BC Building Envelope Council Conference & AGM, 2023
JW Marriott Parq, Vancouver, BC, Canada

Quantitative IR Thermography for Energy Audit of Exterior Building Envelopes

Presenters

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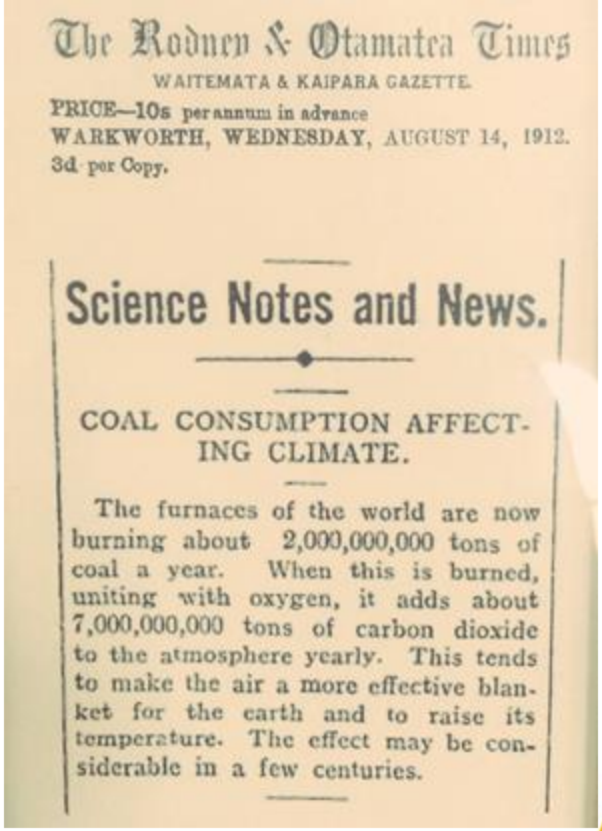
Friday, October 20th, 2023

Climate Change Emergency


The Rodney & Otamatea Times
WAITEMATA & KAIPARA GAZETTE.
PRICE—10s per annum in advance
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.
3d per Copy.

Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

"…… Some people can just let things go, but I can't, especially if there's something that worries me or makes me sad. ……." ***Greta Thunberg***

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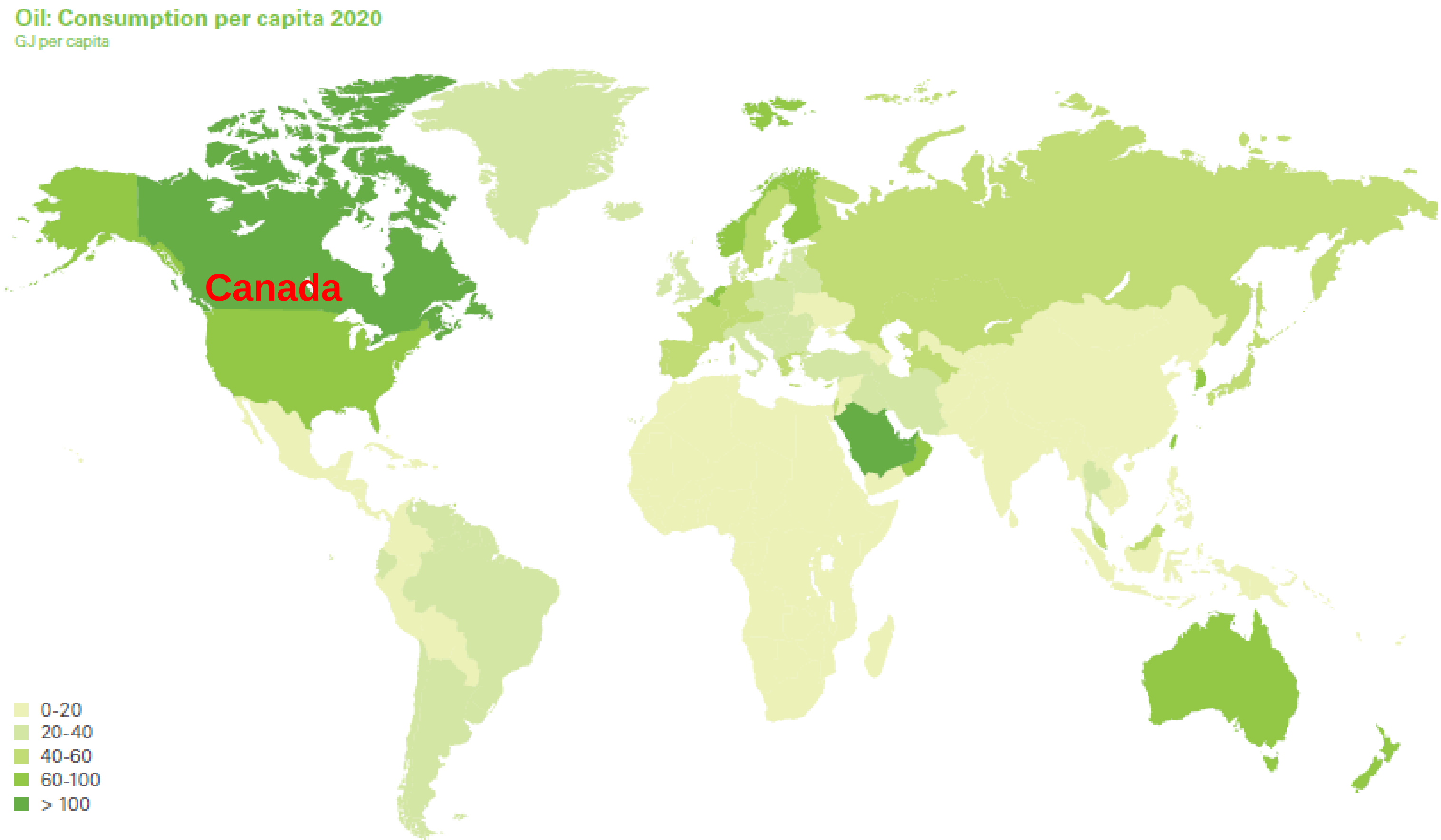
https://www.theguardian.com/world/2019/mar/11/greta-thunberg-schoolgirl-climate-change-warrior-some-people-can-let-things-go-i-cant

Oil Consumption Per Capita 2020

Tonnes



Source: BP (2021)

- Up to 40% of Total Energy demand is Consumed by Buildings (Up to 60% for Urban Areas)
- Need to Improve Energy Efficiency and Reduce Carbon Footprint of Buildings

Outline

- Background
- Development of Quantitative IRT Methodologies
- Challenges/Opportunities in IRT with UAVs
- Development of IRT Webtool
- Conclusions

Background

Current practices:

- Nominal Design U-value (reference tables in building codes)
- Age/Condition assessment of envelope
- Building size (Floor area, Volume, etc.)
- Energy use intensity (EUI)
- In-situ measurement heat flux meter (HFM)
- Qualitative infrared thermography (IRT)

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Background

In-situ measurement with Heat Flux Meter:

- Point measurement
- Long measuring time (at least 72 hours)
- Affected by environmental conditions
- Neglect the effect of thermal bridges and moisture content of materials
- Invasive (mainly installed on the interior surface)

Background

Infrared Thermography (IRT):

- Non-destructive
- Internal and External thermography (Non-invasive)
- Consider the real condition of buildings (degradation of materials)
- Determining non-homogenous areas (damage/ voids)
- Sources of air leakage
- Moisture
- Thermal bridges
- Location of missing insulation

Limitations

The current quantitative approaches:

- Neglect the effect of thermal bridges (e.g., nominal values, HFM).
- Are time consuming & expensive (e.g., HFM & 3D simulation tools)
- May not represent the actual/real thermal performance of building envelope.

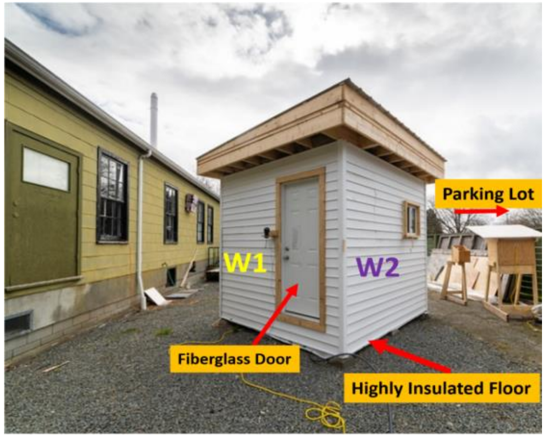
Instead, we need a quantitative approach which is:

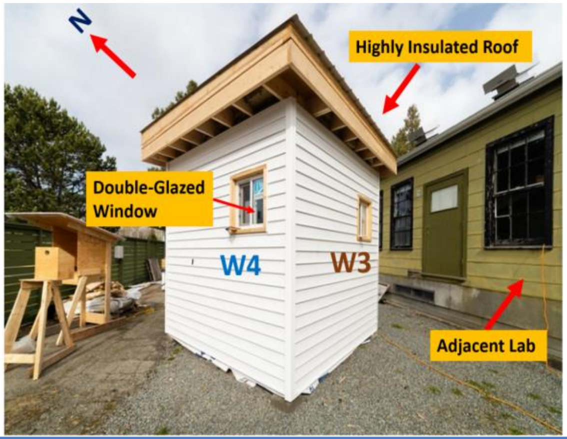
- Comprehensive
- Rapid
- Based on real-condition

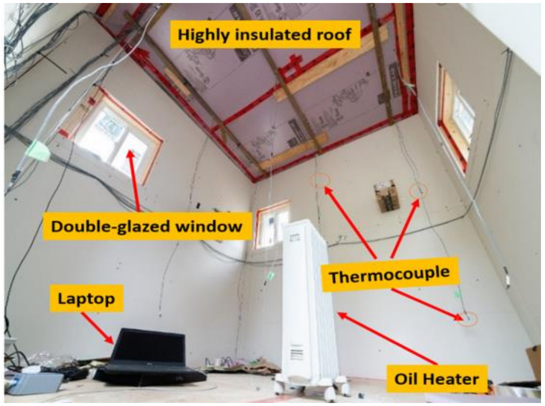
Research Objectives

- ❑ Develop in-situ quantitative approaches for U-value estimation of wall assemblies.
- ❑ Develop a relative quantitative metric for rapid evaluation and subsequent ranking of building envelope thermal performance.
- ❑ Evaluate the potential of IRT with Unmanned Aerial Vehicles (UAV) for quantitative thermal assessment of building envelopes
- ❑ Develop web-based tool for thermal assessment of building envelope and opportunities for improvement.

Research Experimental Set-up







Wall Assemblies	1D R-value
W1 (Interior insulated 2×4)	R-14
W2 (Interior insulated 2×6)	R-22
W3 (Interior and exterior insulated wall with metal furring and z-girts, 2×6)	R-22 + R-10
W4 (Interior and exterior insulated with wood-strapping, 2×6)	R-22 + R-10

Procedure and Data Acquisition

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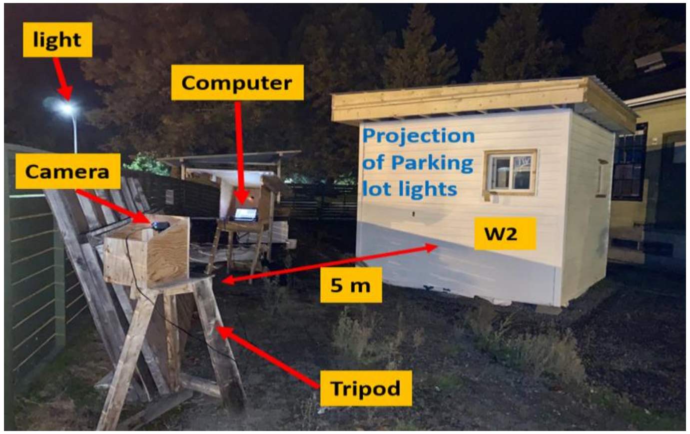
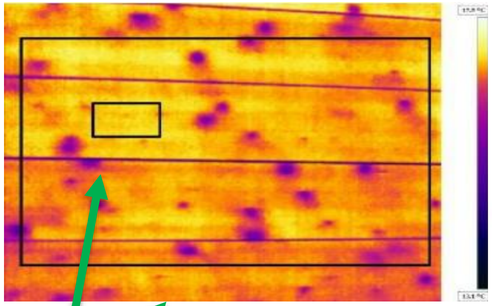
Environmental conditions

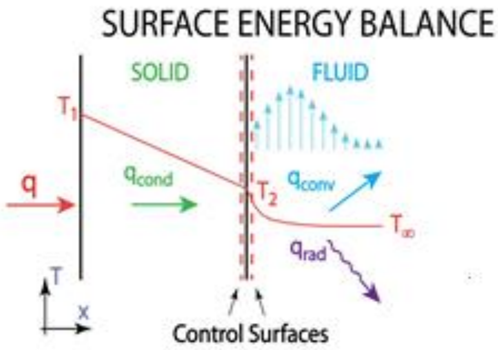
- Temperature gradients (10-15 K)
- Time of test (late evening)
- Rain/Snow (24 hours prior to test)
- Wind speed (< 1 m/s)
- Sky condition (cloudy)



U-value estimation with external IRT



Region of Interest (ROI)



Heat balance on the surface

$$U_{overall} = \frac{Radiation + Convection}{T_{in} - T_{out}}$$

$$U_{overall} = \frac{\varepsilon\sigma\left(T_s{}^4 - T_{out}{}^4\right) + h_c\left(T_s - T_{out}\right)}{T_{in} - T_{out}}$$

IR camera

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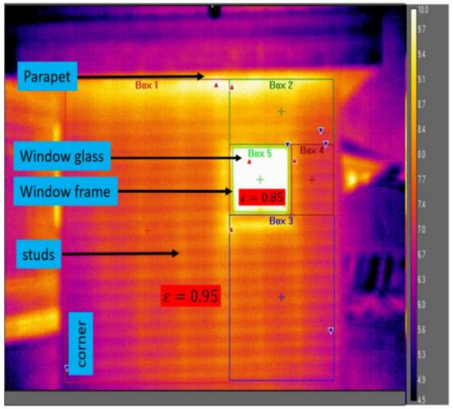
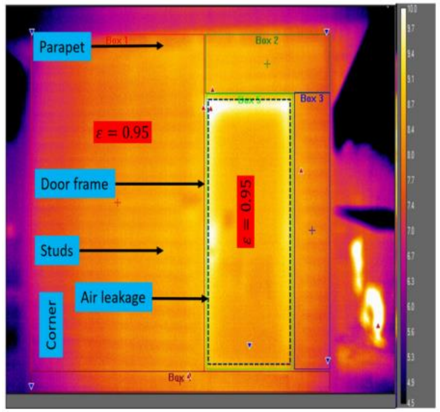
Opaque Wall Effective U-value Estimation





$$T_{s,avg} = \frac{T_1 * A_1 + T_2 * A_2 + T_3 * A_3 + \cdots + T_i * A_i}{A_T}$$

$$U_{overall} = \frac{\varepsilon\sigma\left(T_{s,avg}{}^4 - T_{out}{}^4\right) + h_c\left(T_{s,avg} - T_{out}\right)}{T_{in} - T_{out}}$$

Wall assemblies	IRT-estimated U-value (W/m² K)	3D simulated U-value (W/m² K)	Deviations (%)
Day1			
W1	0.37	0.43	-13.95
W2	0.22	0.31	-29.03
W3	0.09	0.26	-65.38
W4	0.04	0.24	-83.33
Day 2			
W1	0.35	0.43	-18.60
W2	0.26	0.31	-16.13
W3	0.11	0.26	-57.69
W4	0.06	0.24	-75.00
Day 3			
W1	0.37	0.43	-13.95
W2	0.25	0.31	-19.35
W3	0.15	0.26	-42.31
W4	0.10	0.24	-58.33

- ✓ U-values were not identical on different days.
- ✓ Deviations varied in different days and were more for well-insulated wall (W3 and W4)
- ✓ Adverse effect of vignetting (colder corners) on accuracy of results.

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IRT U-value Estimation Enhancement

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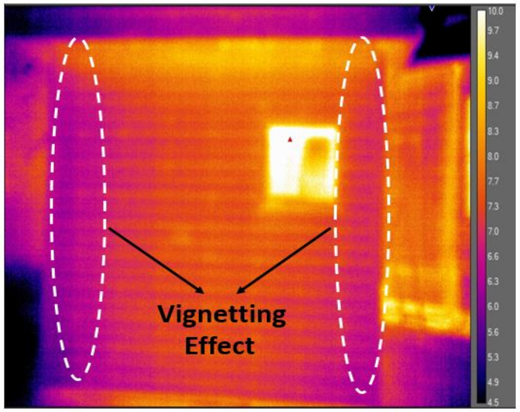
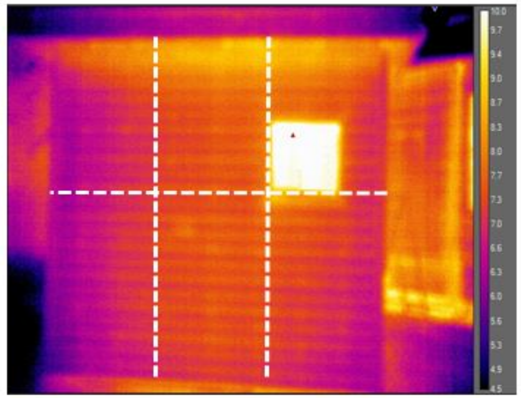
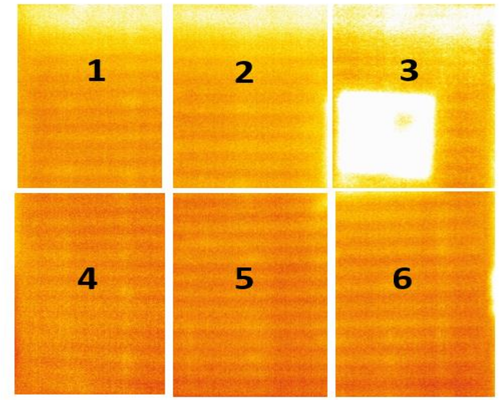
Addressing vignetting effect



Vignetting Effect



Dividing to 6-segments



6 IRT shots from different angles

Wall assemblies	IRT-estimated U-value ($W/m^2\ K$)	3D simulated U-value ($W/m^2\ K$)	Deviation (%)
W1	0.42	0.43	-2.33
W2	0.29	0.31	-6.45
W3	0.23	0.26	-11.53
W4	0.21	0.24	-12.50

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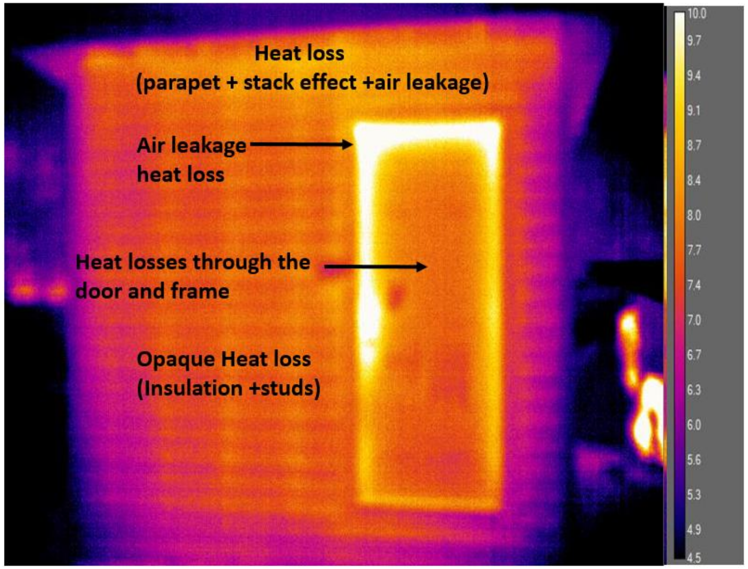
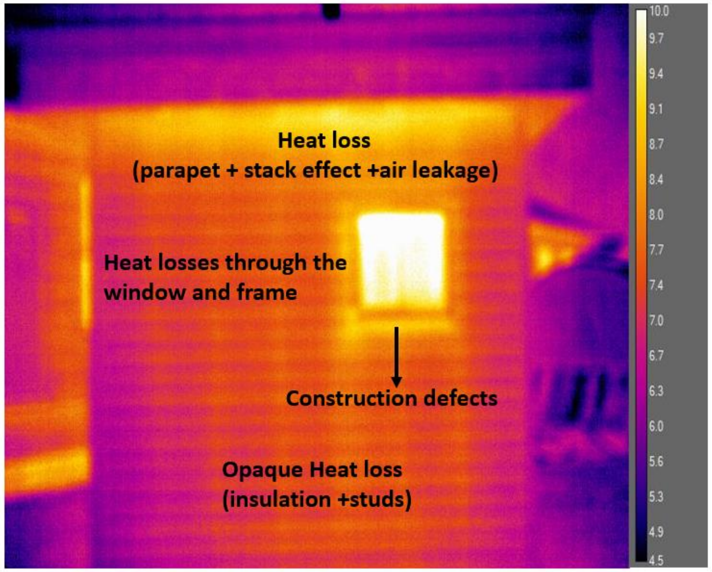
Infrared Index

We need a metric which:

- Considers the overall performance of building envelop(all sources of losses)
- Provides an opportunity for rapid in-situ ranking of the building envelope.





$$Infrared\ Index\ (IRI) = \frac{T_{s,avg} - T_{out}}{T_{in} - T_{out}}$$

Using assumed steady-state condition

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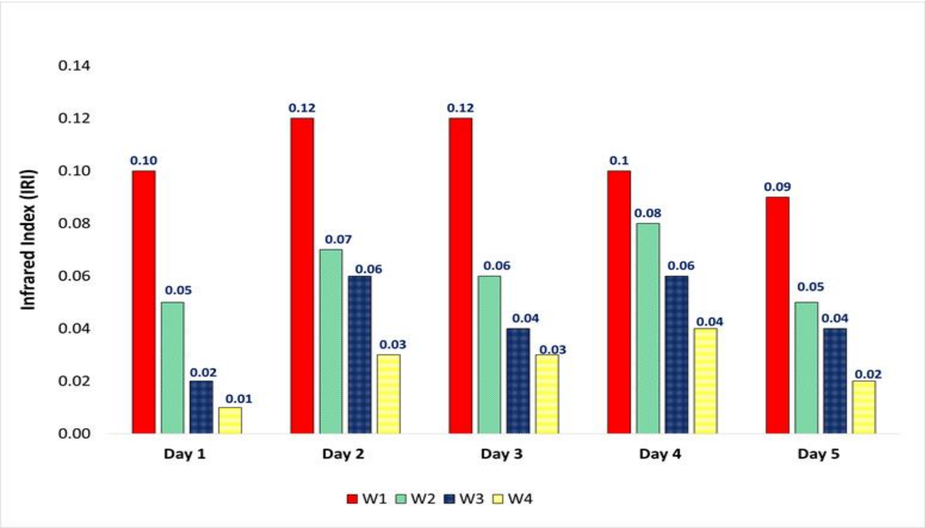
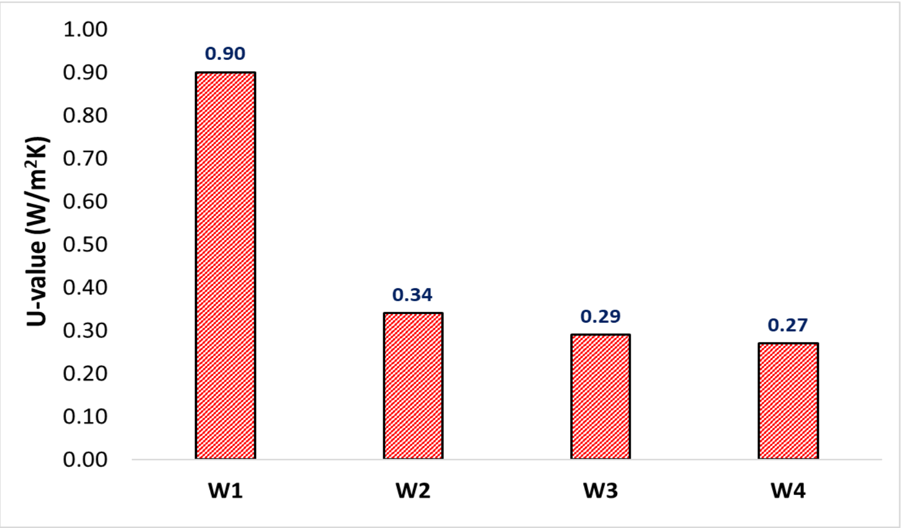
Infrared Index





- ✓ IRI showed a similar ranking in different external conditions.
- ✓ IRI ranking was identical to the U-value ranking.
- ✓ More thermal anomalies in the building envelope can lead to a higher IRI and a poorer overall thermal performance.
- ✓ Higher levels of insulation do not necessarily ensure better building energy performance if air leakage, construction defects, and thermal bridging effects are substantial.

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Infrared Thermography-UAV

- How reliable is the measurement with dynamic IRT.
- Compare the dynamic measurements with stationary IRT.
- Determine the limitations and provide solution to enhance the accuracy of result.

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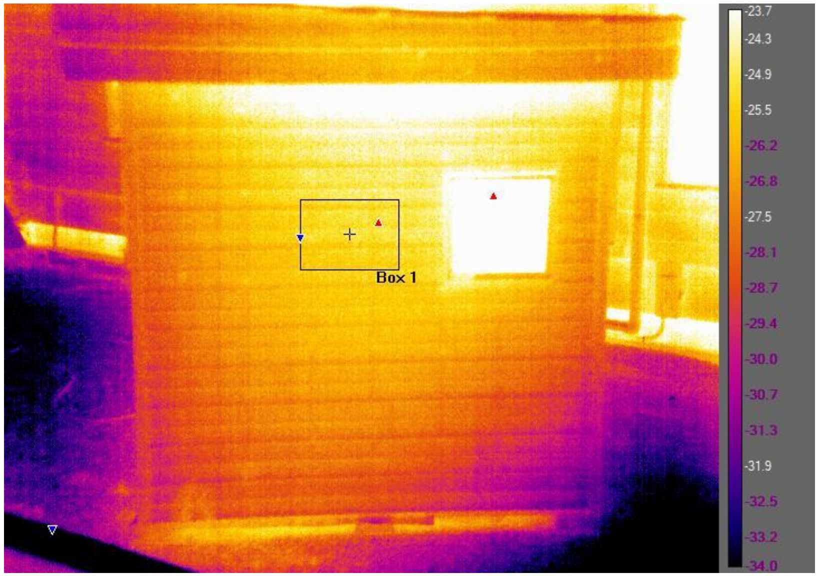
Dynamic vs. Static measurements



Dynamic (Zenmuse XT2) T= -24.42 ºC

Static (FLIR A65) T= + 8.15 ºC

- ✓ Environmental conditions (e.g., wind) influence the accuracy of dynamic IRT unlike lab conditions.
- ✓ Dynamic IRT measurements are not as accurate as stationary measurements.

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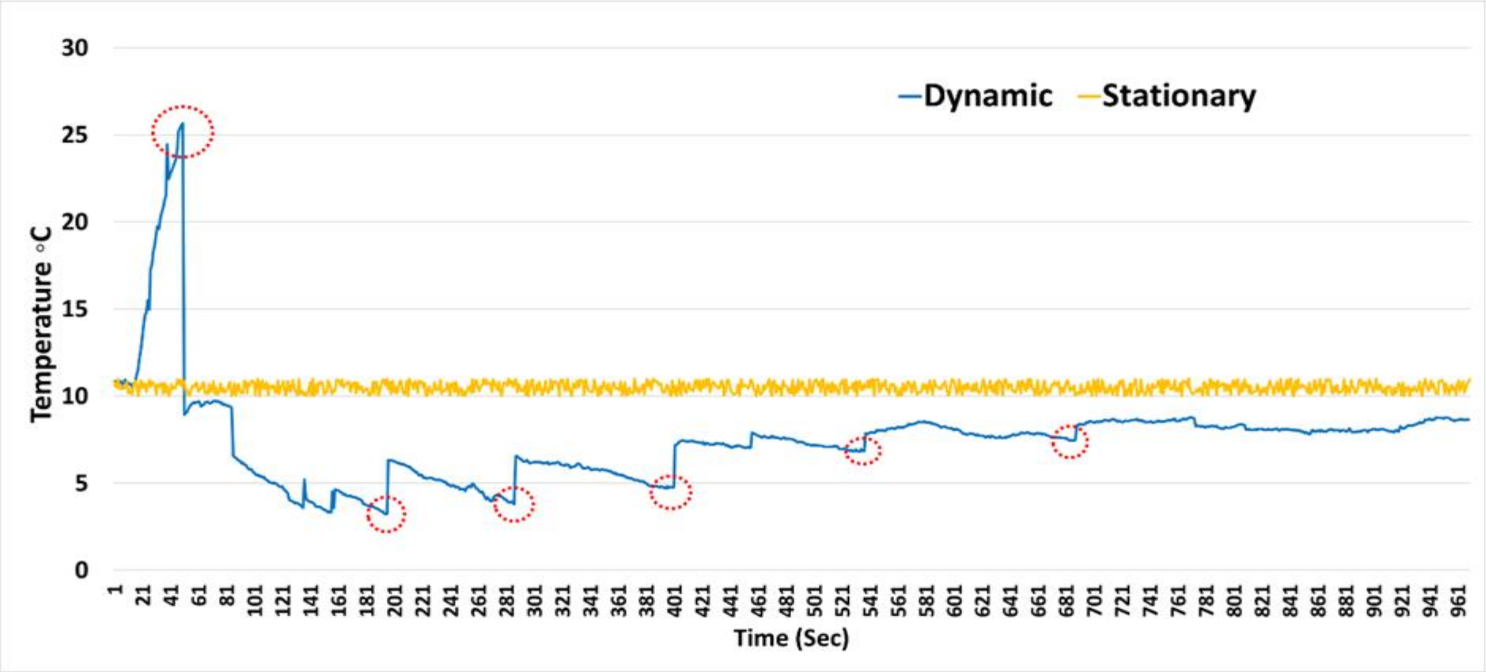
Infrared Thermography-UAV

Time-series dynamic measurement



- The thermal sensor is affected by drone-induced wind during the flight.
- Sensors stabilize with environmental conditions during the flight.

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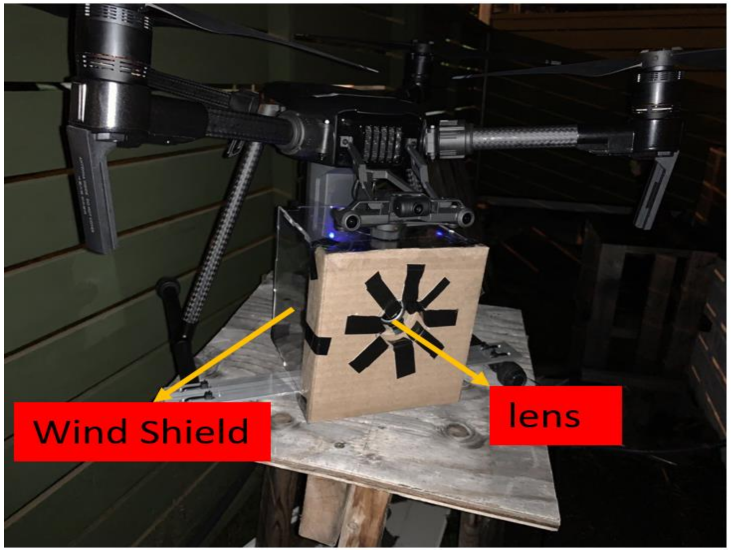
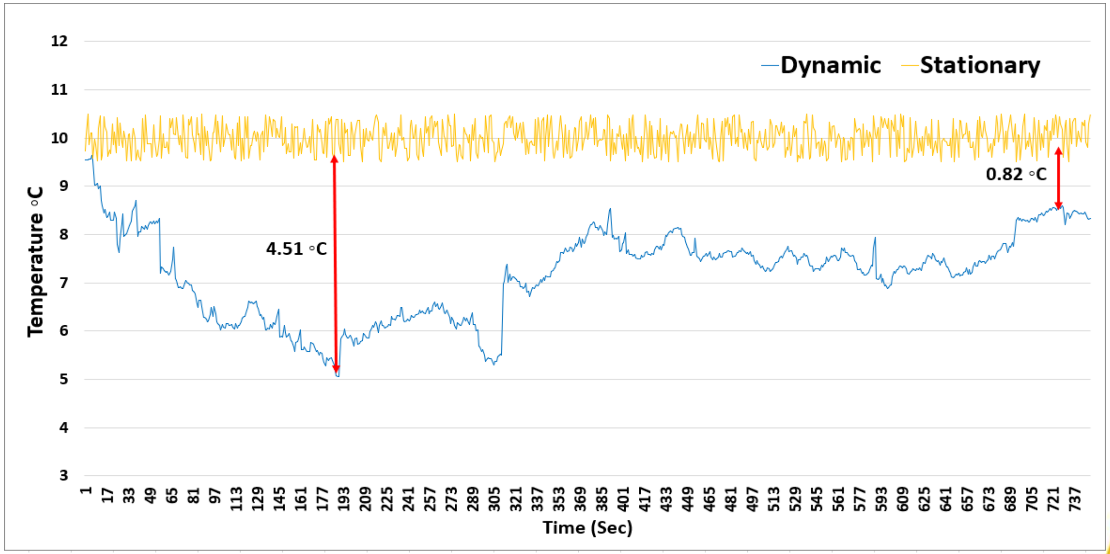
Infrared Thermography-UAV

Results- Effect of wind shield/stabilization





- Shield minimizes the effect of sudden turbulence around the camera during the flight **(Temperature drops less and stabilization faster).**
- Due to the duration of aerial surveys being limited by battery life, a shield facilitates faster camera stabilization consequently allowing for more data collection per flight.
- The proposed method could help decrease the deviation between dynamic and stationary measurements to less than 1℃.

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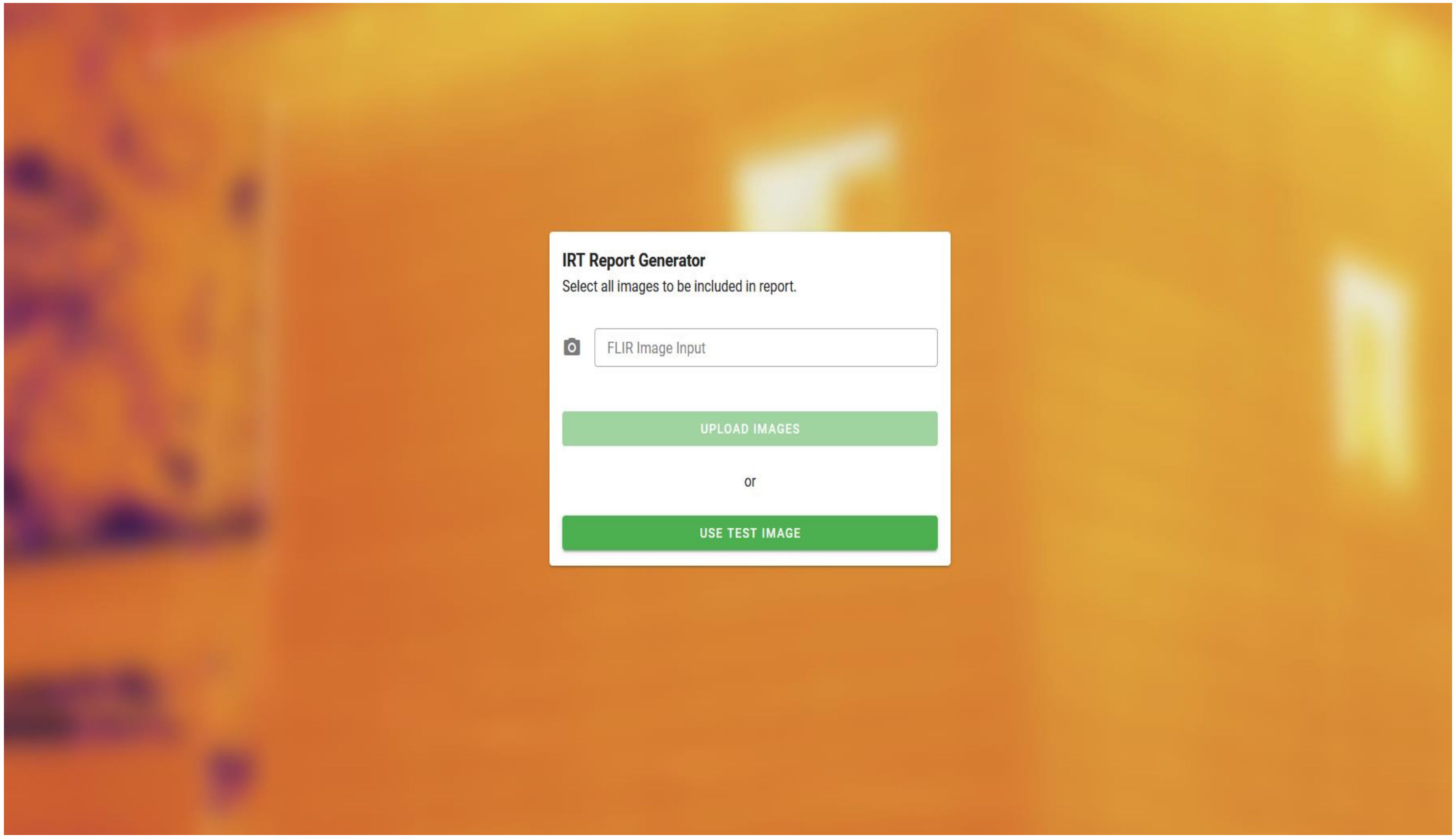
Infrared Thermography-Webtool



https://irt.cive.uvic.ca/

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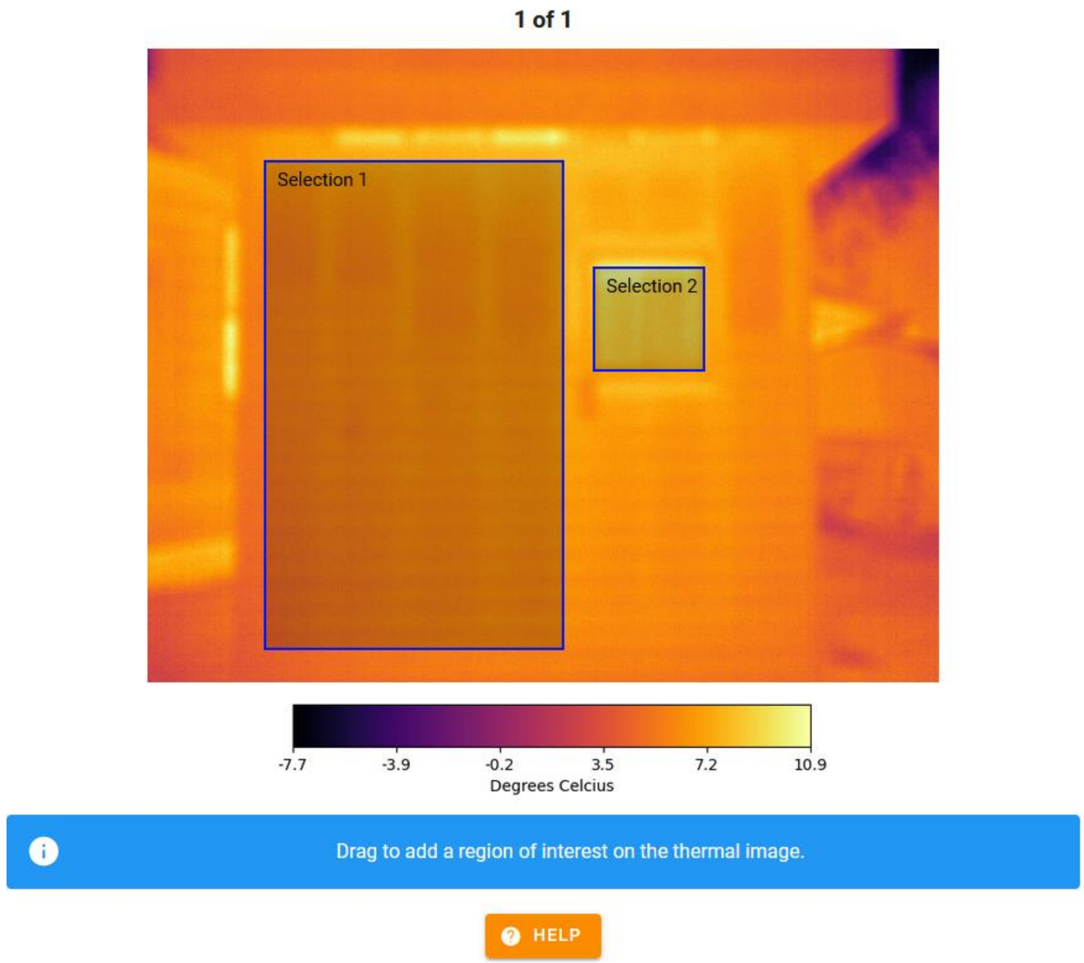
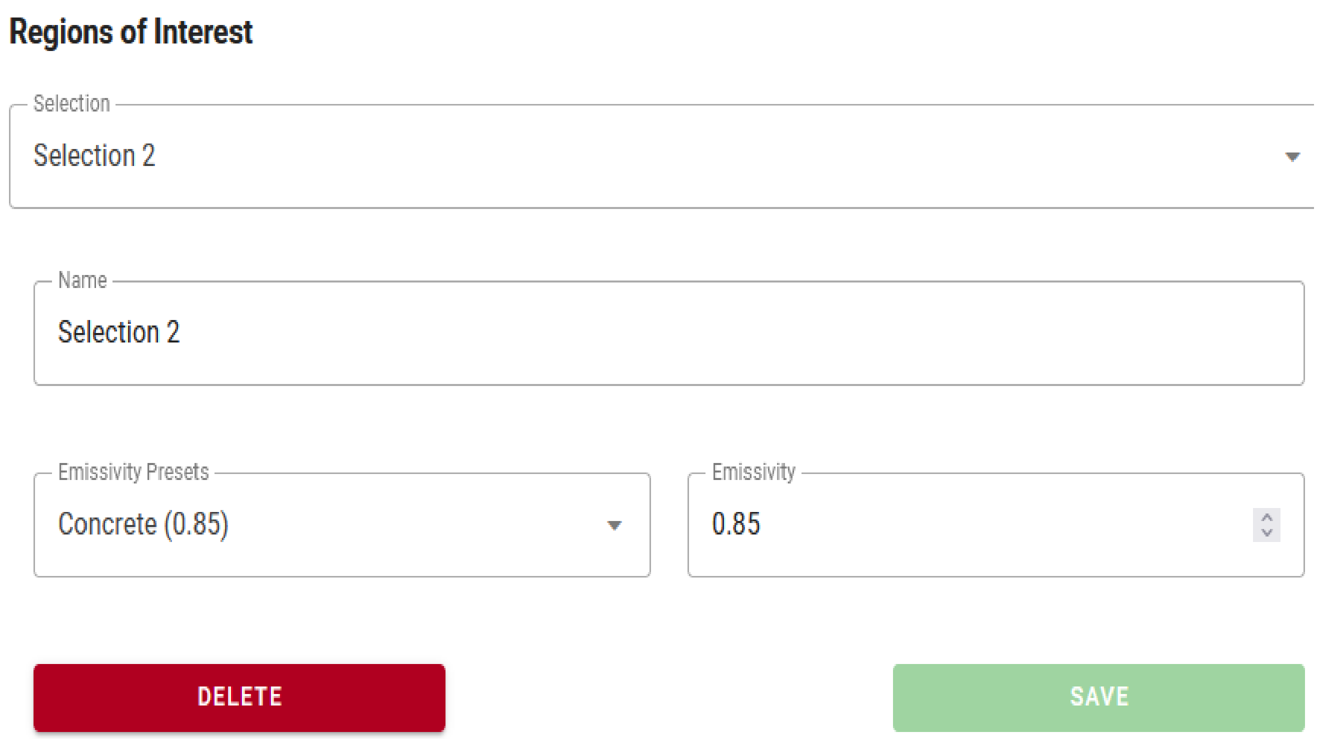
Infrared Thermography-Webtool

1- Selection of region of interest



Infrared Thermography-Webtool

2- Select the material and emissivity



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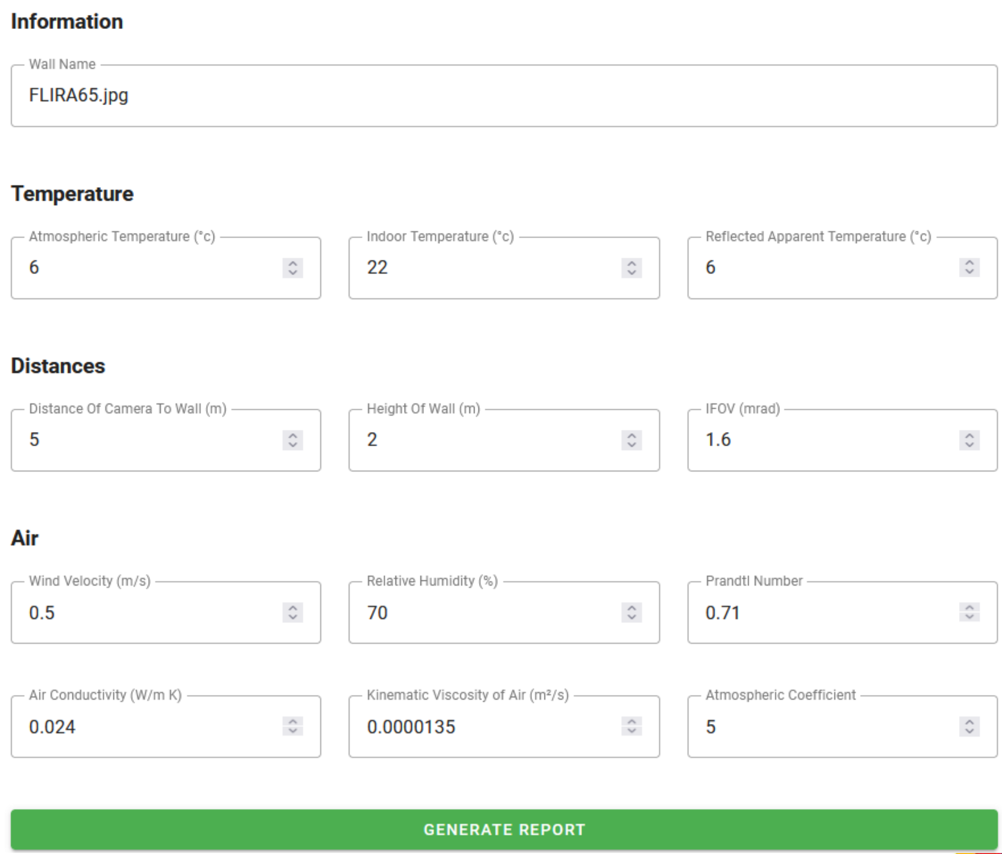
Infrared Thermography-Webtool

3- Boundary conditions Inputs

- Indoor and outdoor temperatures
- Camera Specs
- Outside environmental inputs for convection heat transfer coefficient calculations



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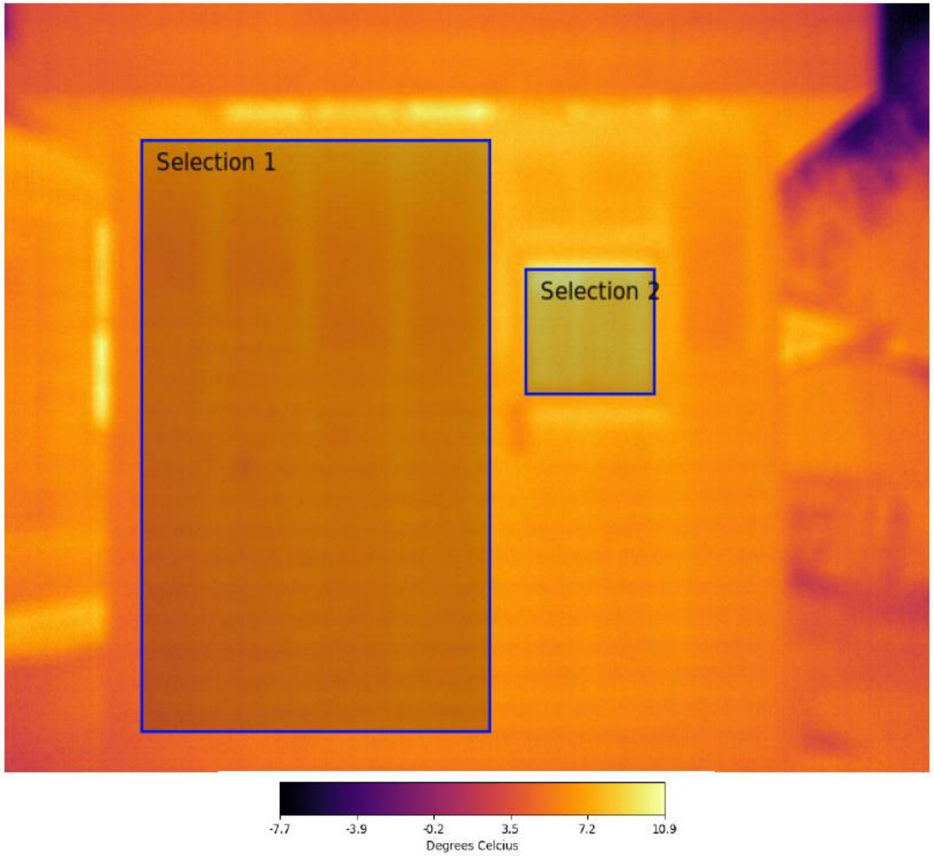
Infrared Thermography-Webtool
4- Report

- Area of ROIs
- Max/Min/Avg temperatures
- IRI values
- U-values



FLIRA65.jpg									
ROI	Area (cm^2)	Avg Temp (°c)	Max Temp (°c)	Min Temp (°c)	IRI	U_{IRT} (W/m^2 K)	$T_{s,avg (WA)}$ (°c)	$IRI_{overall}$	$U_{overall (WA)}$ (W/m^2 K)
Selection 1	6077056.00	6.45	8.66	4.04	0.03	0.19	6.68	0.04	0.27
Selection 2	472768.00	9.57	11.79	7.49	0.22	1.38			

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Conclusions

- Infrared thermography could be a reliable tool for rapid quantitative thermal assessment of building envelope (U-value & IR index).
- Quantitative IRT provides an opportunity for using the estimated U-value as an input for accurate calibration of building energy models for the existing buildings.
- While for the relatively new and carefully constructed structures, the thermal anomalies are expected to be minor; for older buildings or poorly detailed building envelope assemblies, the IR Index may be a more holistic representation of relative thermal performance than 3D-simulated U-values.
- IR Index provides the opportunity for quick surveys of a large number of buildings.

Conclusions

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- Development of this kind of external IRT technique facilitates future utilization of UAVs equipped with infrared cameras for conducting large-scale quantitative surveys in a fraction of the time without the need for current intrusive methods.
- Study on IRT with UAVs provided opportunities to define a more robust thermal imaging protocol for the quantification of building envelope thermal performance.
- IRT Webtool provides complementary information for energy advisors, property managers and citizens to make informed decisions about building envelope thermal performance and opportunities for improvement.

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Research Publications

Mahmoodzadeh, M., Gretka, V., & Mukhopadhyaya, P. (2023). Challenges and Opportunities in Quantitative Aerial Thermography of Building Envelopes. ***Journal of Building Engineering***, 106214

M. Mahmoodzadeh, V. Gretka, I. Lee, P. Mukhopadhyaya, Utilizing External Infrared Thermography to Assess Thermal Performance of Wood-Framed Building Envelopes in Canada, ***Journal of Energy and Buildings***. (2021) 111807

M. Mahmoodzadeh, V. Gretka, K. Hay, C. Steele, P. Mukhopadhyaya, Determining overall heat transfer coefficient (U-Value) of wood-framed wall assemblies in Canada using external infrared thermography, ***Journal of Building and Environment***. 199 (2021): 107897.

M. Mahmoodzadeh, V. Gretka, S. Wong, T. Froese, P. Mukhopadhyaya, Evaluating Patterns of Building Envelope Air Leakage with Infrared Thermography, ***Energies***. (2020) 13 (14), 3545.

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Acknowledgments

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BC Housing

Mitacs

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