NCBFO
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Using thermal imaging to commission building envelopes

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Learning Objectives

1. Understand the effect of the building envelope on the building's energy performance
2. Current methodology to estimate building element performance, advantages and disadvantages
3. What is thermography and how is it used with respect to buildings
4. How can quantitative thermography be used to measure building envelope performance

Billions of dollars spent annually on HVAC costs in Canada

Energy consumed by commercial/ institutional buildings

42%

Statistics Canada

Percentage of total GHG emissions attributed to HVAC

45%

Environment and Climate Change Canada

Percent of existing buildings constructed before energy codes

75%

Department of Natural Resources

Up to 80% energy savings from improving the building envelope

Roadblocks

- Lack of quantification technology
- Stakeholder concerns
- High risk

Building envelope performance overview

- Thermal transmittance – The **rate** of heat flow through a building element/assembly (U-value)
- Thermal resistance – The **inverse** of thermal transmittance (R-Value)

$$R-Value = \frac{1}{U-Value}$$

Building envelope performance overview

- Nominal R-value: Thermal resistance rating assigned to product prior to installation
- Effective R-value: The overall thermal resistance of an assembly.

$$R_{eff} = R_{series} + R_{parallel}$$

Where R_{eff} = total effective thermal resistance of the assembly

R_{series} = sum of nominal R values of continuous layers to the exterior of the frame-cavity component

$R_{parallel}$ = effective thermal resistance of the frame-cavity component

Notice

- We will be using U-values as opposed to R-values moving forward in this presentation.
- We will be using the SI units for the most part. These are sometimes represented as RSI and USI values, but means the same thing.

$$U - Value = \frac{1}{R - Value}$$

Building envelope performance overview

Example:

Element	Nominal values		Calculated value	Measured value	Building code U-value
	RSI-value ($m^2.K/W$)	USI-value ($W/m^2.K$)	USI-value ($W/m^2.K$)	USI-value ($W/m^2.K$)	USI-value ($W/m^2.K$)
Wall	4.54	0.22	0.51	1.40	0.31

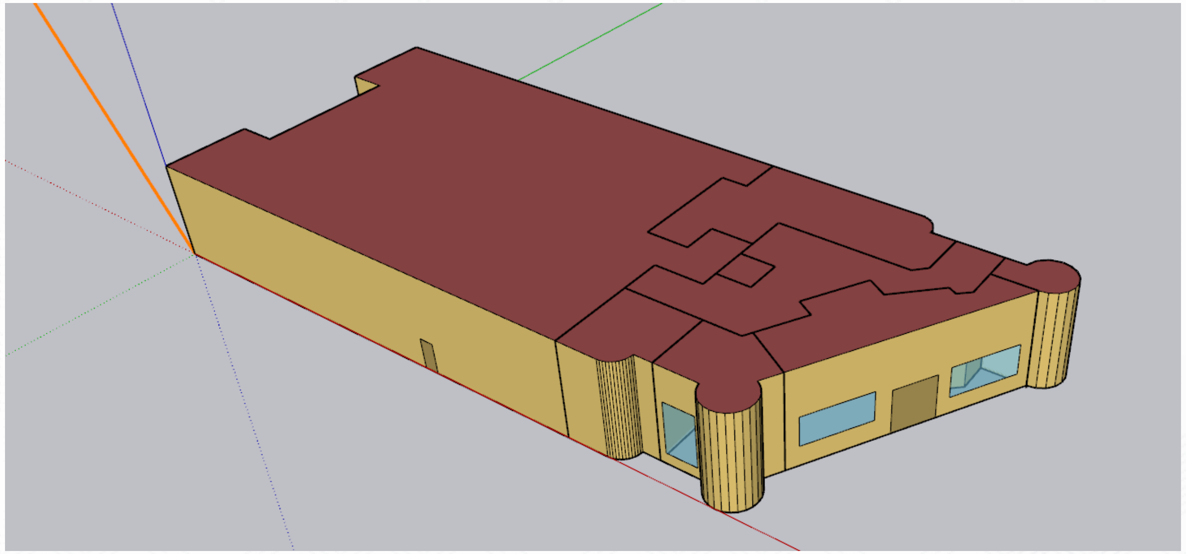
Exterior walls composition:
- Interior l-800r liner c/w air/vapour retarder and caulking at perimeter
- 6″ notched z-bar sub girt
- U-channel sub-girt
- 6″ roxul insulation min r-25.8
- Exterior cladding profile c/w flashings, trims, and sealants
- All interior structural support by structural engineer for siding system to be rated
with fire spray proofing

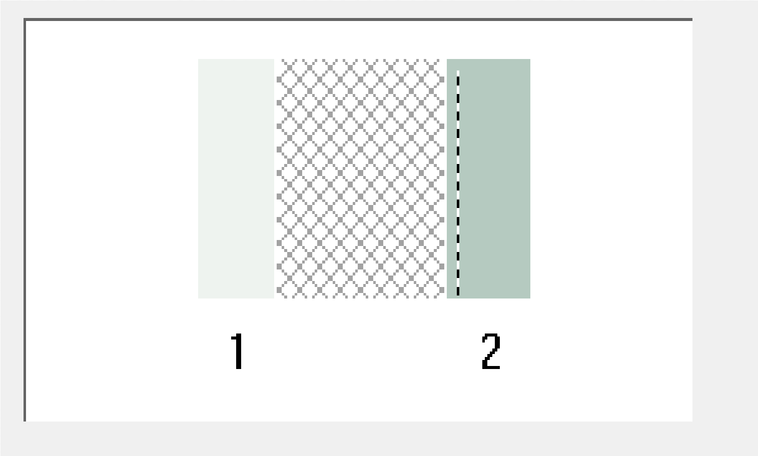
Estimating U-values

3 industry standard methods to estimate building element thermal transmittance

1. Modelling
2. In-situ measurement kit
3. Destructive testing

Modelling





Exterior walls
Inside
➢ 12.7 mm drywall
➢ Poly Vapour Barrier
➢ 50 mm rigid insulation
➢ 63 mm metal studs at 400 mm c.l
➢ 200 mm Concrete Hollow Block
➢ 100 mm Brick
Outside

Modeled U-value	0.79 W/m^2 K
Actual U-value	**1.30 W/m^2 K**

Advantages and disadvantages of modelling

Advantages	Disadvantages
Non-invasive	Analysis only as good as provided information
Remote	May not account for field changes
Can be used predictively (before the structure is built)	Use in retrofit projects may require intense calibration
Can account for interactions between different building systems	Very difficult to model age-based deterioration in retrofit projects
	Difficult to impossible to account for qualitative issues

In-situ U-value measurement

Image source: Testo

- Contains temperature probes, a heat flux meter, and an OAT sensor
- Measurement is conducted from inside the building
- Measurement can take up to 7 days if following ISO procedures

Advantages and disadvantages of in-situ measurement

Advantages	Disadvantages
High accuracy	Time consuming
Real-time measurement accounts for existing issues and age of structure	Sensitive data gathering process
Works well for structures where the entire perimeter is easily accessible	Impractical for anything larger than a home/small commercial property
	Cannot identify qualitative issues

Destructive testing

Image source: West Roofing Systems

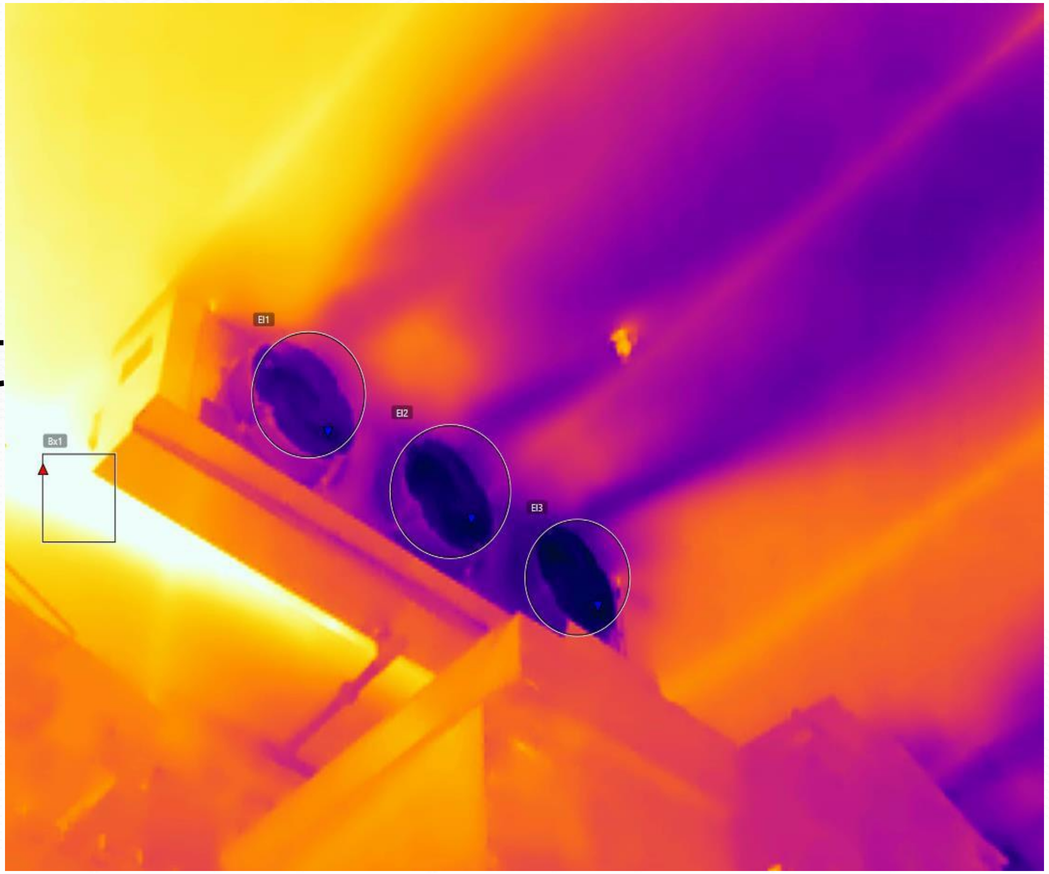
- Core samples are taken from building elements (like roofs)
- Samples are typically assessed based on visual inspection

Advantages and disadvantages of destructive testing

Advantages	Disadvantages
Fairly high accuracy	Created holes need to be filled in, and could further impact the thermal performance of the facade
Real-time measurement accounts for existing issues and age of structure	Direct trade-off between accuracy and destruction of facade
Works well for structures where the the façade is fairly homogenous	May not be practical depending on the structure and its use
Makes a lot of sense to use in roofing retrofits	Does not make much sense in a new construction setting

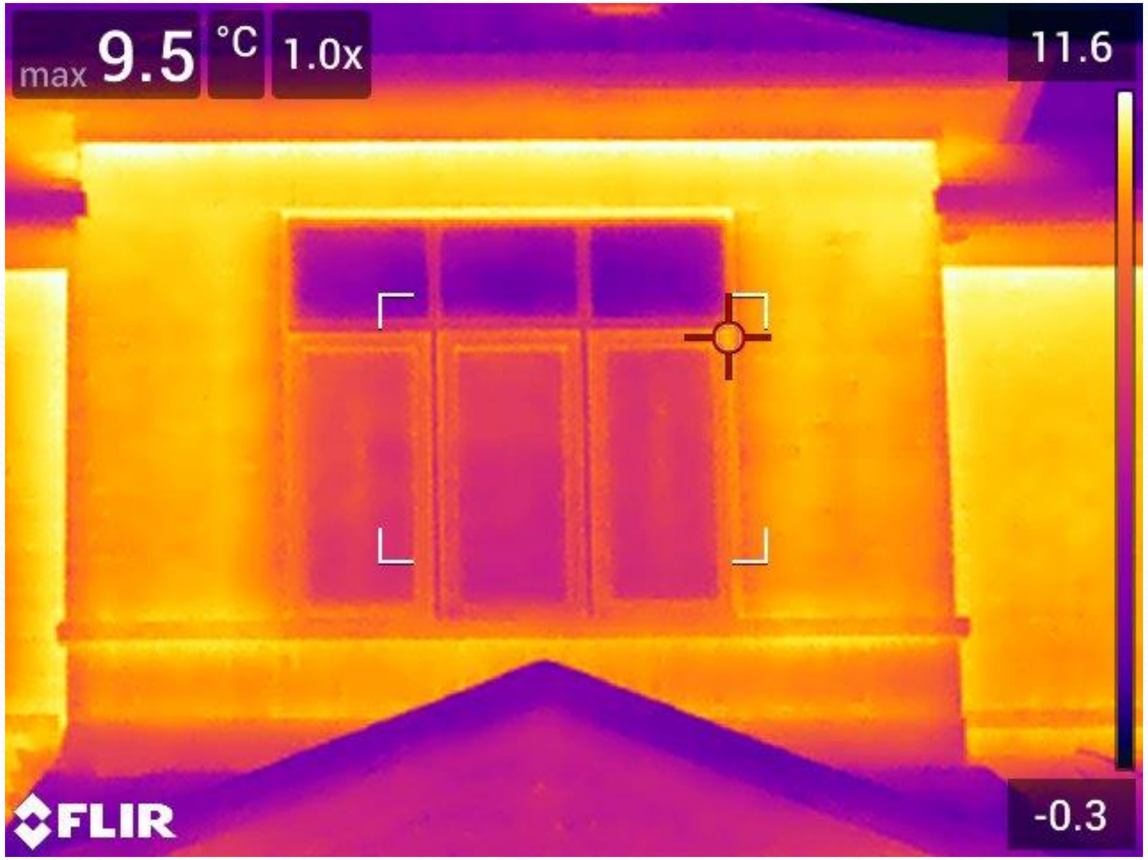
Thermography

Infrared thermography is the process of acquisition and analysis of thermal information from non-contact thermal imaging devices



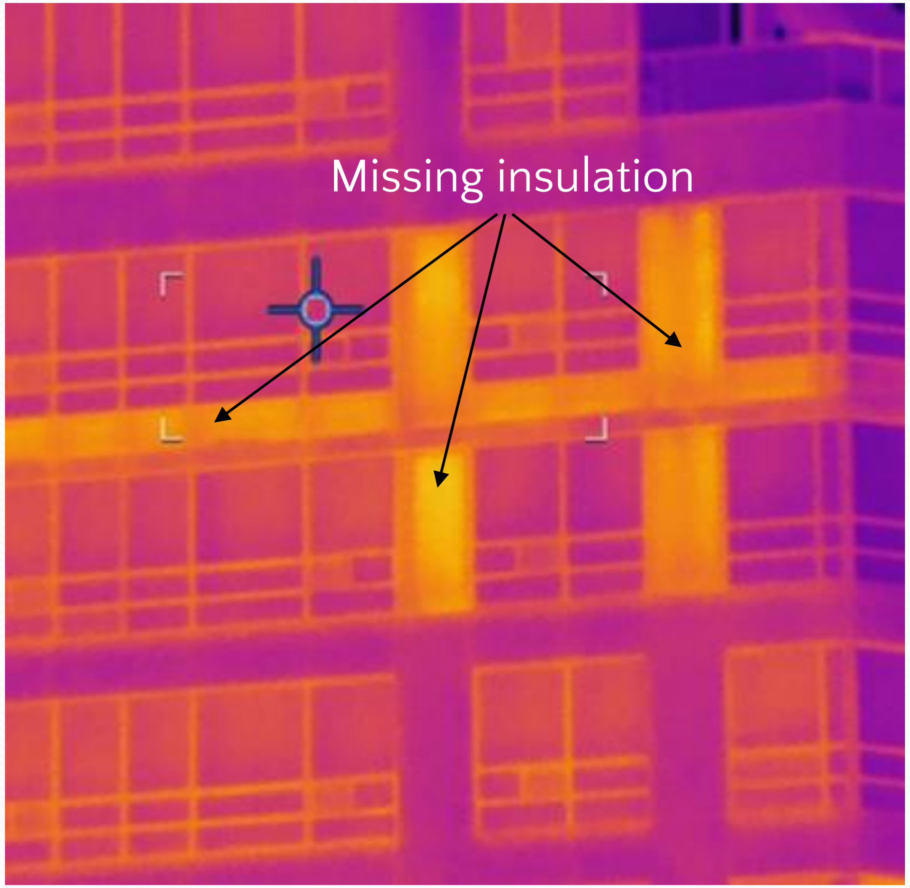
What does this mean?

- IR image “shows” thermal energy radiating from the object
- Darker areas = less energy being radiated
- Lighter areas = more energy being radiated

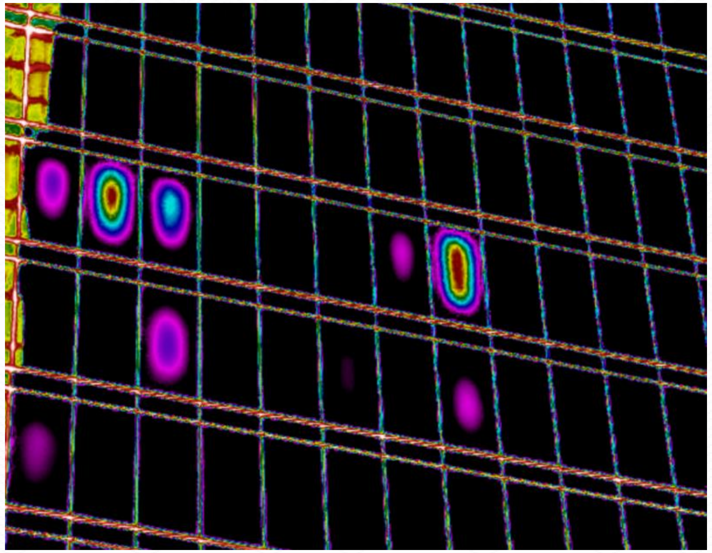


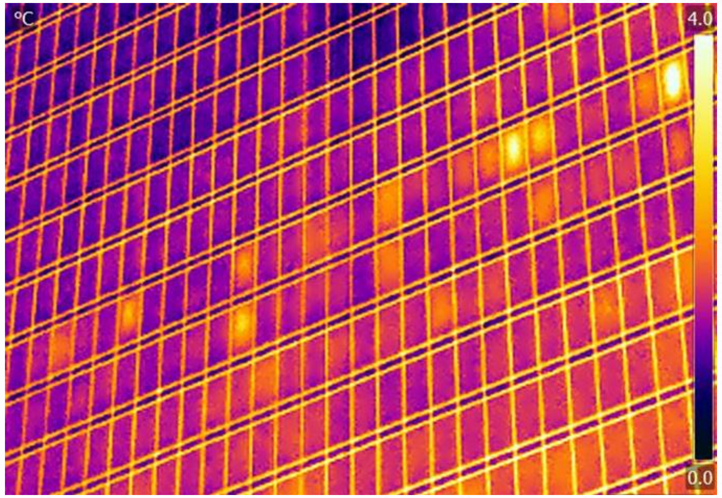
Thermography in buildings

- Already a key part of commissioning building envelopes
- Also used to find electrical and mechanical issues
- Typically concerned with QUALITATIVE readings

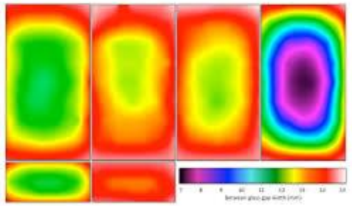


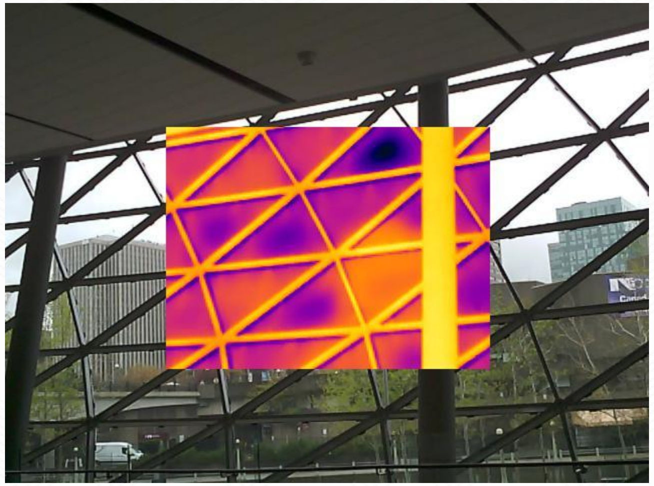
Window and Frame Inspection



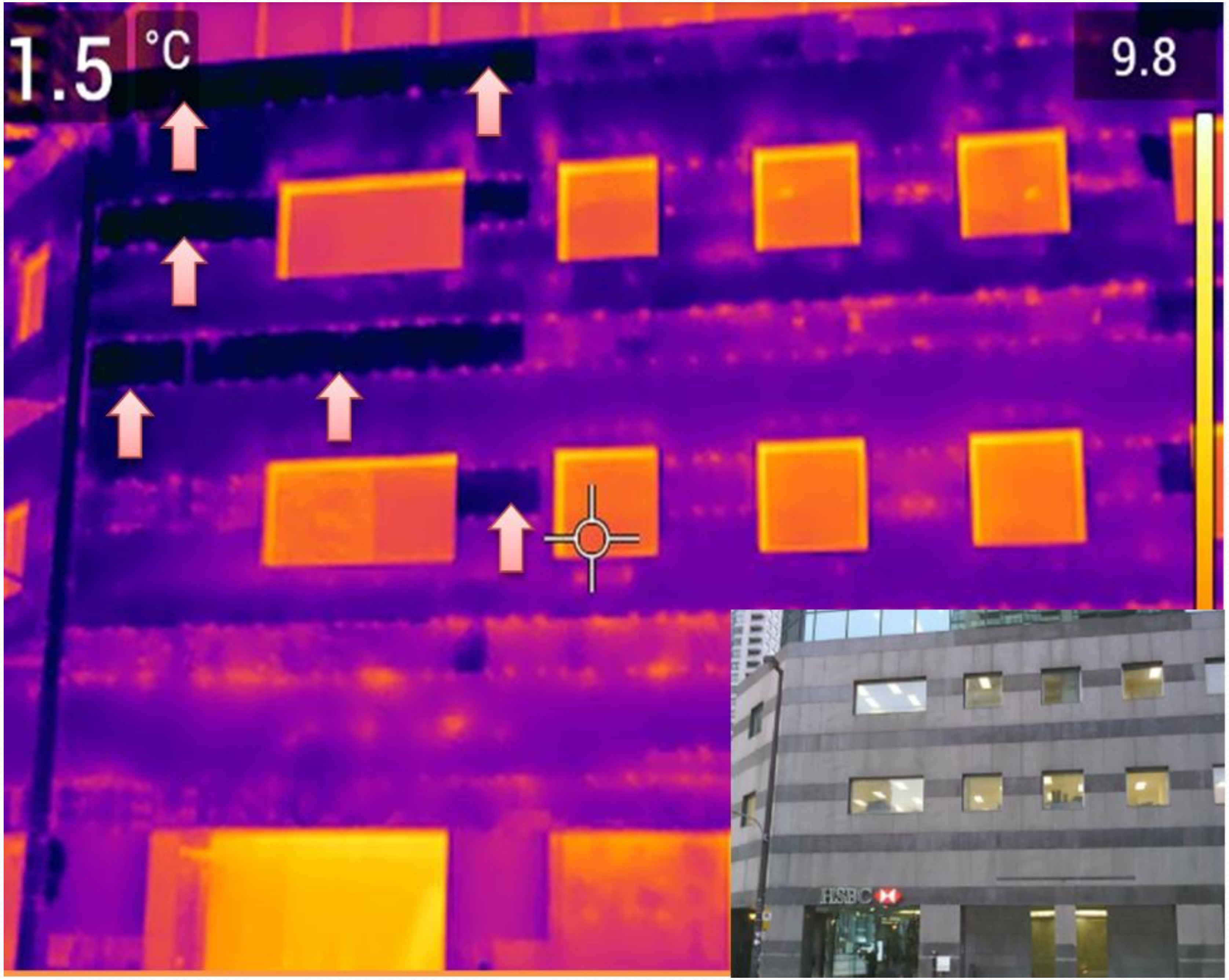


Windows with different amount of ARGON gas

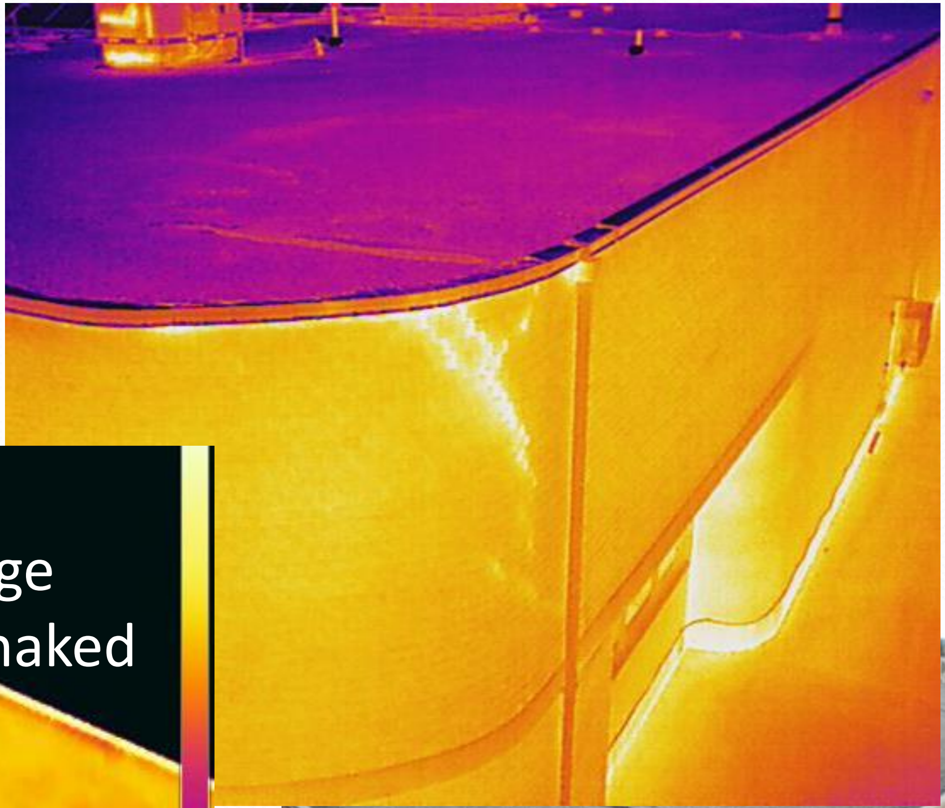




Ice Accumulation



Crack and Leak Detection



Air infiltration

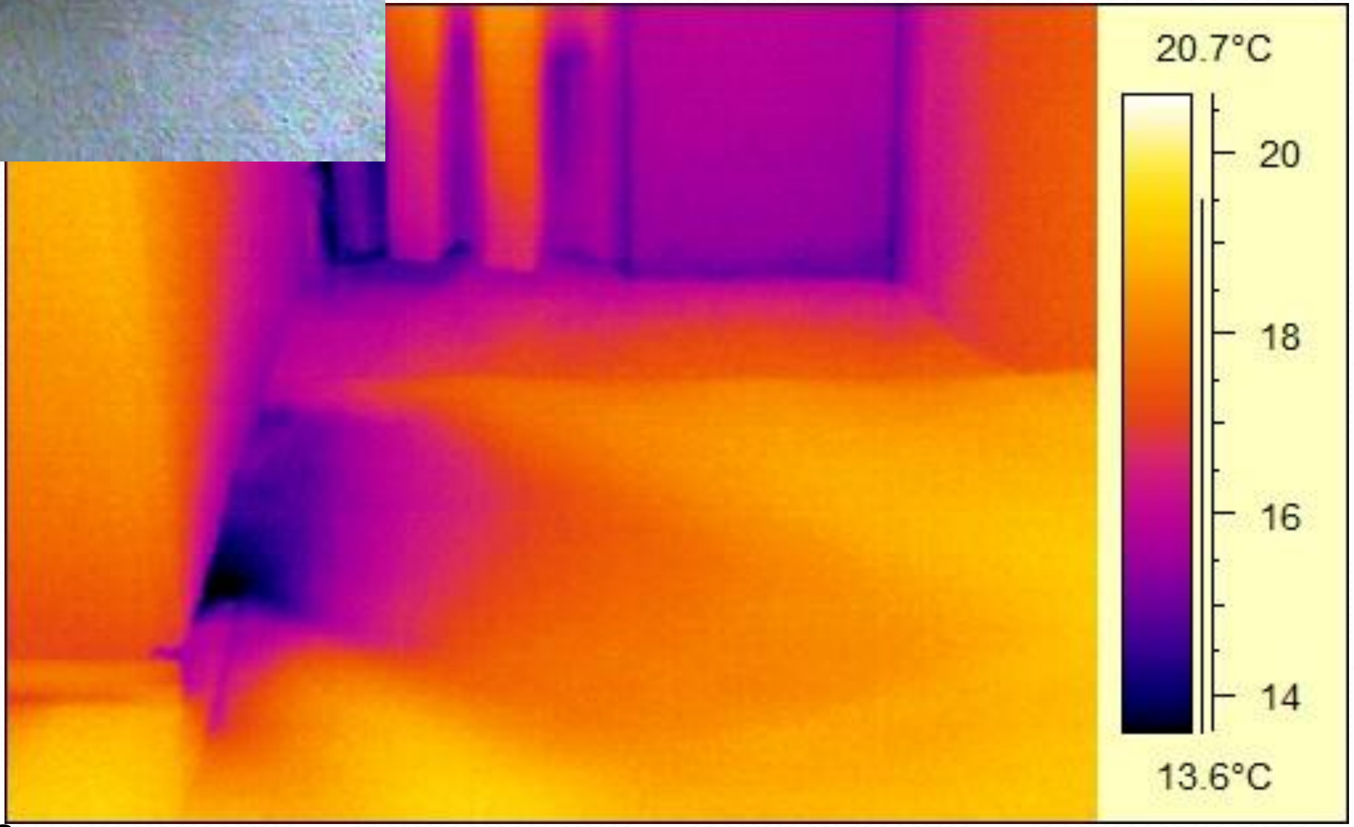


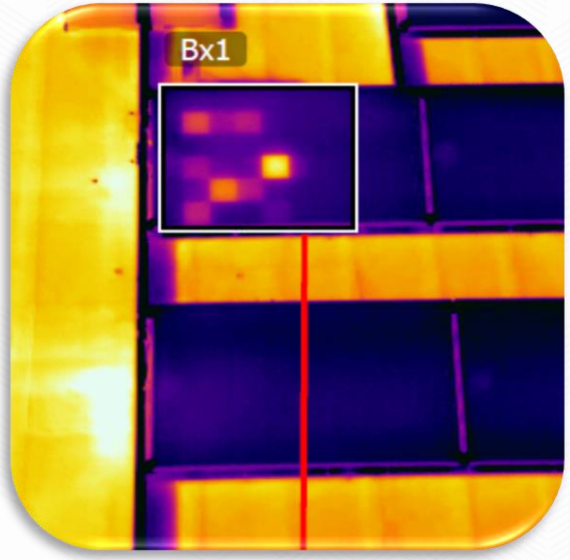
Image source: ITC

Other issues

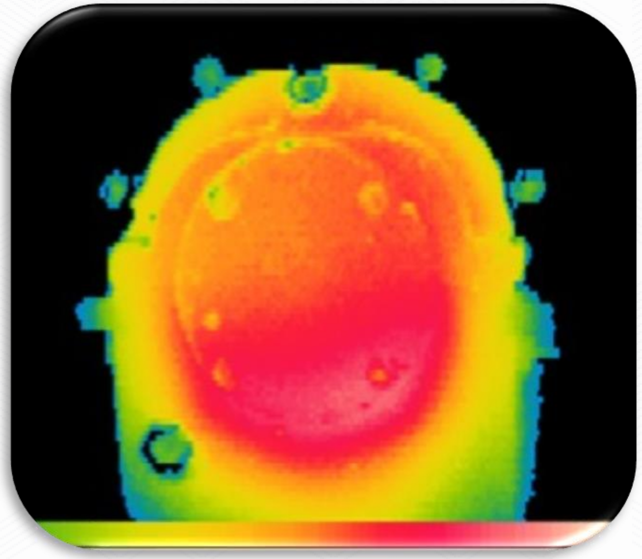
- Thermal Bridging
- Improper Structural Joint
- Inadequate Door Frame Insulation
- Clogged Exhaust Duct
- Surface and sub-surface moisture

Other Applications

Power Lines



Solar



Mechanical

Quantitative thermography

- Thermography can also be used to measure surface temperatures
- This information can be used to determine if equipment is running within its safe operating temperature range, for example.

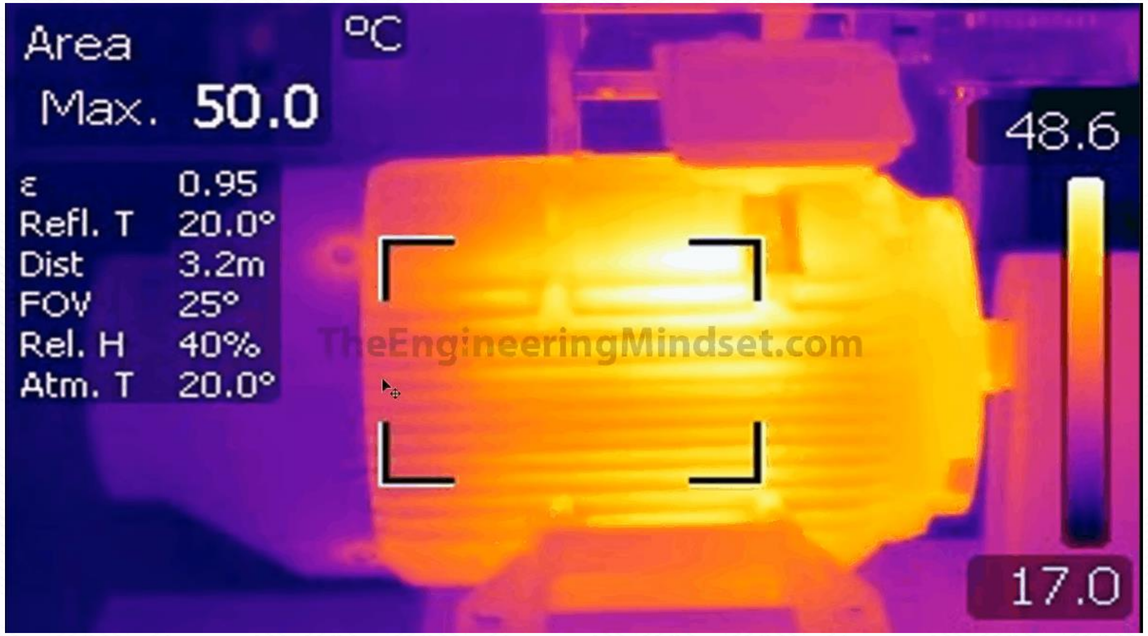
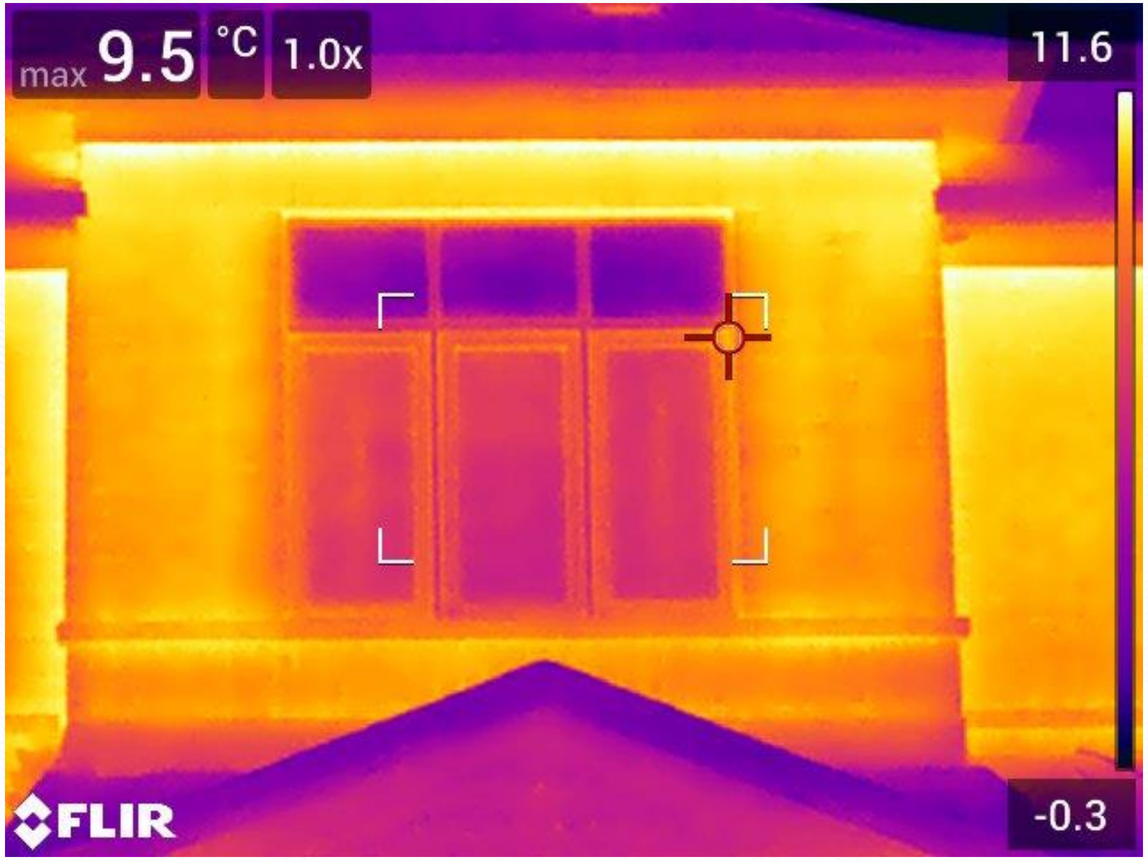


Image source: Engineering Mindset

Quantitative thermography in buildings

- Surface temperatures tell a story when contextualized.

- Qualitative thermography can tell us what the issues are – temperatures tell us how bad they are

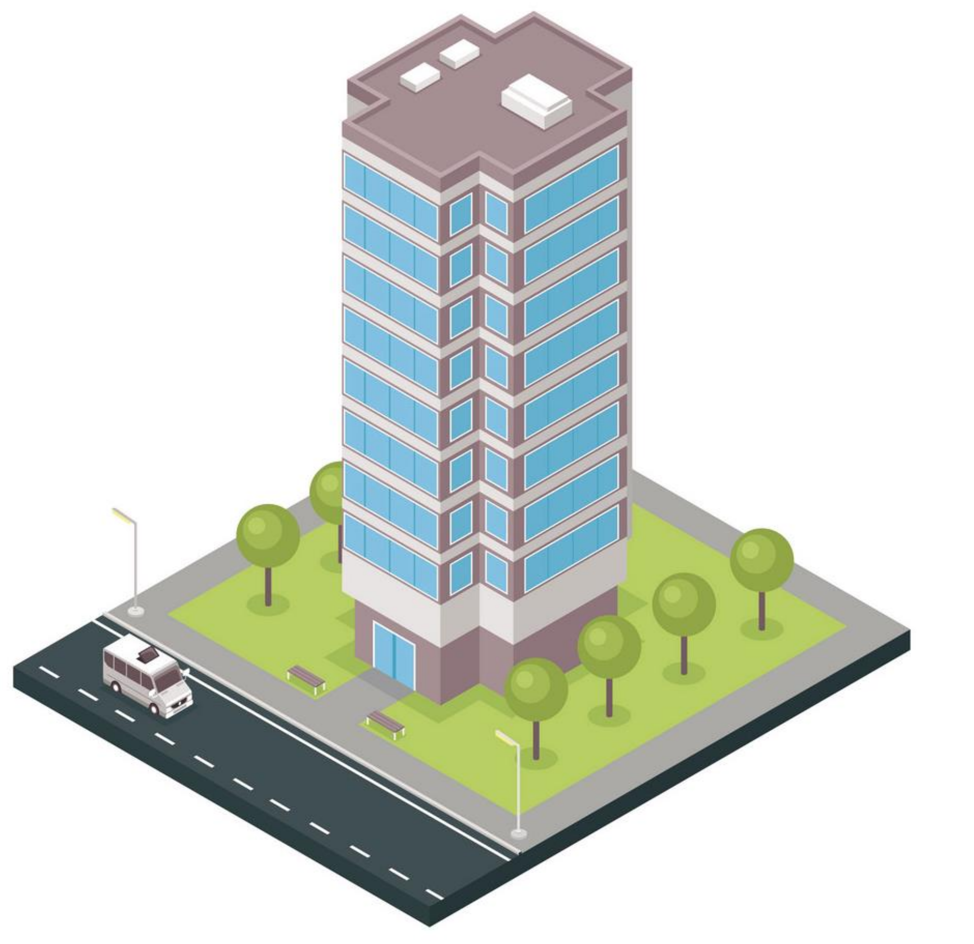


Quantitative thermography in buildings

Can atmospheric data be used along with internal and surface temperatures to estimate thermal transmittance across a building element?

YES!

Thermal transmittance calculations



Key Parameters

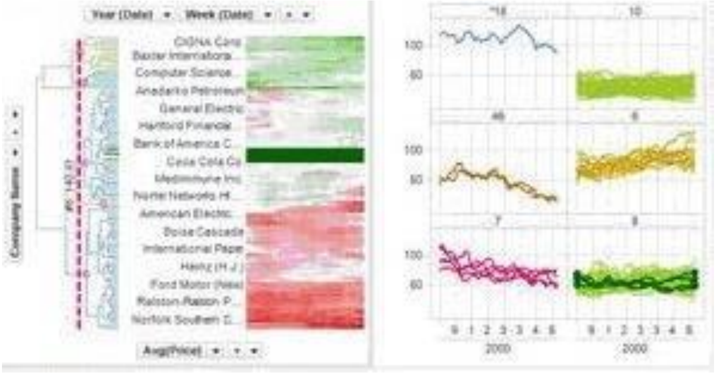
- Surface temperature
- Inside temperature
- Wind Speed
- Ambient Temperature
- Relative Humidity

The process

1 Drone methodically captures thermal images of the

2 Images prepared and processed through

3 Analysis identifies, quantifies and ranks



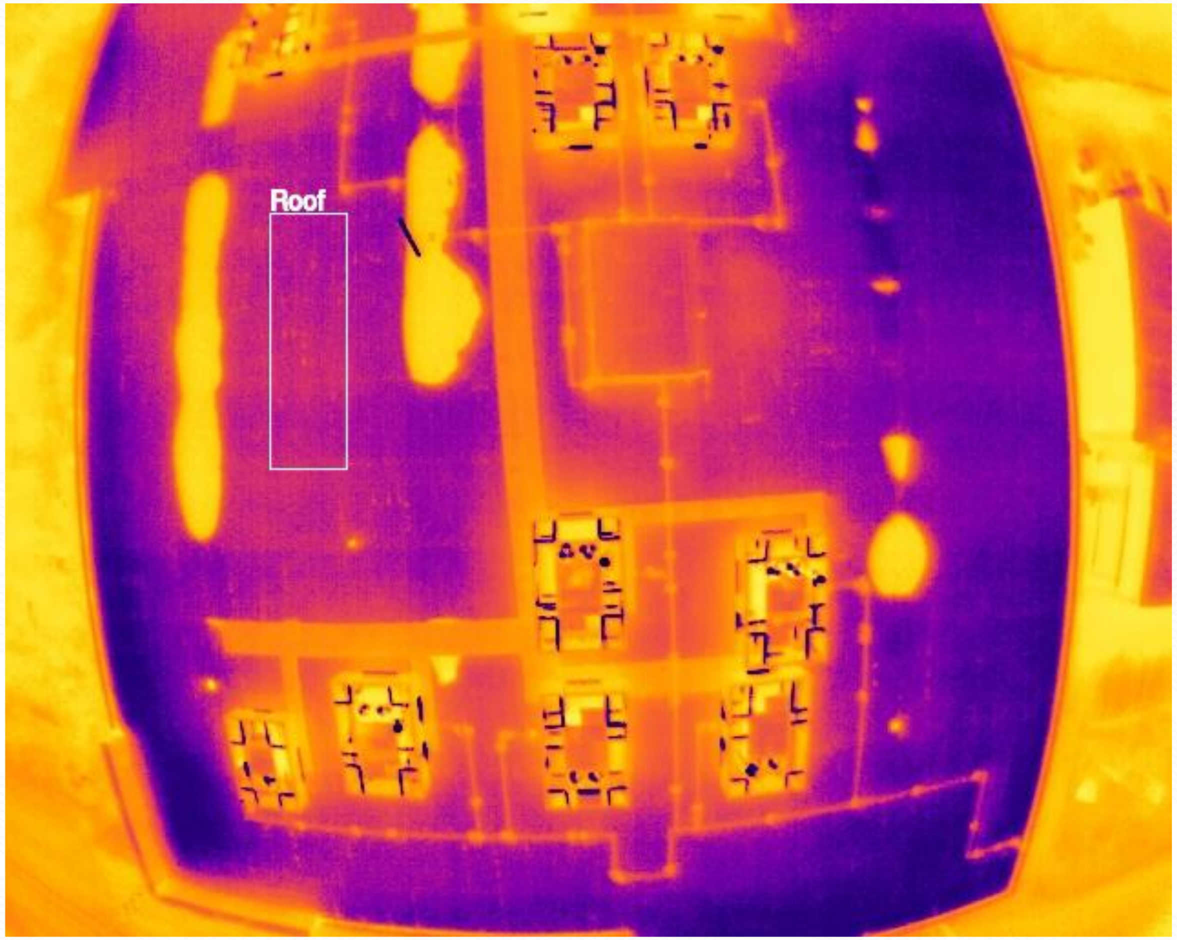
4 Final report includes ROI of repairs

5 Clients have full access to measurable 3D models

Advantages and disadvantages of quantitative thermography

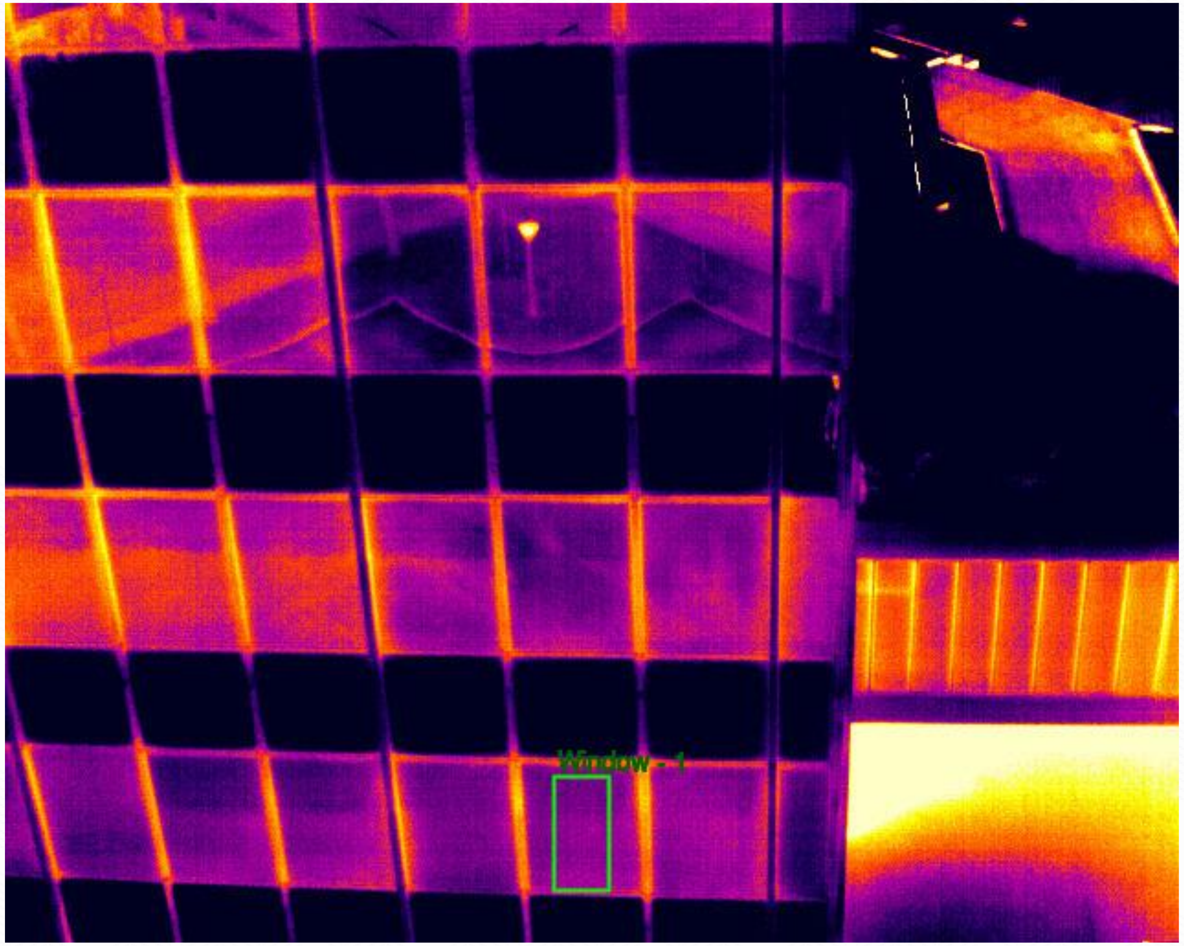
Advantages	Disadvantages
High accuracy	Seasonal – Require a minimum temperature delta of 10 C between the inside and outside of the structure
Very fast due to drone-based data acquisition	Certain locations could have limitations on drone usage
Qualitative issues are highlighted across the entire facade	Cannot find issues that don't leave a thermal signature
Real-time measurement accounts for existing issues and age of structure	
Can use existing thermographic infrastructure in place for qualitative measurement	

Quantification – Roof example



- Avg. U – Value = 0.392
- Building code (2017) U-Value = 0.2
- Annual Energy Loss = 5.87 Wh/m2

Quantification – Window example

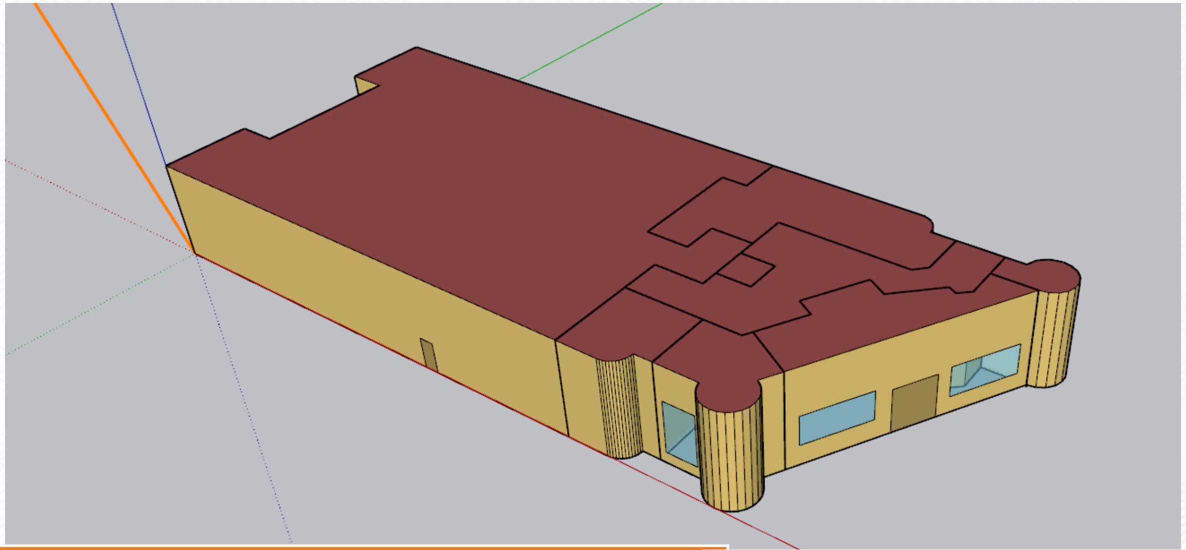


- Avg. U – Value = 3.2
- Building code (2017) U- Value = 2.56
- Annual Energy Loss = 41.7 Wh/m2

Quantification – Wall example

- Avg. U – Value = 1.96
- Building code (2017) U-Value = 0.31
- Annual Energy Loss = 69 Wh/m2

Technology Validation study by U of Ottawa

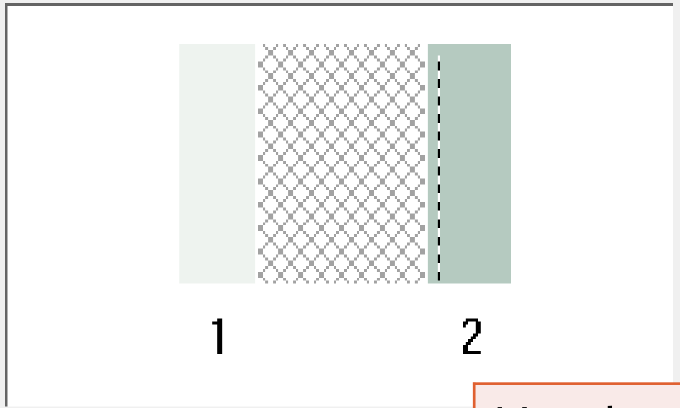


Exterior walls

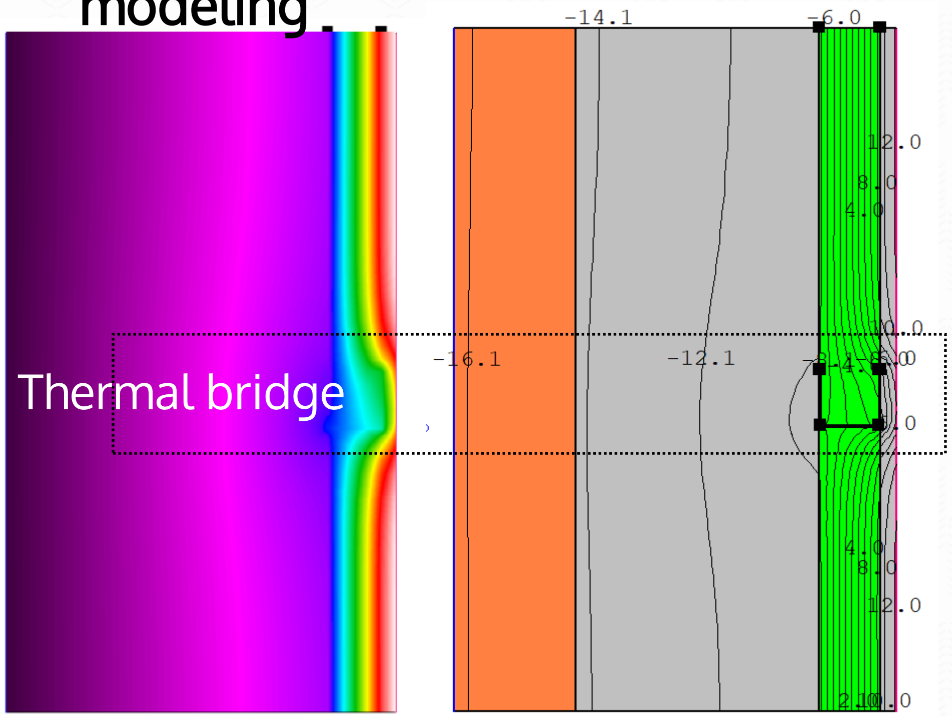
Inside

- 12.7 mm drywall
- Poly Vapour Barrier
- 50 mm rigid insulation
- 63 mm metal studs at 400 mm c.l
- 200 mm Concrete Hollow Block
- 100 mm Brick

Outside



THERM finite element modeling



Flux Magnitude

Isotherms

U-value EnergyPlus method	0.79 W/m² K
U-value THERM method	1.29 W/m² K
U-value Thermography	**1.30 W/m² K**

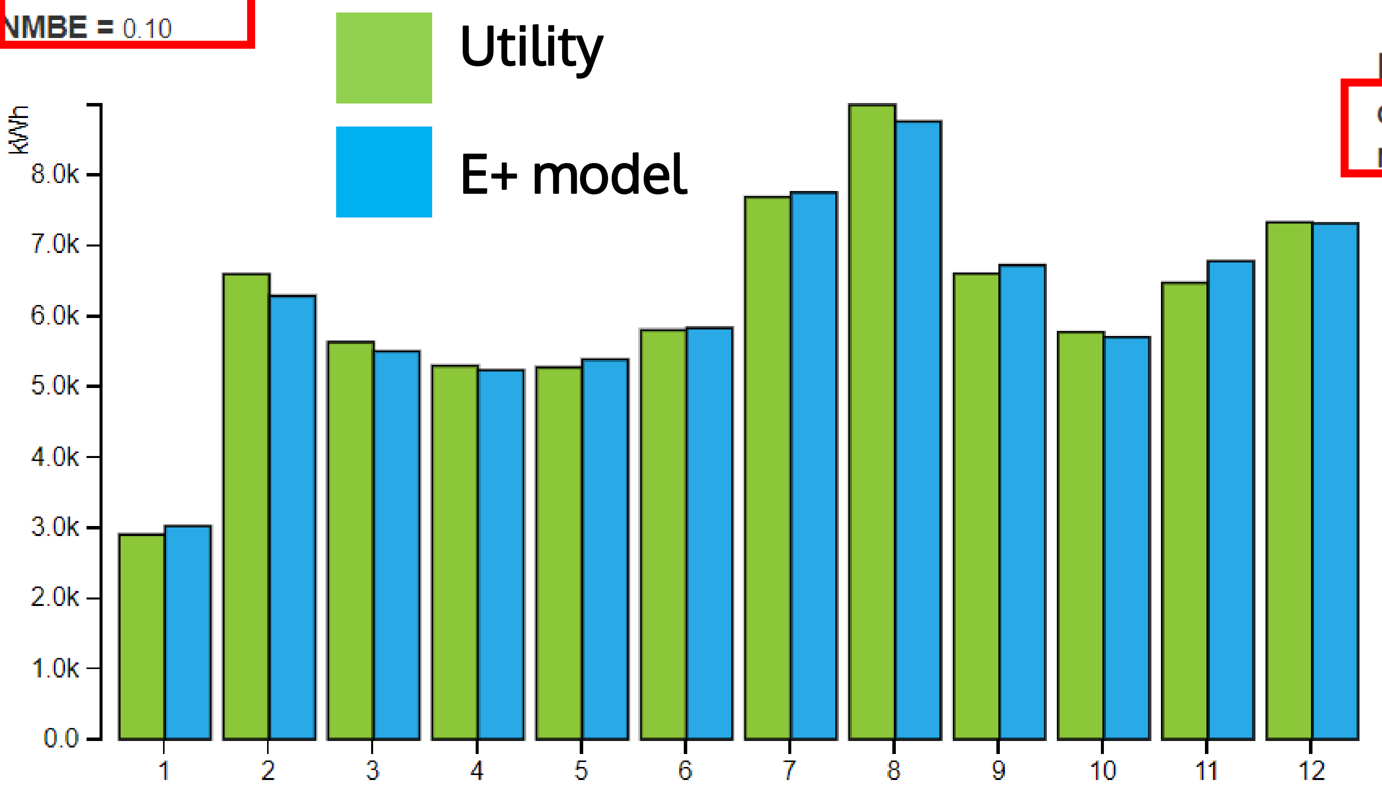
Technology Validation study by U of Ottawa

Total energy use EnergyPlus	398,565 kWh
Total energy use utility bills (2019)	390,504.2 kWh
Percent difference	~2%

- Annual and monthly discrepancies between the energy bills and E+ model comply with **ASHRAE Guideline 14-2014**

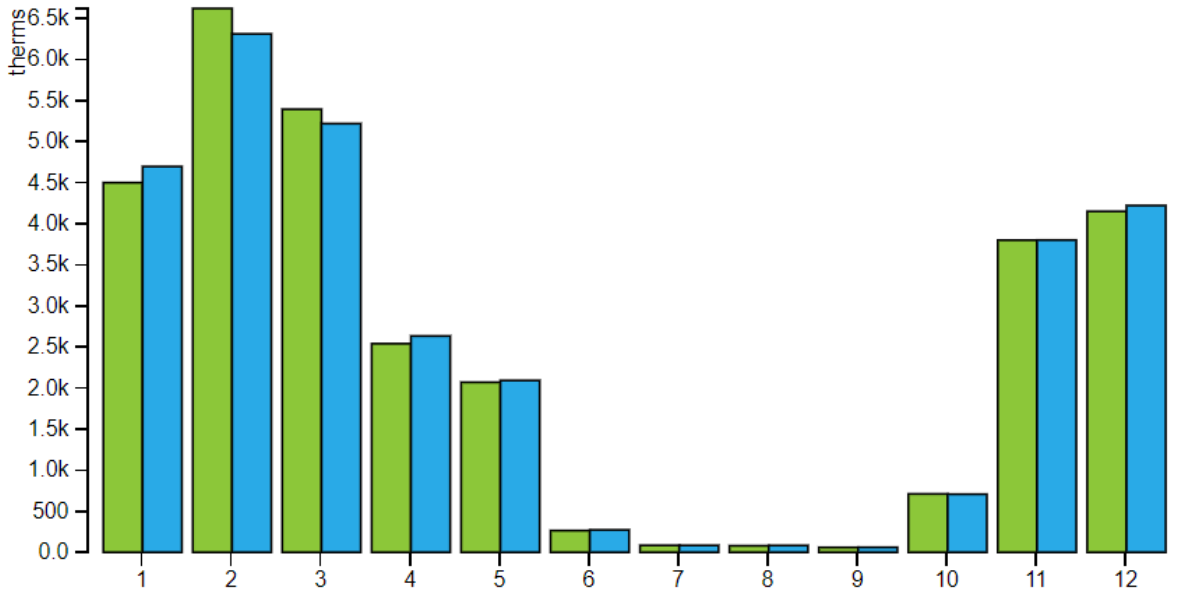
Electricity Consumption (kWh)

CV(RMSE) = 2.75
NMBE = 0.10

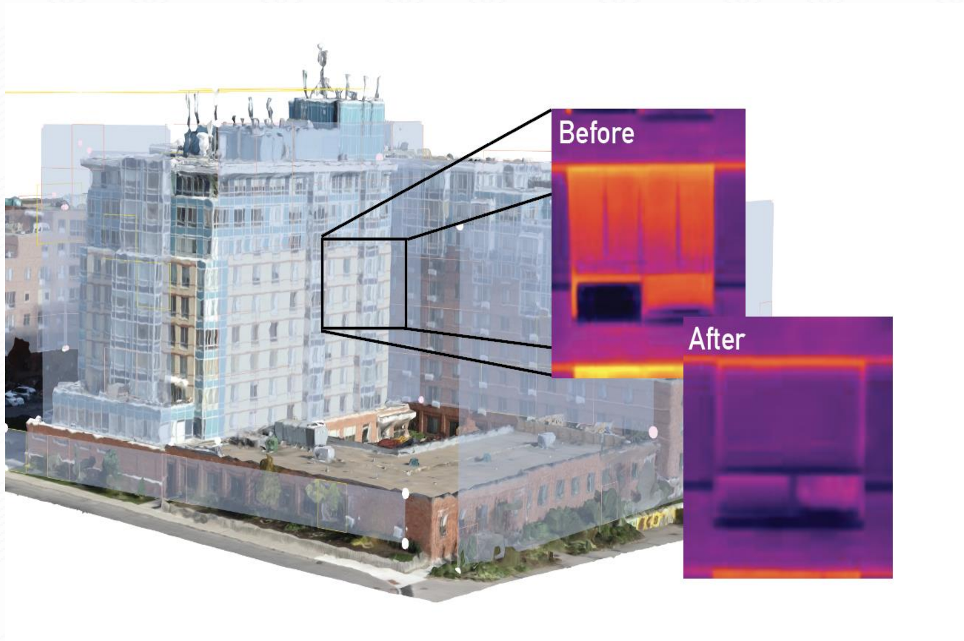


Natural Gas Consumption (therms)

CV(RMSE) = 5.06
NMBE = 0.33



Case Study: Large residential complex built in 1984

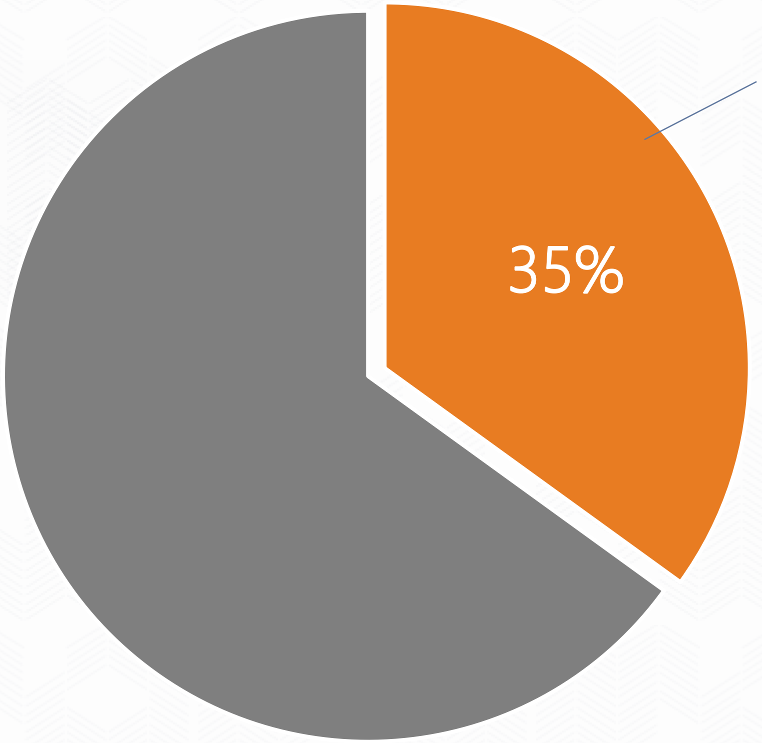


U-Values

Before Retrofit	After Retrofit	National Building Code
3.64	1.58	2.56

Key issues: insufficient thermal insulation at wall/frame connections, uninsulated and failing windows, moisture accumulation behind cladding, cracks in the walls

Total Energy Loss from Envelope



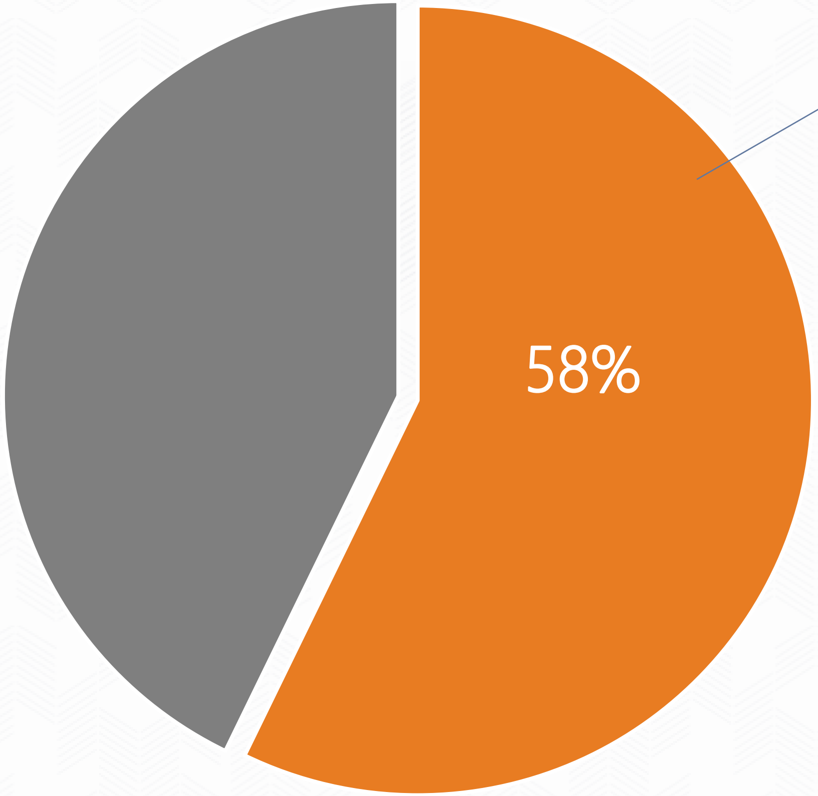
Preventable loss from envelope equates to:

- 1,006 MWh per year
- $100,602 per year
- 171 tCO2e per year

Case Study: Large multi-facility healthcare complex built in 1975

Key issues: thermal bridging, insufficient thermal insulation, moisture accumulation behind cladding and roofing membranes, cracks in the walls, failing windows

Total Energy Loss from Envelope



Preventable loss from envelope equates to

- 4,222 MWh per year
- $591,043 per year
- 718 tCO2e per year

Summary

- HVAC accounts for 40-60% of total energy consumption in buildings.
- Building envelopes are the single largest factor in determining a building's energy consumption and peak demand.
- Current industry best practices in field testing building envelope performance are limited at best.
- Qualitative thermography has been used as a part of the commissioning process for years.
- Quantitative thermography is the quickest, most comprehensive and least invasive of all procedures.

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