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AGENDA

- History & organisation
- Heat Flux : Why?
- Our development kit TP-A
- Our Expertise
- References

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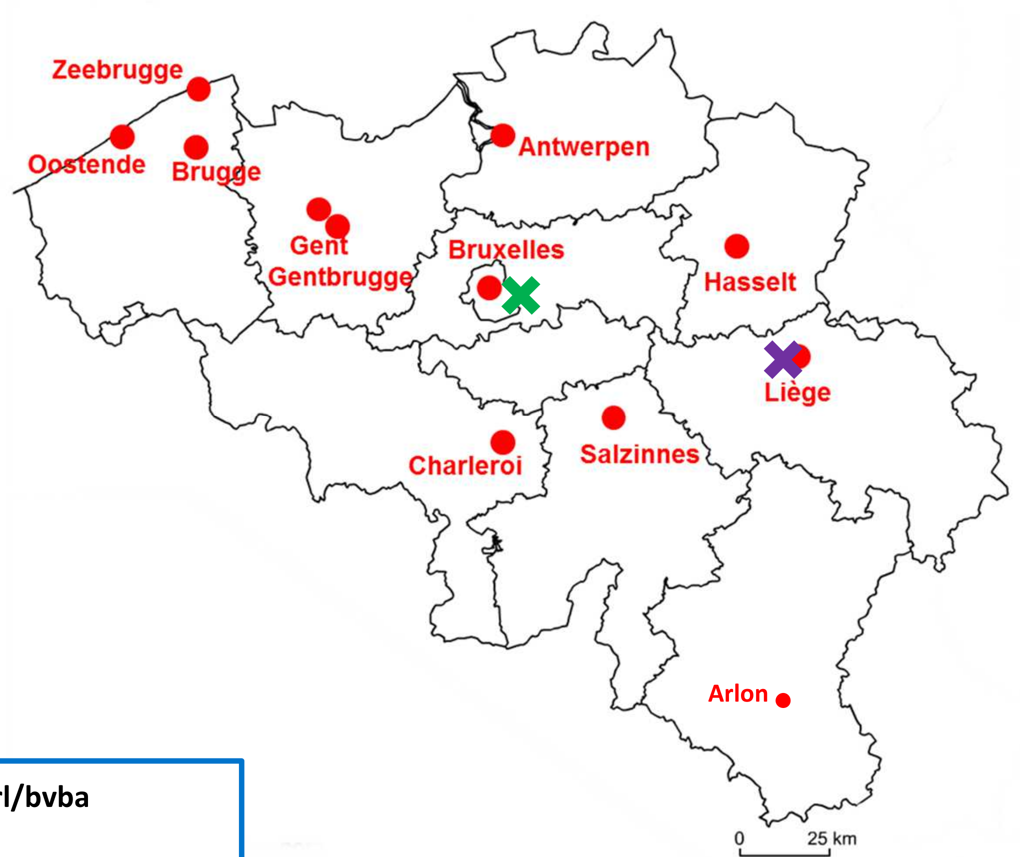
History & Organisation



Thermalplug sprl/bvba

Hermesstraat 2C-1930 Zaventem

Rue du Vertbois 11-400 Liège

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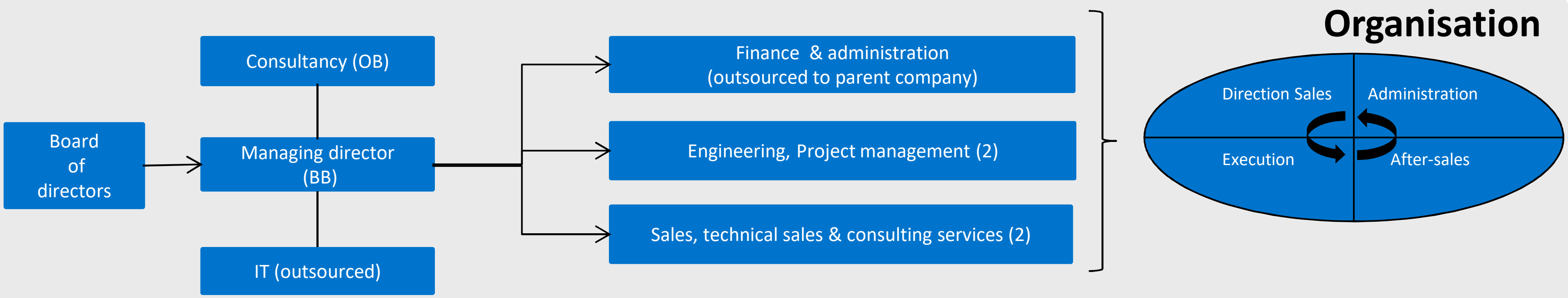
History & Organisation

History:

- ***2014***: *Start of R&D under parent company control*
- ***H1 2015***: *Frist academic prototype*
- ***H2 2015-H1 2016***: *first pre-industrial prototype*
- ***H1 2016***: *creation of Thermalplug sprl*
- ***H2-2016*** *: market ready industrial prototype*
- ***2017***: *launch of product TP-A*

Organisation



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Heat Flux

Heat Flux Basics

Heat is transmitted from a hotter body to a colder body until a thermal equilibrium is reached.

Typical heat flux values

THUMB

130 W/m^2

FRESH BEER

- 150 W/m^2

HOT COFFEE

600 W/m^2

https://youtu.be/-DFokozaFKE

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Why a heat flux Sensor

Compensation of thermal influences

- Hypotheses: Distortions under dynamic thermal influences (in the second/hours range) are not always properly compensated with temperature sensors

- Temperature sensors cannot
  - Measure dynmamics of thermal influences
  - Non-invasively «see» temperature gradients
  - Be placed everywhere in a system (full thermal characzerization is not possible)

- Heat flux sensors enable higher precision, especially in systems where thermal distiortions are in the µm/nm range

Heat Flux sensors enable numerous possibilities
which are not available with temperature sensors

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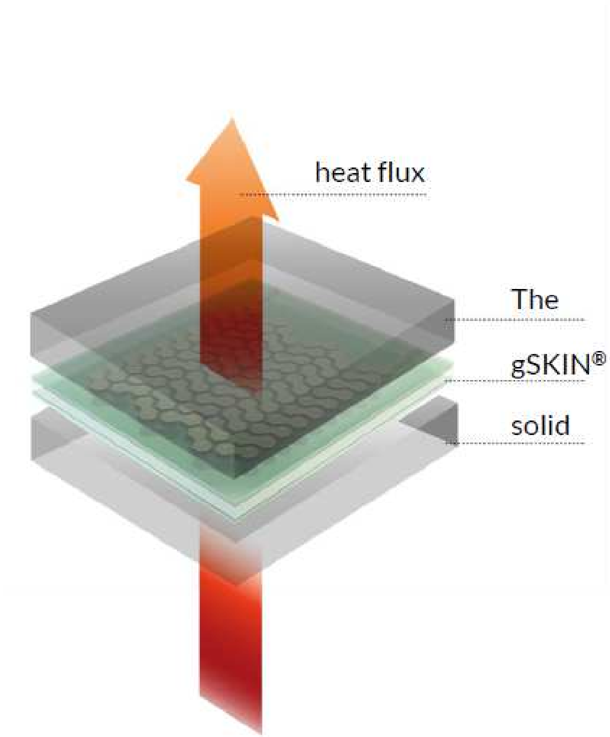
Heat Flux : Sensor

Heat Flux Measurement
Principle



- Heat flows through the sensor
- Sensor generates a voltage
- Voltage is proportional to the heat flux
- Resolutions down to 1 W/m^2, i.e. mW

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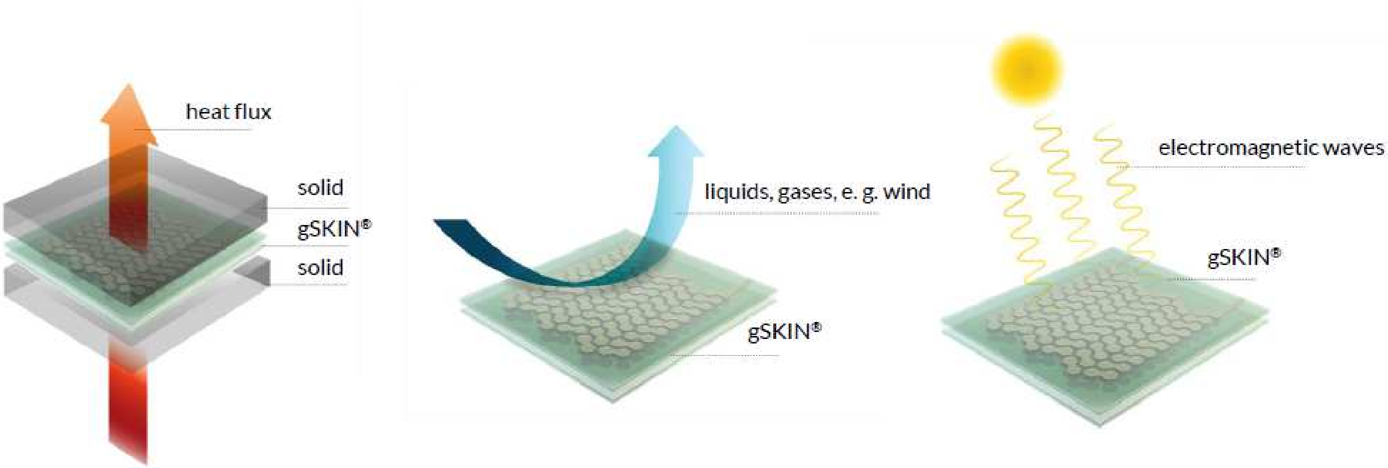
Heat Flux : Sensor

Measure all three Types of Heat Fluxes



Conduction	Convection	Radiation
Heat flux through materials	Heat flux through liquids and gases	Heat flux through electromagnetic waves
Sitting on a wood or stone bench in winter	Exposure to wind chill	Standing next to fire

Heat Flux : Sensor

Permissable temperature and heat flux ranges

Temperature range

-50C to +150C (intermittently to +200C)

Heat flux range

-150 kW/m^2 to +150 kW/m^2

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Heat Flux : Sensor

GSKIN Sensors

- Aluminium
- Silicone
- Laser power measurement

gSKIN®-XM

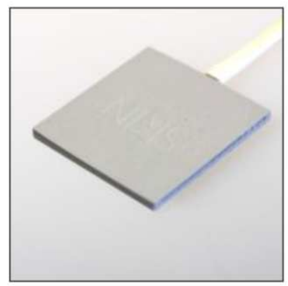
Heat Flux Sensor Size: 4.4mm x 4.4mm Resolves 0.41 W/m2 – 7.9 µW – 140 µK…

gSKIN®-XP

Heat Flux Sensor Size: 10mm x 10mm Resolves 0.09 W/m2 – 9 µW – 30 µK…

gSKIN®-XI

Heat Flux Sensor Size: 18mm x 18mm Resolves 0.03 W/m2 – 9 µW – 10 µK…



gSKIN®-XO (Silicone)

Robust Silicone Heat Flux Sensor Size: 30mm x 30mm Resolves 0.1 W/m2 – 81 µW – 230 …

gRAY C05-HC

Housed Laser Power Detector Apperture: 25 mm Max. Power: 5 W…

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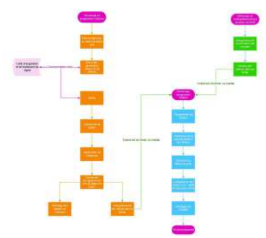
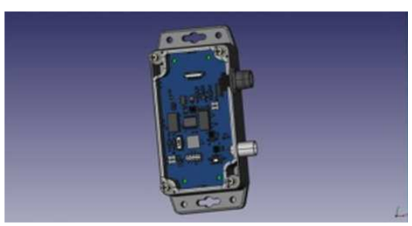
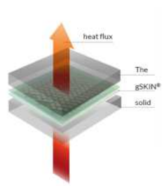
Development kit

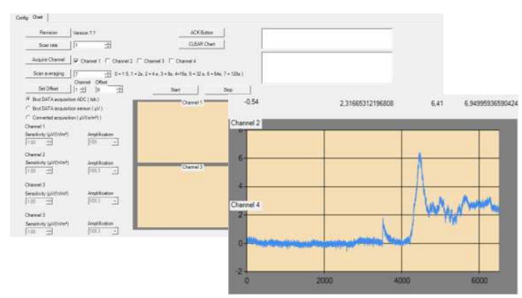
- We provide our know-how for your application development

Thermal Flux Measurement → **Signal Transfer & Preparation** → **Data access and calibration** → **Optimize your processes**









$$y(t) = [\partial 0(t) + X(\Delta T)]/H$$

$$\downarrow$$

$$Z = f(y(t), \dots)$$

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Development kit

Development Kit : TP-A

1. We provide know- how for technical Heath flux signal treatment

Support

2. We support you for integration of our know how in your product

Customer process

3. Your product/process integrating Heat flux measurememt

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Our basic set up

Development kit: TP-A

1. A Gskin © sensor mesures the heath flux Φ(t)

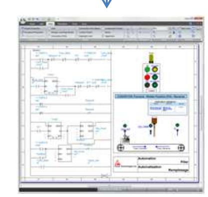
2. Sensor transfer Φ(t) it as an electrical signal f(t)

3. Signal is treated by the calibrated box f(t)→F(T)/C

4. Signal F is transfered to computer or PLC (RS485, 0-10V or 4-20mA)

---

5. Computer/PLC/system calculate back Φ(t) = f(F(t), T°(t),C)



6. Φ(t) is integrated in your own automation process

Customer process

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Possible applications

Control System design application

- Efficient & fast **fouling** detection
- Efficient & fast **radiation** detection
- **Indirect temperature** measurement (non-invasive)
- **Mass flow** measurement (non-invasive)
- **Temperature change** prediction

Design value & Lab measurements

- **Calorimetric** applications
- **Enthalpy** measurements

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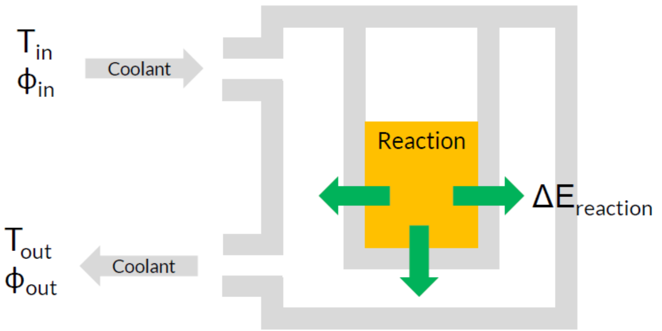
Possible applications

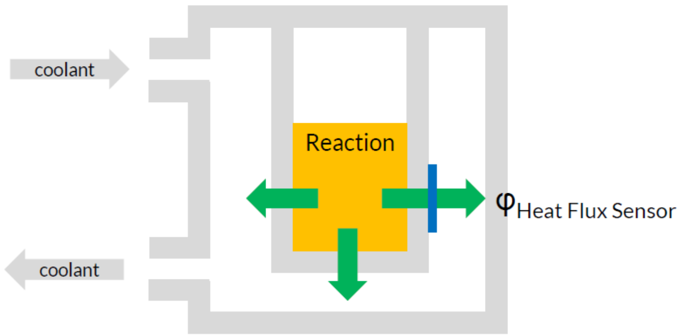
Indirect measurements of heat energy

$$\Delta E_{reaction} = f(T_{in}, \varphi_{in}, T_{out}, \varphi_{out}, \ldots)$$



Measurements of reaction energy

$$\Delta E_{reaction} = f(\varphi_{Heat\ Flux\ Sensor})$$



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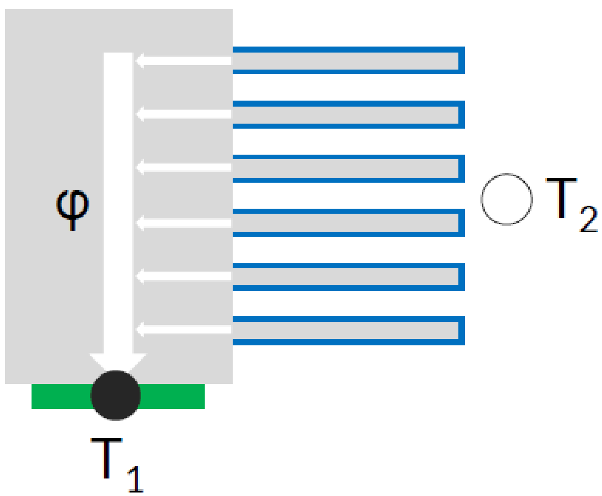
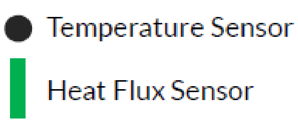
Possible applications

Change of thermal resistance (e.g. fouling)



- $R_{therm1\text{-}2}$ influenced by ice, rust etc.
- R can be calculated by T_1, T_2 and φ
- $R_{therm\ 1\text{-}2} = (T_2 - T_1)/\varphi$



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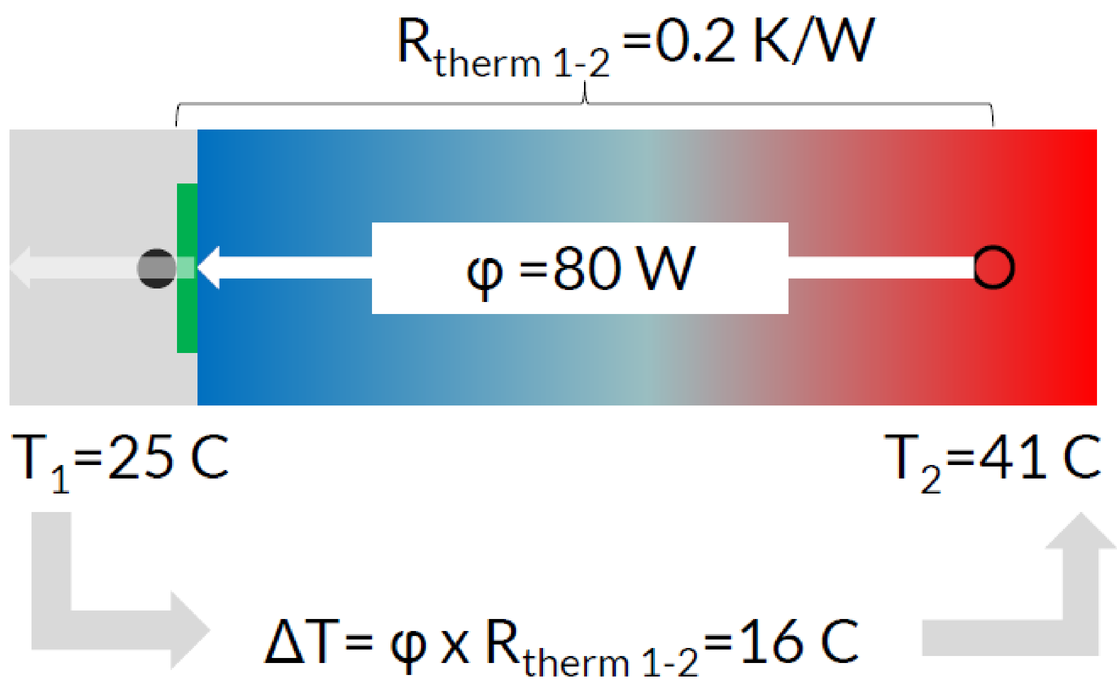
Possible applications

Non-invasive Temperature Measurement & Profiling



● Temperature Sensor

▌ Heat Flux Sensor

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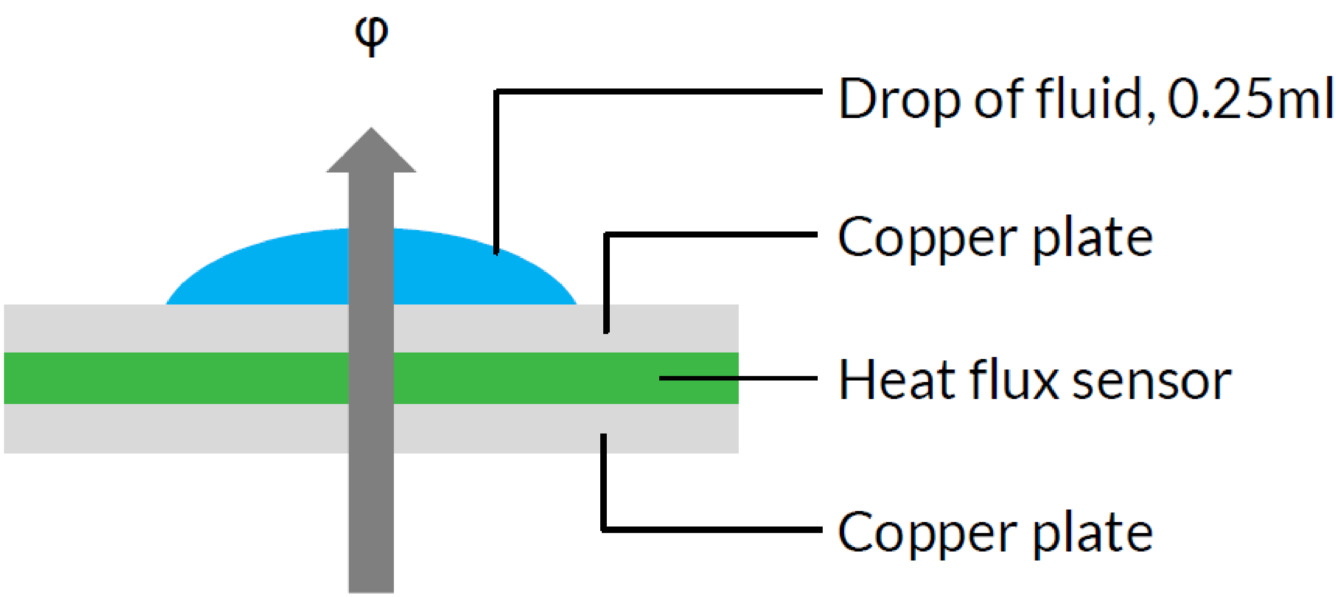
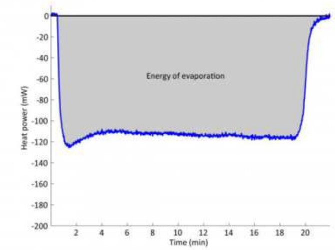
Possible applications

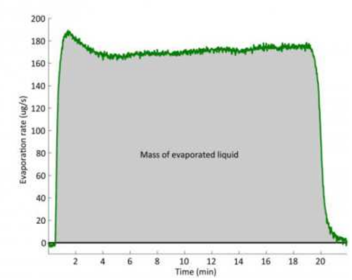
Evaporation and condensation in µg/s



Evaporation energy



Evaporation rate



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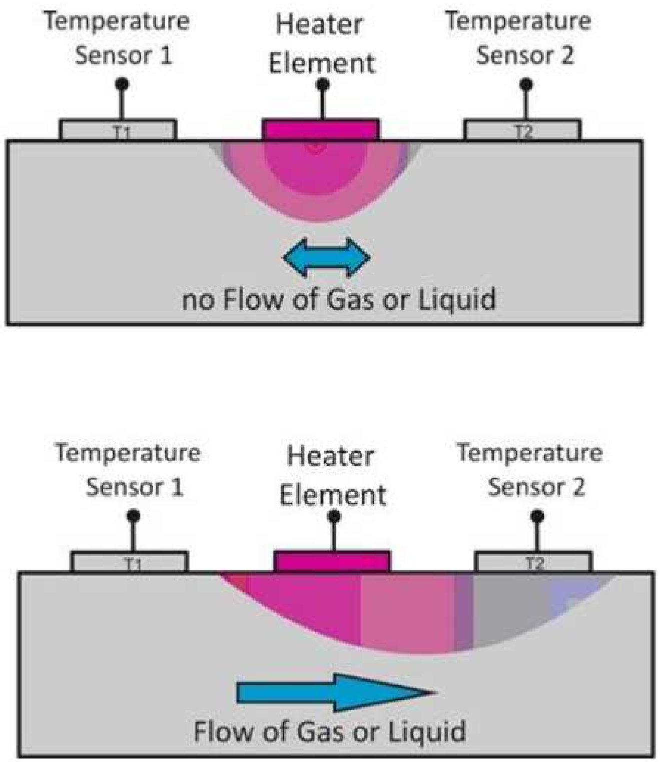
Possible applications

Mass flow



- Use gSKIN instead of temperature sensors
- Higher precision possible
- Non-invasive → more hygienic

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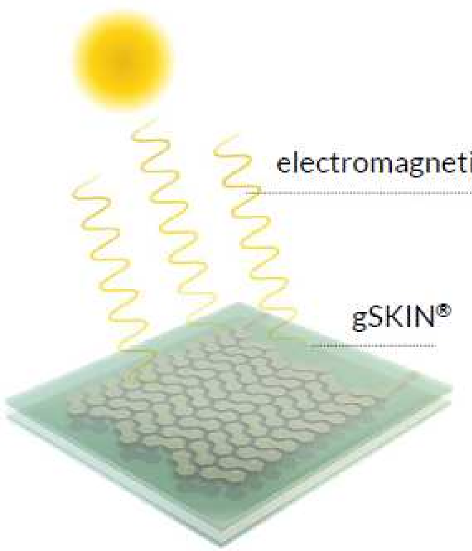
Possible applications

Applications of the gSKIN®: Radiation



- Monitor infrared sources
- Characterize lasers
- Monitor laser power
- Measure solar irradiation
- Detect hot bodies

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Possible applications

Comparison with other detector types

Technology	Thermopile disc	Peltier element	gSKIN®	Photodiode
				
Power range	10 mW - 25 kW	10 µW - 3 W	10 µW - 3 W	10 pW - 100 mW
Power resolution	0.2 mW	1 µW	1 µW	1 pW
Spectral range	190 nm -25 µm	190 nm -25 µm	190 nm -25 µm	200 -1800 nm
Rise time	>0.8 s	>1.8 s	>0.2 s	0.2 s (1 ns)
Area (active area)	>1.1 cm² + passive area	>1.1 cm²	>0.2 cm²	>0.1 cm²

The gSKIN® combines the speed of a diode with the wavelength independency of a thermopile sensor!

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Our Expertise

1. **Thermal flux measurement**
   - Fast
   - Precise
   - Reliable
   - Non invasive

2. **Thermal flux is the derivative of T° → Temperature prediction**

3. **Technical know – how**
   - Real time data availability
   - Compatible with all computers - PLCs
   - Flexible programming

4. **Integration of thermal flux technology in your process**
   - Our know–how is yours
   - Product developement
   - Local support

Your process- your rules !

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Model validation embedded Phase Change Material in facades with heat flux sensors

Introduction

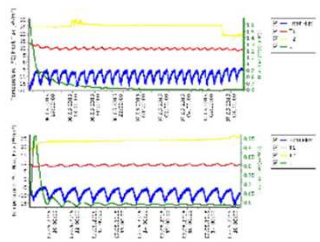
GLASSX is a Swiss company developing and marketing facade products that have unique optical and thermal characteristics (i.e. by using phase change material (PCM)). These translucent facade elements have the advantage of higher energy efficiency due to the combination of translucence, low U-values, variable solar gains and high thermal mass. For product improvements, they developed together with Lucerne University of Applied Science a theoretical model, which includes the sub-cooling effect of the salt hydrate PCM. To validate the model, heat flux sensors from greenTEG were used. The study is described in detail here (only in German).

Experimental setup and results

In the following picture, the experimental setup is shown. To determine the energy flow into the glass and the release from the glass as response from a defined temperature profiling, gSKIN heat flux sensors from greenTEG were used. The gSKIN® heat flux sensor were mounted to the window by normal tape.

Figure 1: Setup for window characterization containing PCM: Image provided by GLASSX.

The following graph shows the comparison between measured and simulated heat flux. According to the authors, the measured heat flux fits very well the calculated heat flux.



gSKIN® application note: U-value Refrigerator

In previous application notes it has been shown that the gSKIN heat flux sensor can precisely map the heat flowing out of a heated building through its walls or windows. In actually the same way it should be possible to measure the heat flowing into a cooled room. This principle can be used to measure the energy efficiency of a refrigerator or a freezer. The consistency of the insulation within a fridge can be analysed or the performance of several cooling devices can be compared. For restaurants or grocery stores with a large cooling need this could be very valuable.

In this case study the U-value of a refrigerator door is measured. This is done by comparing the outcome of two heat flux measurements. The goal of this case study is to examine the reliability and reproducibility of such heat flux measurements for refrigerators.

Measurement object and set-up

A small freestanding refrigerator of Fust Primotecq, type KS 118.1.IB has been measured. This refrigerator is insulated with polyurethane, has a capacity of 118 litre and the datasheet claims an energy use of 0.47 kWh/24h. It is located in a coffee room in a large office building.

The heat flux sensor was placed on the inside of the fridge door, mainly to avoid or at least reduce the impact of people walking by. One temperature sensor is attached next to it inside the fridge, approximately 5 cm from the door surface and the other temperature sensor is placed on the outside, also with a distance of around 5 cm. The first measurement took around 19 hours from the afternoon till the next morning and the second one lasted 9 hours starting in the morning till the beginning of the evening.

Results

Results of both measurement are shown in the following figures. The graph include the heat flux, the fridge temperature (T1), the room temperature (T2) and the derived U-value.

The parameters during both measurement fluctuate according to the same pattern. The room temperature is stable most of the time except for the opening of a window in the first measurement. The fridge temperature is varying according to the cooling of the fridge. The heat flux is responding to the changing temperatures and fluctuates between -5 W/m² and -15 W/m². The U-value is therefore also fluctuating but after a few hours this effect is flattened and the averaged U-value becomes quite stable. The measured U-value in the first measurement is 0.60 W/m²K and in the second measurement 0.59 W/m²K.

Conclusion

Both measurements show the same temperature and heat flux pattern and reach a rather stable U-value after a few hours. The difference in the obtained U-value is negligible (0.01 W/m²K). These measurements show that the door of the refrigerator has a U-value of around 0.60 W/m²K. This seems a reasonable value for an insulated refrigerator door.

Based on these two measurement, heat flux measurements are a reliable and effective method to assess the insulation quality of an refrigerator or freezer in a couple of hours. This method can be especially valuable if the electricity consumption cannot be reliably measured.

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gSKIN® Application Note: Calorimetry

Direct and precise calorimetric measurements with the gSKIN® Sensor

The gSKIN® Heat Flux Sensor enables direct and highly precise measurements of reaction enthalpies in a variety of applications, including calorimetry. Calorimetric measurements are of paramount importance in the fields of chemical engineering, physical chemistry, materials science and biology.

Direct measurement
"Thanks to the heat flow based measurement, you do not need an isolated reaction chamber. For many measurements, you don't even need a thermometer."

Easy to use
"The small size and robust packaging allows for a simple application on virtually all surfaces."

Wide range of sample volumes
"Use the same sensor for the analysis of samples volumes ranging from cubic millimeters to cubic meters."

High sensitivity
"Measure heat energies of less than one millijoule on an assay of just one cm³."

Applications

The fields of application of the gSKIN® Heat Flux Sensor are numerous and vast as the field of calorimetry itself. The small standardized sensors are ideal for measurements in research and development as well as in an educational context. In cooperation with manufacturers of chemical lab equipment, the gSKIN® Heat Flux Sensor can also be tailored and built in as an integral part of high-end chemical synthesis systems.

Process safety control
Calorimetric data is essential for process safety control. The heat release rate of novel chemical reactions must be known in order to design the cooling and heating systems for large scale synthesis. With the help of our sensing solutions, chemical engineers can provide this information already in the research lab while working on small reaction volumes.

Chemical engineering
In order to find the most productive chemical reactions, many different solution combinations must be tested. The direct reaction enthalpy measurement enables higher throughput and more reliable data in analytical research and diagnostic testing.

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gSKIN® Application Note: Molar Enthalpy of Salt Dissolution in Water

Tutorial about how to measure the molar enthalpy of salt dissolution in water

Aim
The aim is to measure the molar enthalpy of dissolution of a salt in water. As an example, we will dissolve 2 g of NaOH in 100 ml Water and derive its molar enthalpy of dissolution at room temperature.

Experimental setup

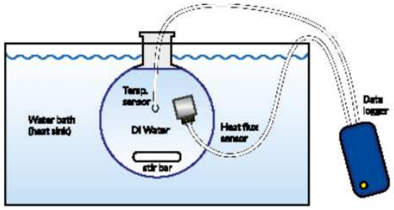

Figure 1: A possible configuration of an experimental setup for measuring the solution enthalpy of a water-soluble salt.

Figure 1 shows a possible experimental setup. To conduct the measurement, the following equipment is needed:

- 1 Heat flux sensor: greenTEG recommends gSKIN®-XE 24 9C and gSKIN®-XO 64 9C
- 1 Datalogger: greenTEG recommends gSKIN® DLOG-4228 (includes 1 temperature sensor)
- (Optional) 1 Temperature sensor: any sensor with a 0.5ºC accuracy. greenTEG recommends to use a datalogger which includes a temperature sensor (e.g. gSKIN® DLOG-4228)
- 1 Reaction vessel, e.g. a 100 ml round flask of Pyrex, filled with DI water
- 1 Stir bar and stirring device
- 1 Water bath
- The salt to be analyzed, in this case 2g of NaOH.

Make sure that all components involved in the measurement are at room temperature. The ambient temperature must not fluctuate during the measurement. Isolate your setup from direct air currents. Make sure to cover the water bath in order to prevent evaporation.

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References

International Renewable Energy Storage Conference **IRES**

Your name:

L. J. Fischer, S. Maranda, C. Haak, J. Worlitschek, Hochschule Luzern Technik & Architektur, Switzerland, G. Bourtourault, Fafco S.A, Bienne, Switzerland

Title:

Heat flux analysis of a latent heat storage

To store thermal energy in a latent heat storage the entire system of phase change material (PCM), heat exchanger, as well as the heat demand and availability have to be regarded in a system context.

With respect to the heat exchanger it is of the essence to deliver sufficient power. In case of latent heat storage this power is a function of the load. A latent heat storage operates at one distinct temperature. Whereas the capacity in a thermal-energy-storage based on sensible heat is indicated by the actual temperature this information is missing in a latent heat storage. The temperature is constant and independent from load! Particularly in case of incomplete charge and discharge the actual capacity is unknown but would be necessary in order to operate the entire system control.

In a latent heat storage plates or tubes are placed or distributed within the container. They are surrounded by PCM. The process of melting and freezing can be described by transient heat transfer, often the modelling is sufficient precise with a quasi-stationary approach. Heat flux is a function of the actual capacity.

The authors will present a technique to measure the current load by direct heat flux measurement on the heat-exchanger surface. Based on this information the prediction of the current capacity becomes available.

As this technique influences the heat transfer itself it is important to compensate by design measurements and calibration. The application of this technique will be explained within an example of a heat-exchanger element with low heat-conductivity and small dimensions. To design the set-up analytical and numerical calculations of the temperature field are necessary. The results are reassessed within an experimental set up and controlled via integral heat balances.

The presentation explains how analytical and numerical calculation of heat transfer will result into a practical approach to measure power and capacity of a latent heat energy storage.

International Renewable Energy Storage Conference **IRES**

1/4 White Paper: A solution to compensate for the smallest thermal influences

greenTEG

A solution to compensate for the smallest thermal influences

Introduction

Nowadays, precision instruments of all types (e.g. metrology instrumentation, precision machining tools, etc.) have reached remarkably high levels of accuracy. Thermal influences are present in all systems and limit the achieved precision e.g. by inducing thermal expansion. In order to compensate for these effects, it is important to measure the thermal influences.
The current approach to control thermal effects is based on multi-parameter models. These models are derived empirically, and are used to measure and predict thermal influences. The most common parameters in such models are temperatures at various locations in the system and situational information (e.g. power consumption of motor). A certain compensation of thermal effects is accomplished with this method. However, in some applications, higher measurement precision and robustness towards external factors like changing ambient temperature is required to obtain a satisfactory compensation.

Reaching higher precision levels with the presently applied multi-parameter models is challenging due to three reasons:

1. **Non-linear temperature profile:** A large number of temperature sensors are necessary to reconstruct the temperature profile with sufficient accuracy.
2. **Temperature resolution:** Standard temperature sensors have a limited temperature resolution, which limits the measurement accuracy.
3. **Heat flow dynamics**: The change in incoming or outgoing heat flow is unknown since it is currently not determined experimentally. An exact statement about whether the system is heating up or cooling down is therefore difficult.

Extending the system with additional temperature sensors addresses only the first of the issues mentioned here. Further, the marginal improvement of precision decreases with each added temperature sensor.

This document suggests using "heat flux" as an additional parameter, and shows its benefits with regards to these three reasons. Heat flux (in W/m^2) can be directly measured with a dedicated heat flux sensor (HFS). Systems that might benefit from heat flux sensors:

- Dosing systems,
- Positioning systems
- Lithography
- Bonding systems
- Metrology systems

To illustrate the potential benefits, Figure 1 shows an example of the improvements gained by adding a single heat flux sensor to a high-precision metrology instrument.

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gSKIN® application note: U-value Glass Measurement

Introduction

Windows are responsible for 10 to 20% of the heat losses in a building during winter time (Axel-Lute, 2009). The thermal performance of a given window glass can vary a lot. U-value may range from 5 W/m²K for single glazed windows to 0.7 W/m²K for triple glazed windows (VFF, 2014). This means that a lot of energy and costs can be saved by replacing a poorly insulated and outdated window with a window according to the latest standards. However, the exact thermal performance of the glass within a window is hard to examine which makes analysing the cost-effectiveness of replacement difficult. In-situ measurement data can therefore be of great value. As with other building envelopes, reliable in-situ measurements of glass can be conducted using heat flux meters. However, as the thermal behaviour of glass differs from that of walls, a different measurement approach is required.

The use of heat flux sensors for U-value measurements is a reliable method to gain U-values as shown by several case study conducted by scientists around the world, including ones from ETH Zurich and greenTEG R&D. In this case study we show the U-value measurement of a double glazed window in an apartment building with a gSKIN heat flux sensor. The measurement had been conducted during night to omit the influence of day light radiations, according to the guidelines for glass measurements provided in ISO 9869. To analyse the effect of daylight on the U-Value, an additional measurement was made during daytime.

The goal of this case study is to obtain insights in the thermal behaviour of glass and the influence of this behaviour on heat flux measurements. Furthermore, it shows how the U-value relates to the value expected after visual inspection and how much energy can be saved by replacing a window in this particular case.

Measured object

The measured window is part of an apartment building from the 1990s and its width is 50 cm and the height is 90 cm. The window is located at the south side of the building. It is a double glazed window with a PVC frame. A metal roll-down shutter is placed 10 cm from the window on the outside. This exterior window shutter can be (partly) closed during the night or day to control the amount of light entering the room. Since these shutters are always down, either open or closed, they are included in the system which is measured. The apartment has a total of 8 m² of window glass facing the outside. The apartment building has not been renovated yet and the observed window has not been replaced since the construction.

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