Disclosure Statement

- I have no affiliation (financial or otherwise) with a pharmaceutical, medical device or communications organization.

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Framework for Analysis of Overheating Risk in Buildings

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Introduction

- **Overheating in buildings is a growing health concern in many countries;**
- **Overheating indicates the indoor conditions that result in discomfort or health issues for building occupants;**
- **Overheating is found in non-AC buildings, buildings having intermittent use of AC, or when power outages or HVAC failures occur;**
- **Current building code does not address overheating or thermal resilience;**
- **This work is a part of project to develop guidelines for the thermal resilience of buildings;**
- **Purpose of presentation: Describe the development of a framework to analyze overheating risk in buildings.**

Reference climate data

- **Reference climate data are necessary to conduct overheating risk analysis;**
- **NRC in collaboration with ECCC developed reference weather data for historical climate and seven scenarios (ΔT = 0.5 to 3.5°C) of projected climate for major Canadian cities;**
- **31 year period is used to capture types of extreme heat events of climate;**
- **Historical weather data are based on observations and reanalysis data;**
- **Projected weather data are based on bias-corrected ECCC's Regional Climate Models (RCM);**
- **Reference weather data are available for sharing with interested parties**

Metric for heat related stress of humans

- **There are many metrics for healthy and young adults;**
- **NRC developed screening criteria to select suitable metrics;**
- **Short listed metrics:**

1. Humidex (**H**); adopted in Canadian weather services;
2. Wet-Bulb Globe Temperature (**WBGT**); adopted in OHS & ISO 7243 standards;
3. Predicted Heat Strain (**PHS**); adopted in ISO 7933;
4. Universal Thermal Climate Index (**UTCI**);
5. Standard Effective Temperature (**SET**); adopted in ASHRAE-55.

Selected Metric

- **Selected the SET index**
- **Added modifications to SET:**
  - **Transient (effect of past events is carried over to current events);**
  - **Thermoregulatory controls for a sleeping person (lower sweating);**
  - **ISO 7933 algorithms for time limit of exposure (3% of body water loss);**

Selection criteria of indices

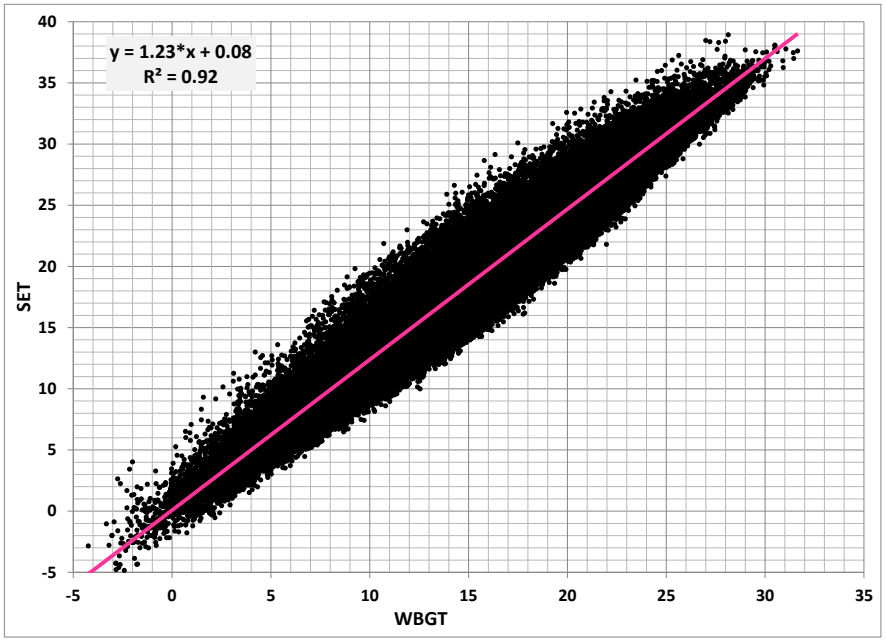
Criterion	SET	UTCI	PHS	WBGT	H
Physiological	yes	no*	no	no	no
Climate variables	yes	yes	yes	yes	T, RH
Subject variables	yes	fixed	yes	no*	no
Transient	yes	no	yes	no	no

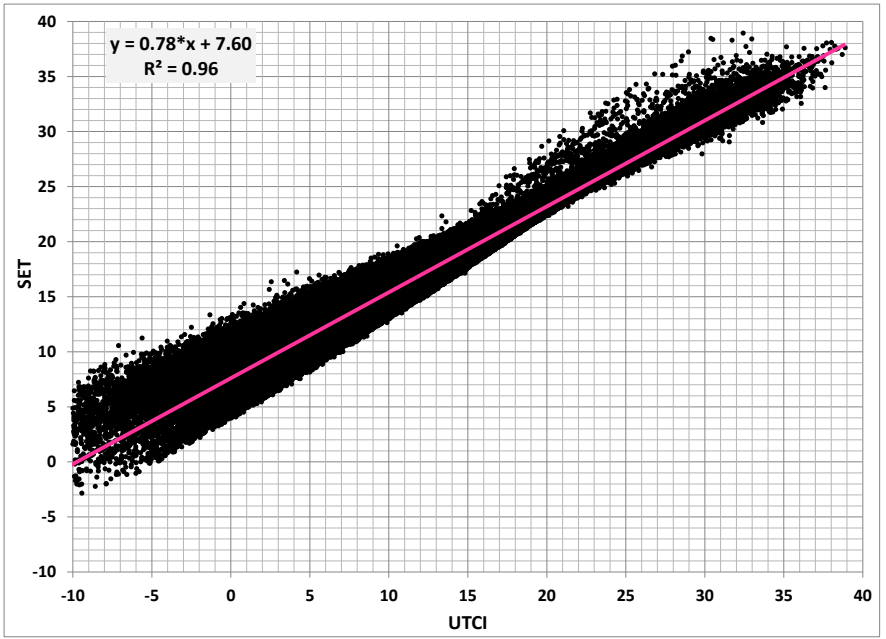
SET (°C)	Physiological state
> 37.5	Failure of thermoregulation
34.5 - 37.5	Profuse sweating
30.0 - 34.5	Sweating
25.6 - 30.0	Slight sweating, vasodilation
22.2 - 25.6	Neutrality

SET scale

Comparison of SET with UTCI & WBGT

Person walking outdoors in summer under sun shade



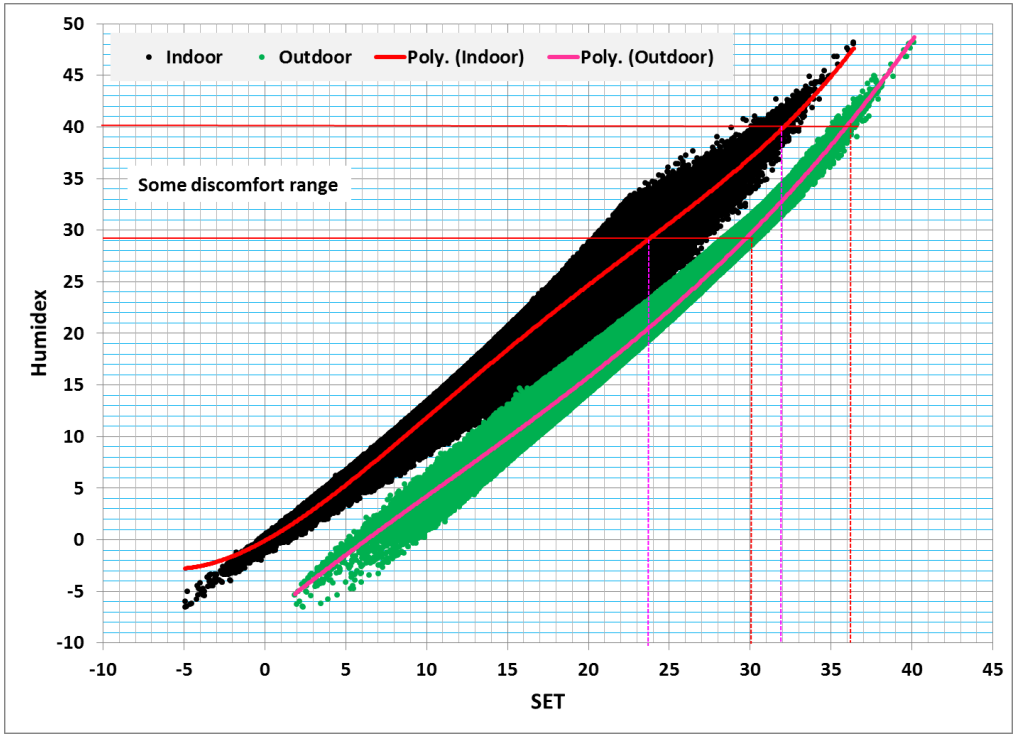


Comparison of SET with Humidex

Person walking outdoors with no wind and sun; or sedentary indoors:

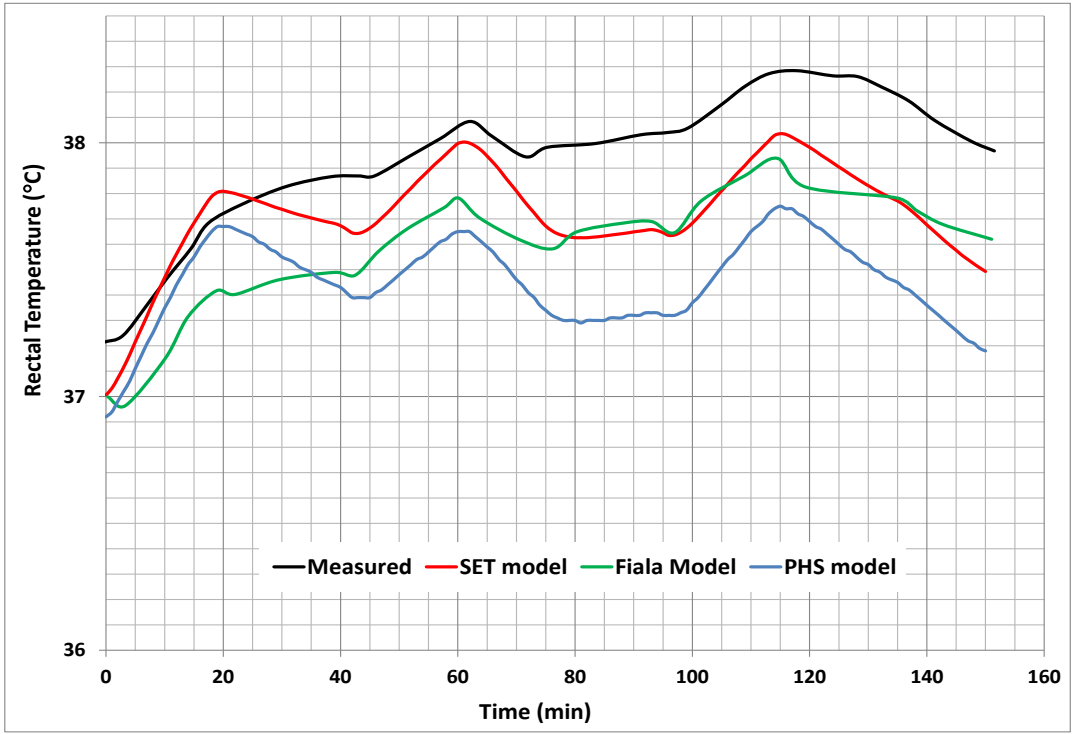
- Humidex values are appropriate for indoor exposure;
- Humidex for outdoor exposure should be corrected:

$$H_{ext} = H_{in} - \text{several units}$$



Validation of SET with Experiments

Laboratory experiments* for female subjects undergoing 13 intermittent activities from cycling, stacking, stepping, and resting in an environment of T = 34°C, RH = 60%



* **Source**: Lundgern-Kownacki et al. (2017)

Definition of heat waves

- **There is no worldwide-accepted definition of heat waves**
- **NRC defines heat waves as continuous meaningful heat events that occur over at least two days;**
- **Meaningful heat event occurs daily over at least a prescribed number of hours and triggers a response of the thermoregulatory system of human subjects under its exposure;**
- **Multiple heat waves are separated by a recovery period of at least one day;**
- **Subjects are assumed walking outdoors under sun shade during daytime and sleeping indoors during nighttime;**

Characteristics of heat waves

- **Severity (degree SET*hour) =** $\sum_{days}(SETH_{night}+SETH_{day})$
  - $SETH_{day} = \sum_{daytime}(SET - SET_{awake}) \cdot \Delta t$
  - $SETH_{night} = \sum_{nighttime}(SET - SET_{sleep}) \cdot \Delta t$
  - SET_{sleep} : corresponds to lower bound of adaptive comfort temp. (varies by month & location)
  - SET_{awake} : 30°C (un-acclimatized person); 31.2 °C (acclimatized)
- **Duration (days) : number of days with** $SETH_{day}$ **> 4 (→ min. body water loss of 1.2%)**
- **Intensity (degree SET) = Severity / Duration / 24**
- **Three types of extreme heat waves are identified:**

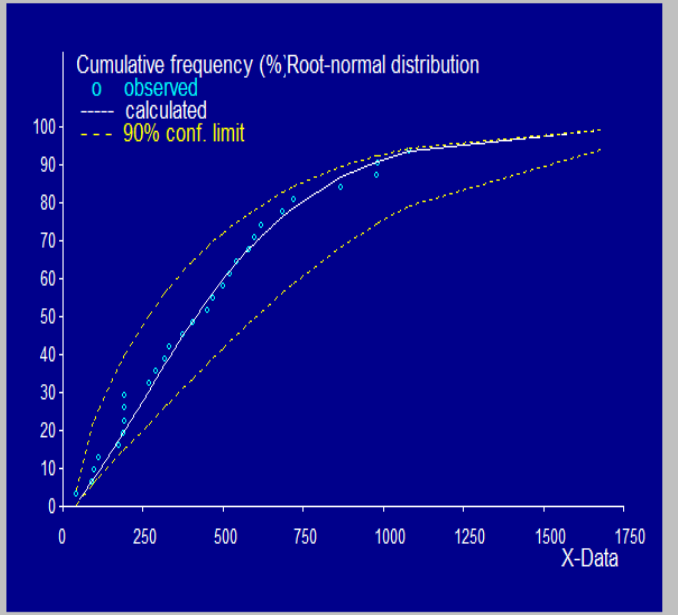
  - long / intense / severe -

Reference Extreme Summer Weather Years

Methodology:

- **Long climate period of 31 years (summer period: May to Sep.)**
- **Heat waves for each year are identified and sorted by maximum duration, intensity, and severity**
- **Maximum value frequency distribution is used to select heat waves with extreme duration / intensity / severity.**
- **Return period is fixed at 15.5 years (second extreme year out 31 years)**
- **Three reference years are identified to correspond to three types of extreme heat waves: long / intense / severe**

Frequency distribution of severity



CumFreq program at www.waterlog.info/cumfreq.htm

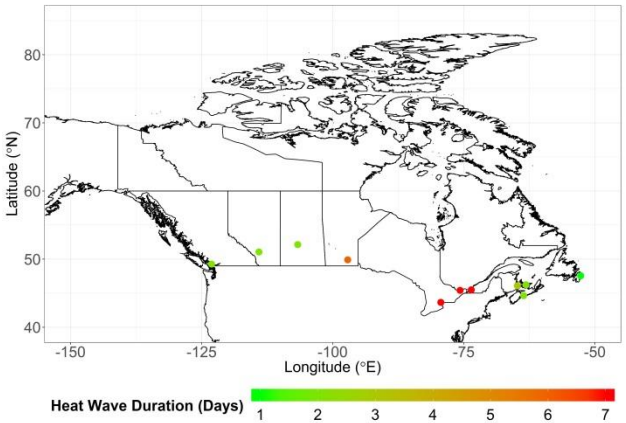
Reference Extreme Summer Weather Years for 3 cities

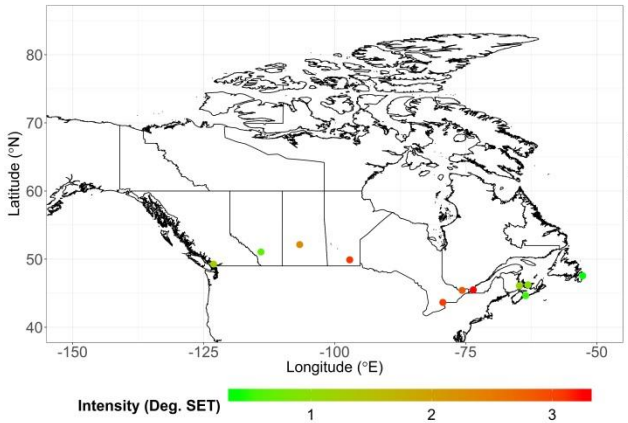
Data are shown for the first three extreme years. Second extreme year is taken

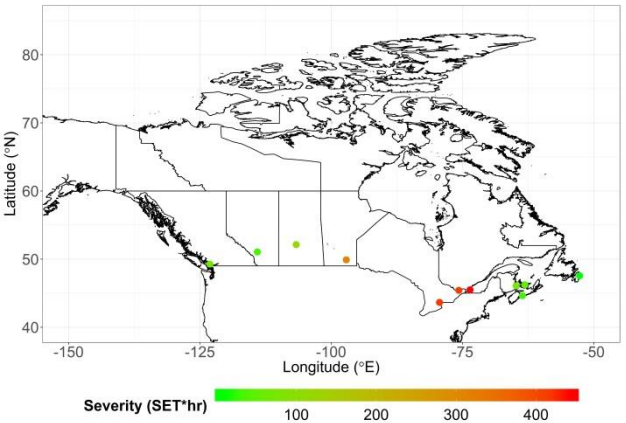
City	Year	Duration	Year	Intensity	Year	Severity
Ottawa	2010	7	2002	3.83	2010	437
	1987	7	2006	2.89	1987	415
	2005	6	1994	2.75	2005	336
Toronto	2006	8	2005	3.28	2013	432
	2013	7	2011	3.07	2006	417
	1988	6	2013	3.00	1987	378
Montreal	2010	7	2002	3.91	2010	522
	1987	7	2010	3.24	1987	442
	2013	6	1994	3.02	2005	380

Maps for Extreme Heat Wave Exposure

Historical period 1986 - 2016







Quebec, Ontario, Manitoba, and Saskatchewan are under higher risk of overheating

Thresholds for outdoor exposure

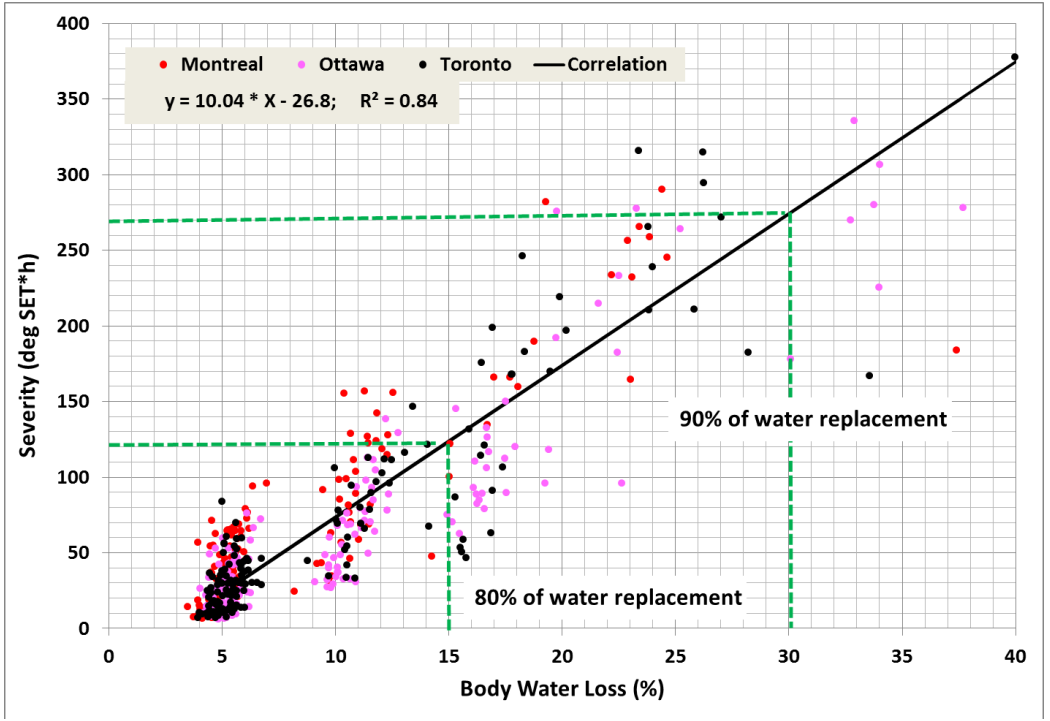
Avoid outdoor exposure if:

- Severity > 124

  (if 80% of subjects drink water)

- Severity > 273

  (if 90% of subjects drink water)



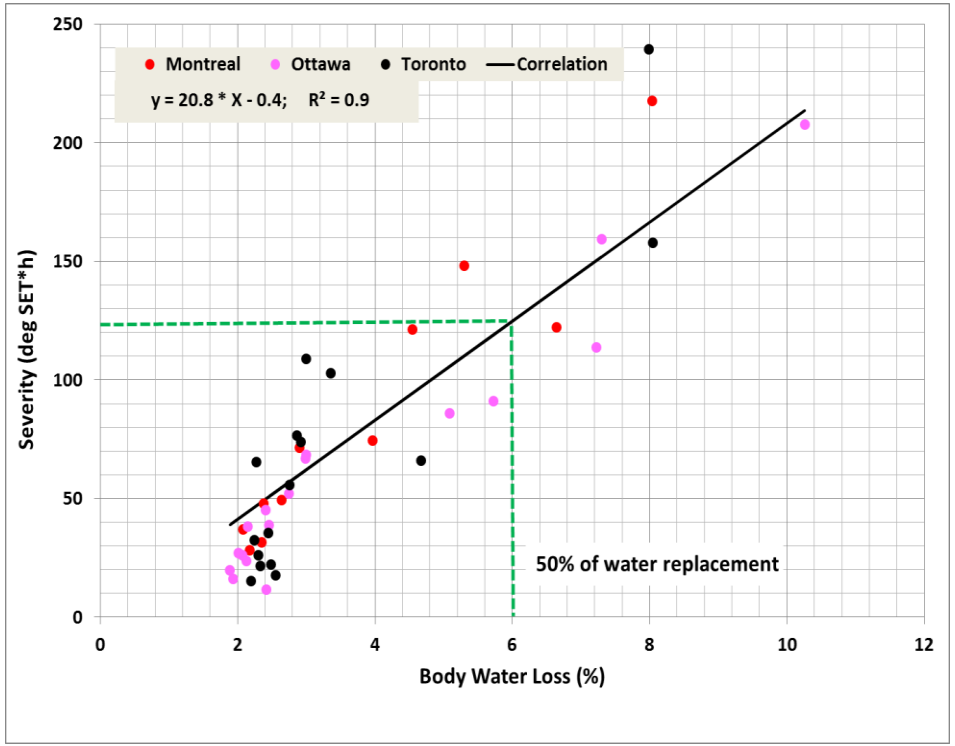
Overheating Characteristics and Thresholds

Characteristics are similar to heat waves but with different threshold values of SET for indoor daytime & nighttime:

- SET_{sleep} : 26°C (averaged value for naked/covered sleeping subjects)
- SET_{awake} : 30 / 31.2°C (healthy people)
- SET_{awake} : 26 / 27.2°C (sensitive people)

Overheating is evaluated under 3 types of heat waves: long, intense, and severe

Overheating is declared if:
Severity > 124
(if 50% of subjects drink water)

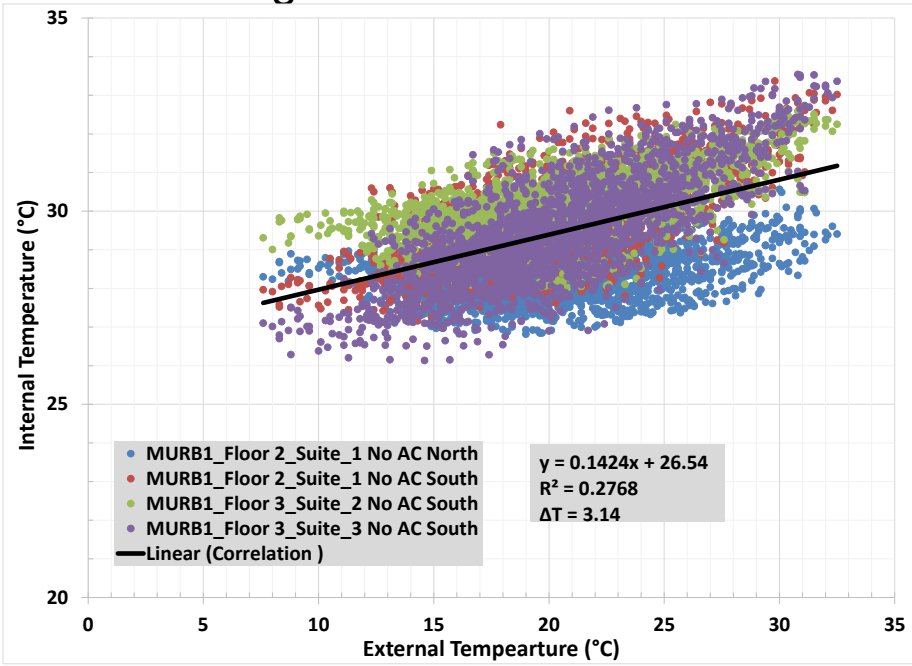


Typical indoor vs. outdoor temperatures in MURBs

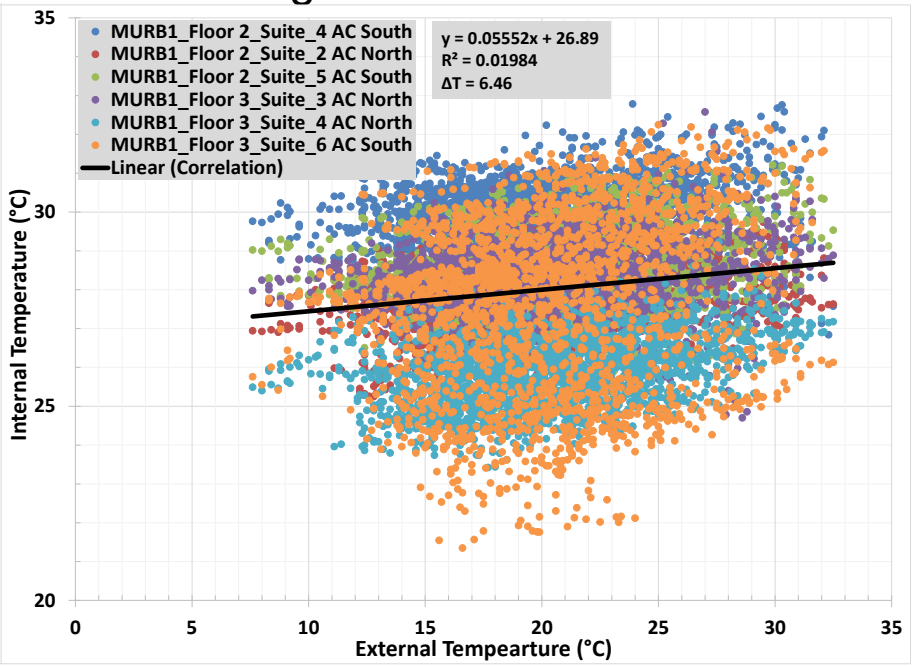
- **Toronto Atmospheric Fund (TAF) conducted field measurements of indoor conditions in 7 MURBs undergoing retrofit to reduce energy use and overheating risk;**
- **Measurement covered three years: before, during & after retrofit;**
- **Indoor temperatures were higher than the adaptive comfort during daytime and nighttime of the summer months (Jun. to Aug.);**
- **During periods of heat waves, indoor temperatures were higher than outdoor temperatures in suites without AC;**
- **High nighttime indoor temperatures resulted in sleep discomfort**

Indoor vs. Outdoor temperatures (Jun. to Aug,)

Building 1: Suites with no AC

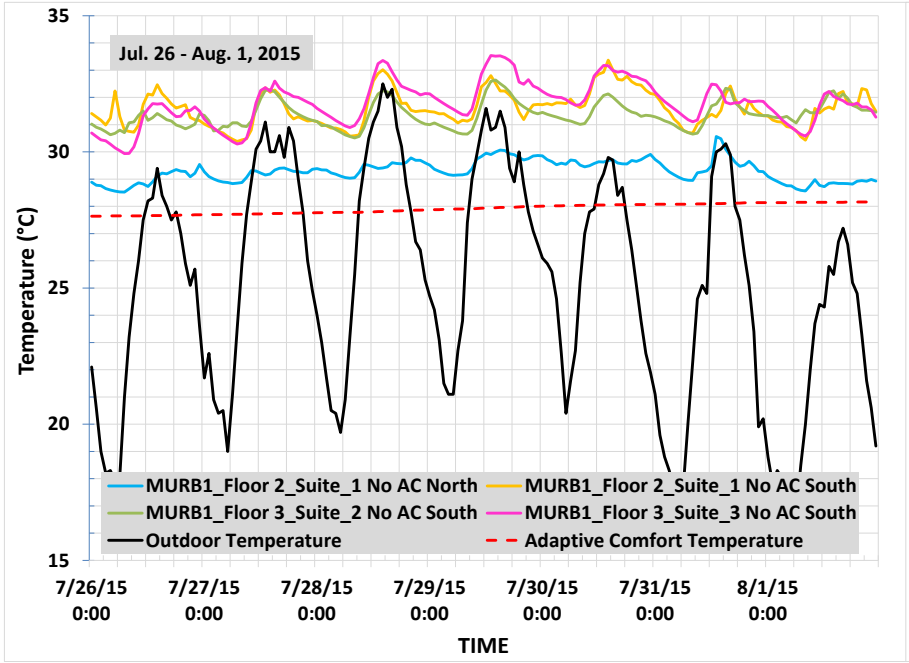


Building 1: Suites with AC

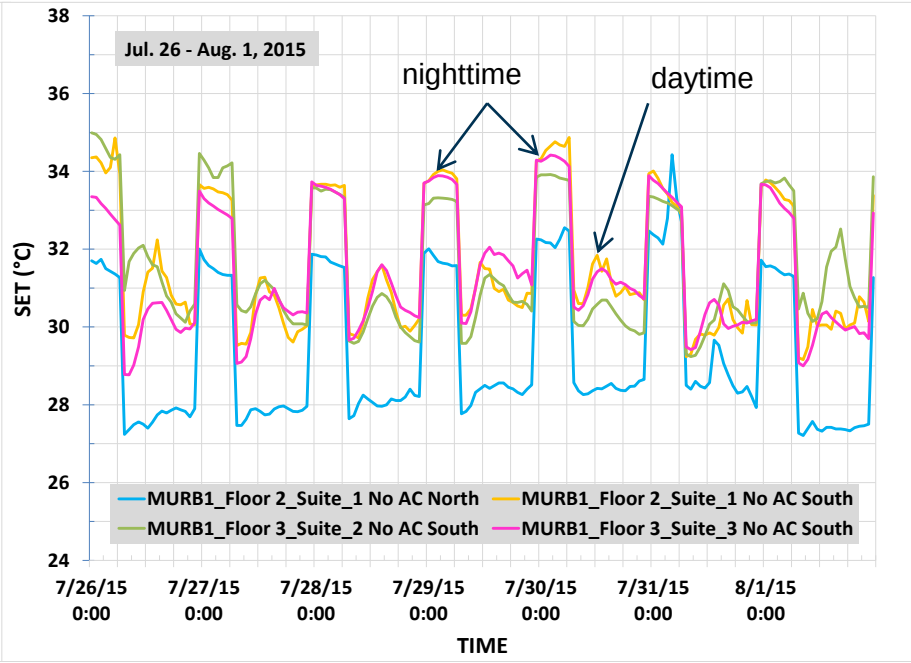


Indoor temperatures during heat wave periods

Building 1: Temperature



Building 1: SET



Conclusion

Framework for overheating risk analysis includes:

1. Reference data for historical and future climate projections
2. Metrics to link climate conditions to the comfort and health of human subjects
3. Definition of heat waves based on physiological response of human subjects
4. Reference extreme summer weather years for overheating risk analysis using building simulation
5. Outdoor heat exposure maps useful for building design and retrofits
6. Overheating definition and thresholds based on thermal conditions and time of exposure and physiological response of human subjects
7. Typical levels of measured overheating in naturally ventilated MURBs helpful to set up indoor thresholds.

Future Work

- **Develop thresholds (T&RH) for the elderly using proper physiological model for the elderly.**
- **Development of archetype models of residential buildings (MURBs, houses) for building simulation**
- **Assessment of overheating risk under historical and future climate projections**
- **Development of guidelines for thermal resilience of buildings**
- **Propose changes to the National Building Code of Canada**

THANK YOU

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