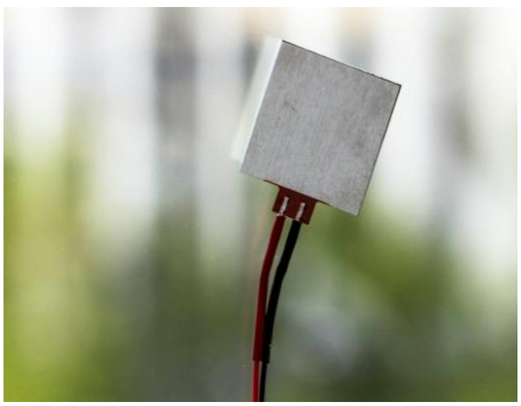
gSKIN® Application Note: Building Physics

Get to know the thermal behavior of your building

Did you ever wonder how much of your heating bill is caused by badly insulated windows or walls? Or how much energy you can save by adjusting the temperature level in a room? Use the gSKIN® Heat Flux Sensor to get answers to these and many more questions! The gSKIN® Heat Flux Sensor features:



Easy read-out
"The heat flux can be easily calculated by the output voltage of the sensor. As the sensor is passive, just use a multimeter or a datalogger to get the voltage values."

Simple mounting & integration
"The sensor is compact, small and thin. You just stick it to the place, where you want to measure your heat flux."

Robust
"The sensor is robust and withstands harsh environmental conditions. This allows good handling and makes it re-usable."

Applications

A building is a complex thermal system. Thermal energy into the building is coming mainly from the heating system and from solar irradiation. The energy exchange between the building and the outside is focused through the roof, walls, windows and thermal bridges e.g. balconies, into the soil and through exchange of ambient air.
Are you interested in better understanding this thermal system? Use the gSKIN® Heat Flux Sensor to:

- compare the amount of **heat transferred through different walls**.
- calculate the **thermal conductivity (K-value)** of walls or windows and find out if you have a well-insulated building.
- quantify the **energy balance** of a room: How much energy is coming from the heating and where is the energy lost?
- calculate the **energy emitted from the heating radiator** for further processing for example to calculate your **heating bill**.
- optimize your heating and **cooling control**.
- analyze the **thermal behavior** of rooms / buildings at different temperature levels.

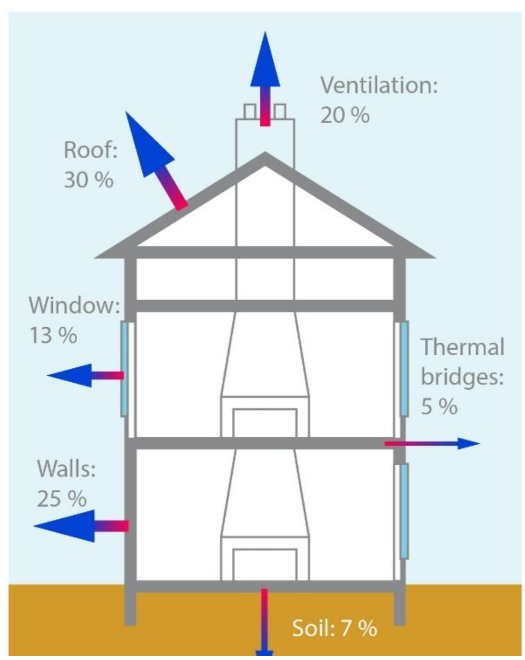


Figure 1: Heat lost from a building on a Swiss winter day in % of total.

Measurements

General

- Thermal energy efficiency studies in buildings require a certain temperature difference between the interior and exterior of a building to achieve good results. With the gSKIN® Heat Flux Sensor you are able to get precise information starting at a temperature difference of 5°C only (Table 2 in the Appendix 2 gives you for more specific information for different building materials).

- Place the sensor on a representative surface. If you have the possibility to make a thermal image (with an infrared camera), it will help you find appropriate spots. General spots of interest are:
  - Walls facing all four directions. This allows you to measure the difference between the walls.
  - On the floor of the lowest level (heat transfer from the hot/cold ground).
  - Under the roof (in many buildings a large amount of heat is exchanged through the roof).
  - Windows (take care that your measurement is not distorted by solar radiation by choosing a shady representative area or by blocking solar radiation from the outside of the window)

- Measure at the inside of buildings preferably. If you place the sensor on the same spot on the inside, you will measure the same heat flux as if it was placed on the outside.

- If you are measuring inhomogeneous walls (i.e. different building material layers, walls with pipes), use multiple sensors to get an overview picture. To obtain more significant measurement results, use multiple sensors on the same wall as well and average their values.

How to set-up the measurement?

The following schematic illustrates a typical measurement setup.

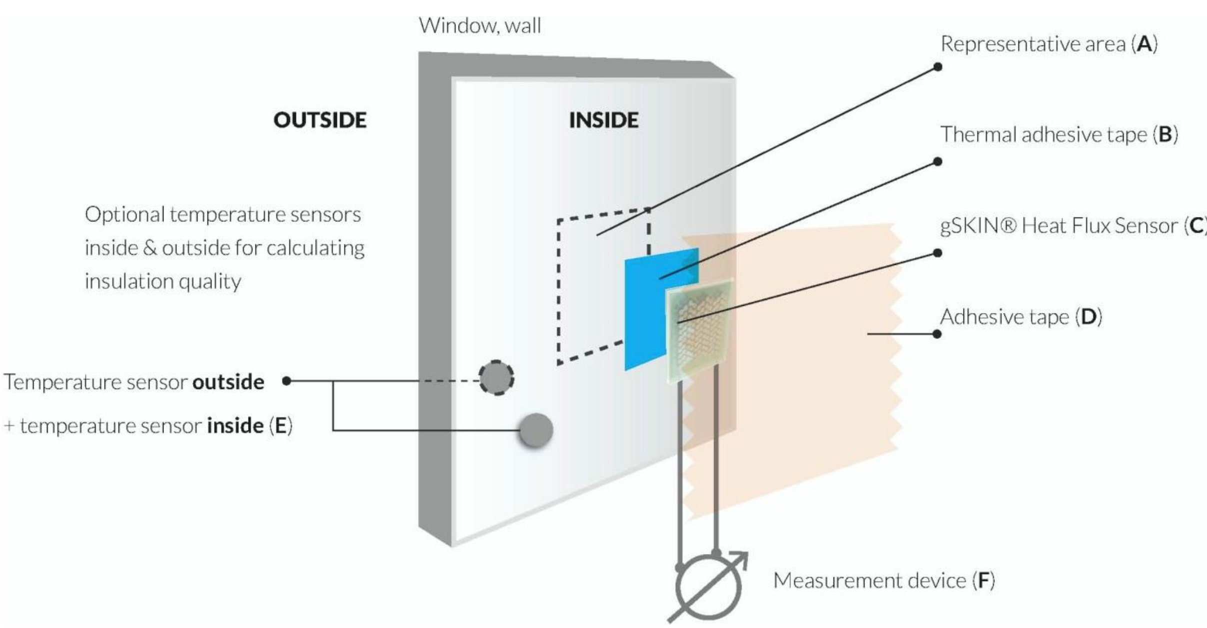


Figure 2: Illustration of a typical measurement set-up.

1. Select a representative area (**A**) of the surface you want to study.
2. Ensure that the area of interest is flat, dry and free of dust and grease by cleaning the respective area with ethanol or isopropanol.
3. Apply the sensor using a thermally conductive adhesive transfer tape (**B**). When mounting the sensor (**C**), make sure no air is trapped as this will distort your measurement.
4. Fix the sensor additionally at the wall e.g. with adhesive tape (**D**).
5. In order to ensure precise measurements we recommend that the surface of the sensor exposed to the air mimics the surrounding wall/window surface. For example, if the surface to be measured is covered with black paint, you will get maximum accuracy by painting the sensor with the same paint.
6. Optional: If you want to calculate the thermal resistance of a wall, you also need to mount 2 temperature sensors (**E**). One sensor to measure the temperature of the internal wall surface and one sensor to determine the temperature on the exterior side in order to determine the temperature difference across the wall.

How to get the measurement data and calculate the heat flux?

- Use a data logger, multimeter or other read-out device (**F**) with a resolution of 1 µV or better.
- Connect the gSKIN® Heat Flux Sensor to your measurement device and record the output voltage V_{meas}.
- Calculate the heat flux Φ by using the sensor-specific sensitivity S_{temp} (which will be delivered with your gSKIN® Heat Flux Sensor; for temperature corrected sensitivity calculation see Appendix 4).
- The equation for calculating the heat flux is:

$$\Phi = V_{meas} / S_{temp}$$

where

Φ	heat flux in W/m^2
V_{meas}	measured voltage in V
S_{temp}	sensor-specific sensitivity in µV/(W/m^2)

Interpretation of your measurement results

How to calculate heating costs?

Based on the measured heat flux, you can calculate how much thermal energy s lost and how heating costs are affected by this. Here is an example for a large, badly insulated single glazing window:

- You have set-up your measurement as shown in the previous chapter and got a heat flux of **80 W/m^2**. This is a typical value for a winter day in central Europe.

- Now calculate the area of interest (e.g. wall, window or floor). In our example we measured a single glazing window with a size of 2 m by 4 m which is **8 m^2**.

- Now we can calculate the thermal power flowing through the whole window by multiplying the heat flux (80 W/m^2)

Figure 3: Badly insulated buildings are expensive.

with the area (8 m^2). Therefore, the thermal power of **640 W** is flowing through this window.[a]

- Now we want to find out how much of our monthly heating bill is caused by this window. We can do this by multiplying the power (640 W) times the hours of a month (720 h). The result is the energy flown through this window during 1 month assuming a constant environment. In this example it is **460.8 kWh**.

- In case you know the financial costs for your thermal energy (e.g. from your oil or gas bill), you can check how much you pay for 1 kWh of thermal energy or use a standard value of **0.10 €/kWh** and multiply this value with the lost energy.

- In our example, you would have to pay **46 €** per winter month only for this badly Insulated window!

You can use the same method to estimate the heat energy emitted by a radiator or by a badly insulated pipe.

How to calculate insulation quality (this requires two additional temperature sensors)?
If you want to know, how well a window or a wall is insulated, follow this procedure.

- Do the measurement set-up with two additional temperature sensors as shown in Figure 2 (see previous section "measurement set-up"). Place one of the sensors inside and one outside of the area of interest. Make sure, that they are placed at opposite spots across the wall and close to the heat flux sensor.

- The equation for calculating the K-value for the insulation quality is

$$\text{K-value} = \Phi / \Delta T \quad [\,W/(Km^2)]$$

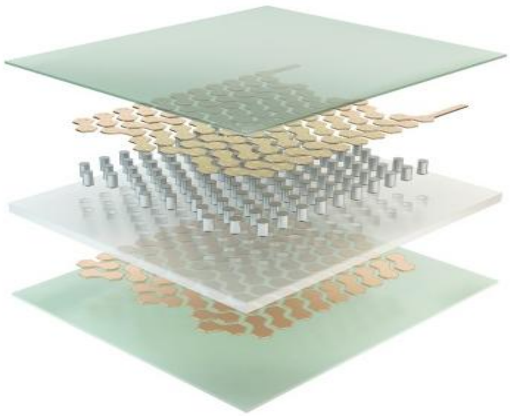
where

K-value	heat transfer coefficient in $W/(Km^2)$
Φ	heat flux in W/m^2
ΔT	temperature difference in °C

- Table 2 in Appendix 2 lists some typical values for building materials and gives you an indication for the quality of your building materials. It also shows typical heat flux values, minimum temperature difference for which heat flux values can be resolved with the gSKIN®, and example values are stated for how much thermal energy is lost in terms of financial cost through an area of 10 m^2 of the specific material in a winter month.

[a] We assume that the heat flux is homogeneously distributed across the whole area.

Appendix 1: Sensor specifications



In Figure 4 the structure of the gSKIN® sensor is illustrated in a schematic drawing.

The thermal sensor consists of axially aligned semiconductor thermocouples connected in series. These thermocouples are embedded in a polymer matrix (transparent in Figure 4).

The sensor is electrically insulated with a layer of epoxy (green in Figure 4). This layer also ensures that it is waterproof.

The sensor can be customized to application-specific requirements. Table 1 gives an overview of customization options.

Figure 4: Exploded view of gSKIN® sensor.

	Standard gSKIN®	**gSKIN® sensors portfolio**
Sensor Output Signal	Raw voltage analog	Digital / Analog
Sensitivity [µV/(W/m²)]	~1.9	Up to 50
Rel. Error	+/- 5 %	
Dimensions [mm x mm]	8.5 x 8.5	any size & shape up to 40 x 40
Thickness [mm]	0.4	0.2 – 0.4
Electrical Resistance [Ω] at 25 °C	<5	
Absolute Thermal Resistance [K/W]	~ 5	
Calibration Temperature Range [°C]	0 / +70	
Operating Temperature Range Min / Max [°C]	-50 / 200	
Sensor Resolution [W/m²] [b]	0.5	
Read-out device	Voltmeter (not incl.)	greenTEG read-out electronics
Cable length [cm]	50	Upon request

Table 1: gSKIN® sensors specifications.

[b] Assuming a standard multimeter as read-out device with a resolution of 1 µV.

Appendix 2: Specifications for different building materials

Table 2 gives an overview on the specifications and typical measurement results for different building materials. It displays the:

- material specific heat conductivity: low values are good e.g. 0.13 W/(mK) for double insulated glass and large values indicate material which conduct heat better e.g. 2.1 W/(mK) for standard concrete materials.
- thickness: for walls we have assumed a thickness of 25 cm.
- K-Value, which describes how much heat flows through a specific building element at a given temperature difference: this value is calculated from the heat conductivity and the thickness.
- minimum ΔT at which heat fluxes can be resolved with the gSKIN® Heat Flux Sensor: this value allows you to plan your experiment at the right time i.e. with a temperature difference, which is high enough.
- typical heat flux for a ΔT of 10 °C for validating your own results.
- energy cost in € per month for a constant ΔT of 10 °C through an area of 10m^2.

Building material	Heat conductivity [W/(mK)]	Thickness [m]	K-Value [W/(Km^2)]	Minimum ΔT [°C]	Heat flux at ΔT=10 °C [W/m^2]	Energy cost[c] [€]
Concrete	2.1	0.25	8.4	0.4	84	61
Brick	0.34	0.25	1.36	2.8	13.6	10
Insulated wall	0.15	0.25	0.6	5.59	6	4
Glass	0.76	0.025	30.4	0.11	304	219
Double glass	0.13	0.05	2.6	1.29	26	19

Table 2: Typical specifications and measurement results for different building materials.

Appendix 3: The importance of a thin and small sensor

The gSKIN® Heat Flux Sensor is thin (400 µm) and has a low thermal resistance (5 K/W; also see sensor specifications). It has the lowest thermal resistance per sensitivity, which is very important for the precision of a heat flux sensor. If the sensor itself has a large thermal resistance it would disturb the measurement by influencing the heat flux.

Figure 5 illustrates this and compares 3 different heat flux sensors (the gSKIN®, a Peltier element and the heat flux sensor of a competitor). It shows the relative error of your heat flux measurement (y-axis) for different applications (x-axis). While all three sensors have low errors when the K-value of the building element measured is low (when it is a good insulator), the errors increase rapidly for larger K-values (non-optimal insulation). While the gSKIN® failure curve stays low due to its low thermal resistance, the values for the Peltier and the competitor's heat flux sensor increase for standard building elements (compare Table 2) to more than 10% and even higher in case of K-value for good thermal conductors.

[c] Assumptions: temperature difference of 10 °C stable during 1 month across the wall; 1 kWh costs 0.1 €.

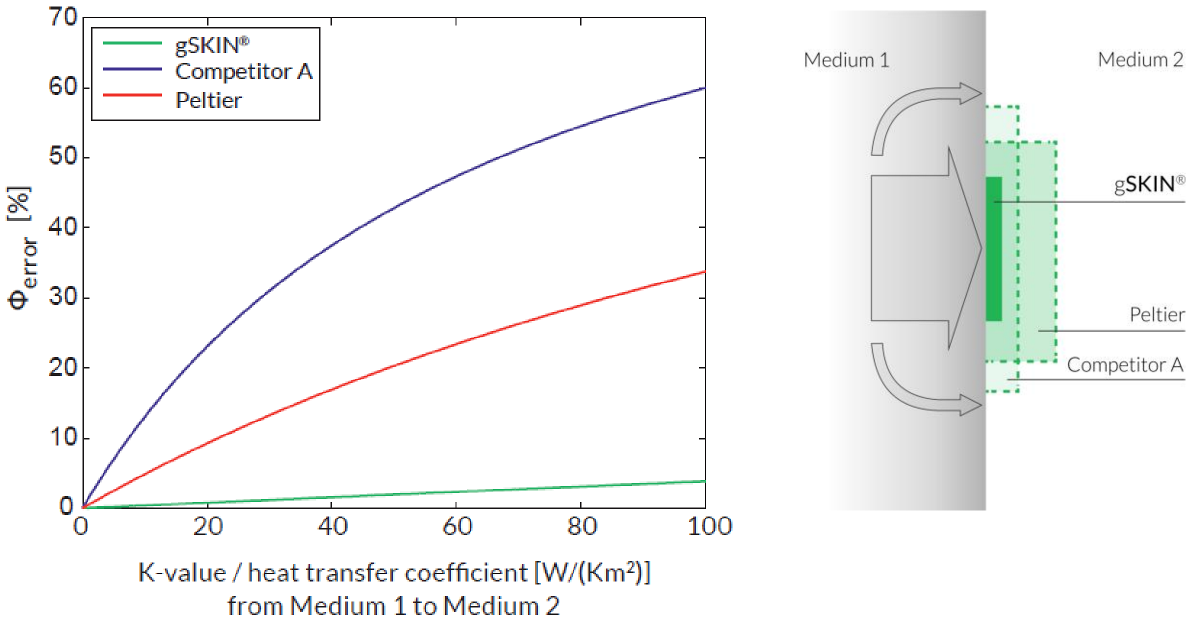


Figure 5: Comparison of the gSKIN® Heat Flux Sensor with a Peltier Element and the heat flux sensor of a competitor. Due to the low thermal resistance of the gSKIN® it can measure building elements with high K-values with high precision.

Appendix 4: Calculation of the temperature corrected sensitivity

The sensitivity value depends on the temperature T_{meas} at which the measurement is carried out. However, for a quick measurement you can use the S_0[d], which is the sensitivity of the gSKIN® at 22.5 °C instead of the temperature-corrected S_{temp} value for the calculation. If a precise result is needed, use the equation to calculate the temperature corrected sensitivity S_{temp}. You can also use the graph on the calibration certificate to find out the temperature corrected sensitivity.

$$S_{temp} = S_0 + (T_{meas} - T_0) * S_1 \quad [\mu V/(W/m^2)]$$

$$T_{meas} = (T_{hot} + T_{cold}) / 2 \quad [°C]$$

where

S_{temp}	temperature corrected sensitivity in $\mu V/(W/m^2)$
S_0	sensor specific sensitivity[e] in $\mu V/(W/m^2)$
S_1	correction factor[6] in $(\mu V/(W/m^2))/K$
T_{meas}	medium temperature at which your measurement takes place in °C
T_0	temperature at which the gSKIN® is calibrated (22.5 °C) in °C
T_{hot} respectively T_{cold}	the interior and exterior temperatures of the building element in °C

[d] Using S_0 as sensitivity will allow you measurements with relative errors of +/- 5% across the full temperature calibration range (0 °C / +70 °C)

[e] Stated in your gSKIN® calibration certificate

Appendix 5: Example for long-term measurements

The following figures give an example for a long-term measurement of 48 hours. One measurement point per minute is sufficient in order to obtain accurate results. These measurements allow for example the calculation of the thermal resistance values as well as the possibility to monitor the thermal behavior of the room.
This measurements show that

- the heat flux follows the temperature difference with a time delay. This is especially true for thick building elements with a large thermal capacity.
- the K-value of the measured building element is between 0.2 and 0.4 W/(Km^2). This wall is very well insulated!

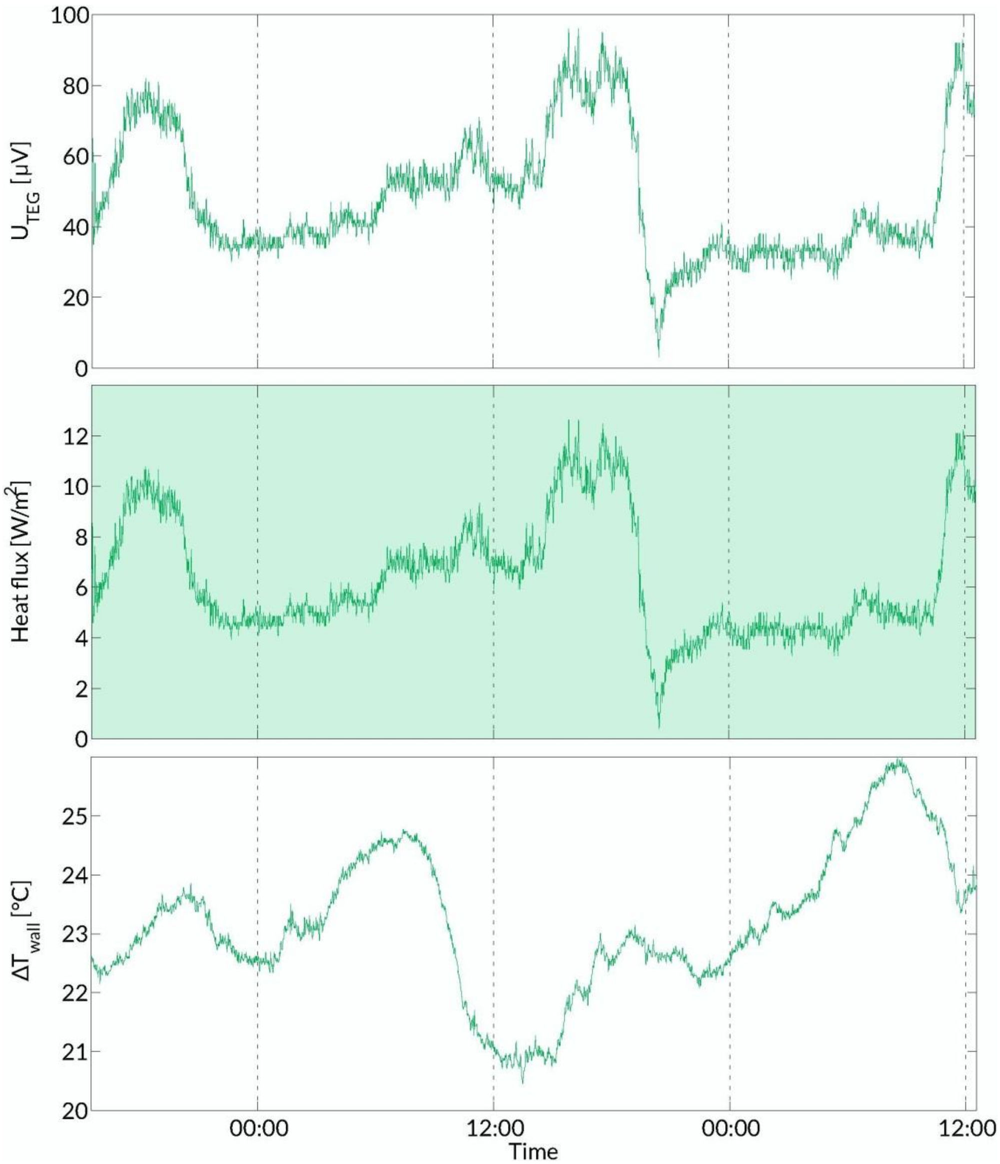


Figure 6: Voltage, calculated heat flux, and temperature difference measured during 48 hours.

Appendix 5: Material list

This list includes the items necessary to assemble the measurement setup described in this application note.

- gSKIN® sensor
- Thermal adhesive tape
- Adhesive tape
- Measurement device
  - Multimeter
  - Datalogger
  - greenTEG electronics
- Temperature sensors

Document information

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Pictures by greenTEG AG and flickr