Internal wall insulation with a new aerogel panel: SLENTITE® for energetic retrofit in historic buildings

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Abstract. We present two recent test case application examples of a new high-performance insulation panel with product name SLENTITE® used as core element of a rendered internal wall insulation system. The first case study refers to the 18th-century building Alte Schäfflerei now the Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings, at the monastery Benediktbeuern, southern Germany, where SLENTITE® was applied in 11/2017. The second test case was installed in 04/2019 in a heritage building situated in the historic center of Luxembourg. In Benediktbeuern, a single layer of insulation material was chosen, in Luxembourg we applied two layers of insulation. In both cases, detail work around the windows was a main task and we gained experience on product processing under real conditions. In terms of indoor room usage, the object in Benediktbeuern is used as exhibition hall with rare traffic and well controlled climate, whereas the object in Luxembourg is used as meeting room without climate control. Measured data of 20 months from the object in Benediktbeuern and first impressions of the performance in Luxembourg are discussed.

1 Motivation

Energetic retrofit of historic buildings can be a challenging task. Old buildings have proven to be statically robust and of value (thus their existence until today), but their indoor conditions or energy consumption also date to old ages and are not always compatible with today's expectations. Energetic retrofit measures such as applying insulation on the building envelope or altering the heating system will change the operating conditions of the historic material. These actions carry therefore the potential risk of damage to the historic object and should be planned with care. Ideally, also the architectural appearance of heritage buildings should be preserved. Methods that avoid applying thick layers of new material thus altering proportions of window and wall, as example, are preferred. Finally, historic objects can be hard to access with large and heavy equipment as used in the construction of new buildings, and emissions of dust or noise during work should be minimized.

The application of a new high-performance insulation product based on nanoporous polyurethane (SLENTITE®) as internal wall insulation system was tested in two historic objects. The product itself is described in detail in a second contribution to this conference [1]; here, we focus on practical aspects of the application and performance data. More background insulation systems in heritage context was published earlier [2].

2 Method

2.1 Scope of the study

In the scope of this work, practical and technical aspects of the new product in the context of heritage refurbishment are evaluated:

(1) Configuration: components and dimensions of insulation system. (2) Logistics: amount and types of insulation and auxiliary materials, ease of transportation and processing, dust and noise during application, time required for the work and until the room could be used again. (3) Hygrothermal performance: calculated and measured thermal resistance of the insulation layer, evaluation of the water content of the wall assembly, IR thermografic analysis of the wall.

2.2 Insulation system

Both test cases have solid masonry walls. The insulation boards are attached to the wall with a mineral adhesive that is also used as base plaster layer. As SLENTITE® is vapor open, the insulation system does not regularly require a vapor barrier [3]. Mechanical fixings could be omitted grace to sufficient tensile and adhesive strength of materials and interfaces; internal tests showed strengths of > 50 kPa in all variants. With a declared lambda value

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of 0.018 W/m·K and a product thickness of 15 mm, one layer of SLENTITE® contributes to the thermal resistance R by 0.83 m²K/W. Compared to a historic wall of 50 cm made of brickwork or natural stone with an estimated R in the range of 0.5 to 1 m²K/W, a single-layered SLENTITE® system can already much improve thermal comfort and energy efficiency. Where better standards are targeted, a two-layered system with then R=1.6 m²K/W can be applied.

The overall thickness of the insulation system including adhesive, basecoat and topcoat layers is about 31 mm for the single and 46 mm for the double layer option. This slim configuration allows to work around windows and other details without touching the existing structures or changing the insulation system. A detailed description of the applied variants at the two sites is reported below.

2.3 Monitoring

To determine the hygrothermal performance of the test refurbishments, at both sites a monitor system was installed. Temperatures and humidity of inner surface, adhesive layer, existing wall and outer surface together with the heat flux were recorded at a standard cross section in a central position of the respective test areas. The sensor positions are indicated in the cross-sectional sketches in Fig. 3 and Fig. 7. Data were recorded in hourly intervals. High quality and calibrated sensors of the suppliers Rotronic (Benediktbeuern) and Ahlborn (Benediktbeuern and Luxembourg) were used. In Luxembourg, meteorological data from the state weather station in Merl [4] 2 km distant to the site were used as data for outdoor conditions.

The effective R-value of the inspected cross section is derived from measured heat flux $\dot{q}$ and temperature data $T_{1,2}$ as follows:

$$R_{\mathrm{eff}}^{1,2} = (T_1 - T_2)/\dot{q} \qquad (1)$$

With inner and outer surface temperatures, the inverse of R gives then effective U-value of the wall:

$$U_{\mathrm{eff}} = \dot{q}/(T_o - T_i) \qquad (2)$$

The effective thermal conductivity, e. g. of the insulation layer, can be derived taking account of the layer thickness d and corresponding temperature signals from both sides of the layer.

$$\lambda_{\mathrm{eff}}^{\mathrm{ins}} = d/R_{\mathrm{eff}}^{\mathrm{ins}} \qquad (3)$$

3 Test sites

3.1 Alte Schäfflerei Benediktbeuern

3.1.1 Building

The Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings [5] is located in the historic “Alte Schäfflerei” (old cooperage) at Benediktbeuern Monastery, south of Munich, Germany [6]. Focus of the center is professional refurbishment of heritage buildings with respect to energy and cost efficiency, material preservation, and ecology. The building is used as exhibition area and meeting room. In the first floor of the building, on the north-west corner, an area of about 12 m² on the west facing wall was insulated with SLENTITE. The area includes a box type window. The building was object to repeated changes in the past and consists mainly of mixed brickwork.

Fig. 1. Indication of the test area on the west façade / Benediktbeuern.

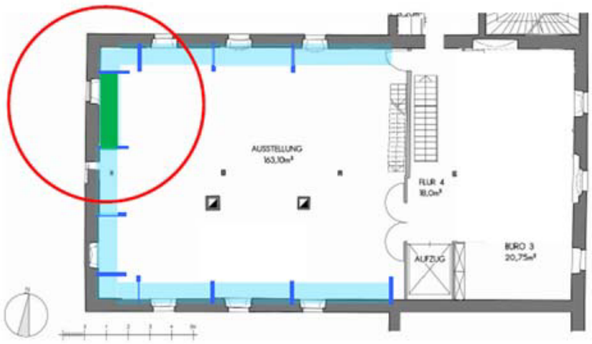

Fig. 2. Orientation and location within the test room in the upper floor of the Alte Schäfflerei / Benediktbeuern.

3.1.2 System configuration

The insulation system was applied in November 2018 over an interface layer designed to allow reversibility [7]. SLENTITE was applied in one layer of 15 mm in a classical rendered system as sketched in Fig. 3.

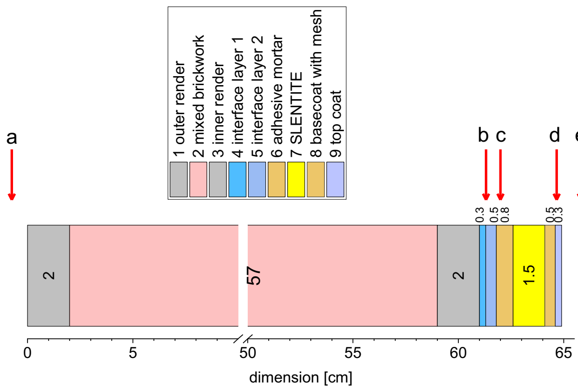

Fig. 3. Cross section of refurbished wall with indication of sensor positions / Benediktbeuern.

3.1.3 Climate

The indoor temperature is conditioned to a target value of 20 °C and relative humidity to 50% rh, with recording and control in the center of the room (*e* in Fig. 3.). In the second winter of the test period, there were some irregularities due to equipment malfunction of the humidifier. Outdoor data showed a few very cold days in early 2018 with extremes reaching -16.9 °C, and a less strong second winter with a minimum of -12.4 °C.

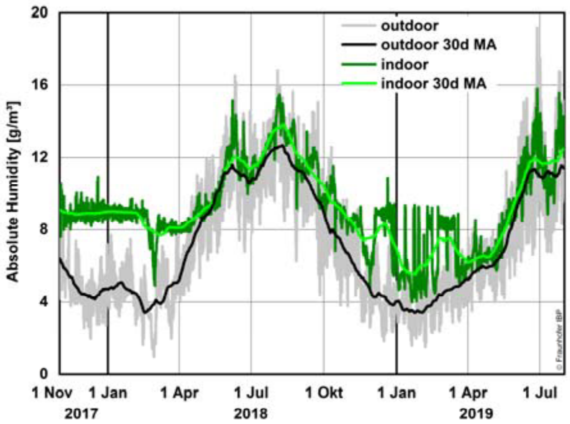

Fig. 4. Absolute humidity indoors (green) and outdoors (black) as hourly measured values and monthly moving averaged values (30d MA) / Benediktbeuern.

The absolute humidity indoors and outdoors is shown in Fig. 4. In the first winter period, the absolute humidity level lies about 9 g/m³ and the outdoor level about 4 to 5 g/m³. The absolute humidity varied in the second winter period from 2 to 5 g/m³ with the irregular conditioning.

3.2 Luxembourg

3.2.1 Building context

University of Luxembourg is running a field test to compare hygrothermal performance of interior insulation systems in a conference room. In the field test, three innovative interior insulation systems with aerogel structure are compared with a conventional interior insulation system made of wood fibers. The insulation thickness varies between 3 and 8 cm, with the goal to achieve a U-value of at most 0.4 W/m²·K as required in Luxembourg.

The test room is located in a historic building in the city center of Luxembourg [8] which is used as a highly frequented meeting room. The wall area equipped with SLENTITE comprises a tall window, faces East and measures about 8 m². The existing wall is about 90 cm thick and made of broken sandstone. This side of the building is strongly exposed to weather.

Fig. 5. Indication of the room and test area as seem from south-east / Luxembourg

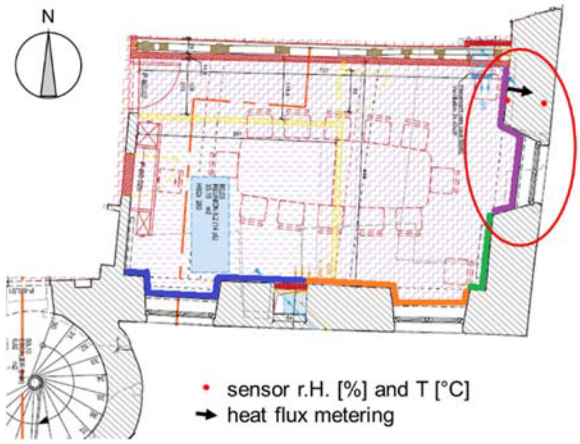

Fig. 6. Location of test area and sensors inside the test room / Luxembourg.

3.2.2 System configuration

The area in Luxembourg was insulated in April 2019 with a two-layered system as sketched in Fig. 7. The insulation panels were installed passing twice over the full area including the large window jambs, working the second pass over the joints of the first pass. The whole room was equipped with a uniform topcoat and finish by a local project team in May 2019, about three weeks after the insulation layers.

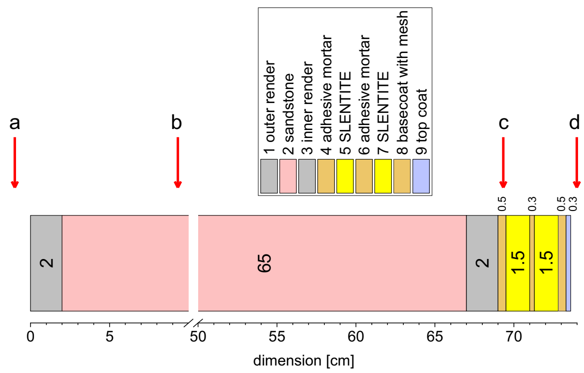

Fig. 7. Cross section of the refurbished wall with indication of sensor positions / Luxembourg.

4 Practical evaluation

4.1 Logistics, workflow

Materials and tools for the refurbishment were as follows: dry mortar in bags and tap water, insulation panels in cartons, mesh in a roll, angle mesh beads; a scaffold, drill with mixing paddle and bucket, jig saw, trimming knife, sand paper, plaster trowel, notched trowel, brush, protective sheeting and tape, protective clothing. This equipment was easily brought on-site also where accessible only via small stairs as in Luxembourg and does not require heavy current or running water immediately at the working spot. The application can be carried out by a single person without problems; we had two persons for working and documenting at both sites.

At the Luxembourg site, we collected the cut-off waste material and determined the net material use of the insulation panels to 93%.

In Benediktbeuern, two craftsmen prepared the insulation system and topcoat within two days on site, allowing a week curing time before working over the basecoat. In Luxembourg, the two layers of insulation were applied in two following days without additional curing of the glue layer in between. For smaller areas, we expect that a faster workover is also possible, as the glue layer can be thin and sets quickly on the vapor open SLENTITE panels.

4.2 Regular cross section and detail work

At both sites, SLENTITE® panels of original product size 55 cm × 36 cm were used for the main flat areas. The existing substrates (special reversible layer in Benediktbeuern, Trasskalk in Luxembourg) were plane, smooth and easy to work over, i. e. well prepared in the research setup of the sites. The adhesive mortar was applied with a notched trowel to the substrate and the pristine panels pressed in place. Special care was taken to avoid thermal bridges at joining panels. The two-layered variant was done similarly, with a second adhesive layer applied on the first insulation layer.

Fig. 8. Avoiding adhesive from entering in joints between insulation panels.

At both sites, some details required special attention. In Benediktbeuern, a rounded detail at the window head was equipped with small trapezoid stripes that were cut by jigsaw on site, as shown in Fig. 9.

Fig. 9. Applying insulation on a rounded area at the window head reveal / Benediktbeuern.

In Luxembourg, curvatures in the area of the wooden beam ceiling were aligned by the insulation using a jigsaw and smoothing planer. As only one room was insulated from the inside, the ceiling connections had to be meticulous and airtight. In the area of the window hinges, small details were modelled with sandpaper as shown in Fig. 10.

Fig. 10. Modelling the insulation panel around details such as connection to historic wood beam ceiling, window hinge / Luxembourg.

Rounded penetrations, here for sensor cables and piping, were achieved by cutting the panels with a small piece of pipe that served as custom made drill head.

5 Hygrothermal performance

5.1 Alte Schäfflerei Benediktbeuern

The performance of the insulation system was evaluated with respect to thermal resistance according to equation (1). Transient results are shown in Fig. 11.

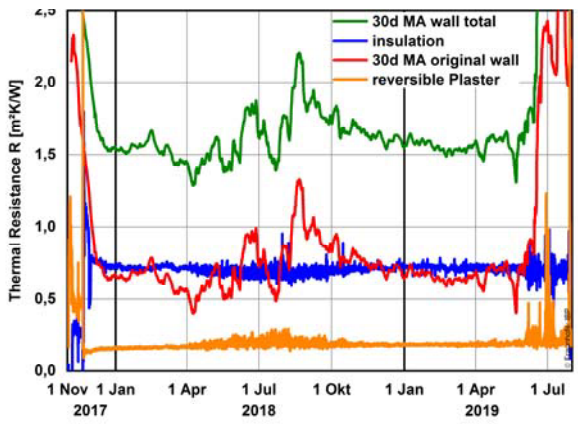

Fig. 11. Calculated thermal resistance of wall cross section as a whole (green, top curve) and individual layers (insulation: blue, at approx. R=0.75) with hourly averaged data and 30 day moving average (30d MA).

The average effective thermal conductivity of SLENTITE® as by equation (3) for the first and second winter is 0.021 W/m·K and thus slightly above the declared lambda value of 0.018 W/m·K (measured as usual at 10 °C in dry material).

Infrared-thermography was used to verify and document the insulation performance over the full test area. The image in Fig. 12 taken from interior shows a well uniform surface temperature of roughly 18 °C to 20 °C. Joints of the insulation panels can be identified as thin lines slightly cooler compared to the Slentite panels. The right lower wall area is cooler due to thermal bridging effect of the adjacent wall corner. Also, a vertical temperature gradient can be observed due to typical indoor air stratification. Both effects are also present in a reference IR thermography of the wall area prior to installation of the insulation system (Fig. 13).

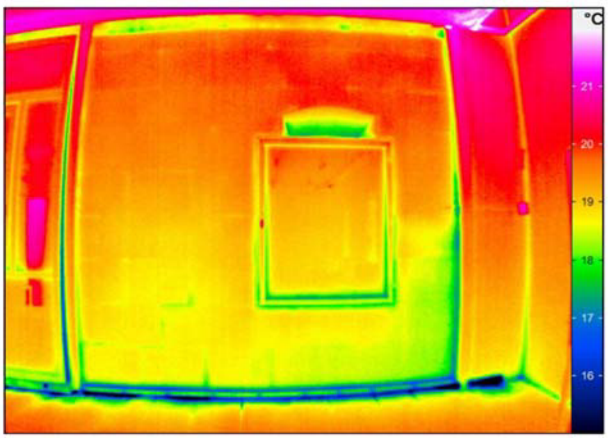

Fig. 12. IR thermography from inside, 22.02.2019 9:00, outdoor temperature 4.8 °C

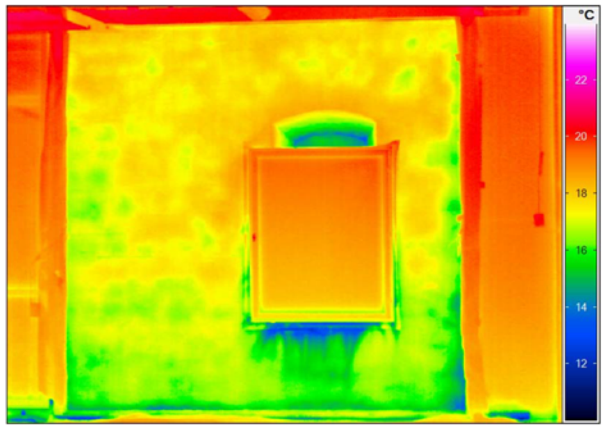

Fig. 13. IR thermography from inside without insulation, 16.11.2017, outdoor temperature 0.0 °C

5.2 Luxembourg

As a result of the extremely hot summer 2019, all insulation systems dried very quickly. At the beginning of the measurements in September there was no residual humidity detected in the adhesive layers. As the façade has good protection against driving rain, the average equilibrated moisture level of the existing wall was below 60% relative humidity in the pore volume. These preliminary results were presented at in September 2019 in more detail [9]. In the following, we discuss recordings from September to December 2019. Apart from a short sensor blackout in early November, data acquisition was regular.

Heat flux $\dot{q}$ and temperature T data from sensors on the inner and outer surfaces (index i, o) was evaluated to determine the effective U-value as in equation (2). The direct and smoothed result is represented in Fig. 14. The evaluation of an 8-day period in November results in a U-value of the insulated wall of about 0.35 W/m²·K. Considering the U-value before the insulation of approx. 0.97 W/m²·K, this corresponds to an improvement of 63 %.

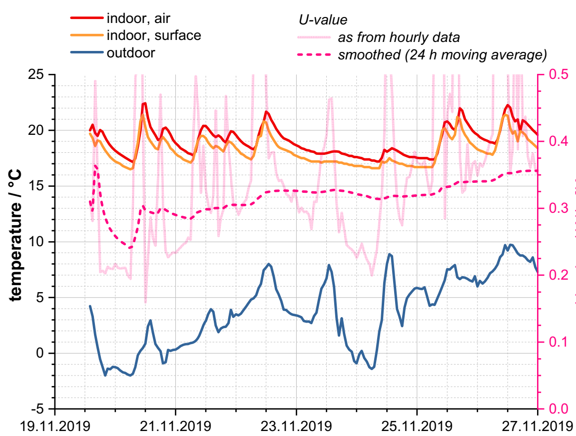

Fig. 14. Sensor recordings and U-value evaluation / Luxembourg.

The recorded moisture and temperature values were compared with a WUFI 6 simulation of the transient heat and moisture flux, since the technical proof of such an internal insulation system is usually carried out with this method. For this purpose, the on-site measured data of the indoor climate as well as data of the outdoor climate of the agricultural weather station Merl were used.

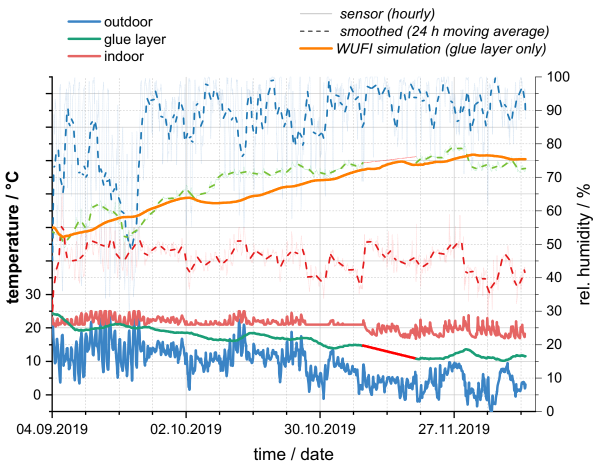

Fig. 15. Simulation compared to measurement / Luxembourg.

Fig. 15 shows the measured temperature and humidity values beneath the interior insulation and the course of the values simulated with WUFI. A good agreement is to be recognized. Conversely, it can be assumed that at least within the experimentally assessed humidity range of 60 - 85%, simulations with WUFI for the SLENTITE® product lead to reliable results for other indoor and outdoor climates if the edge parameters are selected correctly.

In the thermographic images in Fig. 16, corner details of the insulated area are shown. In the left image, a uniform surface temperature of the insulated area and a colder corner at the inner surface to the neighbouring room can be seen. In the right image representing the lower window niche, the window frame appears to be the coldest element. In the installed insulation system, no defects were detected.

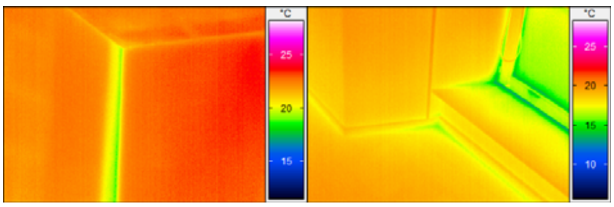

Fig. 16. IR thermographies from inside: top left detail of the main wall area; lower left window detail /Luxembourg.

6 Conclusions, Outlook

In this paper we present the planning, execution and evaluation of two test case refurbishments in heritage buildings with a new kind of insulation panel. Installation was easy and quick, without noise, dust or other annoying issues, with minimum equipment and waste. This allows to access also small, delicate, or remote objects. Typical details around windows and top wall corners could be solved without need for material change, thus minimizing the number of material types to be provided at the site.

The recorded data confirms that the thin and vapor open system configuration resulted in a drying period of a few weeks only, as a combined effect of little humidity supplied by thin mortar layers and low vapor resistance of the insulation layers. This is clearly advantageous for the refurbishment of objects in operation.

Performance evaluation shows that the effective lambda value under practical conditions differs from the declared value by 0.003 W/m·K at most. Joints of the single layered system are visible in thermography, but not of the double layered system. In any case a pattern formation in the visible spectrum as created by dry spots typically seen over dowel heads in exterior insulation is not expected: Here, all surface is well above the dew point including the area over the joints. For the same reason, the internal wall insulation can be classified as effective mould prevention.

The project in Luxembourg will be supervised by the University of Luxembourg until 2022. Until now it can be said that aerogel-based products enable the promised improvement of thermal insulation while at the same time significantly reducing the thickness of the insulation material. This factor plays an important role especially in the cramped conditions in many old buildings and with a high price per square metre of living space.

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