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# Visualization of Passive Building Thermal Performance Metrics

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# Overview

- ROCKWOOL continues to support academic research pertaining to passive measures in low energy buildings.
- This presentation is derived from a project focusing on the research and development of a ***Thermal Resilience Design Guide***.
- The work was conducted by Aylin Ozkan under the supervision of Professor Ted Kesik at the University of Toronto.
- Release of the publication will be announced in 2019.



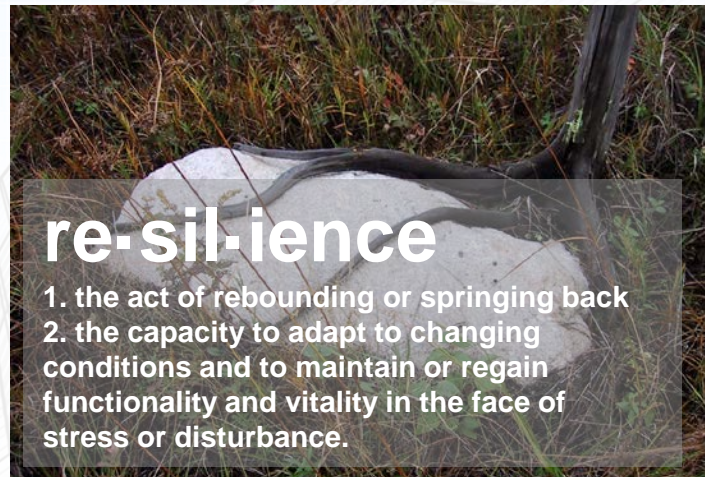
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# What is Resiliency?

Resilience is a complex attribute that is comprised of numerous aspects - some physical, some technical and some social and cultural.

- Architects, engineers and building owners are becoming aware of the urgent need to address resiliency in building design
- Concept goes hand-in-hand with sustainability and safety
- Codes and associations are stepping up to the challenge and beginning to develop guides/standards that address considerations





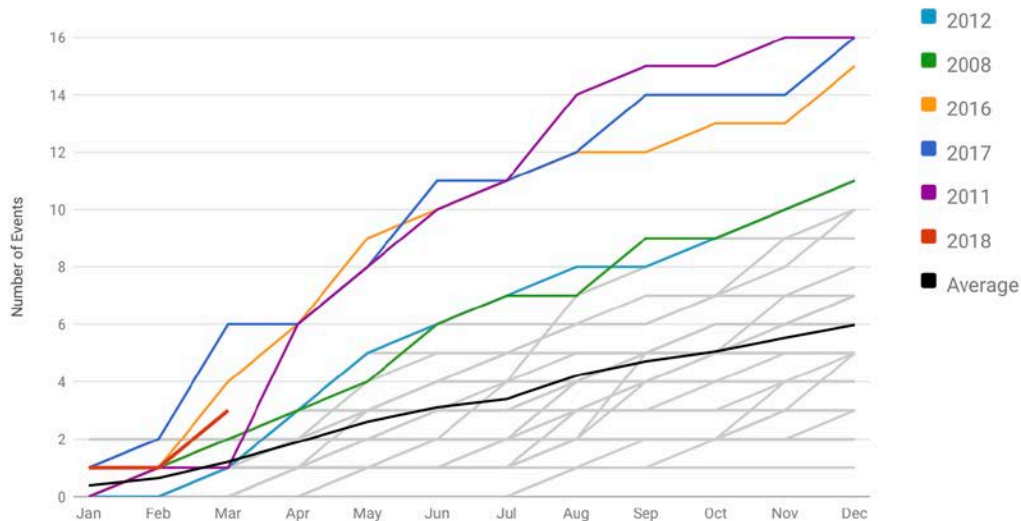
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# Climate Disasters are Escalating

1980-2018 Year-to-Date United States Billion-Dollar Disaster Event Frequency (CPI-Adjusted)

Event statistics are added according to the date on which they ended.



Statistics valid as of April 6, 2018.

Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2018). <https://www.ncdc.noaa.gov/billions/>

- NOAA data indicates a sharp increase in billion-dollar weather and climate disasters that have affected the United States.
- Most of these climate disasters knock out power for extended periods of times.
- Often these events occur during periods of extreme heat and cold.
- Buildings are unable to deliver shelter needs under these conditions.



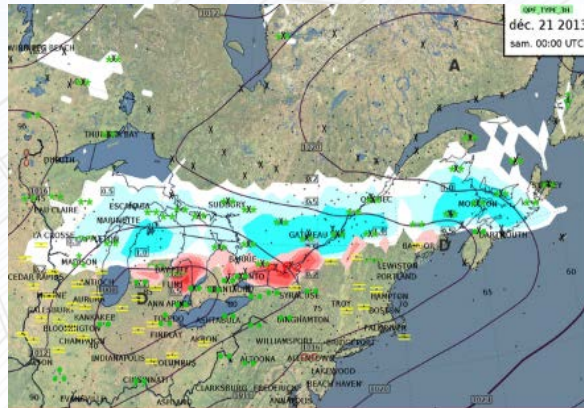
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# Freezing Rain Can Be Deadly

A large North American storm complex impacted the northeastern United States and Canada from December 20 to 23, 2013.

- The storm produced freezing rain and snow to the affected areas which caused massive damage to electric power transmission and trees.
- Many residents had to abandon dwellings that had no heating and quickly became too cold to inhabit.
- The storm resulted in 27 deaths, loss of power to over a million of residents and over \$200 million in damages.



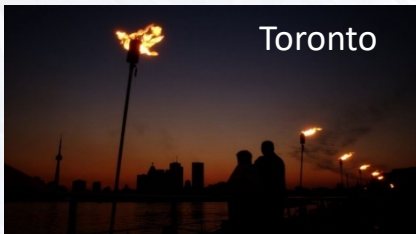
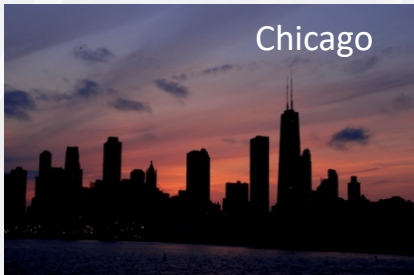


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# Beware Power Outages During Heat Waves



- Northeast blackout of 2003 is the ninth-largest major power outage in the world affecting 55 million people.
- The outage lasted from 1 to 5 days during a period of extreme hot weather.



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**At the peak of winter or summer, our new housing will become uninhabitable within several hours after the grid goes down.**

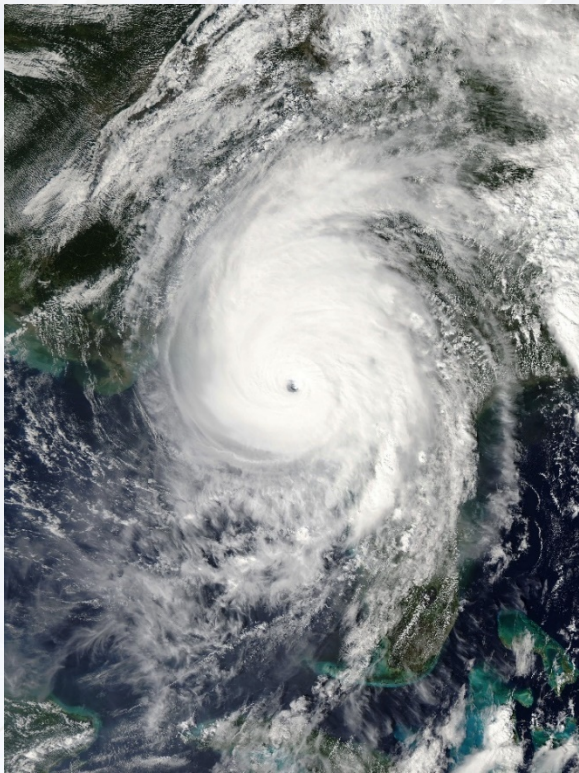




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# Futureproofing



- Our communities will continue to get hit as the frequency and severity of extreme weather events keeps dramatically increasing.
- Infrastructure delivering vital services to our communities is aging and therefore more susceptible to failure.
- Thermal resilience is a critical and cost effective strategy that is easy to deploy and will help keep inhabitants safe.
- It will also help preserve the integrity and value of our building assets.



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# Research Context

- Buildings are complex systems.
- Metrics are difficult to interpret by designers.
- Early stages design decisions are important for thermal resilience.
- Conveying energy performance to designers is critical.





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# Need

- Practical approaches and graphical feedback methods.
- Suitable performance metrics and indicators.
- Simpler evaluations for passive systems integration and optimization.



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# Outline

- Visualization of passive performance parameters;
  - thermal autonomy
  - passive survivability (aka thermal resilience).
- Are these parameters suitable to inform the early stages of design by architects?
- Are passive performance metrics reliable indicators of energy efficiency, comfort and resilience?



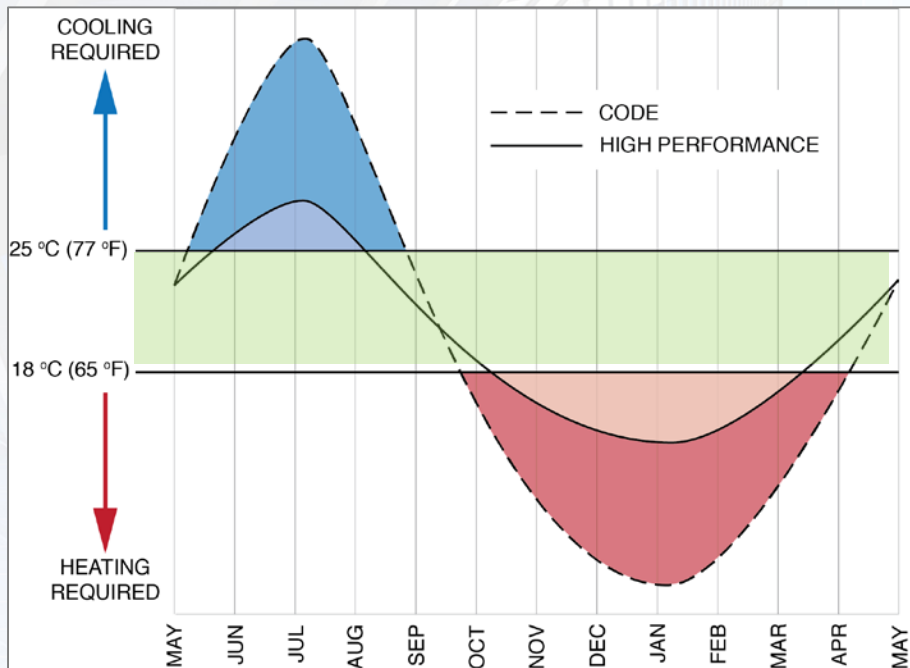


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# What is Thermal Autonomy?



- Measure of the fraction of time a building can passively maintain comfort conditions without active system energy inputs.
- “Free-run” simulations with zero active heating and cooling system inputs.



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# What is Passive Survivability?



Source: *Baby It's Cold Inside*. Urban Green Council New York, 2014.  
<http://urbangreencouncil.org/babyitscoldinside>

A measure of the duration of time that a building remains habitable following a prolonged power outage over an extended period of extreme weather.



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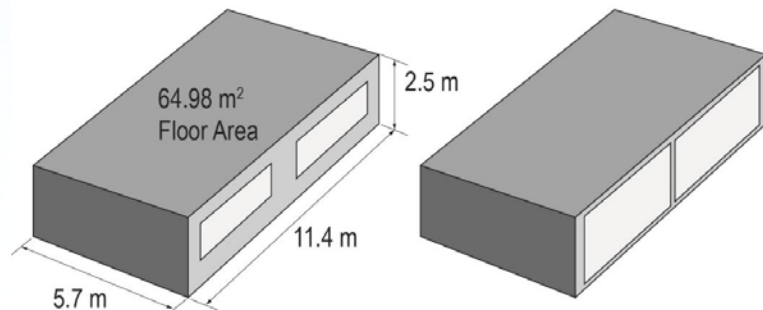
# Methodology

Orientation	South	West	North	East
WWR (%)	40		80	
Wall U-Value (W/m <sup>2</sup> . K)	0.247	0.210	0.180	
Glazing U-Value (W/m <sup>2</sup> . K)	2.50	1.70	1.00	
Glazing SHGC	0.45	0.35	0.25	

Parameters and corresponding values used to perform energy simulations.

**40% WWR**

**80% WWR**



Typical Suites modeled with EnergyPlus using Toronto climate data.



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# Passive Design Strategies

**Base Case:** Minimum envelope requirements

**Case 1:** Minimum **U-Value requirements** of envelope, and higher **SHGC** of glazing.

**Case 2:** Minimum envelope requirements with **movable insulation panels**.

**Case 3:** Better / average envelope properties.

**Case 4:** High performance envelope properties.

**Case 5:** High performance envelope properties and balcony overhang with **bridge**.

**Case 6:** High performance envelope properties and **balcony overhang with break**.

**Case 7:** High performance envelope properties and **enclosed balcony**.

**Case 8:** High performance envelope properties and **operable shading**.

**Case 9:** High performance envelope properties, operable shading and **natural ventilation from 20% glazing area opening**.

**Case 10:** High performance envelope properties, operable shading and **natural ventilation from 5% glazing area opening**.

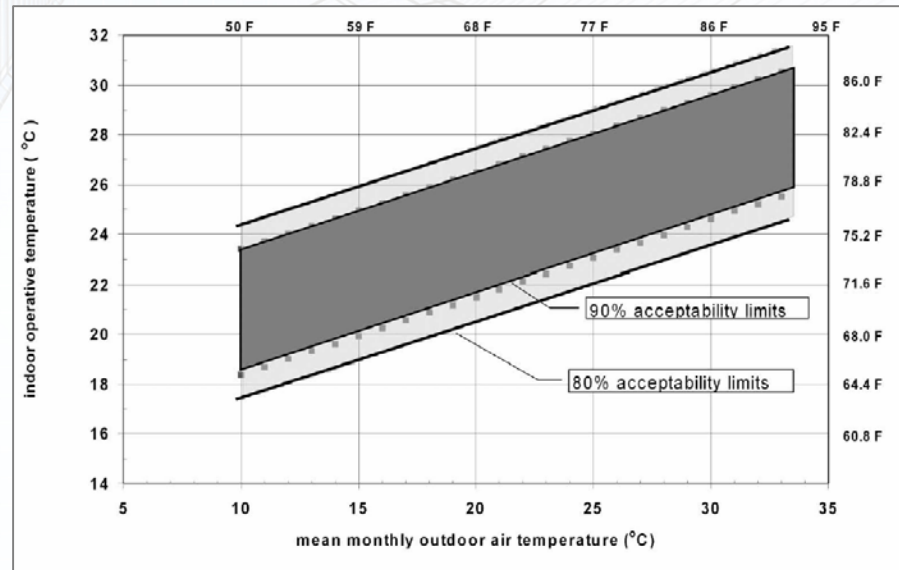


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# Passive Buildings Comfort Modelling

- Adaptive Comfort Model: allowable operative temperature limits may not be extrapolated to the mean monthly outdoor temperatures above 33.5°C (92.3°F) and below 10°C (50°F).
- For PS: Operative temperatures above 30°C (86°F) and below 15°C (59°F) represent a health warning trigger for elderly morbidity.





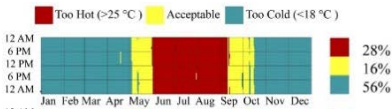
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# Thermal autonomy visualization

A north-facing unit with an 80% (WWR).

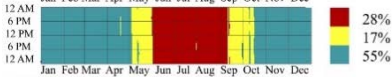
**Base Case:** Min. Envelope



**Case 1 :** Min. Envelope +  
High SHGC



**Case 2:** Min. Envelope +  
Movable Insulation Panel



**Case 3:** Average Envelope



**Case 4:** High Performance Env.



**Case 5:** High Performance Env. +  
Balcony with Bridge



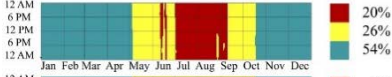
**Case 6:** High Performance Env. +  
Balcony with Break



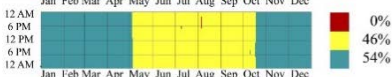
**Case 7:** High Performance Env. +  
Balcony Enclosure



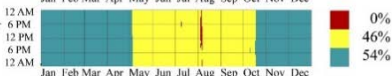
**Case 8:** High Performance Env. +  
Operable Shading



**Case 9:** High Performance Env. +  
Operable Shading + NV 20%



**Case 10:** High Performance Env. +  
Operable Shading + NV 20%





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## Thermal autonomy visualization

A north-facing unit with an 80% (WWR).

**Base Case:** Min. Envelope

**Case 1 :** Min. Envelope +  
High SHGC

**Case 2:** Min. Envelope +  
Movable Insulation Panel

**Case 3:** Average Envelope

**Case 4:** High Performance Env.

**Case 5:** High Performance Env. +  
Balcony with Bridge

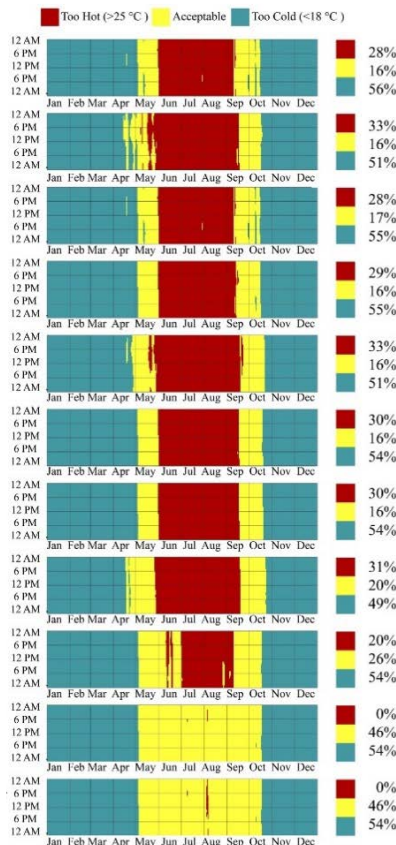
**Case 6:** High Performance Env. +  
Balcony with Break

**Case 7:** High Performance Env. +  
Balcony Enclosure

**Case 8:** High Performance Env. +  
Operable Shading

**Case 9:** High Performance Env. +  
Operable Shading + NV 20%

**Case 10:** High Performance Env. +  
Operable Shading + NV 20%



A south-facing unit with a 40% (WWR).

**Base Case:** Min. Envelope

**Case 1 :** Min. Envelope +  
High SHGC

**Case 2:** Min. Envelope +  
Movable Insulation Panel

**Case 3:** Average Envelope

**Case 4:** High Performance Env.

**Case 5:** High Performance Env. +  
Balcony with Bridge

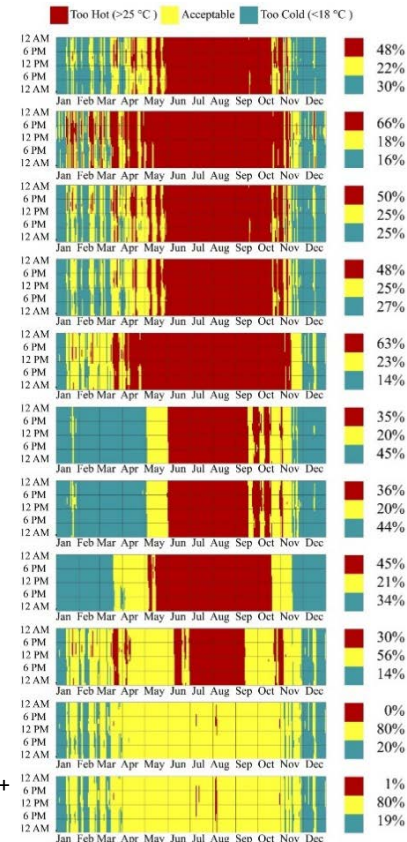
**Case 6:** High Performance Env. +  
Balcony with Break

**Case 7:** High Performance Env. +  
Balcony Enclosure

**Case 8:** High Performance Env. +  
Operable Shading

**Case 9:** High Performance Env. +  
Operable Shading + NV 20%

**Case 10:** High Performance Env. +  
Operable Shading + NV 20%



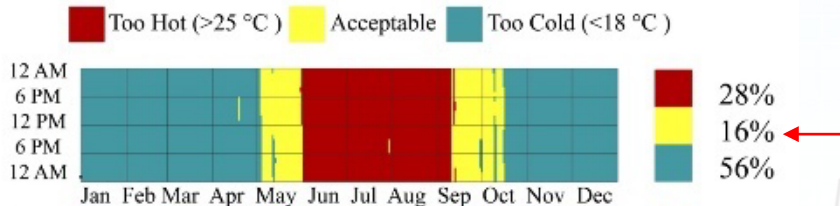


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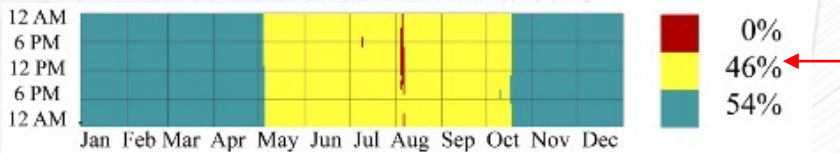
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# Thermal autonomy for apartment suites varies with WWR and solar orientation

## NORTH- 80% WWR

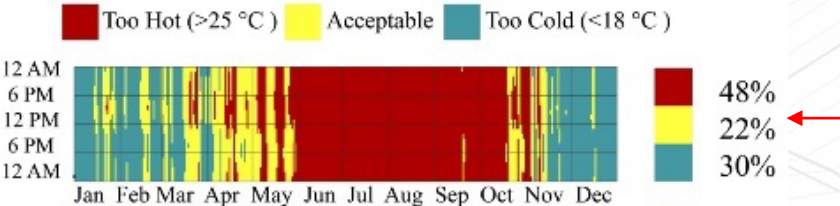


Envelope with min. code requirements

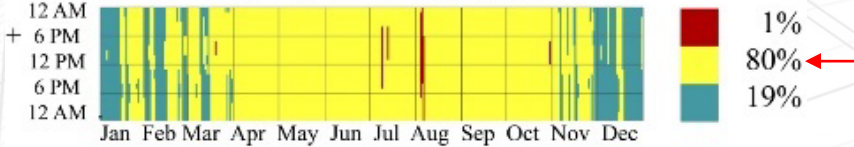


High Performance envelope  
with a shading and natural ventilation

## SOUTH- 40% WWR



Envelope with min. code requirements



High Performance envelope  
with a shading and natural ventilation



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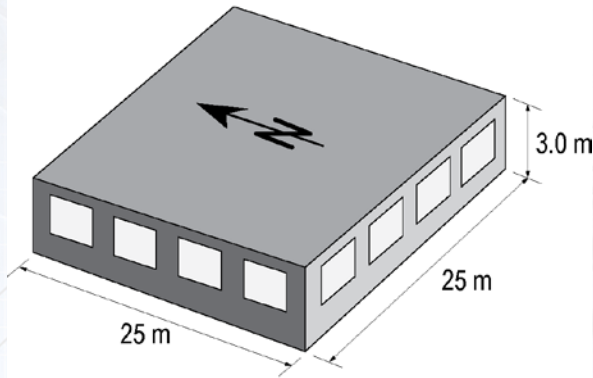
# TA analysis for whole building reveals upper limits for passive systems

- Toronto (Zone 6) is difficult to practically achieve a thermal autonomy above 50%.
- Thermal autonomy over the entire cooling season is achievable, but heating season thermal autonomy is limited.

## Whole Building Modelling

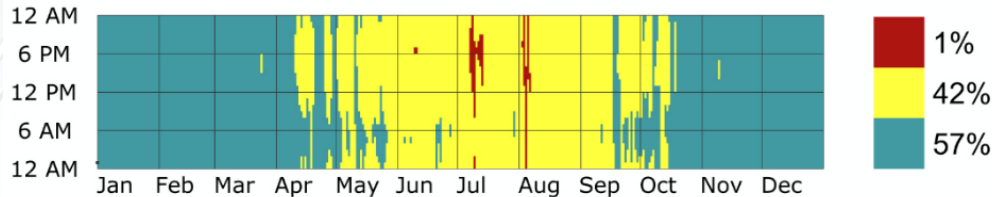
Two thermal mass levels investigated:

- 1) Reinforced Concrete Construction;
- 2) Wood Timber Frame Construction.



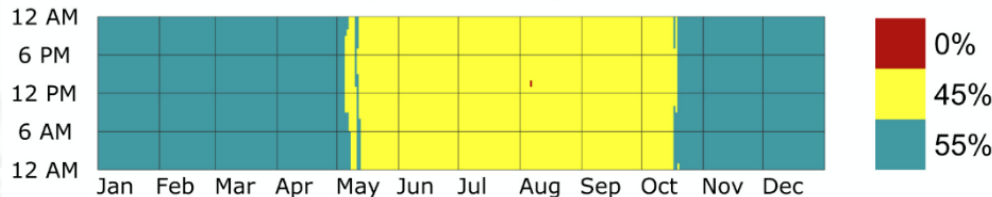
40%, 60% and 80% window-to-wall ratios (WWR).

■ Too Hot ( $>25^{\circ}\text{C}$ ) 
 ■ Acceptable 
 ■ Too Cold ( $<18^{\circ}\text{C}$ )



## TORONTO - Timber Frame Construction 40% WWR

High Performance Envelope + Operable Shading + Natural Ventilation



## TORONTO - Concrete Construction 40% WWR

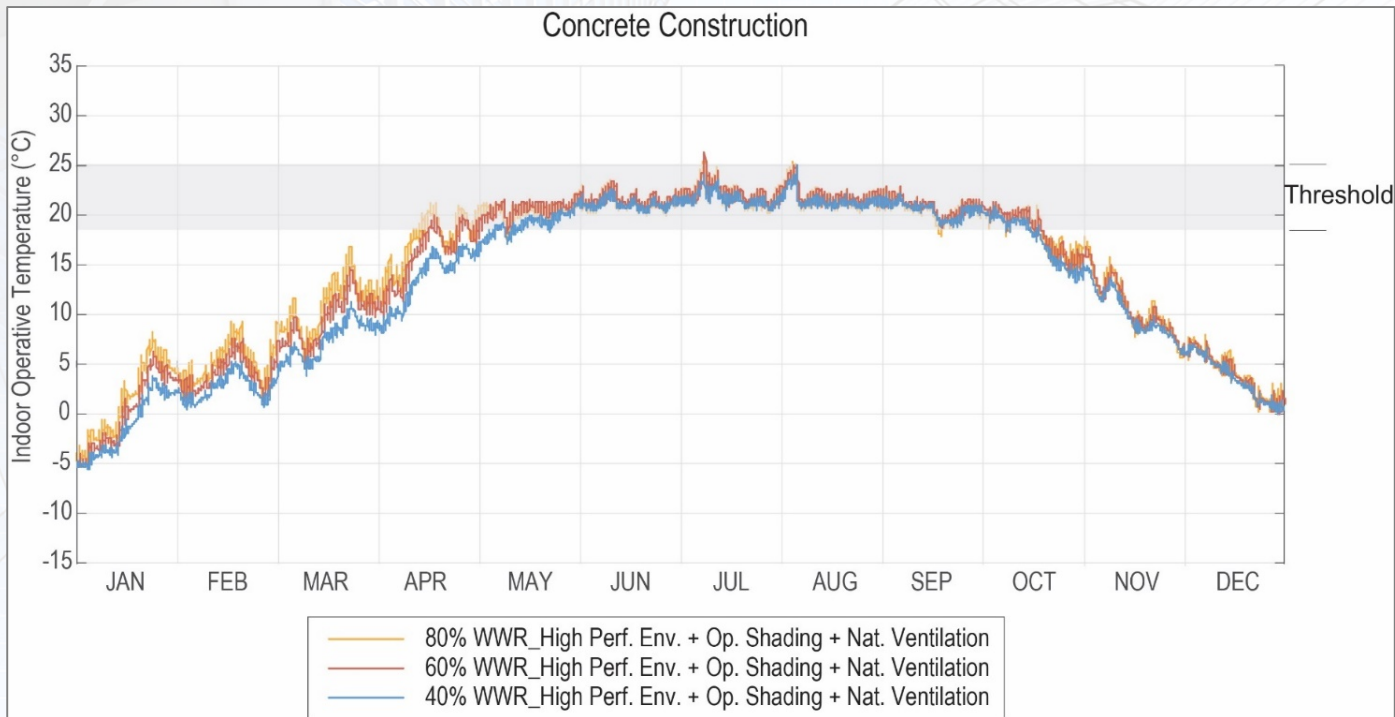
High Performance Envelope + Operable Shading + Natural Ventilation



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Concrete construction delivers a narrow band of daily temperature swings due to the thermal mass effect and an extreme minimum indoor temperature of  $-5^{\circ}\text{C}$  ( $23^{\circ}\text{F}$ ).

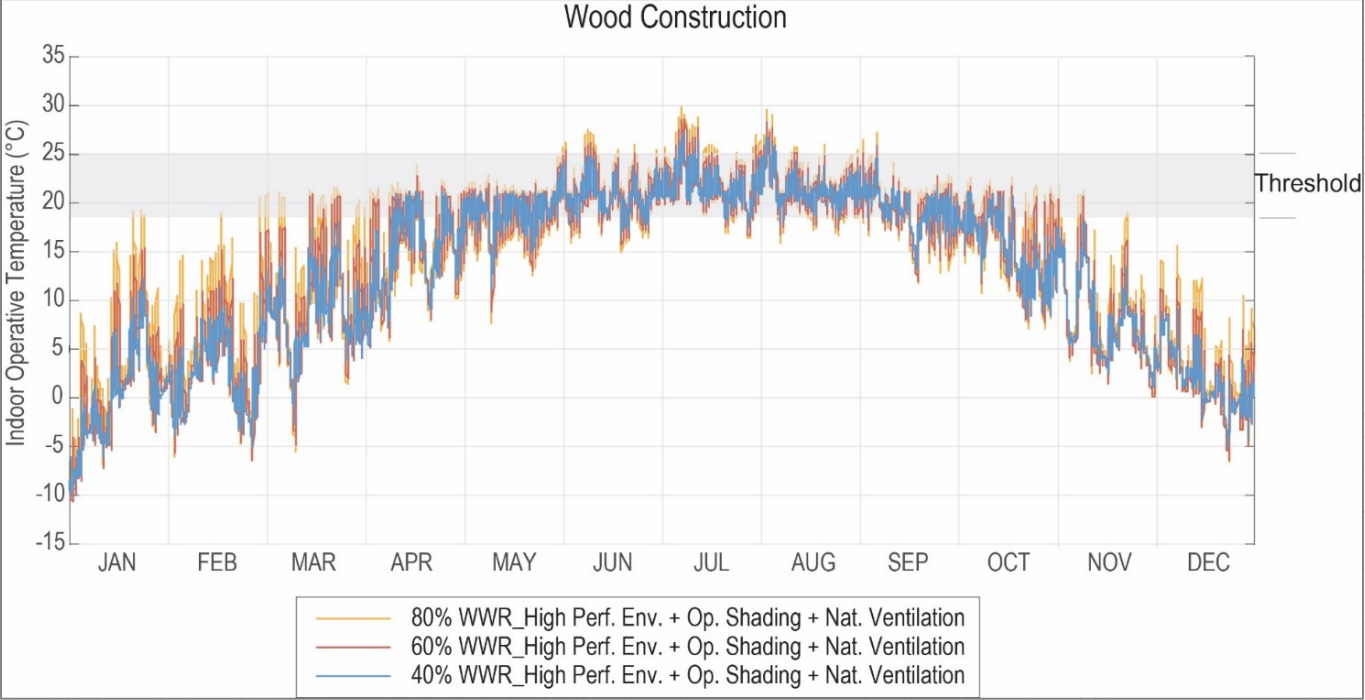




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Timber construction has a much higher range of daily temperature swings and both extreme minimum and maximum indoor temperatures.





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# Energy, Loads and Temperatures Analysis

## ENERGY DEMANDS FOR SPACE HEATING AND COOLING

### TORONTO - 40% WWR

	Annual Space Heating (kWh)	Space Heating Site EUI (kWh/m <sup>2</sup> .yr)	Peak Heating Demand kW	Annual Space Cooling (kWh)	Space Cooling Site EUI (kWh/m <sup>2</sup> .yr)	Peak Cooling Demand kW	Total Site EUI (kWh/m <sup>2</sup> .yr)
Concrete Code Minimum Envelope	18247.9	30.9	10.9	5353.4	9.1	8.3	40.0
Concrete High Performance + Operable Shading + Natural Ventilation	10034.5	17.0	6.1	0.0	0.0	0.0	17.0
Wood Code Minimum Envelope	19967.2	33.8	12.6	7795.2	13.2	12.4	47.1
Wood High Performance + Operable Shading + Natural Ventilation	11115.6	18.8	7.0	118.1	0.2	3.1	19.0

## THERMAL AUTONOMY TEMPERATURES ANALYSIS

### TORONTO - 40% WWR

	Indoor Operative Temperatures (°C)			
	Extreme Minimum	Extreme Maximum	Average Minimum	Average Maximum
Concrete Code Minimum Envelope	-8.5	37.8	8.6	29.6
Concrete High Performance + Operable Shading + Natural Ventilation	-5.8	25.1	8.1	21.2
Wood Code Minimum Envelope	-11.8	45.7	5.5	34.7
Wood High Performance + Operable Shading + Natural Ventilation	-10.1	27.7	6.3	22.5

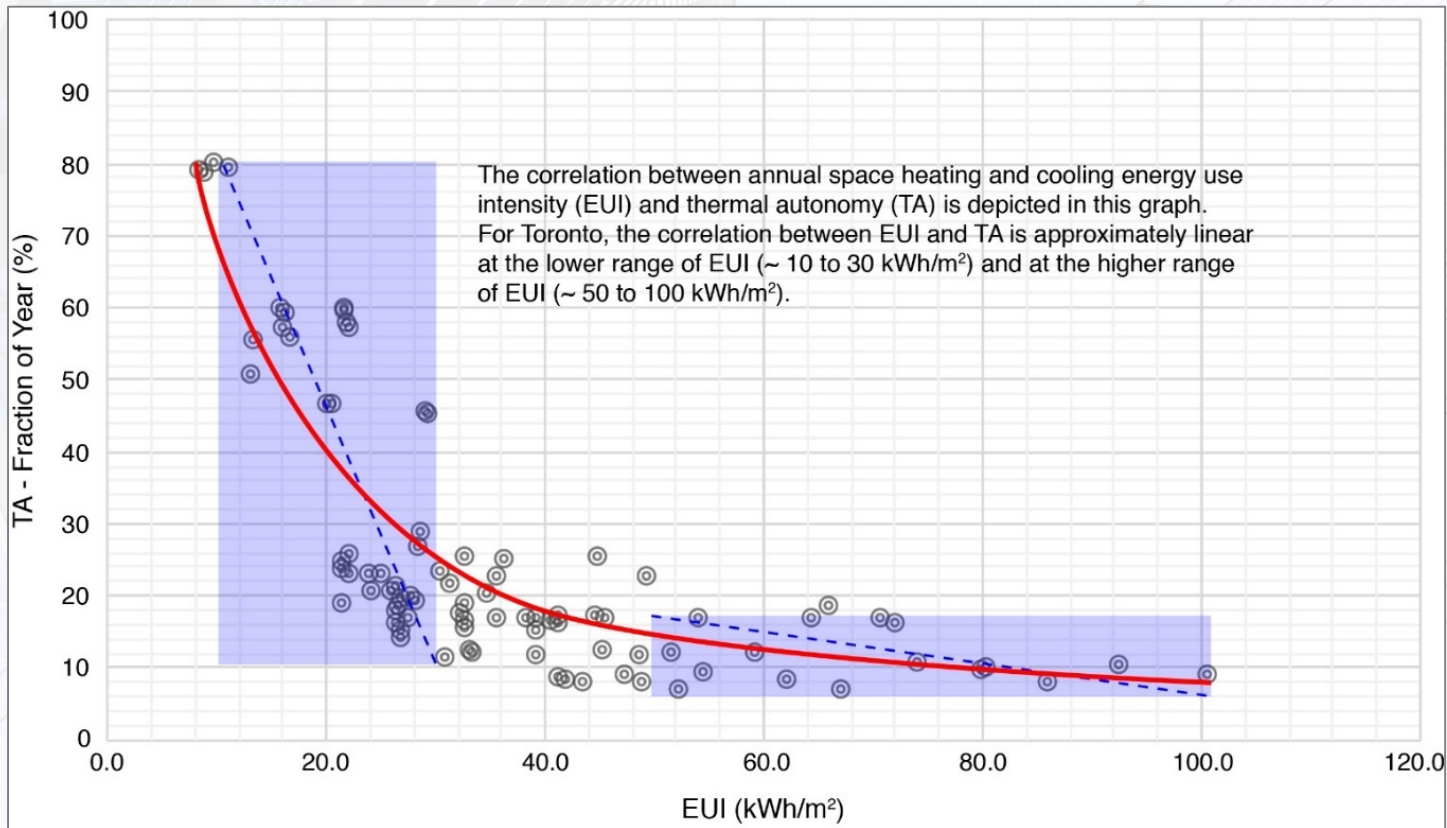


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# Correlation Between EUI and TA

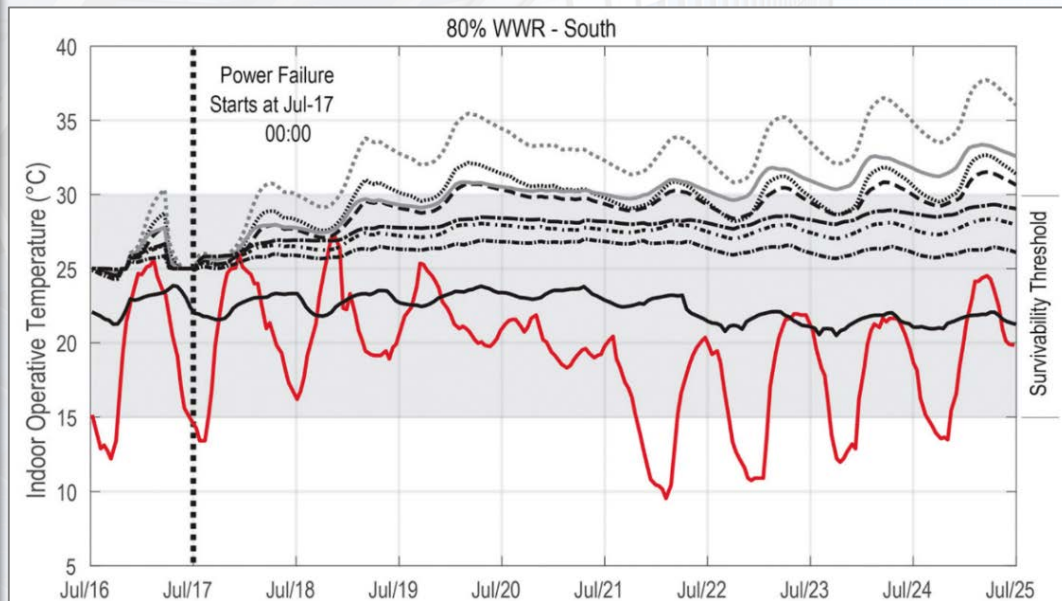




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# Hot Weather Passive Survivability



- Minimum Envelope (38 h)
- Min. Env. + High SHGC (15 h)
- Average Envelope (61 h)
- High Performance Envelope (59 h)
- High Perf. Env. + Balcony with Break (all h)
- High Perf. Env. + Balcony Enclosure (all h)
- High Perf. Env. + Operable Shading (all h)
- High Perf. Env. + Op. Shading + Nat. Ventilation (all h)
- Outdoor Drybulb Temperatures

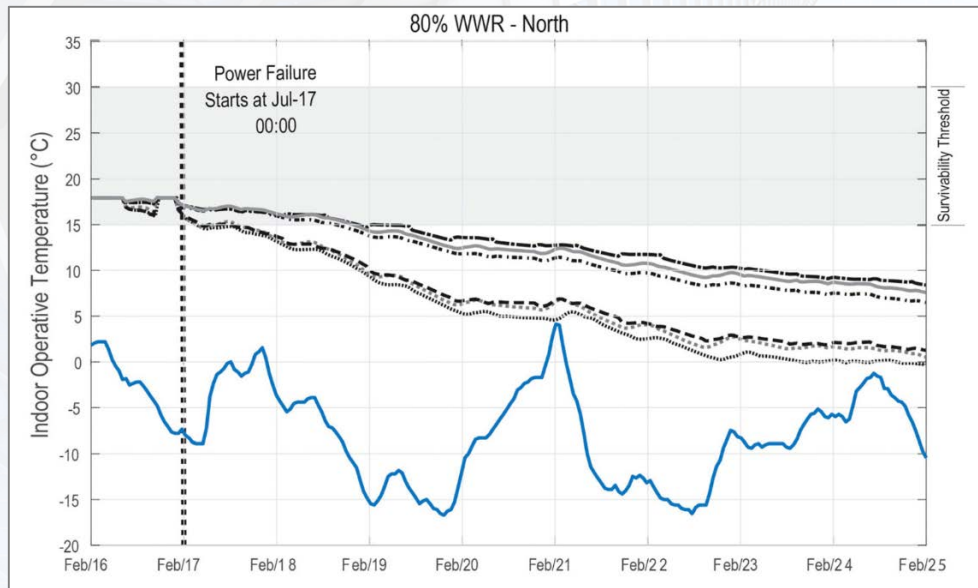
Operable shading and natural ventilation combined with a high performance envelope deliver superior Passive Survivability.



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# Cold Weather Passive Survivability



- Minimum Envelope (6 h)
- Min. Env. + High SHGC (7 h)
- Average Envelope (19 h)
- High Perf. Env. + Balcony with Break (35 h)
- High Performance Envelope (42 h)
- High Perf. Env. + Operable Shading (42 h)
- High Perf. Env. + Op. Shading + Nat. Ventilation (42 h)
- High Perf. Env. + Balcony Enclosure (44 h)
- Outdoor Drybulb Temperatures

Several hours for Code versus several days for high performance.



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# Conclusions from Research

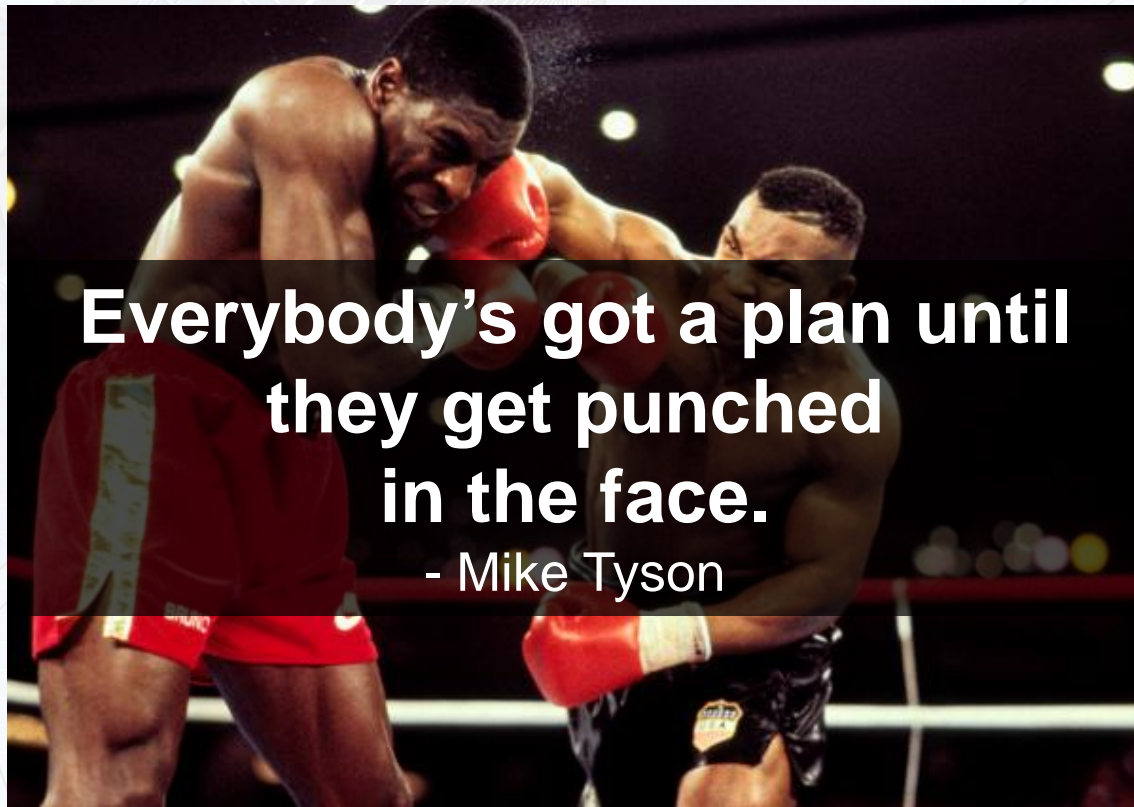
- The visualization of time-based metrics of thermal autonomy and passive habitability are effective early stage design tools.
- Thermal autonomy is well correlated with passive survivability and energy use intensity metrics.
- Consensus benchmarks are needed for the consistent application of time-based metrics in energy modelling.
- There is still a need to define comfort thresholds that are appropriate for the analysis of only-passive measures in naturally ventilated buildings.



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**Everybody's got a plan until  
they get punched  
in the face.**

**- Mike Tyson**



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# Critical Considerations

The research indicates that acceptable thermal autonomy and passive survivability performance demand:

- **Overall Effective Thermal Resistance** – higher than code minimum levels of thermal insulation are needed to achieve a high performance building envelope with acceptable thermal autonomy.
- **Airtightness** – Air leakage cannot be allowed to “short-circuit” the thermal insulation.
- **Window-to-Wall Ratio (WWR)** – excessive glazing areas make it difficult to achieve acceptable TA and PH performance.
- **Natural Ventilation and Shading Devices** – both are necessary to achieve acceptable hot weather performance.



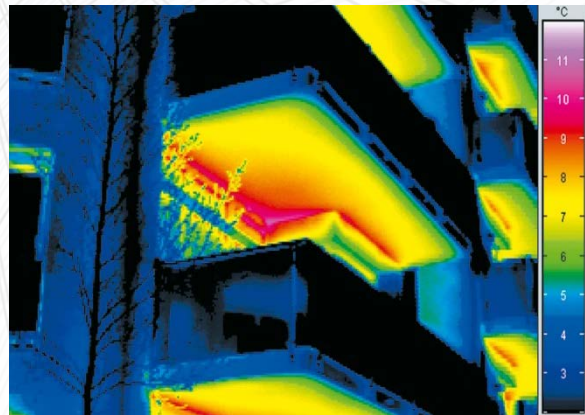
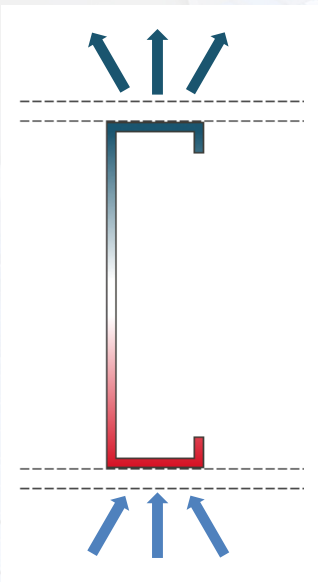
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# Thermal Bridging

A material with higher thermal conductivity transferring heat through an assembly with substantially lower thermal conductivity





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**Thermal bridging can reduce insulation effectiveness by 50% and more, causing the best insulation products to underperform.**



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# Thermal Insulation Effectiveness

- Thickness, type and placement of insulation
- Continuous exterior insulation for optimal performance
- Cladding attachment considerations:
  - Wind & seismic loads
  - Back-up wall construction (wood, concrete, steel)
  - Cladding orientation (panel, vertical, horizontal)
  - Ease of attachment of cladding – returns, corners etc.
  - Combustibility requirements





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# Integrated Air Barrier Systems

- Air barriers must be structural and continuous across all transitions
- Special attention to window opening and penetrations
- Air barriers must be buildable and easy to inspect
- Airtightness testing is essential



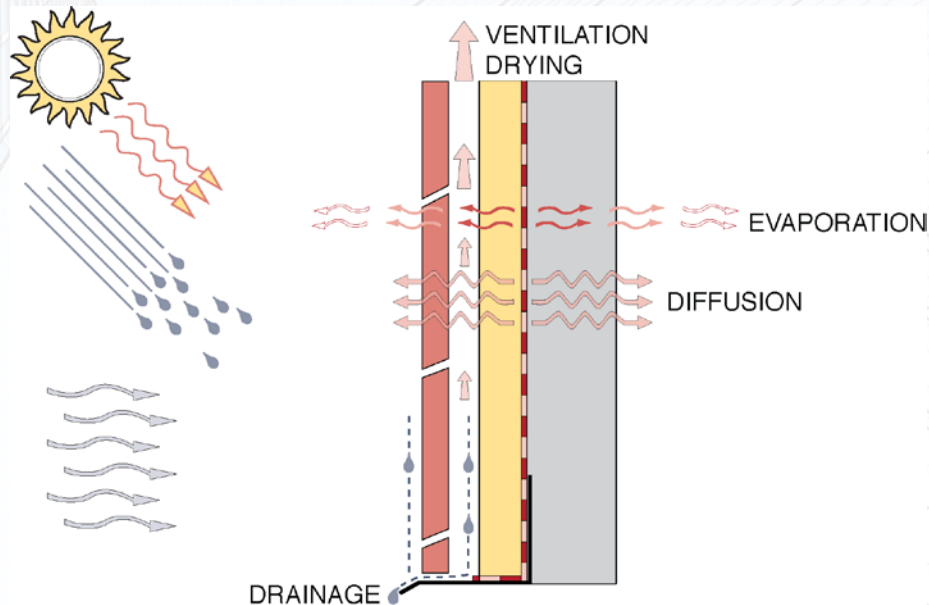


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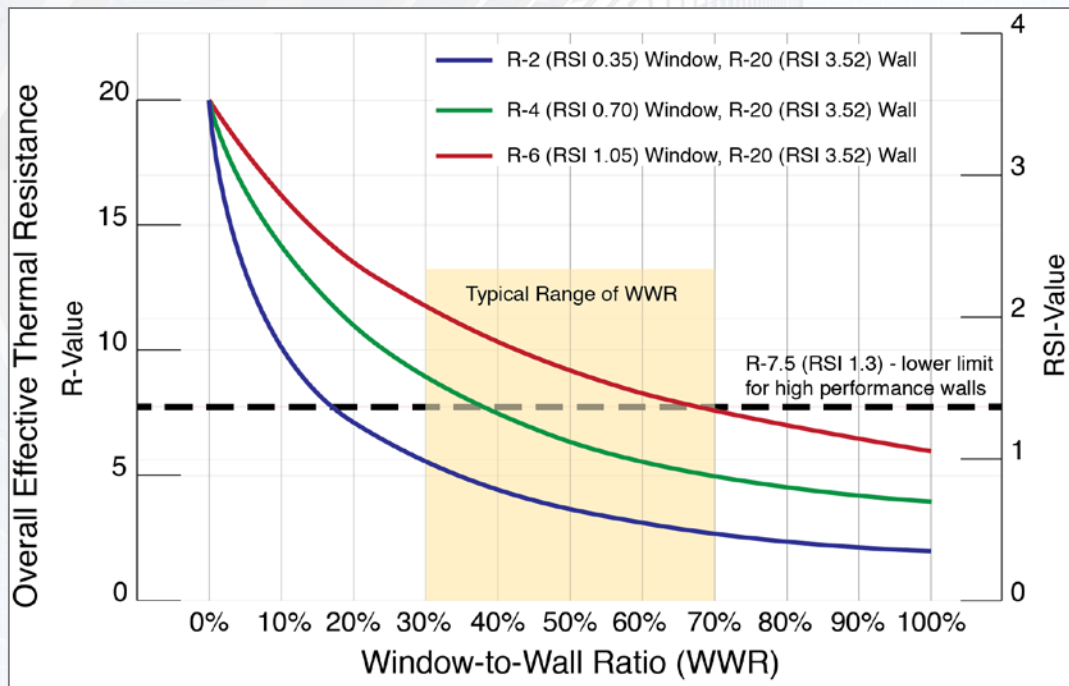
# Durable/Moisture Tolerant Enclosures

- Hygrothermal properties must allow for drying without excessive moisture accumulation.
- Consider wetting mechanism
- Consider vapor retarder requirements based on climate (interior vs. exterior)
- Consider permeability of all materials (permeable vs impermeable)





# Manage Window-to-Wall Ratios



Overall effective thermal resistance for walls generally corresponds to recommended levels for entire enclosure.

- High performance windows combined with thermally efficient opaque enclosures permit ample window-to-wall ratios without compromising TA and PH.



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# Extreme Weather Reveals Inferior Enclosures





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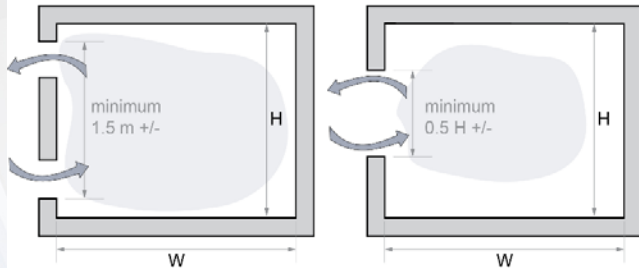
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# Natural Ventilation and Shading Devices

## Natural Ventilation Rules of Thumb

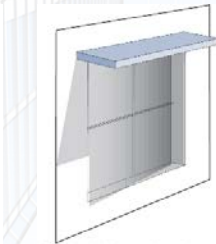
### Single Sided Ventilation

- $W$  (depth)  $< 2.5 H$
- Separate high/low windows more effective than a single opening
- Opening size not less than 5% of floor area (10% with screens)



### Cross Ventilation

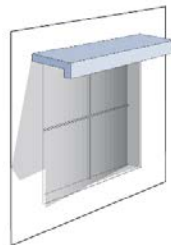
- $W$  (depth)  $< 5 H$
- Separate high/low windows more effective than a single opening
- Opening size, not less than 5% of floor area (10% with screens)



Standard horizontal overhang.



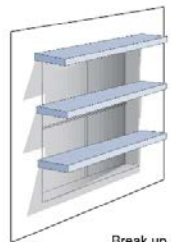
Vertical louvers or fins for east and especially west facades.



Drop the edge for less projection.



Slope it down for less projection.



Break up an overhang for less projection.



- Natural ventilation and shading devices are critical to hot weather passive habitability.
- In colder climates zones (5, 6, 7 and 8) the need for space cooling can be virtually eliminated (dehumidification only required).



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In addition to providing shading and privacy, external louvers and shutters also offer protection against wind-borne projectiles during extreme weather events.



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# Thank you



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