# Exploring in situ U-Value thermal performance of glazing with infrared thermography for an urban multifamily housing complex

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ARCH 563
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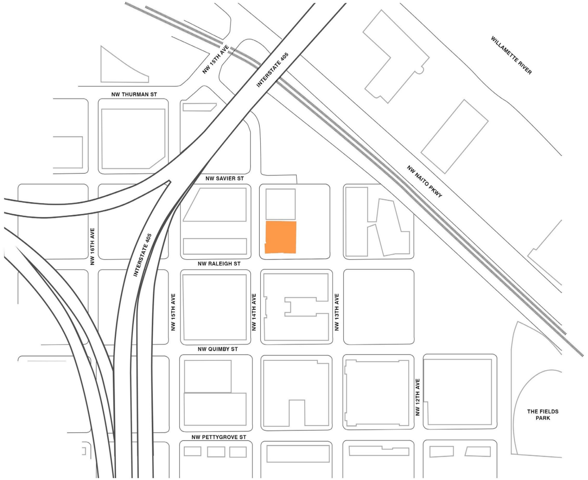
# Research Questions |

1. *How is the exterior glazing performing compared to the anticipated U-values.*
2. *Are there any portions of the building envelope that are “thermal holes''.*
3. *How does the envelope impact the building's energy use?*
4. *Are there design strategies to make the envelope more efficient?*

# Vibrant! | Portland, OR

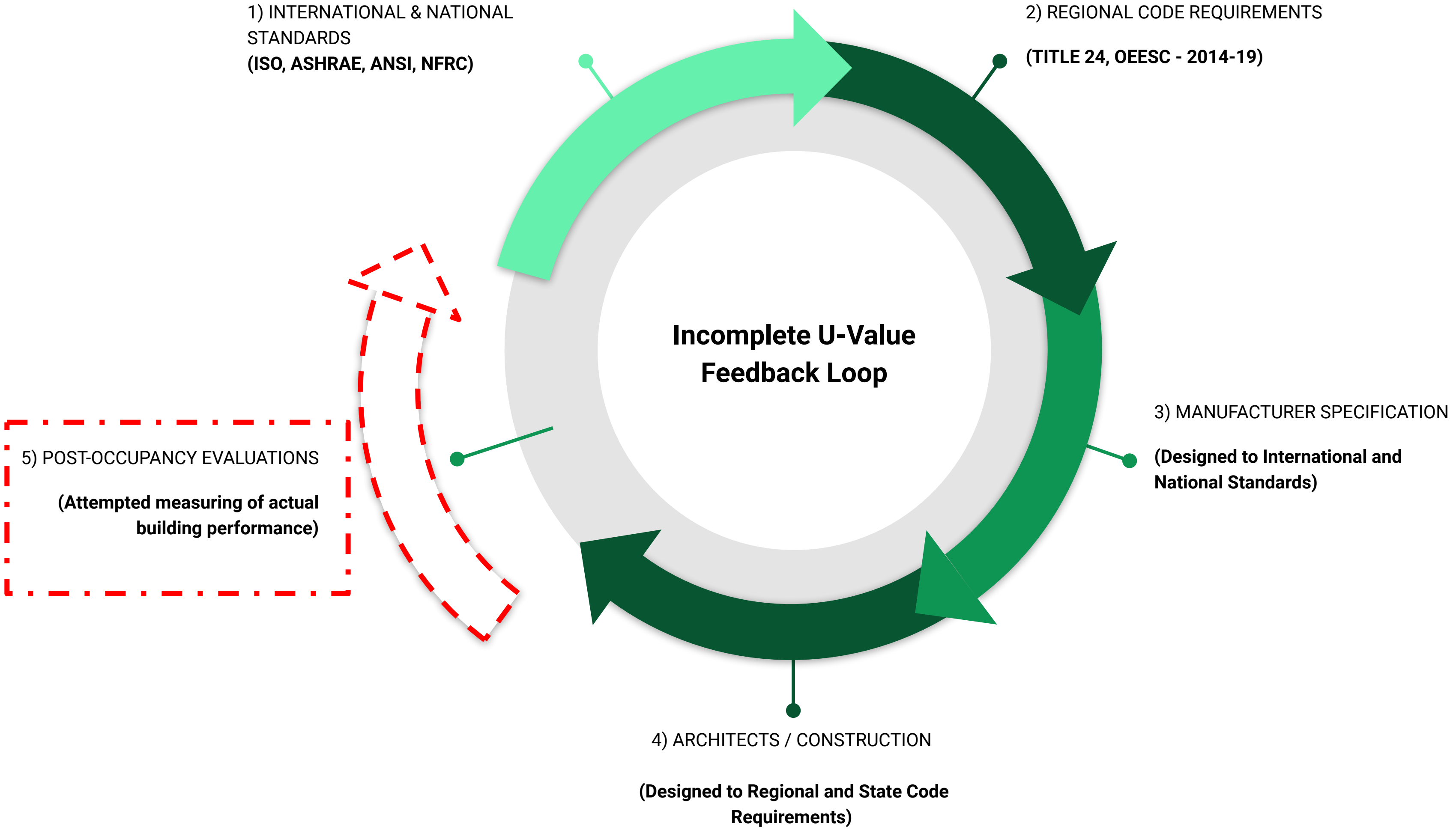
Salazar Architects Inc.

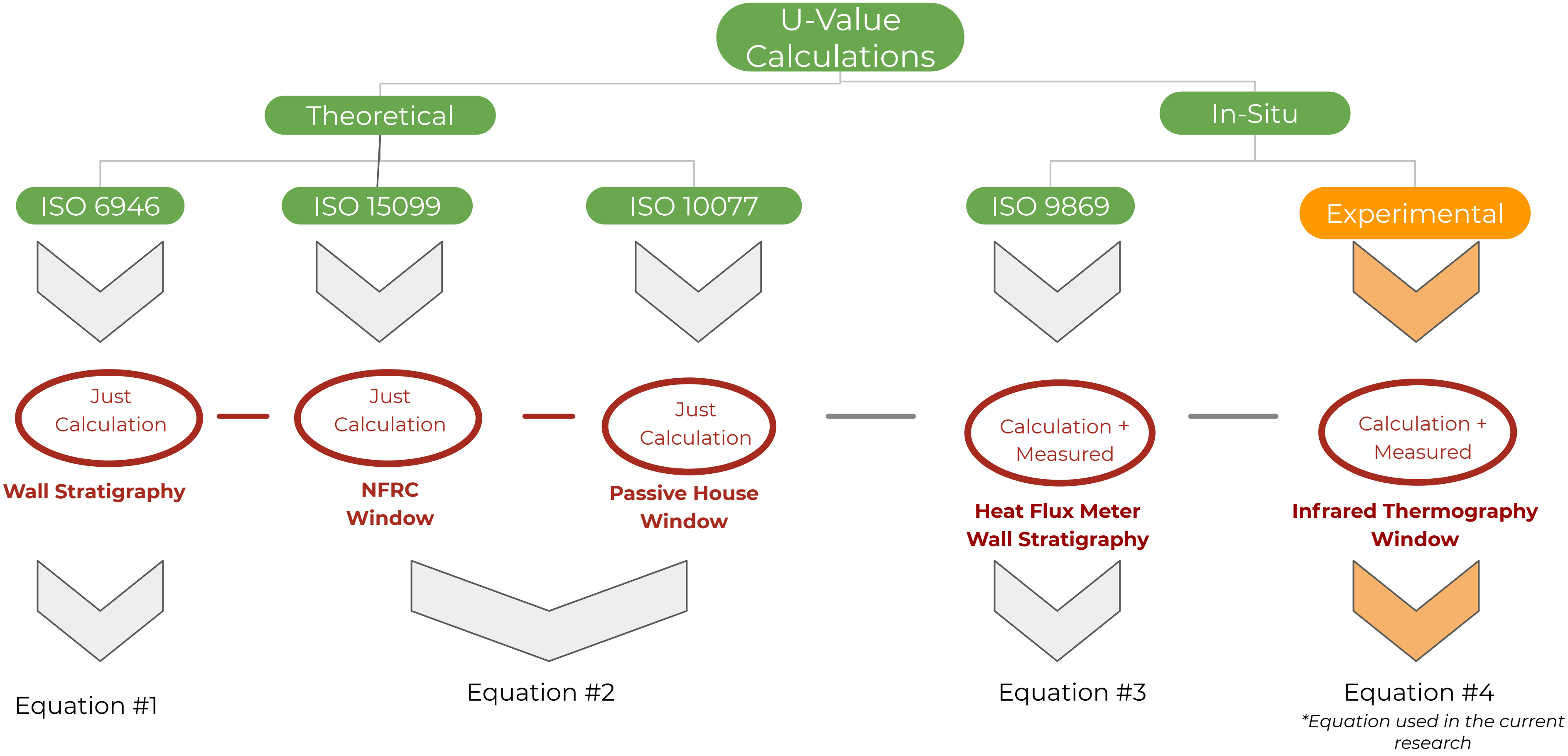



SITE PLAN

0 100' 200' 400'

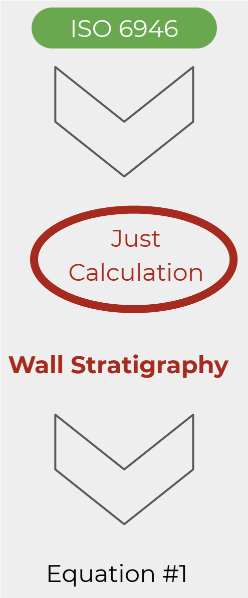
N


1) INTERNATIONAL & NATIONAL STANDARDS
(ISO, ASHRAE, ANSI, NFRC)
2) REGIONAL CODE REQUIREMENTS
(TITLE 24, OEESC - 2014-19)
Incomplete U-Value Feedback Loop
3) MANUFACTURER SPECIFICATION
(Designed to International and National Standards)
4) ARCHITECTS / CONSTRUCTION
(Designed to Regional and State Code Requirements)
5) POST-OCCUPANCY EVALUATIONS
(Attempted measuring of actual building performance)


U-Value Calculations
Theoretical
In-Situ
ISO 6946
ISO 15099
ISO 10077
ISO 9869
Experimental
Just Calculation
Wall Stratigraphy
Just Calculation
NFRC Window
Just Calculation
Passive House Window
Calculation + Measured
Heat Flux Meter Wall Stratigraphy
Calculation + Measured
Infrared Thermography Window
Equation #1
Equation #2
Equation #3
Equation #4
*Equation used in the current research

***Theoretical Calculations*** vs. In Situ Calculations

## Equation #1 ISO 6946 | Calculation for Building Stratigraphy




$$U = \frac{1}{R_T} = \frac{1}{R_{se} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdots + R_{si}}.$$

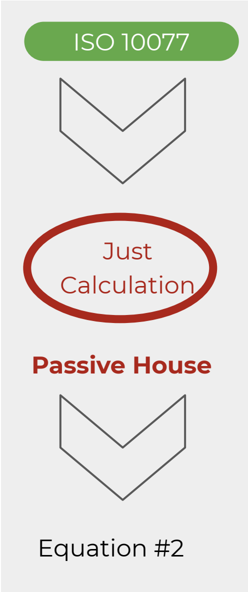
U: heat transfer coefficient
$R_T$: total thermal resistance
$R_{SE}$: external resistance
$d_i$: thickness of the layer
$\lambda_i$: specific thermal conductivity of this layer
$R_{si}$: internal heat transfer resistance

$R_s = 1 / H_c + H_r$

$H_c$ = is the convective coefficient
$H_r$ = is the radiative coefficient

https://www.sis.se/api/document/preview/909393/

# Equation #2 ISO 10077 | Calculation for Glazing or Windows

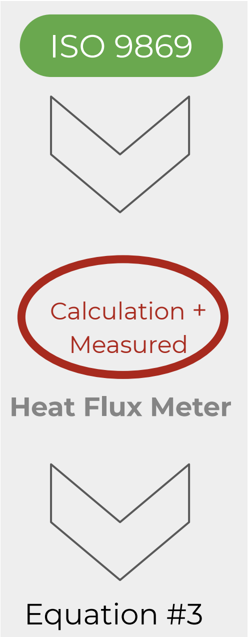



$$U_W = \frac{A_g U_g + A_f U_f + l_g \Psi_g \; (+ \; l_{Inst} \Psi_{Inst})}{A_g + A_f}$$

$U_W$: heat transfer coefficient (window unit)
$A_g$: glazing surface area
$U_g$: U-value of glazing
$A_f$: surface area of frame
$U_f$: U-value of frame
$l_g$: glazing perimeter (glass edge length)
$\Psi_g$: thermal bridging coefficient of glazing
$l_{inst}$: frame perimeter (frame edge length)
$\Psi_{inst}$: thermal bridging coefficient of installation

https://passiv.de/former_conferences/Passive_House_E/window_U.htm
https://www.phius.org/documents/2014-06-26_Baker_NFRC-and-PHIUS-U-Factor-Calculation-Comparison.pdf

Theoretical Calculations vs. ***In Situ Calculations***

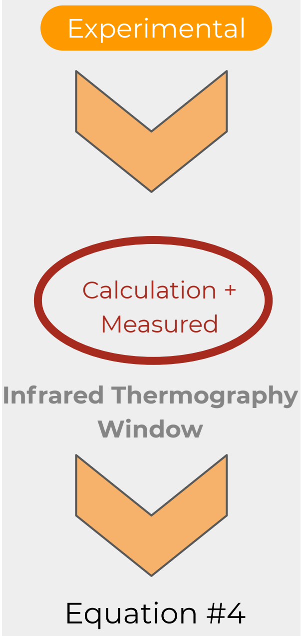



## Equation #3 ISO 9869 | In-Situ Calculation using Heat Flux Meter

$$U\text{-}Value = h_{ci}\frac{T_i - T_{si}}{T_i - T_e}.$$

U: heat transfer coefficient
$h_{ci}$: surface convective heat transfer coefficient
$T_i$: indoor ambient temperature
$T_{si}$: interior surface temperature
$T_e$: outside ambient temperature

# Theoretical Calculations vs. ***In Situ Calculations***




**Equation used in the current research*

## Experimental | In-Situ Calculation using Infrared Thermography

$$U = \frac{5.67\,\varepsilon_{tot}\left[\left(\frac{T_w}{100}\right)^4 - \left(\frac{T_{out}}{100}\right)^4\right] + 3.8054\,v\,(T_w - T_{out})}{(T_{int} - T_{out})}$$

U: heat transfer coefficient
$\varepsilon_{tot}$: emissivity of specific material
$T_w$: surface temperature
$T_{out}$: ambient outside temperature
$T_{in}$: ambient inside temperature
V: velocity of wind

5.67: Stefan Boltzmann constant for radiative heat transfer coefficient

3.8054: convective heat transfer coefficient

https://www.academia.edu/6431750/Infrared_thermovision_technique_for_the_assessment_of_thermal_transmittance_value_of_opaque_building_elements_on_site?auto=download

## Typical In Situ Deviation From Theoretical Calculations Using Infrared Thermography compared to other methods

# 40-45%

### IRT (infrared thermography)

This numbers are typically from building stratigraphy case studies. Not specified as glazing case studies. This is the deviation from using ISO calculations.

- No standardized equation
- Measurement recording errors
- Includes emissivity of surfaces
- Faster testing times
- Can see visual components being tested

# 30-35%

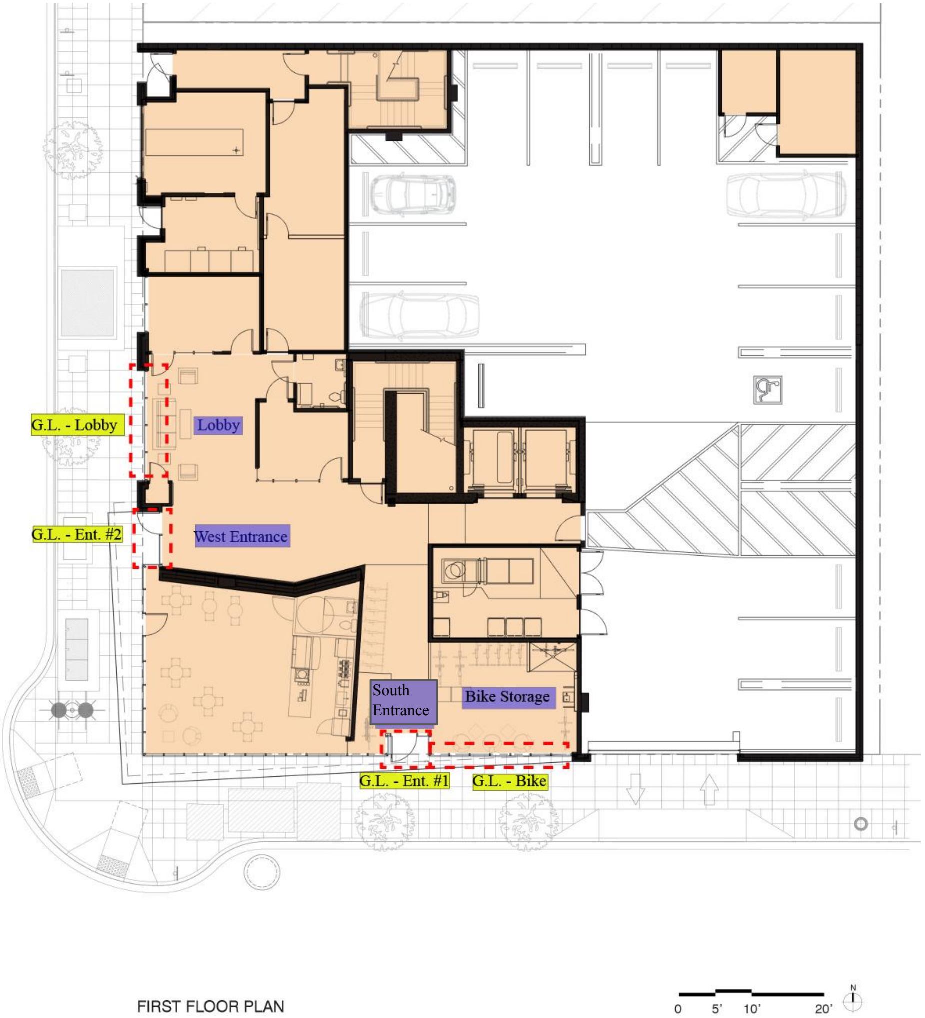
### Heat Flux Meter

This number is the deviation from using ISO standardized calculations.

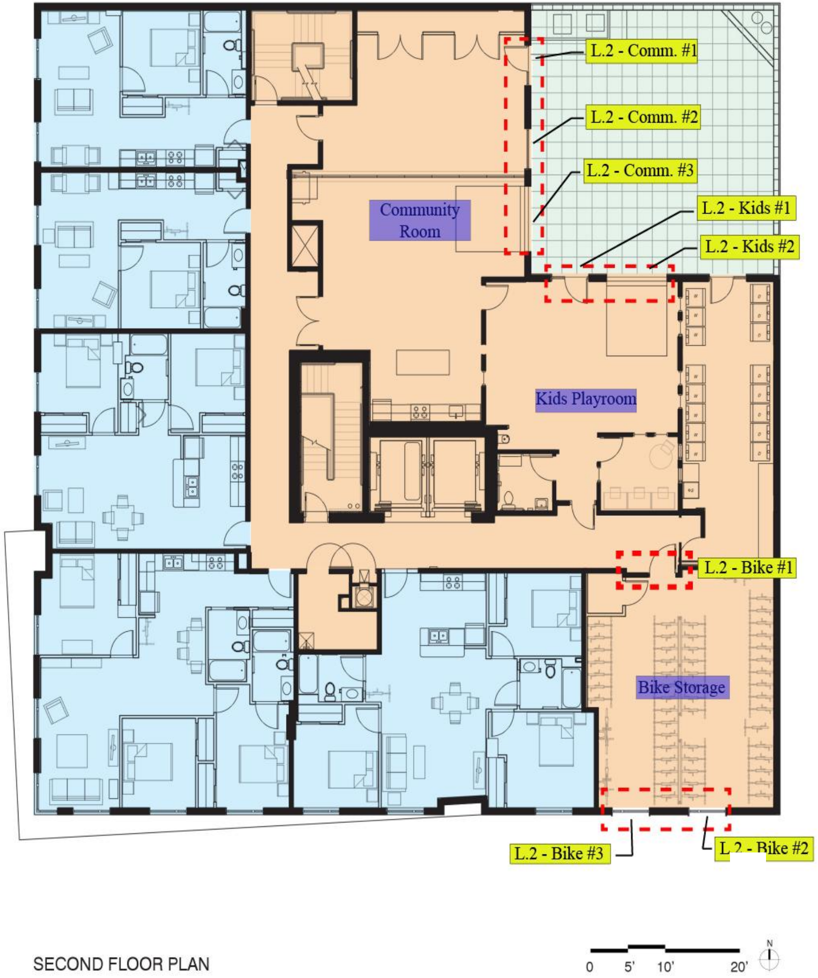
- Only measures one location at a time
- Does not include emissivity of surfaces
- Expensive equipment
- Study over long periods of time

*Takeaway |*

- *There is a documented difference, indicated by previous research, from theoretical calculations to in situ calculations for U-values.*
- *U-Value deviations are found even when using different in situ equipment and ISO standardized calculations. HFM shows deviations of 30-35% from theoretical calculations*




FIRST FLOOR PLAN




SECOND FLOOR PLAN

# Infrared Thermography Data Collection | Representative Example

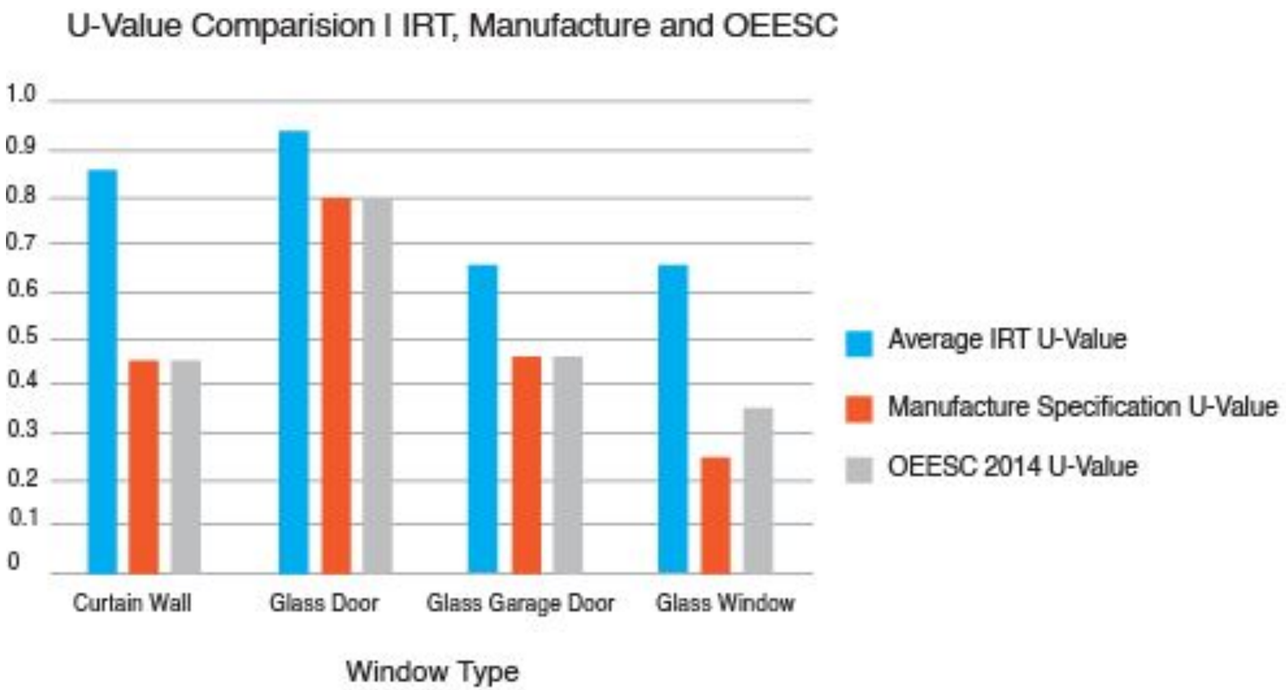

G.L. - Bike Window Type- Curtain Wall
FLIR Thermal Image: Data Collection Day #1

G.L. - Bike Window Type - Curtain Wall
FLIR Picture: Data Collection Day #1

| Data Collection Information | | | | | |
|---|---|---|---|---|---|
| Date: | Time: | Outside Temperature: | Inside Temperature: | Wind Velocity: | Weather Condition: |
| 2.13.2020 | 10:30am - 11:30am | 43°F | 73°F | 3.0 m/s | Cloudy |
| 2.21.2020 | 10:30am - 11:30am | 46°F | 73°F | 1.0 m/s | Sunny |

| U-Value Calculations using temperature recording from IRT [Table 3] | | | | | | |
|---|---|---|---|---|---|---|
| *Location I.D.* | *Glazing Classification:* | *Recorded (F) Day 1* | ***U-Value Day 1*** | *Recorded (F) Day 2* | ***U-Value Day 2*** | *Δ Day 1 & 2 U-Values* |
| G.L. - Bike | Curtain Wall | 59 | **.82** | 61 | **.86** | 5% |
| G.L. - Ent. #1 | Glass Door | 60 | **.87** | 62 | **.92** | 5% |
| G.L. - Ent. #2 | Glass Door | 61 | **.93** | 63 | **.98** | 5% |
| G.L. - Lobby | Curtain Wall | 62 | **.98** | 63 | **.98** | 0% |
| L.2 - Bike #1 | Glass Door | *n/a | ***n/a** | *n/a | ***n/a** | *n/a |
| L.2 - Bike #2 | Glass Window | 57 | **.71** | 57 | **.63** | 11% |
| L.2 - Bike #3 | Glass Window | 55 | **.61** | 58 | **.68** | 10% |
| L.2 - Kids #1 | Glass Door | 62 | **.98** | 63 | **.98** | 0% |
| L.2 - Kids #2 | Glass Garage Door | 59 | **.82** | 59 | **.74** | 10% |
| L.2 - Comm. #1 | Glass Door | 61 | **.93** | 61 | **.86** | 8% |
| L.2. - Comm. #2 | Curtain Wall | 57 | **.72** | 60 | **.80** | 10% |
| L.2 - Comm. #3 | Glass Garage Door | 52 | **.47** | 55 | **.51** | 25% |
| L.U.308 - Main | Glass Window | 59 | **.82** | *n/a | ***n/a** | *n/a |
| L.U.308 - Bedroom | Glass Window | 58 | **.77** | *n/a | ***n/a** | *n/a |
| L.U.502 - Main | Glass Window | 61 | **.93** | *n/a | ***n/a** | *n/a |
| L.U.502 - Bedroom | Glass Window | 60 | **.87** | *n/a | ***n/a** | *n/a |

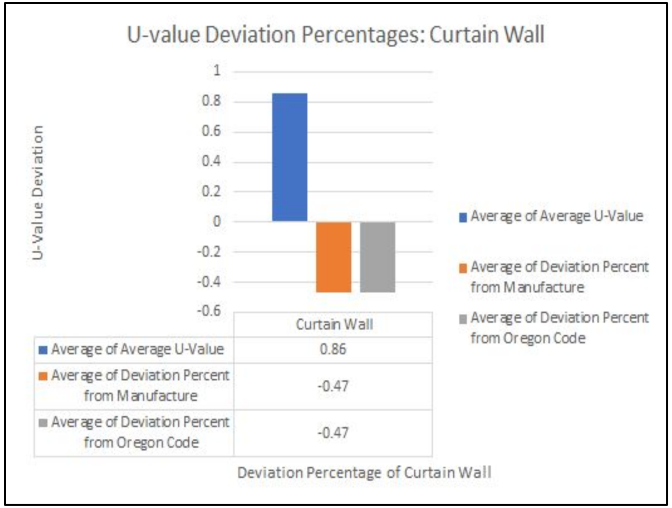
Ground Level  Level 2  Living Units  * Data was not collected

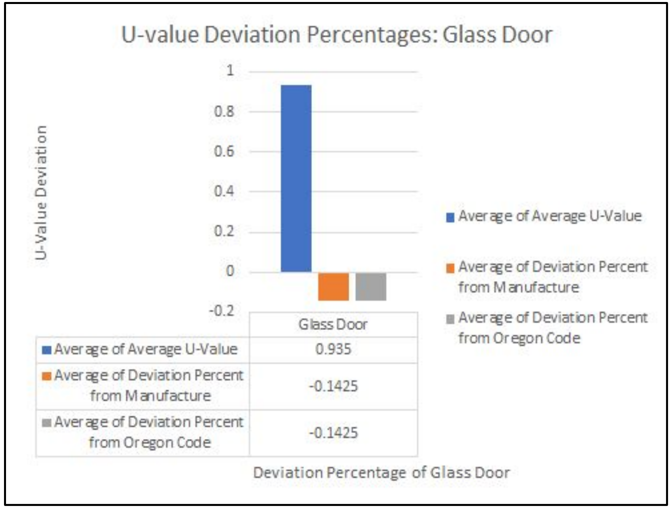

U-Value Comparision I IRT, Manufacture and OEESC
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Curtain Wall
Glass Door
Glass Garage Door
Glass Window
Window Type
Average IRT U-Value
Manufacture Specification U-Value
OEESC 2014 U-Value

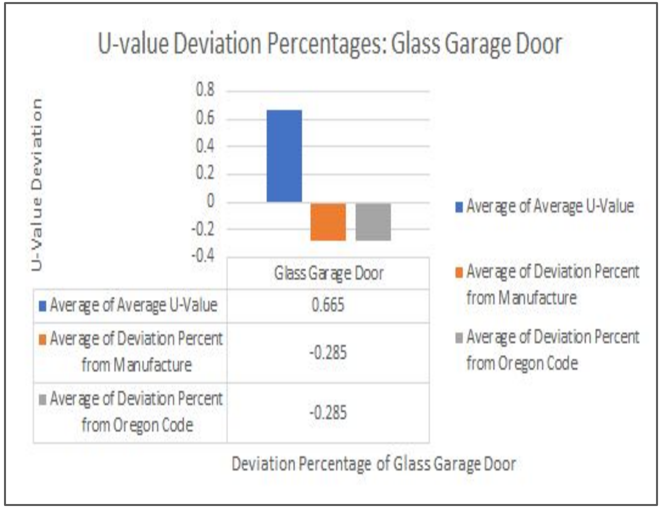
Data Interpretation |

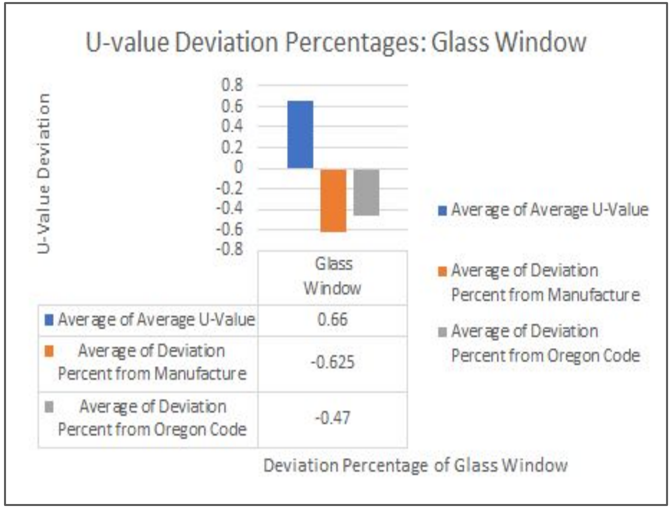
*Takeaway |*

*Deviations in U-values from IRT to Manufacture and OEESC-2014 per individual window type*



# Data Interpretation |


| | Curtain Wall | Glass Door | Glass Garage Door | Glass Window |
|---|---|---|---|---|
| Average U-Value | 0.86 | 0.935 | 0.665 | 0.66 |
| Deviation Percent from Manufacture | -0.47 | -0.1425 | -0.285 | -0.625 |
| Deviation Percent from OEESC 2014 | -0.47 | -0.1425 | -0.285 | -0.47 |

*Takeaway:*

Curtain Wall | 47%

Glass Door | 14%

Garage Door | 29%

Glass Window | 47% - 63%

**IRT Expected Deviation 40% - 45%**

# Infrared Thermography Data Collection | Representative Example

## *Data Collection: Day #1*

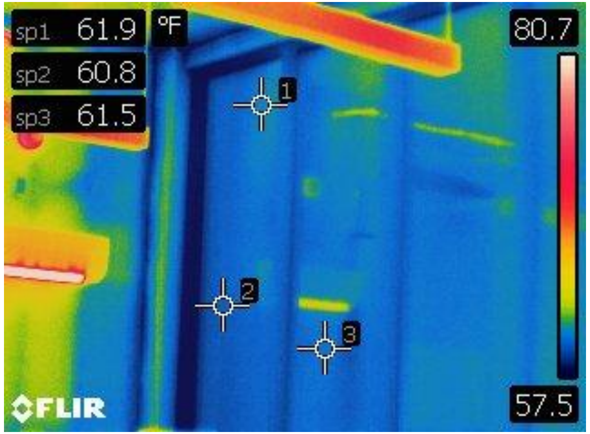
| *U-Value Calculations* | |
|---|---|
| IRT | .82 |
| Manufacture | .45 |
| OEESC | .45 |


G.L. -Bike Window Type - Curtain Wall
FLIR Thermal Image: Data Collection Day #1 (above)
Data Collection Day #2 (below)

G.L. - Bike Window Type - Curtain Wall
FLIR Picture: Data Collection Day #1 (above)
Data Collection Day #2 (below)

## *Data Collection: Day #2*

| *U-Value Calculations* | |
|---|---|
| IRT | .86 |
| Manufacture | .45 |
| OEESC | .45 |




# IRT | Research Constraints and Next Steps

## Data Collection Limitations

- Wall should be greater than the outdoor environment temperature (< 2 F)
- The difference between the indoor environment temperature and outdoor environment temperature should be at least (10-15)
- Limit direct solar irradiation
- Weather must be “fair” (clear sky, possibly sunny and non-rainy or windy)
- Wind speed must be lower than 1 m/s
- Typical climate of the site. Humidity values can significantly alter the thermal performance of the building material.
- Proper installation of the building elements in construction
- Managing of the building by users (heating/cooling and windows opening/closing)
- Maintenance work
- Measurements should be done only during evening; best time is 3:00am - 4:00am

## Future Research with IRT for U-Values

- Data collection over times of year (winter and summer) show differences in U-values results using IRT.
- IRT data was collected anywhere from 3 -10 days with averages calculated for surface temperatures
- Researchers have indicated using both HFM and IRT for in-situ U-value calculation. (Power in different equipment strategies and calculations)
- Equations for U-value based on IRT is still in development. 2019 most recent research article.
- More studies need to specifically include glazing parameters in IRT calculations, most are for building stratigraphy.

## *Takeaway |*

*IRT over the last 30 years has mostly been used for qualitative data collection, however over the last 10 years it has been used for quantitative in situ measurements. These experimental calculations are still not yet applicable to average users and are not yet standardized by the industry.*

***However, a difference between design U-values and in situ U-values are evident from previous research***

## *Takeaway |*

- *40% of energy consumption comes from residential and commercial buildings*
- *U-value are one of the most important calculations for determining the performance of the buildings envelope.*
- *Cost of the evaluation was cited as the largest barrier to use, followed by logistical or time constraints. While portions of the market may support costs of $5,000 or above, some key markets may require much lower costs, e.g. $2,000.*
- *Areas of improvement are in creating more incentive programs for POE research to give owners more options. Additionally firms could incorporate POE research into their service package.*
- *Organizations like Passive House are moving away from established systems and creating their own metrics and operations for energy performance. (Needs to be scaled up and more approachable)*