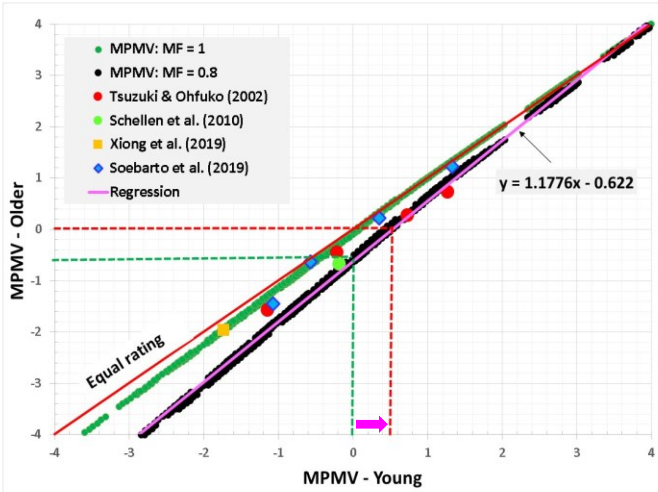
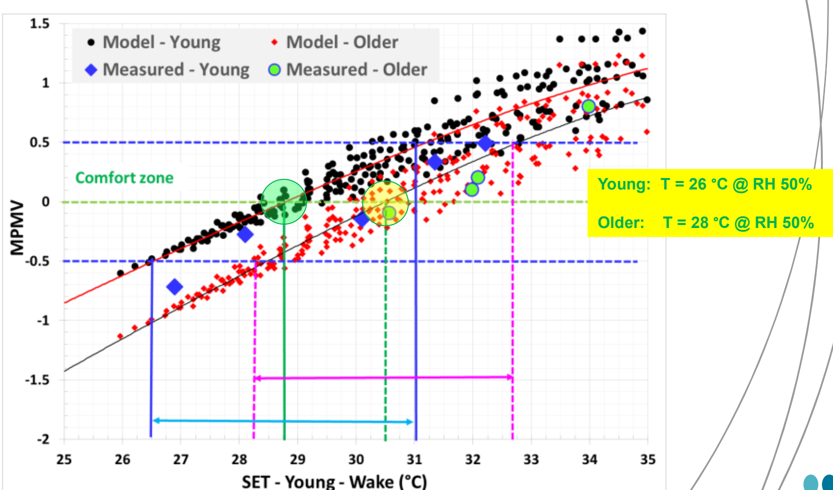
Thermal comfort for older people versus young

Older people having: - same metabolic heat (MF=1); and
- 20% (MF=0.8) lower than young



Thermal comfort requirement for sleep

Metabolic rate of older people is 20% lower than young adults



Proposed metric for overheating

- **Adopted the occupant-based approach:**
  - Account for all occupied spaces during day/night times
  - Evaluation over heat wave time frame
  - Limit criteria based on heat-related health outcomes
- **Attributes of overheating events:** ↓

Duration (days): D = Number of days with: $\sum_{wake}^{sleep}(\text{SET}_t - \text{SET}_d)^{+} \cdot \Delta\tau \geq 4\ °\text{C}{\cdot}\text{h}$

$$\textbf{Severity}(°\text{C} \cdot \text{h}): \textbf{S} = \sum_{i=1}^{N\_days} \left\{ \sum_{sleep}^{wake} (\text{SET}_t - \text{SET}_n)^{+} \cdot \Delta\tau + \sum_{wake}^{sleep} (\text{SET}_t - \text{SET}_d)^{+} \cdot \Delta\tau \right\}$$

Intensity (°C): I = S / (D * 24)

- **Three main types of events: Long, Intense, Severe, or combination of them**
- **Each event may result in different health effect**

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Comfort thresholds for overheating

- **Two threshold values of SET are needed for :**
  - Daytime exposure : SET_d
  - Nighttime exposure (sleep): SET_n
- **They are building and occupant depended**

Suggested threshold values of SET *

Building Type ↓	SET_d (°C)					SET_n (°C)
	Reference young occupant	Young adults		Older adults		Young / Older adults
		with adaptation	without adaptation	with adaptation	without adaptation	
Residential	1 met & 0.5 clo (wake); 0.7 met & 1.38 clo (sleep)	30 (31.2)	27 (28.2)	28.2 (29.4)	26.8 (29)	30/32
Office	1.1 met & 0.57 clo (wake)	30 (31.2)	27 (28.2)	28.2 (29.4)	26.8 (29)	N/A
High school	1.2 met & 0.57 clo (wake)	30 (31.2)	27 (28.2)	N/A	N/A	N/A
Primary school	1.2 met & 0.57 clo (wake)	27 (28.2)	25 (26.2)	N/A	N/A	N/A
Senior home	1 met & 0.5 clo (wake) 0.7 met & 1.64 clo (sleep)	N/A	N/A	28.2 (29.4)	N/A	32
LTCH	1 met & 0.5 clo (wake) 0.7 met & 1.64 clo (sleep)	N/A	N/A	N/A	26.8 (28)	32
Hospital (Patient room)	1 met & 1.57 clo (wake) 0.7 met & 1.64 clo (sleep)	N/A	27 (28.2)	N/A	26.8 (28)	30/32

***Values of SET between () are for people acclimatized to heat**

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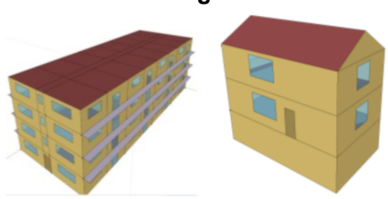
Overheating Limit Criteria

- **Health outcomes**
  - Body dehydration (3% for young and 2% for older)
  - Rehydration rate (water loss replacement): 80% (assumed)
  - Maximum core temperature 37.6°C
- **Criteria for:**
  - Exposure duration Limit
  - Severity Limit
  - Intensity Limit

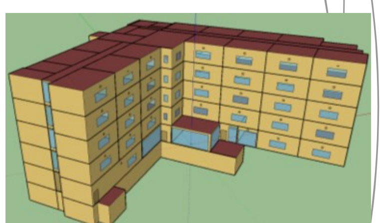
These depend on types of buildings and occupant vulnerability to heat

Application to buildings

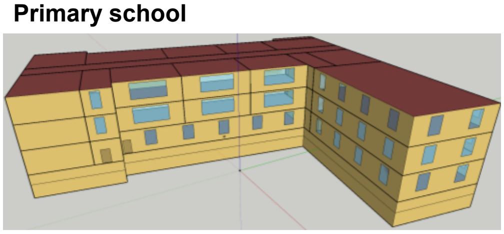
Residential buildings



Long Term Care



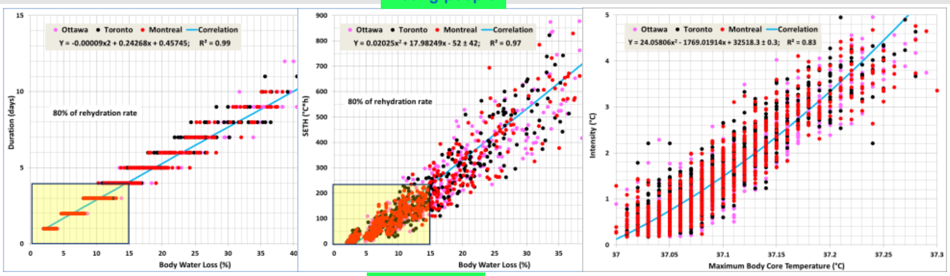
Primary school



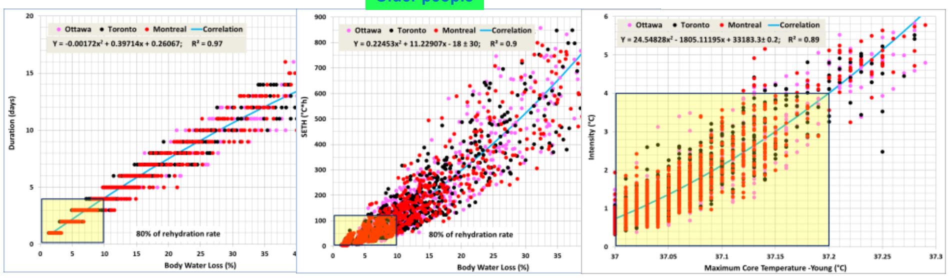
Senior social building

Limit Criteria for overheating: Residential: Independent living style

Young people



Older people



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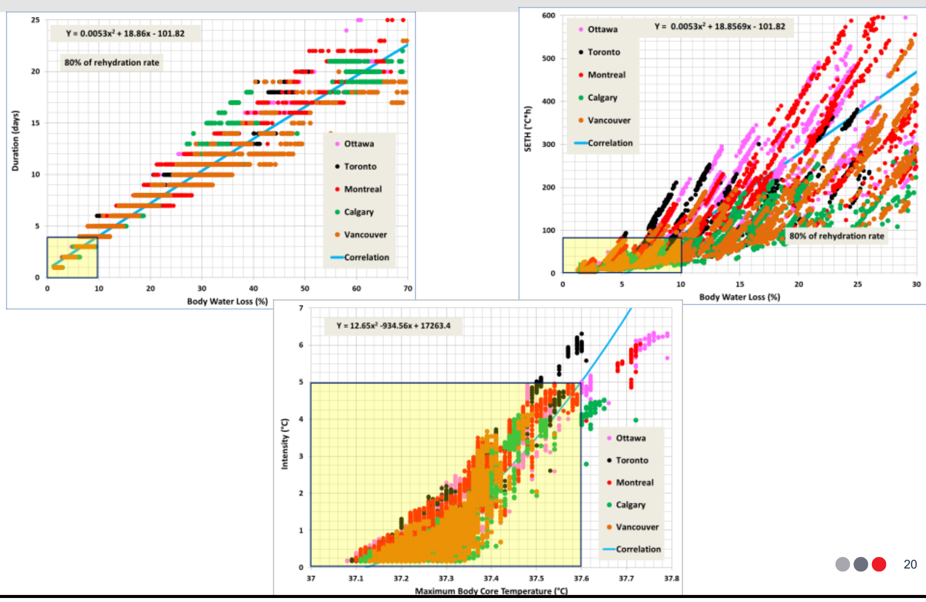
Limit Criteria for overheating: Long Term Care Supported living style



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Application: Long Term Care: New built

- Evaluation of ventilation measures

1. Nighttime mechanical ventilation in common spaces (lounges & halls; 5x min outdoor flow rate)
2. Nighttime ventilation using bedroom exhaust fans
3. Natural ventilation by opening windows if Tin > 28°C & Tout

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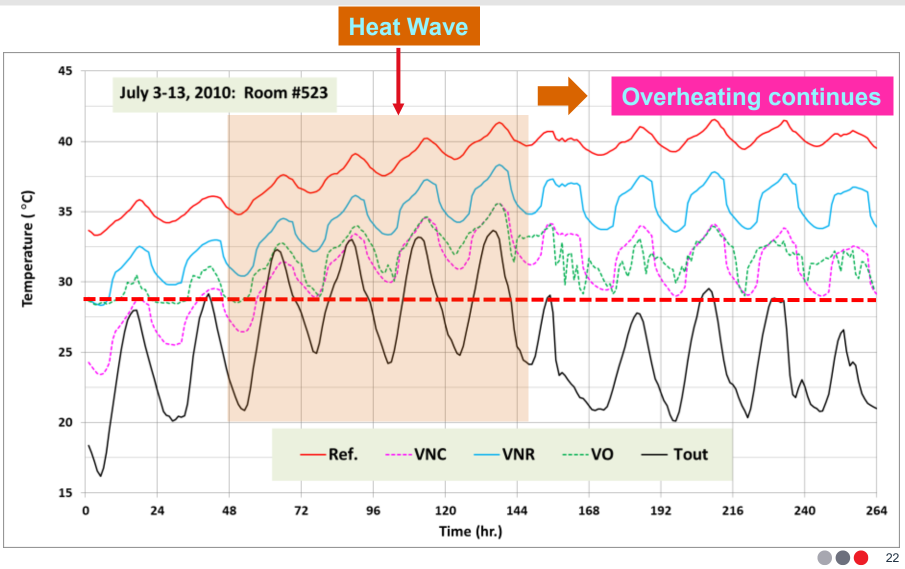
Application: Long Term Care: New Built



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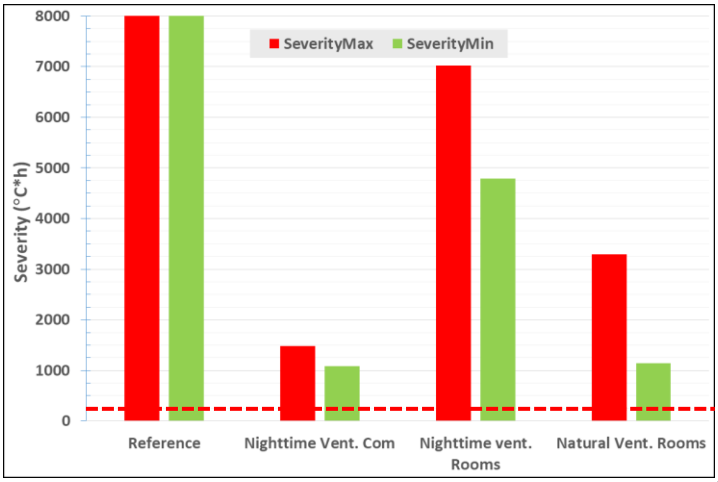
Application: Long Term Care

Note: Newly built LTC will need mechanical cooling



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Conclusion

- **Overheating evaluation will need:**
  - Comfort metrics to accommodate types of building occupants (children, young, older adults)
  - Heat stress metrics to limit any heat- related health injury
- **Proposed overheating metric limits heat-related health problems in terms of:**
  - Exposure duration Limit
  - Severity Limit
  - Intensity Limit
- **Application to LTC shows:**
  - Nighttime mechanical ventilation of the common spaces or opening windows of patient rooms are effective to reduce overheating risk.
  - New built LTC will need mechanical cooling
  - New built LTC without AC should be purged (opening windows) immediately after heat waves

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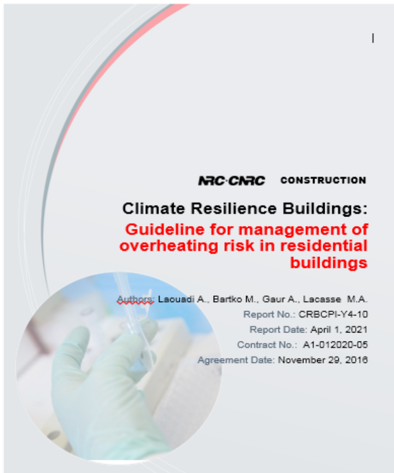
Guideline:

https://nrc-publications.canada.ca/eng/view/object/?id=9c60dc19-ca18-4f4c-871f-2633f002b95c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Climate Resilience Buildings:

Guideline for management of overheating risk in residential buildings

Authors: Laouadi A., Bartko M., Gaur A., Lacasse M.A.

Report No.: CRBCPI-Y4-10

Report Date: April 1, 2021

Contract No.: A1-012020-05

Agreement Date: November 29, 2016

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Thank you

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