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High performance aerogel containing plaster for historic buildings with structured façades

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Abstract

This contribution reports on ongoing efforts exploring the potential of aerogel-based plasters on historical façades. As a case study, aerogel-based plaster was applied without reinforcement meshes to a small area in the historical main building of the Vienna University of Technology. The objective is to examine the long-term behavior of the plastered surfaces. For this, a monitoring infrastructure has been implemented, which enables the in-situ measurement of temperature, humidity, and heat flux within different layers of the construction using a wireless sensor system. These measurements are intended to offer a before-after comparison of the thermal behavior of the treated components.

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Keywords: Retrofit; Aerogel-based Plaster; Historical Building; Wireless Monitoring; In-situ Measurements

1. Introduction

The continuous efforts to reduce energy consumption in buildings and the insight that the retrofit of the existing building stock will have the highest impact on the success of this endeavor have propelled the development of aerogel based high performance insulation materials [1]. One of these is the recent combination of traditional plaster deployment techniques with the high-tech material SiO_2 aerogel [2]. Aerogel is a synthetic, highly porous ultralight material that is able to offer high thermal insulation levels [3]. As this aerogel containing plaster (F222) is

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seamlessly adaptable to structured façades, it can be considered as a promising option for improving the thermal behavior of historic buildings without changing their physical appearance, and thus their cultural significance within European cities. The present contribution reports on ongoing efforts exploring the potential of aerogel-based plasters on historical façades. As a case study, aerogel-based plaster was applied to a small area in the historical main building of the Vienna University of Technology. The aerogel plaster application serves in this case experimental purposes and was conducted without reinforcement meshes. The primary objective is to examine the long-term behavior of the plastered surfaces. Toward this end, a monitoring infrastructure was implemented, which enables the in-situ measurement of temperature, humidity levels, and heat flux within different layers of the construction by means of a wireless sensor system. These measurements are intended to offer a before-after comparison of the thermal behavior of the treated building components [4]. Additionally, a set of indoor sensors and a weather station continuously monitor outdoor conditions and those in the adjacent rooms. The results of the first complete in-situ monitoring campaign prior and post retrofit are presented and discussed.

Nomenclature

T	Temperature [°C]	indices:		
q	Heat Flux [W/m^2]		i	internal
U	Thermal Transmittance [W/m^{2}K]		e	external
Λ	Thermal Conductance [W/m^{2}K]		j	individual measurement
R	Thermal Resistance [m^{2}K/W]		AM	Average Method
λ	Thermal conductivity [W/mK]		1D	One dimensional steady state

2. Wall partitions and sensor installation

At the top story of the historical southern façade built in the 1950's, four wall partitions were designated for the application of the F222 plaster. These wall partitions were identical prior to retrofit consisting of a gypsum plaster of 15 mm applied on the internal side, a masonry wall of hollow bricks of 250 mm thickness and an external lime-cement rendering of 20 mm. To assess the thermal behavior of the existing wall prior to retrofit temperature, moisture and heat flux sensors were installed on both the internal (Fig. 1a) and external surfaces (Fig. 1b) of all four wall partitions in late 2013. Then a period of about 5 months of data acquisition followed during winter and spring 2014. Around mid-2014 the aerogel-containing F222 plaster was applied with different finishing for each of the four layers. Specifications to these external finish layers for each wall partition are summarized in Table 1. The most important feature of these layers is the vapor diffusion which influences the drying time of the applied plaster layers.

Table 1. The external finish applied on top of the F222 plaster on the four wall partitions

	External finish and its properties
Wall partition F1	Röfix 380 fine grained + Röfix PE 819 Sesco, lime wash, diffusion open, stores moisture
Wall partition F2	Röfix 750 coarse grained + Röfix PE 225 Reno, silicate paint, diffusion open
Wall partition F3	Röfix 380 fine grained + Röfix PE 819 Sesco, lime wash, diffusion open, stores moisture
Wall partition F4	Röfix 380 fine grained + Röfix PE 419 Etics, silicon resin paint, diffusion open, water repellant

Fig. 1. Position of the temperature and humidity sensors (a) internal surface; (b) external surface prior to retrofit; (c) on the F222 plaster beneath the finish (not visible) after retrofit

Before applying the final finish (without a reinforcement mesh) an additional series of temperature and moisture sensors were fixed on the applied F222 plaster and then covered by the final finish of around 1.0 mm thickness (Fig 1c). The data acquisition of the retrofitted wall partitions continues to this day and will do so for a period of an additional year to get a reasonable hygro-thermal quasi steady state of the whole façade.

3. Analysis of the in-situ measurements

In a preliminary analysis of the available data, the measured temperature on the internal and external surface as well as the heat flux on the external side of the original wall were used to determine the evolution of the conductance of the respective wall partitions before and after the retrofit. For this purpose the average method according to the ISO standard 9869 [5] was used which assumes that the conductance Λ can be obtained by dividing the mean density of heat flux by the mean temperature difference according to:

$$\Lambda = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_{si,j} - T_{se,j})} \tag{1}$$

The results of this calculation are presented for prior to retrofit in Figure 2a and for post retrofit in Figure 2b. The values for the conductances of the four wall partitions (F1-F4) prior to retrofit meet the theoretical expectation of being identical within the limits of measurement accuracy. The slight differences may result from the non-homogeneity of the old wall construction itself and the possible different exposition to the heating devices inside the building. Between January and March 2014 there is a slight increase followed by a decrease in all four observed conductances which is due to uptake and release of moisture during the cold period of the year causing an increase and a following decrease of the heat transfer through the wall partitions.

For the evaluation of the post retrofit situation the calculations were started from September 2014 onwards, avoiding the drying period of the applied plaster resulting in high conductances due to the high water content and representing only a transition period to a quasi-steady state expected after the drying out. Here the behavior of the four wall partitions differs remarkably. This shows a different drying of the wet layers induced by the different properties of the respective finishing layers already mentioned in Table 1. Nevertheless, there is a clear convergence of the conductances which indicates that an additional period of measurement is still needed to reach the quasi-steady state in all wall partitions.

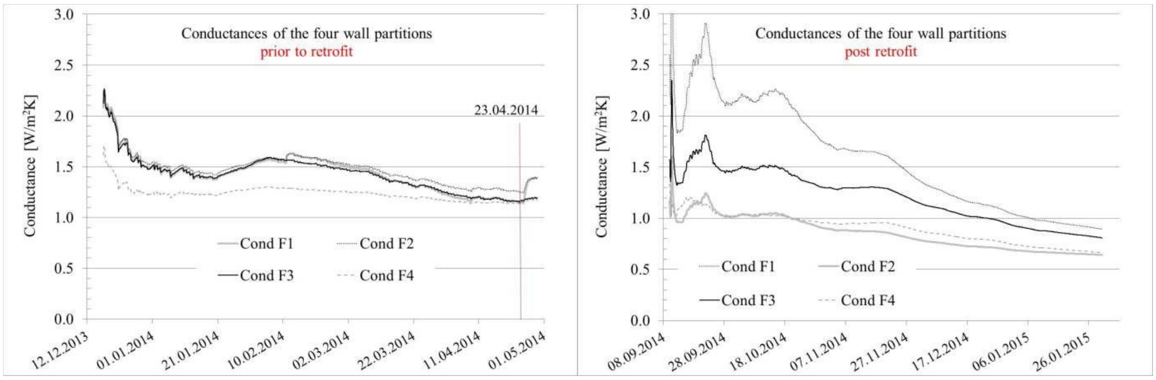

Fig. 2. Conductance of the four wall partitions by the average method (a) prior to retrofit; (b) post retrofit.

In order to get a better insight into the hygric behavior of the retrofitted wall partitions the measured relative humidity on both sides of the critical layer of the F222 plaster has been depicted in Figure 3. For all partitions a clear drying out at the internal side of the respective F222 layers is visible which indicates that this process is still ongoing. For partition F4 this is slower but at the same time the humidity on the external side for this case is lower than in all other 3 which is a result of the water repelling final finish containing a layer of silicon resin paint. A similar but smaller effect is also detectable for partition F2 probably caused by the silicate paint applied (Table 1).

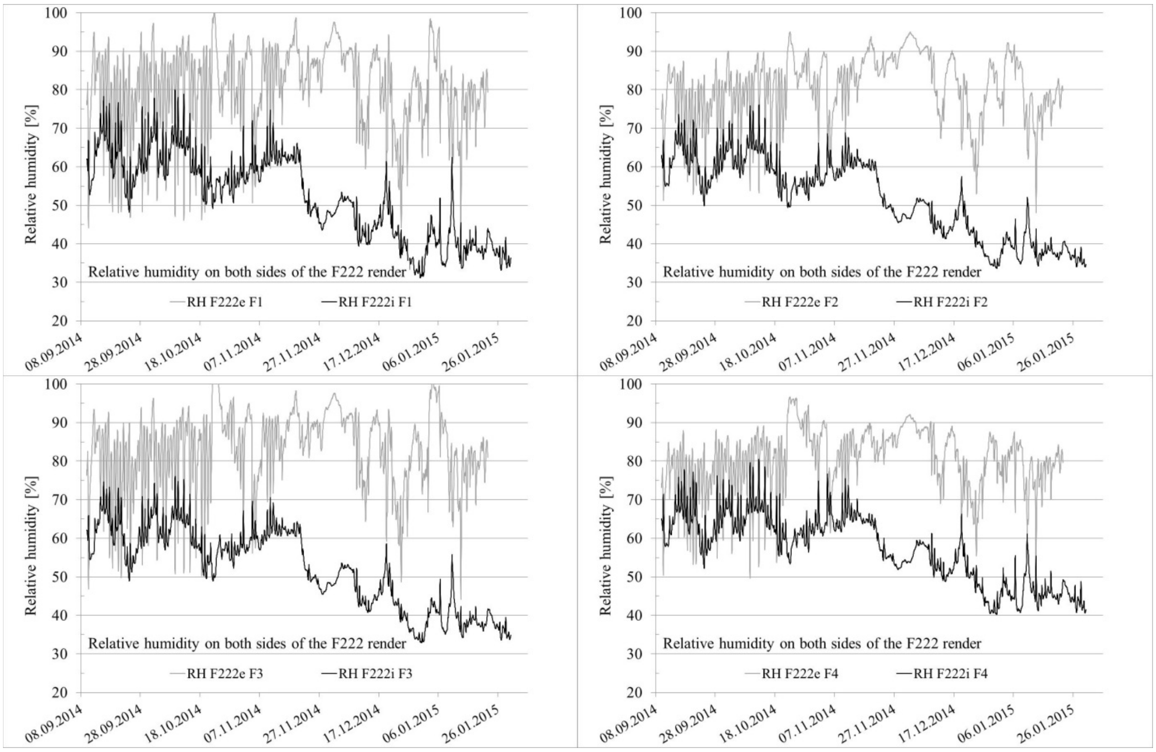

Fig. 3. Measured relative humidity on both sides of the applied F222 plaster for all four wall partitions F1-F4.

A summary of the calculated thermal transmittance U_{AM} based on the conductances determined by the average method and by assuming a standard sum of internal and external surface resistances of:

$$R_{total} = R_{si} + R_{se} = 0.125 + 0.040 = 0.165 \ [m^2K/W] \quad (2)$$

is shown in Table 2 and compared to a one dimensional steady state calculation of U_{1D} (ignoring moisture impact) for each wall partition prior and post retrofit. The assumed material properties and thicknesses for the calculation are summarized in Table 3. It has to be stated that the calculated values for the original layers of the wall are very approximate and are not based on measurements. The value for the F222 layer is the one corresponding to 20°C at 50% rel. Humidity which is a rather dry value.

Table 2. Calculated U-values based on the average method applied to the measured data prior and post retrofit. A theoretical 1D steady state value is given for comparison.

Prior to retrofit	U_{AM} [W/m²K]	U_{1D} [W/m²K]
Wall partition F1	0.97	1.12
Wall partition F2	1.04	1.12
Wall partition F3	0.98	1.12
Wall partition F4	0.97	1.12
Post retrofit		
Wall partition F1	0.78	0.44
Wall partition F2	0.58	0.44
Wall partition F3	0.71	0.44
Wall partition F4	0.60	0.44

The agreement for the situation prior to retrofit is quite satisfactory keeping in mind that the theoretical steady state value is based on assumptions and does not include moisture effect whereas the in-situ measured value corresponds to the reality on site. For the post retrofit situation the deviations are still large as the drying process has not been finished yet. The tendency of the evaluated conductances (Fig. 2b) shows this behavior hence, an additional measuring period is still needed.

Table 3. Properties of different materials used for the calculation of the 1D steady state value U_{1D} in Table 2 .

Material	*Thickness* [mm]	λ [W/mK]
Original internal plaster	15	0.20
Original hollow-brick wall	250	0.40
Original external plaster	20	0.80
Aerogel-containing F222 plaster	40	0.029

4. Improvement of the internal comfort

Another aspect of the retrofit procedure is to achieve an improvement in the internal comfort conditions. One such indicator is the difference between the internal air temperature and the temperature at the internal surface of the wall. This temperature difference enhances both radiative and conductive heat transfer between the air and the wall.

The measured internal air temperature and the inner surface temperatures are depicted for prior to retrofit (Fig 4a) and post retrofit Fig 4b). A clear difference of about 4°C prior to retrofit reduces to mainly less than 1°C for 3 out of 4 wall partitions. The partition F4 has a higher relative humidity on the inner surface causing a larger difference to the internal air temperature of about 2°C. A planned future investigation of the combined heat and moisture transfer analysis will hopefully explain this behavior.

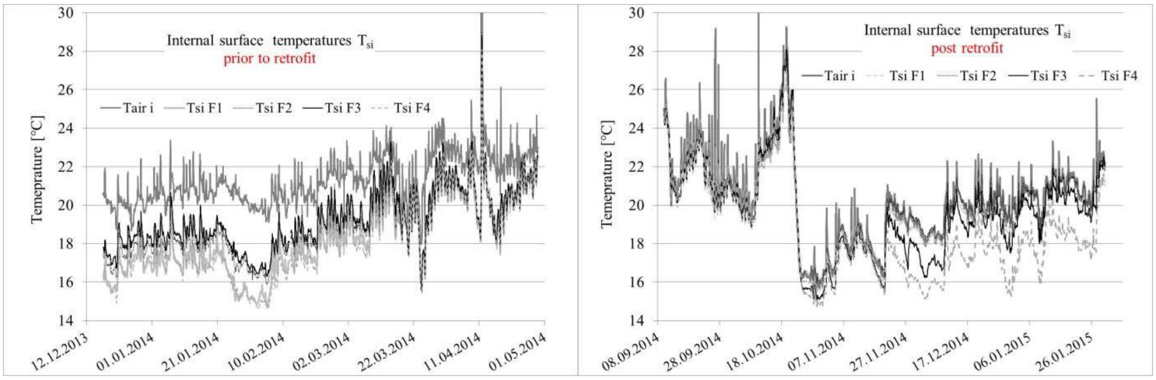

Fig. 4. Measured internal surface temperature T_{si} for all four wall partitions (a) prior to retrofit; (b) post retrofit

5. Summary and outlook

A preliminary analysis of an elaborate in-situ measurement of a hollow-brick wall prior to and post retrofit has been given based on the average method. It was found that the retrofitted wall partitions with their different final finish layers have not reached a quasi-steady state condition yet which shows the need for an additional period of data acquisition for at least 1 year. Furthermore, a combined analysis of combined transient heat and moisture transfer as well as a dynamic evaluation method [5] would bring more insight into the investigated matter.

It is also noteworthy to mention that no cracking was observed on any of the four retrofitted wall partitions after a period of 6 months although no reinforcement mesh was used. This is also in the focus of the present investigation.

Acknowledgements

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