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ScienceDirect

Energy Procedia 78 (2015) 848 – 853

Energy Procedia

6th International Building Physics Conference, IBPC 2015

# Evaluation of three different retrofit solutions applied to the internal surface of a protected cavity wall

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## Abstract

A south-east oriented façade of a protected building of Politecnico di Milano has been retrofitted on its inner surface with respect to energy consumption and thermal comfort. Three prototype solutions including special perlite boards and aerogel composite materials have been used. The wall has been monitored by a wireless system of temperature, moisture and heat flux sensors before and after retrofit for about 6 months each. The acquired data enabled the determination and transient behaviour of hygro-thermal properties of the investigated façade before and after retrofitting using the average method. Measured results were compared to those obtained from thermo-hygric simulations.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

*Keywords:* Retrofit; wireless monitoring; historic building; hygrothermal performance; aerogel based material; perlite based material.

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## 1. Introduction

As the existing building stock in Europe has the highest potential in reducing the energy demand, retrofitting has got a high priority in different national and regional research programs. The EASEE Project of FP7 within the concept of “Energy saving technologies for buildings envelope retrofitting” aims at developing a tool-kit for energy efficient retrofitting of existing buildings including those under protection by using advanced insulation materials. Within this framework, a part of a building of Politecnico di Milano has been chosen as a retrofit demo object. The wall is a part of a façade of one of the buildings at the university campus, built in 1965 based on Architect Gio Ponti’s project and is classified as cultural heritage. Since it was out of question to alter the external side, internal retrofitting was

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.006

envisaged especially with low thickness insulations to keep the reduction of the inner volume of the room at a minimum. Different insulating components including special perlite boards and aerogel-based blankets were designed and developed and installed at the internal side on 3 designated wall partitions. These have been monitored for their hygro-thermic behavior for a period of 1 year and the results are analyzed and presented here. As an improvement towards previous investigations [1-3] the present study includes a long term remote monitoring before and after retrofit of 3 different insulation components on the same wall with an extensive hygrothermic simulation and analysis of the measured data.

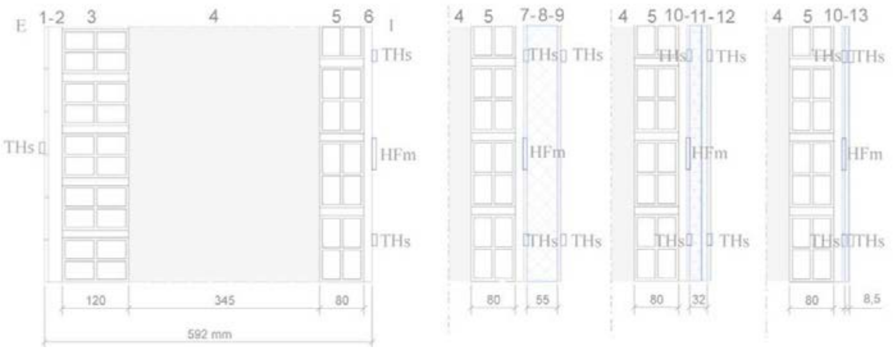
| **Nomenclature** | | Suffixes: | |
|---|---|---|---|
| $\Lambda$ | thermal conductance [$Wm^{-2}K^{-1}$] | eq | equivalent, corrected value |
| U | thermal transmittance [$Wm^{-2}K^{-1}$] | j | measurement index number |
| q | heat flux [$Wm^{-2}$] | se, si | exterior surface, interior surface |
| T | temperature [°C] | ST,DRY | calculation at steady state, dry values |
| RH | relative humidity [%] | AM | average method |
| $\lambda$ | thermal conductivity [$Wm^{-1}K^{-1}$] | WUFI | 1D thermohygric analysis |
| R | thermal resistance [$m^2KW^{-1}$] | bet | sensor position behind insulation |
| | | gap | sensor inside air cavity |

## 2. Demo wall description

The demo wall is an unventilated cavity wall with South-East orientation. It has a total area of 11.34 $m^2$ and is divided into three sections accommodating the 3 retrofit solutions. The wall belongs to a meeting & teaching room normally occupied by users but not constantly. The room is conditioned by means of a fan coil system during winter and summer with an air temperature set point of 20°C. It is partially centralized but the user can arbitrarily switch on or off the system.

### 2.1. Base cavity wall

The unventilated cavity wall is composed of two hollow brick walls of 8 cm (inside) and 12 cm (outside) with an unventilated air cavity of 34.5 cm between them. The two brick walls are not connected in any way in the area under consideration. This has been verified by infrared thermography. The internal plaster is cement lime based with gypsum finishing. The outer surface is covered with ceramic tiles. The whole wall thickness is 59.2 cm. The details of the wall before and after retrofit are shown schematically in Figure 1.



LEGEND:
1- Ceramic tiles; 2- cement based adhesive render; 3- hollow bricks 12cm th.; 4-air cavity; 5 - hollow bricks 8cm th.; 6 - lime-cement plaster with gypsum finishing; 7- cement-based glue; 8-perlite board; 9- cement besed filler and resin render; 10- resin-based glue; 11- aerogel-based flat laminated panel; 12- resin based filler and resin render; 13- flexible aerogel-based blanket with fabric; THs-Temperature, relative humidity sensors; HFm-heat flux meter.

Fig. 1. Vertical cross section through the demo unventilated cavity wall before retrofit (left) and the schematic representation of the three different retrofit solutions, together with sensors scheme.

### 2.2. The three retrofit solutions

- **A.1** 5.5 cm of improved natural perlite board s with specific render as glue and filler, applied to a total area of 4.59 m$^2$
- **B.1** Laminated panel composed of silica aerogel impregnated unwoven fibrous blankets fixed to a rigid support of 2.8 cm thickness, with specific render as glue and filler, applied to a total area of 3.38 m$^2$
- **B.2** Flexible “wallpaper”, silica aerogel impregnated unwoven fibrous blankets with finishing textile with a total thickness of 0.7 cm, applied to a total area of 3.37 m$^2$

The main hygro-thermal properties have been measured by means of laboratory tests . For the present investigations the conductance of the base cavity wall and the three retrofit solutions are given in Table 1. The thermal conductivity, measured at dry condition and ambient temperature, of the insulation perlite board and the aerogel based blanket were 0.063Wm$^{-1}$K$^{-1}$ and 0.025 Wm$^{-1}$K$^{-1}$ respectively. For the installation on the test wall, no anchors but only continuous gluing layers have been used,. The only exception is *B.2*, in which a mechanical system has been added on the top and the bottom of the wall to keep the inner fabric layer tensioned.

## 3. In-situ monitoring set-up

A monitoring campaign using a complete set of sensors necessary for the thermal conductance evaluation, has been carried out from December 2013 until the present time (January 2015) and is still running. The collected data correspond to 7 months before retrofit and 6 months after retrofit. Summer and winter periods are available for both conditions.

### 3.1. Type and position of sensors

Humidity and temperature sensors (SHT25 - Sensirion), with a typical accuracy tolerance of ±1.8 %RH and ±0.2 °C respectively, have been installed on the external (beneath a shielded air volume) and internal surface of the three wall partitions, before retrofit. Calibrated heat flux meters (HFM) have also been installed, on the internal surface of the wall partitions at a height of 1.35m from the floor level. Furthermore, inside and outside air temperature and air relative humidity have been measured too. After the retrofit, additional SHT25 sensors have been installed on the internal side at the same position in height as the previous ones.

### 3.2. Collected data

A wireless communication system and a GPRS modem enabled on-line visualization of the measured data and downloading into CSV format. The recording time step was 6 minutes and the data were later transformed into hourly values. The evolution before and after retrofit of the two surface temperatures and the heat flux for the partition with the *B.1* solution is shown in Figure 2 (a).

## 4. Calculation and numerical simulation

### 4.1. Theoretical 1-D calculation at steady state

The thermal characteristics of the wall at steady state have been calculated before and after retrofit, according to [4], and using thermal conductivity at dry condition, heat capacity and density of each material. The properties of internal and external render and ceramic tiles of the base wall are reference typical values. The thermal conductivity of the hollow bricks have been corrected considering the presence of mortar joints ($\lambda_{eq}$=0.29 W m$^{-1}$K$^{-1}$ for external brick wall and $\lambda_{eq}$=0.27 W m$^{-1}$K$^{-1}$ for internal brick wall), according to [5]. The thermal resistance of air layer has been approximated to 0.18 m$^2$K W$^{-1}$ complying with [4], considering that the thickness is slightly higher than the limit value of 30 cm. For each layer of retrofit solutions, measured thermal conductivity and density, together with reference values of heat capacity, have been used. The results at steady state are $\Lambda_{ST,DRY}$ -value (W m$^{-2}$K$^{-1}$) and $U_{ST,DRY}$ -value

(W m$^{-2}$K$^{-1}$). The second one is obtained adding surface thermal resistances ($R_{si}$ = 0.13 m$^2$K W$^{-1}$, $R_{se}$ =0.04 m$^2$K W$^{-1}$ from [4]). The final values are shown in Table 1.

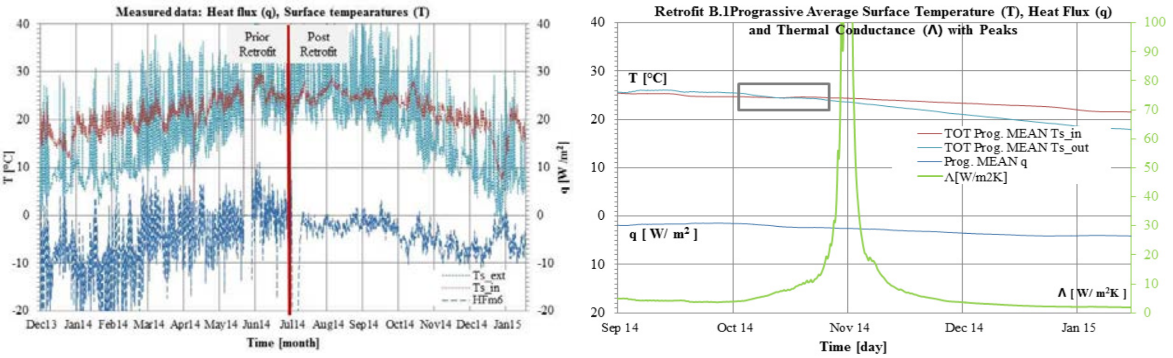


Fig.2. (a) Evolution of temperature on both sides and of the heat flux meter on the internal side of the wall partition corresponding to retrofit solution B.1; (b) the progressive average values for both surface temperatures, heat flux and the resulting conductance.

### 4.2. Thermal transmittance from in-situ measurements using the “ Average Method”

The measured surface temperatures and heat flux have been used for estimating the $\Lambda_{AM}$ -value and consequently the $U_{AM}$ -value of the wall before and after retrofit with the progressive “Average Method” according to [6]:

$$\Lambda = \frac{\sum_{j=1}^{n} q_j}{\sum_{J=1}^{n} \left(T_{sij} - T_{sej}\right)} \tag{1}$$

A time interval with stable conductance values has been selected to avoid periods where the progressive average of $T_{si}$ is crossing the progressive average of $T_{se}$, resulting a division by zero (Fig. 2b). Even smaller intervals of months and weeks were chosen for each of the 3 wall partitions, verifying when conditions declared in [6] were fulfilled. An operational error of ± 8% and ±0.2 °C have been assumed for heat flux measurements and temperature sensors respectively.

### 4.3. Transient hygro-thermal performance

The 1-dimensional hygro-thermal behaviour of the base wall and the retrofit partitions have been determined by WUFI® Pro 5.3 [7], which considers coupled heat and moisture transfer. The input data included the measured relative humidity on both surfaces. The resulting $\Lambda_{WUFI}$ -value (W m$^{-2}$K$^{-1}$) and $U_{WUFI}$ -value (W m$^{-2}$K$^{-1}$) are compared to the previous calculation methods as well as the measured data (Table1).

## 5. Results and discussion

### 5.1. Comparison of methods

Thermal conductance values obtained by different methods are compared in Table. 1. $\Lambda_{ST,DRY}$ is the lowest because it is based on the steady state and λ’s constant dry value. $\Lambda_{AM}$ is the mean asymptotical value with standard deviation (maximum uncertainty of 8.39%), obtained by measurements using the average method and it is used for comparison with results obtain from WUFI calculation ($\Lambda_{WUFI}$) at transient condition, with λ depending on moisture content. The difference between $\Lambda_{AM}$ and $\Lambda_{ST,DRY}$ is up to 25.46%, which reveals the underestimation due to steady state dry condition. The difference between $\Lambda_{AM}$ and $\Lambda_{WUFI}$ is 0.03% for base wall, but it reaches 17.08% for retrofit *B.1*. Besides the approximation of air cavity in WUFI which considers only diffusive but not convective moisture transport, the reason is due to simplification of contact between layers and sensors in the model with respect to reality.

Table 1. Steady state and transient thermal properties of the retrofitted wall partitions.

| | $\Lambda_{ST,\,DRY}$ | $\Lambda_{AM}$ | $\Lambda_{WUFI}$ | $U_{ST,\,DRY}$ | $U_{AM}$ | $U_{WUFI}$ | $\Lambda_{AM}$ – | $\Lambda_{AM}$ – |
|---|---|---|---|---|---|---|---|---|
| | ($W\,m^{-2}K^{-1}$) | ($W\,m^{-2}K^{-1}$) | ($W\,m^{-2}K^{-1}$) | ($W\,m^{-2}K^{-1}$) | ($W\,m^{-2}K^{-1}$) | ($W\,m^{-2}K^{-1}$) | $\Lambda_{ST,\,DRY}$ | $\Lambda_{WUFI}$ |
| Base Wall | 1.069 | 1.249±.0.010 | 1.250±0.002 | 0.905 | 1.030±0.008 | 1.031±0.002 | 14.43% | 0.03% |
| Retrofit A.1 | 0.525 | 0.668±0.041 | 0.556±0.007 | 0.482 | 0.600±0.037 | 0.508±0.007 | 21.48% | 16.18% |
| Retrofit B.1 | 0.571 | 0.766±0.064 | 0.635±0.008 | 0.520 | 0.678±0.057 | 0.573±0.008 | 25.46% | 17.08% |
| Retrofit B.2 | 0.829 | 0.918±0.019 | 0.926±0.013 | 0.727 | 0.794±0.016 | 0.800±0.011 | 9.73% | -0.87% |

### 5.2. Comparison before and after retrofit

From data collected in Table.1 and from the graph below (Fig.3a and 3b) we can evaluate the thermal conductances of the wall partitions using the “Average Method”, before and after retrofit for a long time period. A decrease in $\Lambda$ -value of 46.98% for *A.1*, 38.33% for *B.1* and 26.23% for *B.2* is obtained in respect to the base wall. for a period of 63 days analysis (from 15th November to 17th January), the average asymptotical $\Lambda$ -value remains mainly within ±5% for each solution.

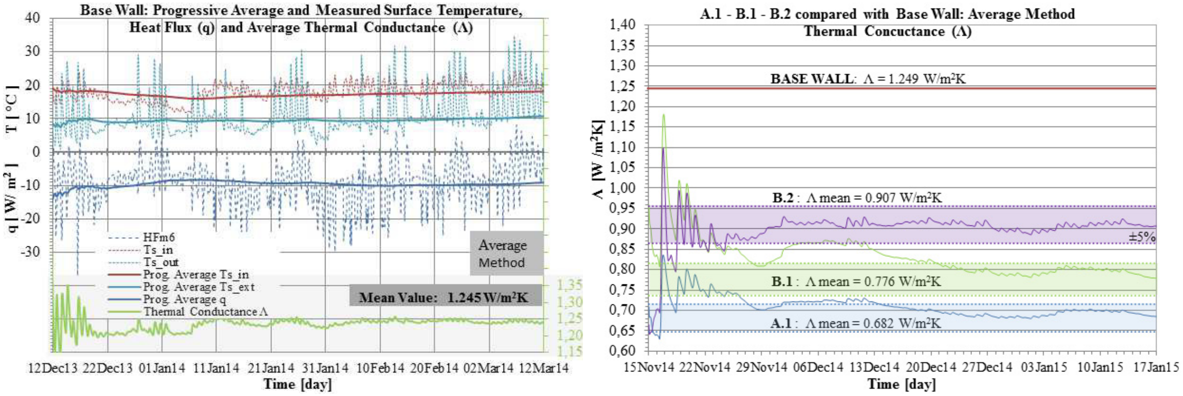


Fig. 3. (a) Measured and progressive averaged values of external and internal temperatures together with the heat flux for base wall; (b) comparison of the thermal conductance of the base wall with the three retrofit solutions calculated by the average method including error gap width.

### 5.3. Moisture induced increase of the U-value and WUFI results

The input boundary conditions are $T_{si}$, $RH_{si}$, $T_{se}$, and $RH_{se}$, data obtained from measurements. The WUFI results are $q$, $T_{s\_bet}$, $RH_{s\_bet}$, $T_{s\_gap}$, $RH_{s\_gap}$, to be compared with data measured by sensors (HFm and THS) at the same positions on the wall. The aim of the analysis is to validate the assumptions made for WUFI and discuss deviations. In Figure 4 density of heat flux, ($q$) and temperature at interface between wall and insulation layer ($T_{s\_bet}$) are shown for retrofit *B.1*. The courses of calculated values are similar to the measured ones. Higher temperature and lower heat flux are obtained by WUFI calculation which is probably due to the higher assumed content of moisture inside the layers of the demo wall than it is in reality. A careful sensitivity analysis may help to get calculated values closer to measured ones.

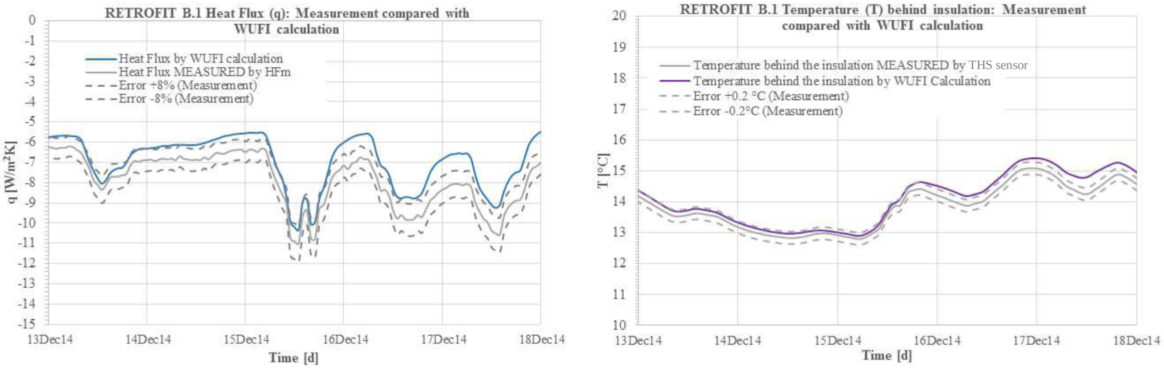


Fig. 4. Comparison of measured quantities and the corresponding calculated values obtained from WUFI: (a) Heat flux density $q$ (b) temperature between the wall and the insulation layer $T_{s\_bet}$.

## 6. Conclusions and outlook

By means of monitoring a demo wall, it was possible to have a large number of data, before and after retrofit. Thanks to early analysis, we were able to asses by average method the thermal conductance, obtaining how much measured data deviate from theoretical steady state and from calculated data obtained in transient condition with WUFI model. In a further step, the whole measured data will be analyzed by the dynamic method described in [6] including storage effects and compared to the ones presented here. A sensitivity analysis in WUFI will be carried out.

## Acknowledgements

The present investigation has got financial support from the EU under Grant Agreement n. EeB.NMP.2011-3-285540EU FP7. The technical support of R. Bischof (DECENTLAB) and R. Vonbank (Empa) is highly appreciated.

## References

[1] BakerB. U-values and traditional buildings. In situ measurements and their comparisons to calculated values. Historic Scotland, Technical paper 10, Glasgow Caledonian University, January 2011.
[2] Byrne A, Byrne G, Davies A, Robinson AJ. Transient and quasi-steady thermal behaviour of a building envelope due to retrofitted cavity wall and ceiling insulation. Energy and Buildings 2013;61:356-65.
[3] Ascione F, de Rossi F, Vanoli GP. Energy retrofit of historical buildings: theoretical and experimental investigations for the modelling of reliable performance scenarios. Energy and Buildings 2011;43:1925-36.
[4] EN ISO 6946:2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method.
[5] EN 1745:2012Masonry and masonry products - Methods for determining thermal properties; German version
[6] ISO 9869-1:2014 Thermal insulation - Building elements - In-situ measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter method.
[7] WUFI: Software for calculating the coupled heat and moisture transfer in building components, http://www.wufi.de/index_e.html