Project Environmental Engineering

Heat transfer coefficient of a building element. Methods comparison.

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1. Objectives

The aim of this study is to conduct and evaluate two different methods of measuring the thermal transmittance (U-Value) of a construction component. As an example, a wall of a refrigerator was taken.

This measurement will bring the possibility to compare both methods, which will be carried out in stable conditions, inside the laboratory of the university.

The U-Value will be measured with the two following methods:

1. Temperature Based Method carried out with model Testo 635
2. Heat Flux Method carried out with GreenTEG’s gSKIN® U-Value Kit

To simplify we will call them: Temperature-Based Method (TBM) and Heat-Flux Method (HFM).

2. Heat transfer fundamentals

Heat is a form of energy that can be transferred from a system to another due to the difference of temperature between them.

Energy can be transferred in three different ways: conduction, convection and radiation. Every one of them need a temperature difference, and the result is that the heat is transferred from the potential with higher temperature to the one with lower temperature.

To understand the experiment which is carried out, it is important to explain the process of conduction and convection.

2.1 Conduction

Conduction can take place in solids, liquids and gases. In liquid and gas, conduction is based on collisions and molecules diffusion during their random movement. And in solid, it is due to the combination of vibrations in the molecules in a lattice, and the transport of energy through free electrons.

The velocity of heat conduction through the system depends on the geometrical configuration of it, thickness and material it is made of and the temperature difference between its ends or limits.

Of course, we are going to simply calculations, to the point where we consider the simplest case to our favor.

Thus, we consider a stationary state, that the temperature is evenly distributed and a closed system.

Under these conditions, the heat transfer through a wall is proportional to the temperature difference through it and the area of heat transfer, but inversely proportional to the thickness of the wall.
By taking this in consideration, we can write the following formula, which is Fourier’s law of heat conduction, where

$$\dot{Q}_{\text{cond}} = -k \cdot A \frac{dT}{dx} = -k \cdot A \frac{T_1 - T_2}{L} \ (W) \ \ (1)$$

Where:

$\dot{Q}_{\text{cond}}$: heat transfer through the wall (J/s=W).

$k$: thermal conductivity (W/(m·K)).

$A$: transversal area of heat transfer ($m^2$).

$L$: wall thickness (m).

$\Delta T$: temperature difference (K).

Another way to write equation (1) is:

$$\dot{Q}_{\text{cond}} = \frac{T_1 - T_2}{R_{\text{wall}}} \ (W) \ \ (2)$$

The thermal resistance of the wall $R_{\text{wall}}$ is:

$$R_{\text{wall}} = \frac{L}{k \cdot A} \ (\frac{K}{W}) \ \ (3)$$

and area related:

$$R'_{\text{wall}} = \frac{L}{k} \left( \frac{m^2 K}{W} \right) \ \ (4)$$
The thermal conductivity $k$ is the property of a material to conduct heat. Each material has its specific thermal conductivity and because of many determinations realized through the years, these values are well-known as shown in the Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W/m°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At 25°C</td>
</tr>
<tr>
<td>Iron</td>
<td>80</td>
</tr>
<tr>
<td>Low carbon steel</td>
<td>54</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>16</td>
</tr>
<tr>
<td>Tungsten</td>
<td>180</td>
</tr>
<tr>
<td>Platinum</td>
<td>70</td>
</tr>
<tr>
<td>Aluminium</td>
<td>250</td>
</tr>
<tr>
<td>Gold</td>
<td>310</td>
</tr>
<tr>
<td>Silver</td>
<td>420</td>
</tr>
<tr>
<td>Copper</td>
<td>401</td>
</tr>
</tbody>
</table>

*Table 1. Influence of temperature on thermal conductivity of different materials. (Yunus A Çengel 2004)*

From the previous table, we can notice that thermal conductivity is slightly influenced by the temperature.

The influence of temperature on heat conductivity depends on the material, and particularly on internal structure.

Materials with high conductivity values are good conductive materials, and with low conductivity values are isolators.

As shown in *Figure 2* metals are good conductors. It is linked to their crystalline structure.

*Figure 2. Thermal conductivity in different materials and phases at room temperature. (Yunus A Çengel 2004)*
The main difference between metals and crystalline solids is that crystalline solids are only good conductors of heat, but not electricity, unlike metals which are good for both.

2.2 Convection

Convection is one of the ways to transfer heat. It is based on particles of fluid or gas at different temperatures, which are in contact, initiating the movement between the distinctly parts. It can be classified as natural or forced convection, depending on how it has been initiated the motion of the fluid.

Conduction and convection could be considered similar on the matter that both need a material medium to occur.

Convection heat transfer is tightly linked to the fluid mechanics, which include fluid at rest or on motion, and the interaction of fluid particles with other fluid particles. Of course, it is necessary to examine the characteristics of the fluid or fluids, that are investigated. Some of the examples are: internal or external flow, compressible or incompressible flow, laminar or turbulent flow, natural or forced flow, etc.

Experience shows that convection heat transfer strongly depends on the fluid properties such as: dynamic viscosity, thermal conductivity, density, specific heat and fluid velocity. It should be also considered the geometry and the roughness of the solid surface apart from the type of the fluid flow. Due to these variables, convection is considered the most complex mechanism of heat transfer. Despite the complexity, it can be expressed by Newton’s law of cooling:

$$ Q_{\text{conv}} = hA_s(T_s - T_\infty) \quad \text{(W)} \quad (5) $$

Where:

$Q_{\text{conv}}$: heat transfer (W).

$h$: convection heat transfer coefficient (W/m²·°C).

$A_s$: heat transfer surface area (m²).

$T_s$: temperature of the surface (°C).

$T_\infty$: temperature of the fluid surrounding the surface (°C).

It is important to draw attention to the convection heat transfer coefficient, which is the value of heat transferred between a solid surface and a fluid. This coefficient is not a simple value. Because convection depends on multiple variables mentioned before, it is difficult to determine it. In addition, the convection heat transfer coefficient changes through the fluid. In this case, it is determined by taking average value.

The convection heat transfer coefficient is influenced by the type of flow: laminar or turbulent.

Laminar:

$$ Nu = \frac{h \cdot l_s}{k} = 0.664 \cdot Re^{0.5} \cdot Pr^{1/3} \quad \text{Re}_L < 5 \cdot 10^5 $$
Turbulent:  
\[ Nu = \frac{h \cdot L_c}{k} = 0.037 \cdot Re^{0.8} \cdot Pr^{1/3} \quad 0.6 \leq Pr \leq 60 \]

\[ 5 \cdot 10^5 \leq Re_L \leq 10^7 \]

Where:

\( Nu \): Nussel number.

\( Pr \): Prandlt number.

\( Re \): Reynolds number.

\( L_c \): characteristic length (m)

\( h \): convection heat transfer coefficient in laminar flow (W/(m\(^2\)·K)).

It is seen that the coefficient is influenced by the Reynolds number, which determines the type of the flow. In Figure 3 is shown how it changes through the fluid flow.

\[ h_{x,\text{laminar}} \]: convection heat transfer coefficient in laminar flow (W/(m\(^2\)·K)).

\[ h_{x,\text{turbulent}} \]: convection heat transfer coefficient in turbulent flow (W/(m\(^2\)·K)).

\[ h_{\text{average}} \]: mean convection heat transfer (W/(m\(^2\)·K)).

It is seen that the maximal convection heat transfer coefficient value is at the transition between turbulent and laminar flow.

Figure 3. Representation of the average heat transfer coefficient for a plate with laminar and turbulent flow. (Yunus A Çengel 2004)
2.3 Heat transfer through a wall

*Figure 4,* shows how the heat is transferred through a construction component, e.g. a wall of a building or of a fridge.

![Thermal resistance network for a heat transfer through a plane wall subjected to convection on both sides. (Yunus A Çengel 2004)](image)

Regarding *Figure 4,* it is possible to write the heat transfer as:

\[ \dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}} \quad (\text{W}) \quad (6) \]

Where:

\[ R_{\text{total}} = R_{\text{conv},1} + R_{\text{wall}} + R_{\text{conv},2} = \frac{1}{h_1 A} + \frac{L}{k A} + \frac{1}{h_2 A} \quad \left(\frac{K}{W}\right) \quad (7) \]

\[ U \cdot A = \frac{1}{R_{\text{total}}} \quad \left(\frac{W}{K}\right) \quad (8) \]

where:

- \( \dot{Q} \): total heat transferred (W).
- \( T_{\infty 1} \): temperature outside the fridge (°C).
- \( T_{\infty 2} \): temperature inside the fridge (°C).
- \( h_{1,2} \): convection heat transfer coefficient outside (1) and inside (2) the fridge’s wall (W/m²·K).
- \( k \): conduction heat transfer coefficient of the fridge’s wall (W/m·K).
- \( L \): thickness of the fridge’s wall (m).
- \( A \): total transversal area (m²).
As shown in equation (8), the U-value depends on \( h, k, \) and \( L. \) The specific heat flow (\( q \)) is the total heat flow (\( \dot{Q} \)) divided by the area \( A \)

\[
q = \frac{\dot{Q}}{A} \left( \frac{W}{m^2} \right) \quad (9)
\]

The heat flow is proportional to the thermal transmittance and the temperature difference between both sides:

\[
\dot{Q} = UA(T_{\infty 1} - T_{\infty 2}) \quad (W) \quad (10)
\]

thus:

\[
U = \frac{q}{(T_{\infty 1} - T_{\infty 2})} \left( \frac{W}{m^2 \cdot K} \right) \quad (11)
\]

### 3. Measuring Methods

Basically, there are 2 methods to measure the U-value:

**[1] Temperature Based Method carried out with model Testo 635**

Further information


Instructions Manual


**[2] Heat Flux Method carried out with GreenTEG’s gSKIN® U-Value Kit**

Further information

https://www.greenteg.com/U-Value/

Instructions Manual

3.1 Temperature Based Method (TBM)

The *Figure 5* shows the convection resistance at a surface, which allows to approximate \( q \).

![Figure 5. Schematic for convection resistance at a surface. (Adaptation from Yunus A Çengel 2004)](image)

As shown before and in *Figure 5*:

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

\[
= \frac{1}{R_{si}} (T_{si} - T_{\infty 2}) \left( \frac{W}{m^2} \right) \quad (12)
\]

\[
U = \frac{1}{R_{si}} \frac{T_{si} - T_{\infty 2}}{(T_{\infty 1} - T_{\infty 2})} \left( \frac{W}{m^2 \cdot K} \right) \quad (13)
\]

In the TBM, \( R_{si} \) is taken as a constant value: \( R_{si} = 0.13 \left( \frac{m^2 \cdot K}{W} \right) \)

Thus, by simply measuring the temperatures \( T_{si}, T_{\infty 1}, \text{and} \ T_{\infty 2} \) the U-value can be determinated under the condition of stationary state (no changes of temperatures).

This is done with a measure device from the company TESTO, the Testo 635 Humidity/temperature/pressure dew point measuring instrument. The outside temperature is measured with a temperature sensor Type K (NiCr-Ni) and the inside temperature with the sensor NTC. With all this temperatures it is capable to give a U-Value measure.
Recommendations

Testo recommends that, the measurement should be carried out during the night, or in a place which prevent solar radiation on the wall.

It is also recommended to measure within at least 15°C difference, between the inside and outside air temperature, making the results more precise, because of the bigger difference between temperatures.

3.2 Heat Flux Method (HFM)

The advantage of the HFM is, that measures the inside and outside temperature of the air $T_{∞1}, T_{∞2}$ 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 equation (8).

This method works even with small differences of temperature, for example 5 ° C. With this method, the heat flux $q$ is measured.

The way to measure $q$ (W/m²) is using a Heat Flux Sensor or Heat Flux plate. The Heat Flux Sensor is in principle a little piece of the wall, where the thermal resistance $R_{HFM}$ is very small and exactly known.
Additionally, the temperature difference between both sides of the heat flux plate \((T_{HF1} - T_{HF2})\) are measured very accurately. With

\[
q = \frac{T_{HF1} - T_{HF2}}{R_{HF}}
\]

the heat flux can be determined.

*Image 5* shows the design of such a Heat Flux Sensor.

![Image 5. Layers (Package, Contacts, Thermopiles, Substrate, Interconnects) of gSKIN® Heat Flux Sensor. (Instruction Manual for gSKIN® Heat Flux Sensors for R&D Applications)](image)

The HFM is described in detail as a standardized method in ISO 9869, which also considers other factors such as the weather situation, the thermal mass of the wall, etc...

The HFM method is carried out with a measuring device from company greenTEG, the gSKIN KIT, which includes a sensor gSKIN-XO 67 7C, a logger DLOG-4321 including 2 temperature sensors, an operating software Windows and mounting tape.

The high sensitivity (min. 7 [µV/(W/m²)]) of the modules coupled with its thin design and low thermal resistance ensure precise measurements with minimal influence on the thermal flow.

In *Image 6* we can observe how the gSKIN sensor works and how the Heat Flux goes through it.

![Image 6. Illustration of how the gSKIN sensor works when the heat flux goes through it. (Instruction Manual for gSKIN® Heat Flux Sensors for R&D Applications)](image)
The Heat Flux $\varphi$ is calculated by the gSKIN system through the following formula:

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

(14)

Where

$\varphi$: heat flux (W/m²).
U: sensor output voltage ($\mu$V).
S: temperature-corrected sensitivity of the sensor ($\mu$V/(W/m²)).

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

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

(15)

Where

So: sensitivity at calibration temperature, in ($\mu$V/W/m²)
Sc: linear correction factor, in ($\mu$V°C/W/m²)
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 each gSKIN® Heat Flux Sensor purchase in the calibration certificate. *(Instruction Manual for gSKIN® Heat Flux Sensors for R&D Applications)*

This method provides a U-value from the heat flux and the external and internal temperatures according to *Figure 5*. From the *Equation (11)*, this method obtain the U-value:

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

(11)
4 Measurements

The measurements have been carried out inside of a laboratory in the university during a weekend. Due to this, the procedure has been performed under quasi-static conditions (temperature, solar radiation, wind, external influences from people around etc.), both inside and outside of the fridge.

4.1 Equipment description

Below are briefly described the equipment specifications which are considered as most relevant for the measurement.

FRIDGE

The fridge is the model FKUv 1610 Premium from LIEBHERR.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross capacity, total</td>
<td>141 l</td>
</tr>
<tr>
<td>Product dimensions (H/W/D)</td>
<td>83 / 60.0 / 61.5 cm</td>
</tr>
<tr>
<td>Energy consumption in 24h</td>
<td>0.698 kWh / 24h</td>
</tr>
<tr>
<td>Insulation material</td>
<td>Rigid Polyurethane Foam (PUR)</td>
</tr>
<tr>
<td>Insulation thickness (L)</td>
<td>55 mm</td>
</tr>
</tbody>
</table>

*Table 2. Data fridge. (Adapted from FKUv 1610 Datasheet)*

TBM Method

The Testo 635-2 (serial number 60457208) is the one used for this study. This Testo was calibrated under the observation of a DIN EN ISO 9001:2008 certified quality assurance system.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature resolution</td>
<td>0.1ºC (-40…+199ºC)</td>
</tr>
<tr>
<td>Temperature Sensor Accuracy</td>
<td>±0.3 ºC (-60 to +60 ºC)</td>
</tr>
<tr>
<td>NTC (humidity probe)</td>
<td>±0.2 ºC (-25 to +74.9 ºC)</td>
</tr>
<tr>
<td>U-value accuracy</td>
<td>± 0.1 (W/ m²K)</td>
</tr>
</tbody>
</table>

*Table 3. Datasheet Testo. (Adapted from Testo 635 Datasheet)*

HFM METHOD

The GreenTEG’s gSKIN® U-Value Kit (article number A-044714) is the one used for this study. It is calibrated under steady conditions with a method which is oriented towards ISO8301 standard.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature external Sensor Resolution</td>
<td>0.1ºC</td>
</tr>
<tr>
<td>Temperature external Sensor Accuracy</td>
<td>± 0.5 (-10...+65 ºC)</td>
</tr>
<tr>
<td>Heat Flux Resolution per area</td>
<td>0.09 (W/m²)</td>
</tr>
<tr>
<td>Maximum U-value accuracy</td>
<td>14% from value</td>
</tr>
</tbody>
</table>

*Table 4. Datasheet gSKIN. (Adapted from V3.6 for gSKIN Heat Flux Kit Datasheet and ISO 9869-1 (2014))*
4.2 ISO 9869-1:2014

This ISO (International Organization for Standardization) Norm (ISO 9869:2014-08, Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance) was published in 1967 and revised and extended in 2014. Following are some most important points summarized.

In Chapter 4 “Apparatus”, it states that the device should consist of at least one heat flow meter (HFM) and two temperature sensors (inside and outside). These sensors should be suitable for the measurement circumstances and protected from external influences, such as radiation. This is due for the gSKIN.

For the “Calibration procedure” (Chapter 5) it is necessary to evaluate the different materials by doing an absolute test method. The gSKIN calibrates the heat flux sensors by a measurement setup, by using NIST traceable thermal reference materials. The surface and air temperature sensors are calibrated for several temperatures in the determined range. And the gSKIN’s temperature sensors are factory calibrated.

In Chapter 6 “Measurements”, it is important to ensure that the sensors are mounted in a way, that will give a representative result for the whole experiment. To make this sure, a minimum duration of the experiment of 72 hours (3 days) is required, if the temperature is stable. If not, it should be extended to a week (7 days). The data acquisition must not be interrupted.

In Chapter 7, “Analysis of Data”, are given some advices depending on the elements heat capacity. If they have a low heat capacity (<20kJ/m²), the analysis should rely on data taken at night. But if they have it high, the analysis should be carried out over a period of a multiple of 24 hours and at least 72 hours.

It is important to know the “Accuracy” of the results, Chapter 9, where the measured U-value may deviate by a maximum of 14% from the actual U-value (after considering all possible sources of errors).

Finally, a “Test report” (Chapter 10) is needed, which must include data on the element measured, data of the measurements and on the method of analysis.
4.3 Execution on site

Measurement period

Testo doesn’t provide any information about how long the measurement must be done. The gSKIN indicates due to the ISO 9869 that the measured time must be at least 72 hours. But greenTEG indicates also in an earlier study of a fridge wall that within a couple of hours the results are trustworthy.

With both methods were measured for a period of 41 hours because it was observed that after this period U-value results from both methods were constant.

Sensors location

Concerning the location of the sensors, the criteria and recommendations of Testo method were followed. The gSKIN indicates in a previous study that in a fridge the heat flux sensor should be placed inside of the fridge to prevent possible influences caused by people or other circumstances around.

In this case, there was no such a possible influence because the measurement, was done in a place where nothing could affect. The measurements were carried out with both devices under the same conditions.

The Heat Flux sensor of the gSKIN was placed on the outside wall of the fridge, as well as the surface temperature sensor of Testo. All temperature sensors were positioned close to each other to measure the same values, see Image 7&8.

Images 7&8. Devices sensors placement
5. Results

The results from the measurements are shown in the following graphs, which were provided by the software of both devices.

5.1 Results TBM

![Graph 1. Fridge data collection with Testo](image)

*Graph 1* shows the variation of the U-value and the temperatures measured by the Testo device during the period of 41 hours.

In order to examine the results using the same nomenclature as in the explanation of the temperature based method (TMB), *Table 5* is showing the corresponding designations.
According to Equation (13), the variables can be called:

<table>
<thead>
<tr>
<th>Testo name</th>
<th>Variable</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>C:1</td>
<td>U-value</td>
<td>W/m²K</td>
</tr>
<tr>
<td>C:2 (Tw)</td>
<td>$T_{si}$</td>
<td>°C</td>
</tr>
<tr>
<td>C:3 (Tι)</td>
<td>$T_{∞2}$</td>
<td>°C</td>
</tr>
<tr>
<td>C:4</td>
<td>$T_{∞1}$</td>
<td>°C</td>
</tr>
</tbody>
</table>

Table 5. Variables Testo measurement (Self made)

The variation of the temperature inside the refrigerator ($T_{∞1}$) fluctuates between 5 and 10 °C cyclically. These cycles maintain an average temperature of 7.74 °C.

The outside surface temperature ($T_{si}$) is a little lower than the outside temperature ($T_{∞2}$) because it is in contact with the wall of the refrigerator. The difference is 0.49 °C.

The ambient temperature in the laboratory is varying over time according to day and night rhythm between 20-25 °C.

The U-value varies over time, following the patterns of variation of both indoor and outdoor temperatures. This causes that peaks constantly occur and the value is not constant. The value fluctuates between 0.126 and 0.351 W/m²K.

As seen in Equation (8) the U-value is depending on material property such as conduction heat transfer coefficient $k$, the dimensions such as thickness $L$ and the convection heat transfer coefficients $h_1 = h_{si}$ and $h_2 = h_{se}$. The latter are not constant due to the described variations while in the TBM method the $R_{si} = \frac{1}{h_{si}}$ is taken constant. Therefore, variations of the U-value are achieved.

The mean U-value from this measurement is 0.258 W/m²K.
5.2 Results HFM

**Measurement result:**

<table>
<thead>
<tr>
<th>Logger data:</th>
<th>Mean measured values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial No:</td>
<td>Heat Flux (HF): 5.8 W/m²</td>
</tr>
<tr>
<td>Type:</td>
<td>Inside temp. (T1): 7.8 °C</td>
</tr>
<tr>
<td>Sensitivity:</td>
<td>Outside temp. (T2): 22.4 °C</td>
</tr>
<tr>
<td></td>
<td>Measurement time (t): 41.20 h</td>
</tr>
</tbody>
</table>

**U-value analysis using average method (Section 7.1, ISO 9869-1:2014):**

- Analysis start time: 2018-07-06 20:21:16
- Analysis end time: 2018-07-08 13:33:11
- Analysis period: 41 h
- U-value: 0.39 W/(m²K)

Graph 2. Fridge data collection with gSKIN

*Graph 2* shows the variation of the U-value, temperatures and heat flux measured by the gSkin device during the period of 41 hours. As with the results of Testo, the nomenclature will be adapted as follows in *Table 6:*

<table>
<thead>
<tr>
<th>gSKIN name</th>
<th>Variable</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Flux</td>
<td>q</td>
<td>W/m²</td>
</tr>
<tr>
<td>T1</td>
<td>T_{\infty1}</td>
<td>°C</td>
</tr>
<tr>
<td>T2</td>
<td>T_{\infty2}</td>
<td>°C</td>
</tr>
<tr>
<td>U</td>
<td>U-value</td>
<td>W/m²K</td>
</tr>
</tbody>
</table>

*Table 6. Variables gSkin measurement. (Self made)*
As in the Testo results, the interior temperature of the refrigerator \( (T_{\infty 1}) \) and the exterior temperature \( (T_{\infty 2}) \) follow the same cyclic patterns. Due to this the heat flux varies between 0 and 14 \( \text{W/m}^2 \).

As the explanations of the method in Chapter 3.2 have shown, when the temperatures difference \( T_{\infty 1} \) and \( T_{\infty 2} \) varies, the heat flux will do so proportionally, so that the U-value remains constant.

\[
U = \frac{q}{(T_{\infty 1} - T_{\infty 2})} \left( \frac{W}{m^2 \cdot K} \right) \quad (11)
\]

The U-value is constant at 0,39 \( \text{W/m}^2 \text{K} \) after about 12 hours, the transient oscillation time, up to the end of the measurement time (41 h).
6. Summary and Conclusion

The results of both measuring equipment are presented in the Table 7:

<table>
<thead>
<tr>
<th>Variable</th>
<th>TBM-method (Testo)</th>
<th>HFM-method (gSKIN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean U-value (W/m²K)</td>
<td>0,258</td>
<td>0,39</td>
</tr>
<tr>
<td>Mean $T_{\infty 1}$ (°C)</td>
<td>22,6</td>
<td>22,4</td>
</tr>
<tr>
<td>Mean $T_{\infty 2}$ (°C)</td>
<td>7,7</td>
<td>7,8</td>
</tr>
<tr>
<td>Heat flux (W/m²)</td>
<td>---</td>
<td>5,8</td>
</tr>
<tr>
<td>Measurement time (h)</td>
<td>41</td>
<td>41</td>
</tr>
</tbody>
</table>

*Table 7. Results Testo and gSKIN*

Both measuring devices provide a U-value in situ without knowing the material of the measured building component. However, the achieved U-values are very different.

The reliability of the results for both methods varies due to the method in which U-value is measured. It is shown that the HFM method is much more accurate. Unlike the TBM method it gives a constant U-value under varying conditions.

Additionally, the HFM method is in accordance to the ISO 9869, the TBM method not.

As a conclusion it can be summarized that the HFM method is better suited for the practical use of determining U-values of building components where the materials are unknown.
7. Sources


AUSTRALIAN URETHANE SYSTEMS PTY LIMITED, *Thermal Insulation Of Rigid Polyurethane Foam*

Publications GreenTEG:

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- In situ U-value measurement: Heat flux method versus temperature based method
- gSKIN® application note: U-value Refrigerator
- U-Value verification measurement of a Minergie-certified building with greenTEG’s gSKIN® U-Value Kit
- gSKIN® Anwendungsbeschreibung: U-Wert Bestimmung bei bewohnten Gebäuden
- Wandfeuchte und U-Wert Messungen zur Detektion von Schimmelbildung
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- greenTEG AG 2005, Instruction Manual for gSKIN Heat Flux Kit.
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