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Switchable Thermal Insulation for increasing energy efficiency of building façades

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Abstract

A Switchable Thermal Insulation (STI) for using solar energy in winter was developed and evaluated at a test façade. As opposite to STI developed in previous research which was sealed by expensive and thermally inefficient stainless steel sheets, the new device with a switching function based on hydrogen and getter materials was sealed by high barrier foils. The results show a high energy input of about 67 kWh m⁻² by using solar energy at the façade during one heating period. With a combination of STI and a massive wall the captured solar heat is transported through the façade with a time offset. Thus, nightly inside wall heating is possible.

Keywords: *building façade, switchable thermal insulation, vacuum insulation panel, hydrogen getters, high barrier foil, wall heating*

1. Introduction

Switchable thermal insulations (STI) based on hydrogen and getter materials were researched at ZAE Bayern in the end of the 90s (Horn et al., 2000; Meister et al., 1997). In the context of this research a demonstrator was built, which showed an excellent performance in using solar energy at building façades. During a heating period (October to April) a building energy input of 88 kWh m^{-2} through the demonstrator was reached by using solar energy (Horn, 2001). The demonstrator shell was realized by stainless steel sheets to avoid gas exchange with the environment. The research was continued in the funded project “Enotec” (Ebert et al., 2014). In this context a demonstrator shell was developed based on high barrier foils to reduce the thermal bridge at the demonstrator edges and to lower the costs of the element in contrast to a stainless steel STI.

2. Functional principle

The developed STI affords the opportunity to switch its thermal conductivity between a highly conductive and an insulating state on demand. Therefor a highly heat-insulated function block consisting of a getter material and an electric heater is placed in an evacuated porous insulation layer which is surrounded by a gas barrier such as a metallic shell. In case of the heat-insulating state of the STI the (cold) getter and hydrogen are ligated chemically. Due to the evacuated state of the porous insulation layer the gaseous thermal conductivity is compensated and the thermal conductivity of the insulation layer material dominates the effective thermal conductivity. In this state the thermal insulation is similar to the thermal insulation of a standard vacuum insulation panel (VIP). To get in a highly conductive state the function block is heated to a fixed temperature by low electric power. Thus, hydrogen is released by the getter and distributes in the porous insulation layer. Hydrogen has a high thermal conductivity about $186 \cdot 10^{-3}$ W m^{-1} K^{-1} and causes a significant rise of the effective thermal conductivity (see Figure 1). As shown in Figure 1 the thermal conductivity in the high-conducting state ($\approx 170 \cdot 10^{-3}$ W m^{-1} K^{-1}) is about 40 times higher than that in the insulating state ($\approx 4 \cdot 10^{-3}$ W m^{-1} K^{-1}) due to the increased hydrogen pressure.

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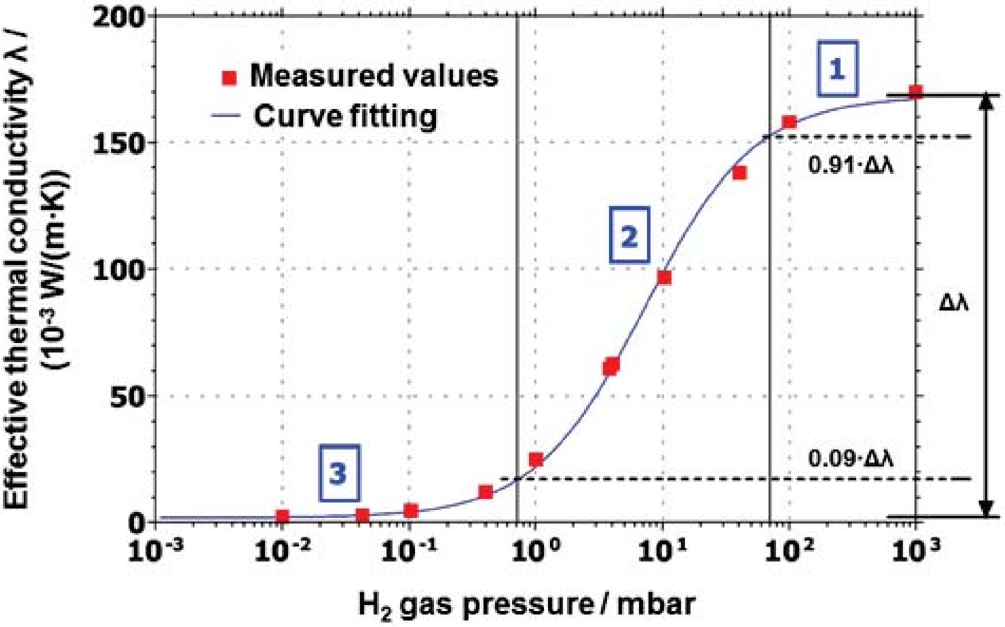

Figure 1: Thermal conductivity for a porous glass fiber system as a function of hydrogen gas pressure (Horn, 2001).

3. Use of solar energy

The STI setup shown in Figure 2 is used for capturing solar energy at the façade during a heating period. For the integrated STI a switching factor of 24.5 between high-conducting and high-insulating state was measured. The sand-lime brick wall behind the STI with a thickness of 0.24 m provides a good thermal storage so that heat is released indoors even during the night or during overcast sky. On the STI a metal sheet was installed to absorb solar radiation on the one hand and to press the STI on the sand-lime brick wall with a metal frame on the other hand. In order to prevent the heated absorber from cooling by outside air convection in winter, a glass panel was installed at a distance of about 40 mm from the absorber and was sealed at the edges. For the heating period 2014/2015 a monitoring of heat flux (inner surface), temperatures and switching states in the STI was initialized.

Figure 2: STI demonstrator with dimensions 80 cm x 50 cm, installed at a massive test façade. Left figure: Real STI demonstrator setup without surrounding insulation and plaster. Right figure: Real STI demonstrator setup after thermal insulating (black coloured) and plastering (white coloured).

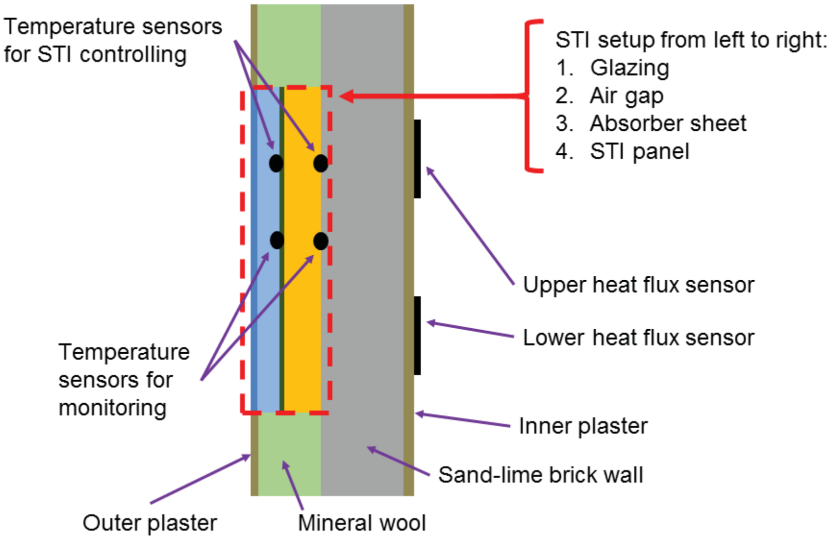

Figure 3: Sketched cross-section of the real STI setup with massive wall and surrounding thermal insulation and plaster.

4. Results

While conventionally insulated façades without STI show a negative energy input (heat losses), the measured heat flux on the test façade resulted in a (positive) energy input of about 67 kWh m^{-2} during the heating period 2014/2015. It should be noted, that the heat flux meters did not sense lateral heat fluxes to the sides, the top and the bottom of the sand-lime brick wall (see figure 3). Thus, the actual energy input probably will be significantly higher. Figure 4 shows this behavior. The one-dimensionally simulated heat flux values represent an ideal behavior of the STI test façade without lateral heat fluxes. For these calculations, a self-developed validated one-dimensional numerical simulation model for heat transfer was applied. The heat equation is therein solved by means of the finite volume method considering the switchability of the STI's thermal conductivity, convection and thermal radiation in the air gap as well as heat conduction (not in air gap), of course.

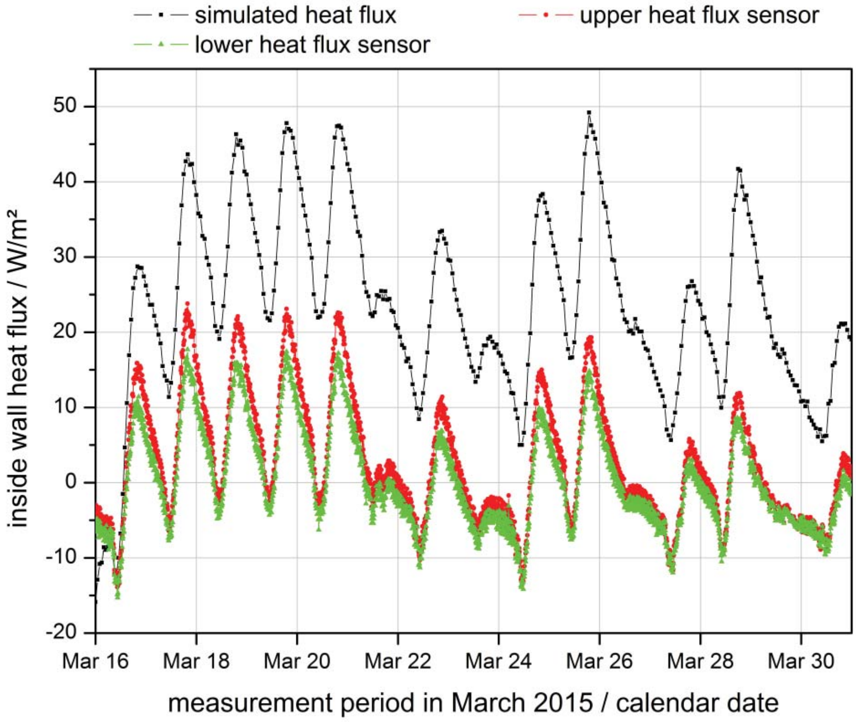

Figure 4: Measured and simulated heat flux of the STI test façade.

Meteorological data such as solar irradiance and air temperature recorded during measurements of the heat flow meters was used as boundary conditions for the simulations. While the simulation data show a very good agreement, regarding the curve progression the measured heat flux is significantly lower. The difference between measured and simulated heat flux mainly is due to already mentioned lateral heat fluxes in the sand-lime brick wall. However, in the one-dimensional simulation model the considered system boundaries are at the edges of the STI setup. Thus, heat is only possible to flow through the area behind the STI setup – in contrast to the real demonstrator setup.

The high thermal capacity of the sand-lime brick wall behind the STI causes a time offset to the heat input into the room. The time offset between absorber temperature peaks and inside wall heat flux peaks in Figure 5 is about 5 to 6 hours and shifts the heat gains into the room to the night hours. The higher the density, specific heat capacity or wall thickness the higher the time offset will be.

For comparison the heat transfer of a conventional façade with the same heat transfer coefficient as the STI setup in heat-insulating state (U = 0.22 W m^{-2} K^{-1}) was numerically simulated in WUFI (Künzel, 1994) for one heating period. Initial and boundary conditions as well as climate data were adapted to measured monitoring data. The simulation revealed an energy input of about -18 kWh m^{-2}. Taking the measured energy input of the STI of about 67 kWh m^{-2} into account the energetic benefit of the STI yields 85 kWh m^{-2}. During the heating period, a small maximum electrical power consumption of 1.5 kWh m^{-2} is necessary to switch the STI.

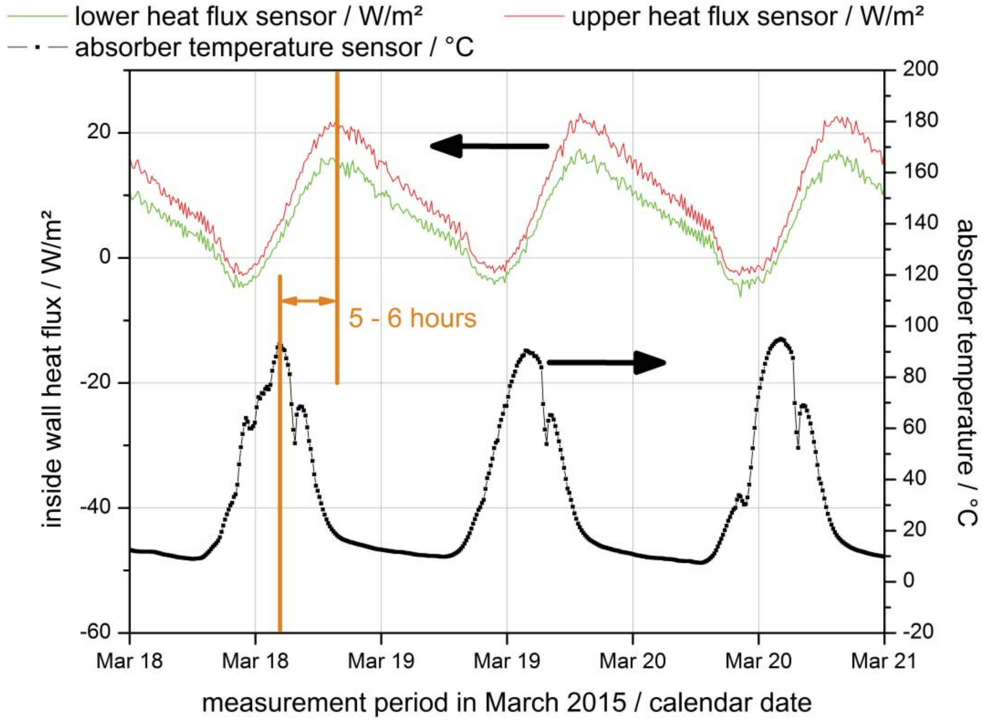

Figure 5: Time offset between absorber temperature peaks and inside wall heat flux peaks due to the thermal capacity of the sand-lime brick wall behind the STI.

5. Outlook

To raise the energy input of the STI during a heating period the thermal conductivity in the high-conducting state – respectively the switching factor – has to be increased by optimizing the function block. The getter material amount in the STI needs to be adapted to an ideal hydrogen filling so that costs for the expensive getter material are minimized while a high thermal conductivity is assured in the high-conducting state. Moreover, the STI can be used as a nightly summer cooling device by using low outdoor temperatures in combination with the high-conducting state.

6. Acknowledgement

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