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Efficiency verification of a combination of high performance and conventional insulation layers in retrofitting a 130-year old building

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ABSTRACT

The performance and applicability of a newly developed high efficiency insulation material to retrofit old buildings was investigated in a pilot project supported by the Swiss Federal Office of Energy (SFOE). One half of an old stone walled building situated in the city of Zurich dating from 1877 has been retrofitted by means of a high efficiency thermal insulation layer of 20 mm thickness containing aerogel on the external side, and a conventional insulation material of 20 mm on the inner side of the stone walls. This procedure promised a theoretical reduction of the steady state *U*-value of the wall by approximately a factor of 3 without compromising the original appearance of the building. To verify this, in-situ measurement of the *U*-value as well as infrared thermography has been performed during the cold weather period of early 2011 when there was a large temperature gradient between indoor and outdoor climate.

1. Introduction

The stock of residential buildings constructed before the 1970s which have low performance regarding energy saving makes up more than 3/4 of the total existing residential buildings in European countries [1]. Correspondingly many efforts have been undertaken to retrofit such buildings in the past few years and are still going on. Among others the FP7 Cooperation Work Programme of the European Community has allocated a budget of EUR 140 million in 2012 for the “Energy Efficient Buildings Initiative” [2]. The issue of retrofitting becomes more complex for listed historical buildings with additional tight requirements to keep their outer façade unchanged and the overall appearance of the surroundings unaffected by retrofit measures. Adding conventional layers of 8 to 10 cm thickness for an effective reduction in energy consumption causes a number of practical problems when applied internally or externally to an old listed building. The appearance of high performance thermal insulation products on the construction market with thermal conductivities lower than 25 mW/mK has opened new perspectives in retrofitting listed buildings.

The building used for the present investigation has solid stone walls, dates from 1877, and is one of a number of semi-detached houses (Fig. 1) forming a small district in the city of Zurich, Switzerland. There was a strict requirement regarding the overall appearance of the building and its position among the neighbouring buildings to remain unchanged. The aim was to significantly reduce the overall energy consumption. As a pilot project different measures were taken to reach this goal only for one half of such a double-house. The roof and the floor above the cellar were insulated by means of conventional mineral wool. However, for the outer façades a thick insulation was not applicable due to structural changes which would violate the above requirement on the one hand and applying it as an interior insulation on the other hand would have reduced significantly the size of the already small rooms. A solution was found by using 2 cm of a high performing fibre insulation mat containing aerogel which allows a reduction in thickness (by a factor of 2–3) compared to conventional insulation materials, together with an insulation rendering to be installed on the external side and a conventional insulation of 2 cm of expanded polystyrene (EPS) on the inner side of the stone walls. It has to be kept in mind that the price of high efficiency thermal insulation compared to the conventional material with the same thermal resistance is still higher by a factor of 4. By adding these two insulation layers on both sides of the old stone wall it was expected to reduce the total thermal transmittance (*U*-value) to 0.48 $W/(m^2 K)$

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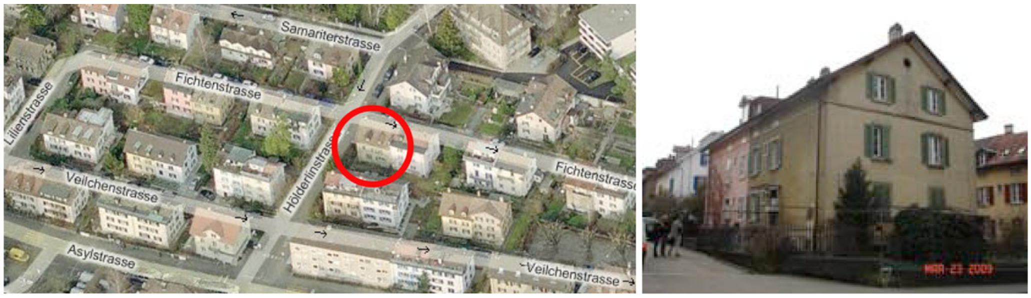

Fig. 1. The investigated double-house is indicated by the circle. The retrofitted half is encircled (left). Front view from the main street prior to retrofit (right).

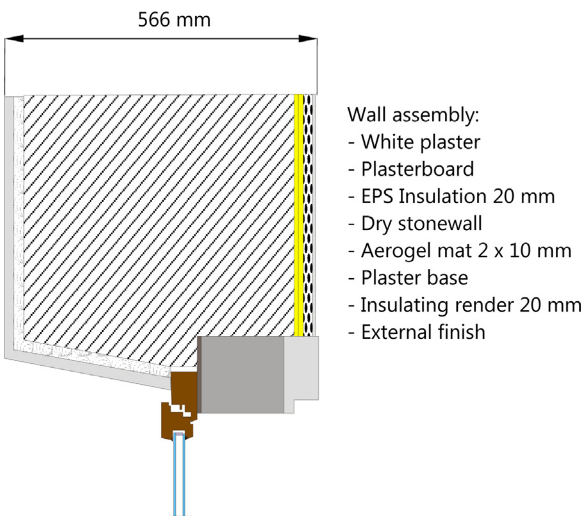

Fig. 2. Details of the retrofitted wall with lintel (left: room side, right: external side).

i.e. down to about 1/3 of its initial value. Besides, the use of insulation layers on the exterior side improves the thermal stability of the whole structure and suppresses the room temperature from swinging as shown in [3]. The heating system based on oil-fired heating and radiators in the rooms was replaced by a ground source heat pump and underfloor heating.

The present study verifies the thermal performance of the refurbished outer wall with south orientation by means of in-situ *U*-value measurements in accordance with the International Standard ISO 9869 [4] applying both the average as well as the dynamic method and comparing the results with the one dimensional steady state calculation of heat flux for a wall made of multiple parallel layers. As a second and more qualitative verification of the thermal behaviour infrared thermography was carried out to enable a comparison between the retrofitted and non-retrofitted halves of the house. Infrared thermography was also useful to ensure the absence of irregularities (i.e. thermal bridges) in the area where heat flow and temperature sensors were positioned. The evaluation of the heating system's performance needs a longer period of monitoring and is not part of the present analysis.

2. Details of the retrofitted wall

Fibre mats containing Aerogel represent a high performance insulation material and have been applied here at a thickness of 20 mm on the external side of the building. On the internal side a conventional insulation material (expanded polystyrene) has been applied to meet the above mentioned target of *U*-value reduction to 1/3 of its original value. The details of the retrofitted wall including a window lintel are shown schematically in Fig. 2. To enhance further the thermal resistance of the building and to even out irregularities in the stone wall surface an insulation rendering of an average thickness of 20 mm was put on top of the aerogel fibre mats. A thin layer of 5 mm (on average) of conventional rendering was used as a finish on the external surface of the retrofitted stone walls. Fig. 3 shows a sequence of pictures showing the different steps of application regarding the aerogel fibre mat applied to the façades.

Fig. 3. A sequence of the external application of the aerogel containing fibre clockwise from top left to bottom right.

3. Measurements

The equipment used for in-situ measurements were two temperature sensors, a heat flux sensor and a data acquisition device. The present study also includes measurements of thermal conductivity of building materials by means of a guarded hot plate apparatus and infrared thermography for detecting the temperature distribution on the external wall surface. The room side temperature and humidity were also measured to have an