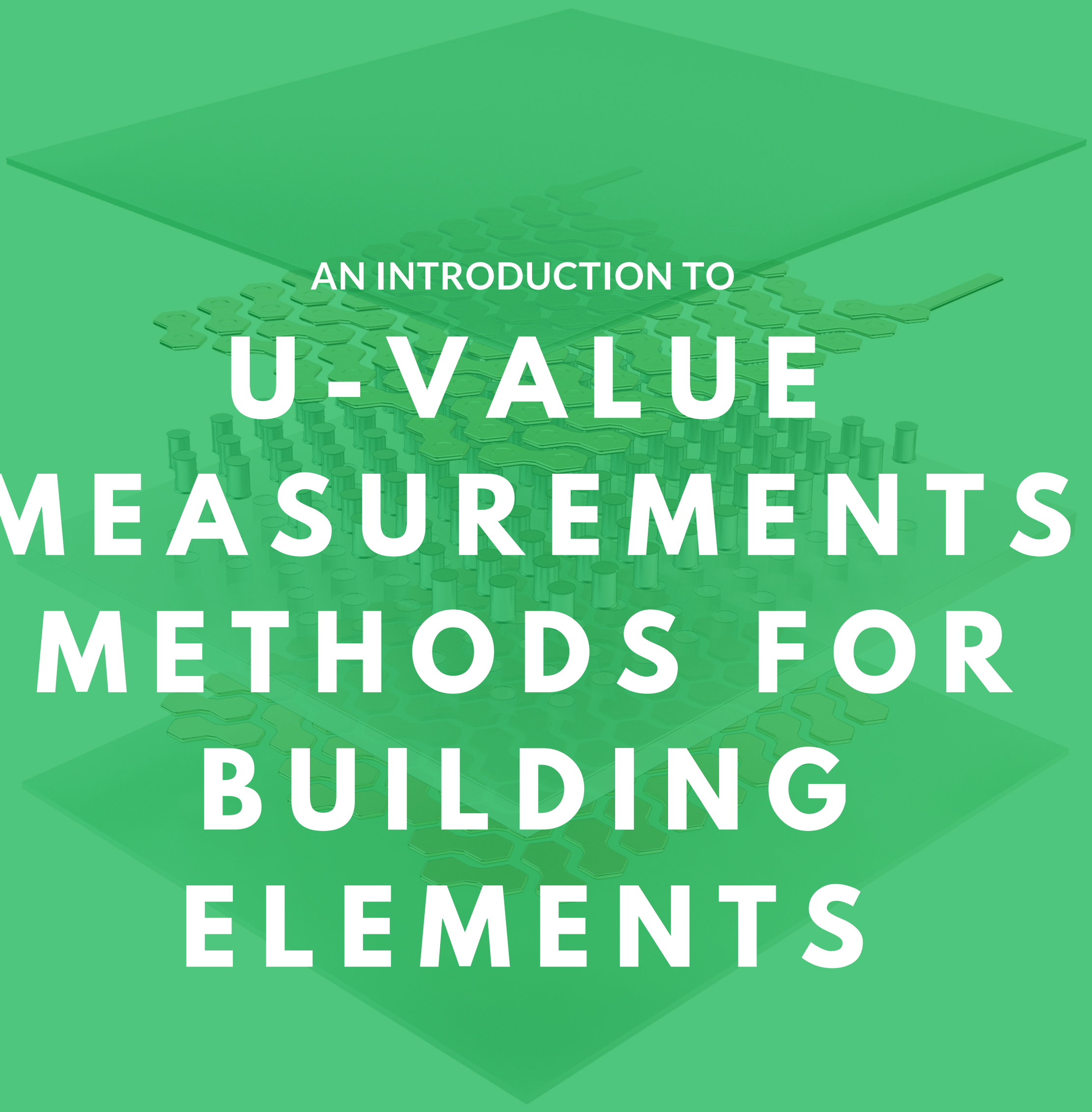

AN INTRODUCTION TO U-VALUE MEASUREMENTS METHODS FOR BUILDING ELEMENTS

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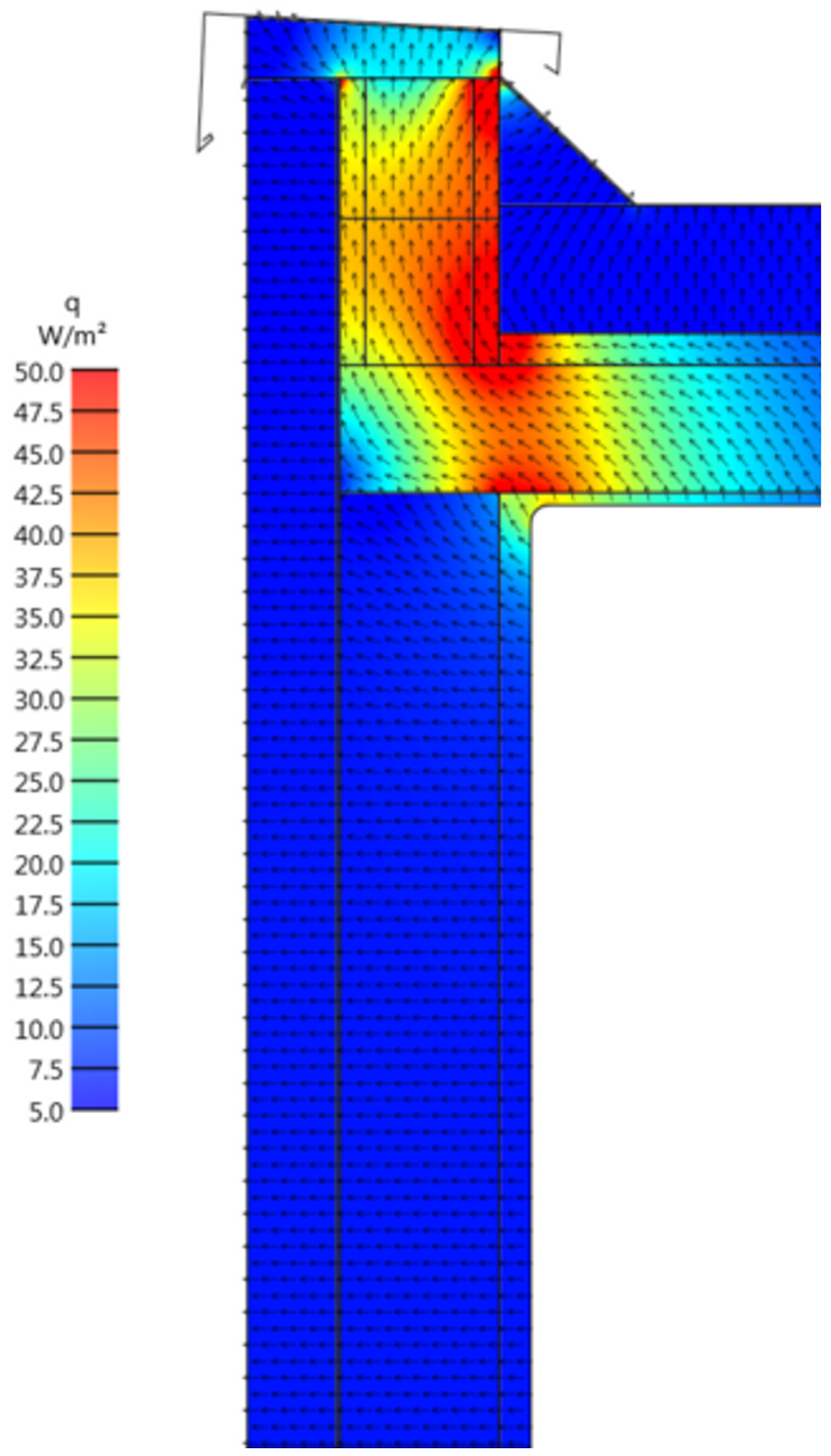
It's about accuracy and reliability

COMPARISON OF TWO DIFFERENT METHODS

Researching insulation materials requires precise measurements of the U-Value.

U-value calculations are useful in setting standards and providing a means of comparing alternative solutions. However, they are simplifications of reality, and performance in use rarely match the prediction because of many reasons. That's why researchers should always measure the real performance, not just calculate it. We can basically choose between two different measurement methods:

- **Temperature based method.** This approach is based on three or more temperature measurements inside and outside of a building element. The heat flux is roughly approximated by measuring the inside temperature and the wall temperature assuming a constant thermal boundary resistance between the inside wall surface and the inside air.
- **Heat flux based method.** The heat flux data (Q) is obtained from a heat flux sensor attached to the inside of the wall. The inside temperature (Tin) and outside temperature (Tout) are measured with two temperature sensors.



Measurements are the best way to detect insulation performance gaps, such as thermal bridges. Above, a heat flux view of a classical thermal bridging effect in the attic area of a concrete roof. Source: Wikipedia.

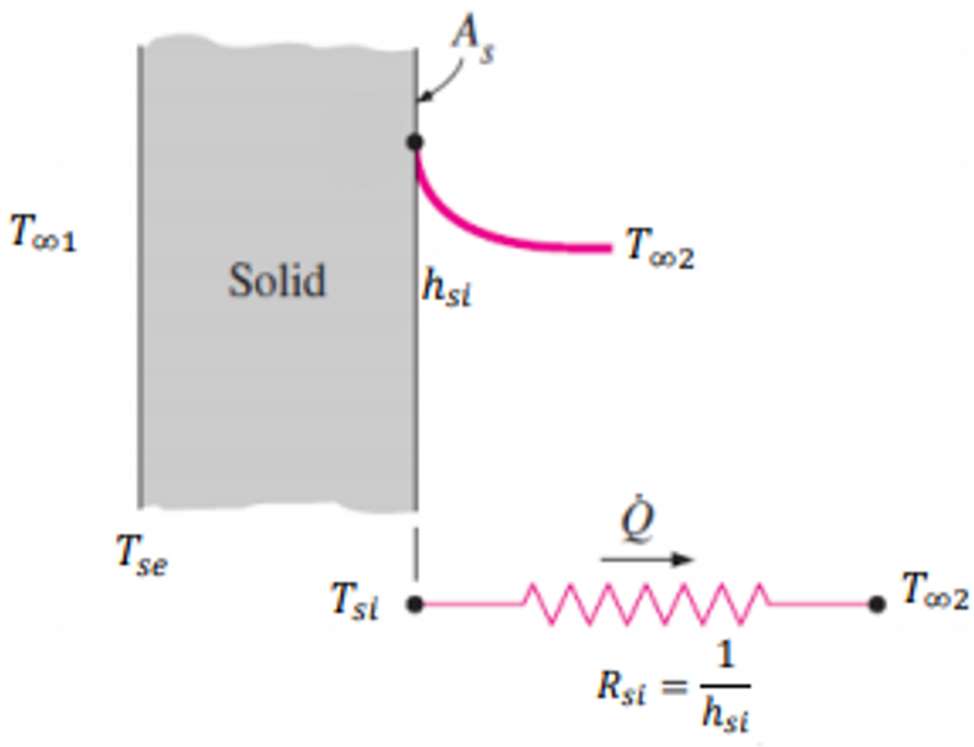
Once the heat flux is measured, it is possible to figure out the U-Value, or thermal transmittance, of any insulation material.

How does it work?

TEMPERATURE-BASED MEASUREMENT METHOD.

Using temperature measurements to measure the U-Value.

This method uses temperature sensors to figure out the thermal transmittance value (or U-Value) of a building element. It uses the convection resistance of a surface to approximate the heat flux (q).



Schematic for convection resistance at a surface, from Yunus A Çengel 2004(1)

$$R_{si} = \frac{1}{h_{si}}$$

$$q = U(T_{\infty 1} - T_{\infty 2}) = h_{si}(T_{si} - T_{\infty 2})$$

$$= \frac{1}{R_{si}}(T_{si} - T_{\infty 2})\left(\frac{W}{m^2}\right)$$

$$U = \frac{1}{R_{si}} \frac{(T_{si} - T_{\infty 2})}{(T_{\infty 1} - T_{\infty 2})} \left(\frac{W}{m^2 \cdot K}\right)$$

Thus, by simply measuring the temperatures Tsi, $T\infty 1$, and $T\infty 2$ the U-value can be determinated under a stationary state (no temperatre changes), as well as with a constant value for R_{si} .

$$R_{si} = 0{,}13 \left(\frac{m^2 \cdot K}{W}\right)$$

Limitations of the temperature measuring method.

While this method generates quantitative data, it is hardly usable for in-situ measurements. To apply this method, a minimum stable temperature difference of 10 °C between the inside and outside temperature is required.

Such temperature differences do not occur very often in most regions, and are most likely not achieved continuously throughout the year. Moreover, both the inside and outside conditions have to be constant during the measurement period and no solar radiation is allowed. These requirements make it very hard to obtain reliable data via multiple temperature measurements.

(1) Yunus A Çengel 2004: Heat transfer: a practical approach, New York, McGraw-Hill 2nd ed

How does it work?

HEAT FLUX-BASED MEASUREMENT METHOD(HFM).

Using heat flux measurements to measure the U-Value.

The way to measure the heat flux, or q (W/m²), is using a heat flux sensor or heat flux plate. The heat flux sensor is a small element where the thermal resistance $RHFM$ is very small and exactly known.

Additionally, the temperature difference between both sides of the heat flux plate ($THFM1-THFM2$) are measured very accurately. The heat flux can be determined with the following equation:

$$q = \frac{T_{HFM1} - T_{HFMA}}{R_{HFM}}$$

The Heat Flux φ is calculated by the heat flux sensor system through the following formula:

$$q = \varphi = \frac{U}{S}\left(\frac{W}{m^2}\right)$$

Where
φ: heat flux (W/m2).
U: sensor output voltage (µV).
S: temperature-corrected sensitivity of the sensor (µV/(W/m2)).

Advantages of the heat flux measuring method.

The advantage of the HFM is that it measures the inside and outside temperature of the air $T\infty1$, $T\infty2$ and the specific heat flow q. When all the three parameters are measured, it is possible then to calculate the U-Value directly as shown in the equation.
This method works even with small temperature differences. It also provides a more accurate U- Value, compared to the previous one, giving a constant measurement even under changing conditions, not a single approximation.

The temperature-corrected sensitivity (S) of the sensor is calculated using the following formula:

$$S = So + (T_s - T_o) \cdot Sc \left(\frac{\mu V}{W/m^2}\right)$$

Where
So: sensitivity at calibration temperature, in $\left(\frac{\mu V}{W/m^2}\right)$

Sc: linear correction factor, in $\left(\frac{\mu V \cdot °C}{W/m^2}\right)$

To: calibration temperature, in °C
Ts: mean sensor temperature level, in °C

Values So, Sc, and To are sensor specific calibration values and are provided together with sensor purchase in the calibration certifícate.

This method provides the U-value from the heat flux and the external and internal temperatures. The U-value is obtained using this equation:

$$U = \frac{q}{(T_{\infty 1} - T_{\infty 2})} \quad \left(\frac{W}{m^2 \cdot K}\right)$$

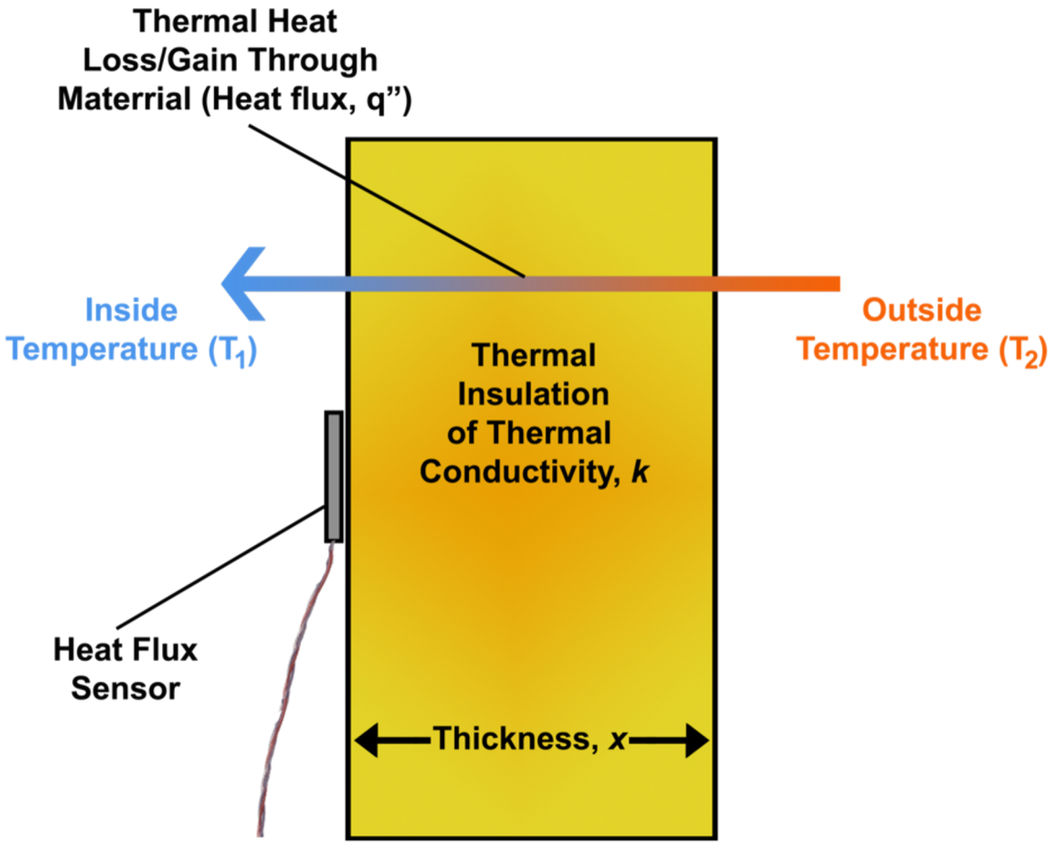


Diagram depicting a heat flux measurement using a single heat flux sensor located on either surface or embedded within the material. Source: Wikipedia

ISO specifications for the heat flux method.

The heat flux method for U-Value measurement is described in detail as a standardized method in ISO 9869 (unlike the temperature method). This standard also considers other factors such as the weather situation, the thermal mass of the wall, the setup of the sensors, or the duration of the measurements. For more info, visit the link: https://www.iso.org/standard/59697.html

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