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EFFECT OF APPLIED INTERIOR THERMAL INSULATION SYSTEMS ON THE ENERGY PERFORMANCE OF A HISTORICAL/CONTEMPORARY MASONRY

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The paper is aimed at the investigation of the effect of applied internal thermal insulation system on the energy performance of historical and contemporary masonry. For that reason, sandstone masonry and ceramic brick masonry were selected as representative examples and their energy performance was analyzed using hygrothermal simulations in two states. First, each wall was simulated without being thermally insulated to obtain reference values of energy performance. Then, the walls were thermally insulated – sandstone masonry with mineral wool and ceramic brick masonry with wood fiber insulation – and new performance after wall retrofitting was quantified. All simulations are performed for two different locations to analyze the effect of boundary conditions as well. The paper demonstrates how the computational simulation using advanced moisture-dependent material parameters can be utilized for accurate assessment of thermal and energy performance of building envelopes under dynamic conditions, which is often omitted by national standards or black-box simulation tools. The results clearly indicate that application of thermal insulation on the interior side can significantly contribute to the reduction of annual heat losses varying from 66.7% to 87.2% depending on the material of thermal insulation and the location of the building.

Keywords: Heat losses, Refurbishment, Wall retrofitting, Historical buildings.

1 INTRODUCTION

The Energy Performance Building Directive (Directive 2010/31/EU 2010) is targeting for improving of the energy efficiency of both new and existing buildings in Europe (EPBD 2010). However, the implementation of energy improving measures has not been very efficient so far. Typically, the historical buildings are not often considered in most energy saving polices. The importance of including of historic buildings in the energy improving efforts is obvious as 26.4% of all existing buildings are dated before 1945 (Troi 2011). The limitations associated with energy retrofitting of historic and contemporary buildings come mostly from the need for specific preservation requirements. Those requirements aim to preserve the original façade, which excludes the application of exterior thermal insulation systems (Jerman *et al.* 2019). The internal insulation system is then the only possibility to improve thermal and energy performance of such buildings. Although applying internal insulation in buildings is known to generate increased hygrothermal risks leading to mold growth or decay (Janssens and Hens 2003, Künzel and Zirkelbach 2013), the energy improvement can be significant (Walker and Pavía 2015).

In this paper two different wall enclosures, representing historical and contemporary masonry, are investigated in order to analyze the impact of applied internal thermal insulation system on the energy performance. The historical wall assembly is represented by sandstone masonry, the contemporary wall is made of ceramic bricks. Both walls are exposed to two different climatic loads from the territory of the Czech Republic and the results are compared before and after wall retrofitting. The results show that application of thermal insulation layer on the walls has crucial impact on the energy performance of the building and also special attention should be paid to selection of proper material and to the location of the building as well.

2 STUDIED BUILDING ENCLOSURES

The assessment of energy retrofitting was done on two different wall assemblies representing both historical and contemporary masonry. Within the retrofitting, each masonry was provided with internal insulation systems suitable for the type of load-bearing construction. The sandstone masonry was provided with mineral wool, the ceramic brick masonry was provided with wood fiber boards.

Table 1. Basic parameters of the materials involved in studied wall assemblies.

	Ceramic brick	**Sandstone**	**Mineral wool**	**Wood fiber board**	**Plaster**
Bulk density (kg·m^{-3})	1831	2076	270	147	1244
Porosity (%)	27.9	16.1	93.6	90.1	49.8
Thermal conductivity (W·m^{-1}·K^{-1})	0.59 – 1.74	2.10 – 3.88	0.04 – 0.70	0.07 – 0.69	0.30 – 0.94
Specific heat capacity (J·kg^{-1}·K^{-1})	825 – 1254	674 – 947	810 – 3850	2088 – 3855	1054 – 1592
Water vapor diffusion resistance factor (–)	8.8 – 22.1	6.9 – 11.8	3.5 – 3.9	4.11 – 5.12	5.52 – 7.52
Apparent moisture diffusivity (m^2·s^{-1})	1.08×10^{-6}	3.63×10^{-6}	2.51×10^{-10}	5.53×10^{-6}	3.27×10^{-8}

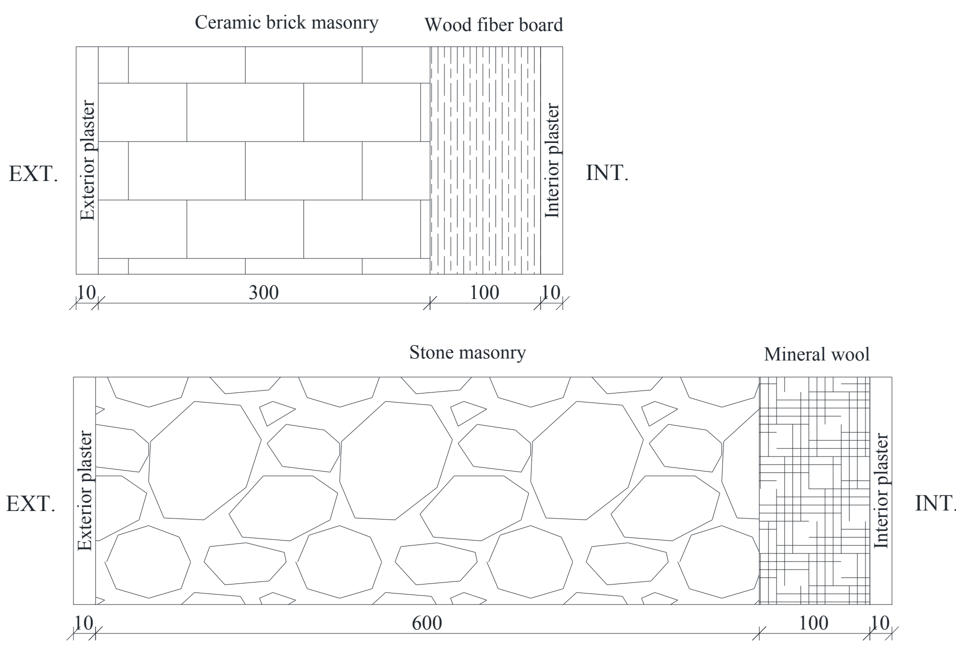

Figure 1. Scheme of the studied wall assemblies.

Interior systems need to meet quite specific requirements regarding their hygric performance. As reported by Vereckeen and Roels (2017) or Finken *et al.* (2016) the moisture the systems should by vapor tight to avoid or prevent moisture condensation. If such an attribute of the system is not possible to guarantee, it must be able to quickly redistribute liquid moisture to compensate this drawback. This can be mostly ensured by involving capillary active or hydrophilic insulation materials such as wood fiber boards or mineral wools in case they are designed properly. The scheme of the studied wall assemblies is shown in Figure 1. The material parameters are shown in Table 1. The material parameters of sandstone were adopted from Kočí *et al*. (2014), ceramic brick from Kočí *et al*. (2018a), mineral wool from Jiřičková and Černý (2006), wood fiber boards from Jerman *et al*. (2019) and plaster from Kočí *et al*. (2016).

3 COMPUTATIONAL MODELING

The investigation of the impact of the wall retrofitting on the energy performance of studied wall assemblies was done using the modified Künzel's mathematical model. The suitability of the model for application within the modelling of thermal insulation system was successfully verified using 2D critical laboratory experiment (Kočí *et al.* 2018b). The model describes heat and moisture transport through porous body governed by balance equations as seen in Eqs. (1) and (2)

$$\frac{dH}{dT}\frac{\partial T}{\partial t} = div\left(\lambda \mathrm{grad} T\right) + L_{\mathrm{v}} div\left(\delta_{\mathrm{p}} \mathrm{grad}\, p_{\mathrm{v}}\right) \tag{1}$$

$$\left[\rho_w \frac{dw}{dp_v} + \left(n - w\right)\frac{M}{RT}\right]\frac{\partial p_v}{\partial t} = div\left[D_g \,\mathrm{grad}\, p_v\right] \tag{2}$$

where H (J·m^{-3}) is the enthalpy density, T (K) is the absolute temperature, λ (W·m^{-1}·K^{-1}) is the thermal conductivity, L_{v} (J·kg^{-1}) is the latent heat of evaporation of water, δ_{p} (s) is the water vapor diffusion permeability, p_{v} (Pa) is the partial pressure of water vapor in the porous space, ρ_{w} (kg·m^{-3}) is the density of water, w (m^3·m^{-3}) is the moisture content by volume, n (-) is the porosity of the porous body, M (kg·mol^{-1}) is the molar mass of water vapor, R (J·K^{-1}·mol^{-1}) is the universal gas constant, and D_g (s) is the global moisture transport function. More information on the modified model was provided by Kočí *et al*. (2018b).

The assessment of thermal and energy performance of the investigated walls was based on the calculation of time variation of heat flux density $q(t)$ on the interior surface of the construction during a year. Eq. (3) express the calculation of heat flux density

$$q\left(t\right) = \lambda_{\mathrm{ip}}\left(w,t\right)\frac{\Delta T_{\mathrm{e}}\left(t\right)}{\Delta x_{\mathrm{e}}} \tag{3}$$

where $\lambda_{\mathrm{ip}}(w,t)$ (W·m^{-1}·K^{-1}) is the moisture-dependent thermal conductivity of the interior plaster, Δx_{e} (m) is the thickness of the element adjoining to the face side of the wall in the main direction of the heat flux, and ΔT_{e} (K) is the temperature difference between the opposite sides of the element adjoining to face side of the wall in the main direction of the heat flux.

During the entire simulation, the boundary conditions for interior were kept constant at 21 °C and 55% of relative humidity allowing direct comparison of the studied constructions and to provide data for the analysis of the effect of thermal insulation layer. The exterior conditions were represented by hourly weather data from the Test Reference Year for the location of Čáslav and Karlovy Vary, both in the Czech Republic.

4 RESULTS AND DISCUSSION

The objective of the paper was to analyze the effect of applied internal insulation layer to the studied historical and contemporary wall assembly. For that reason, the constructions were simulated first without thermal insulation layer on the interior surface in order to obtain reference performance. The simulations were carried for 6 years with the periodic year-long dynamic boundary conditions defined by TRY in order to avoid the results being affected by the initial conditions. Then, the performance was evaluated on the basis of quantification heat flux density on the interior surface over the last year of simulation. For that reason, temperature and relative humidity were monitored.

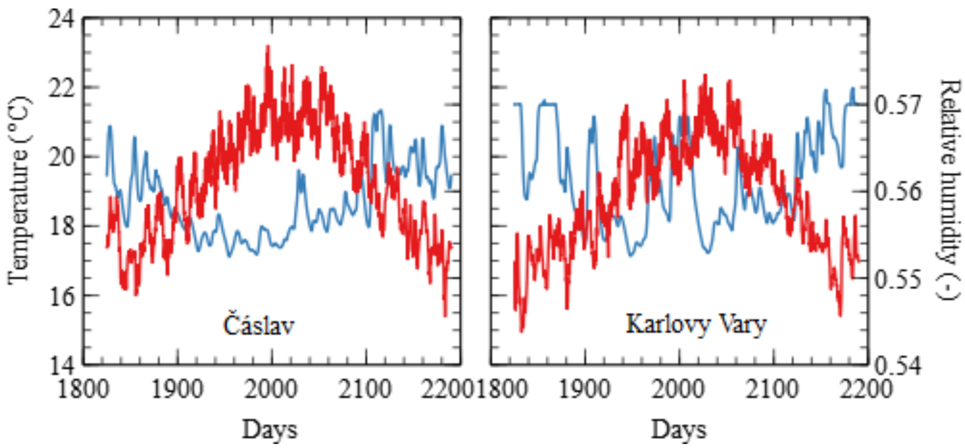

Figure 2. Temperature and relative humidity variations for uninsulated brick wall.

The hygrothermal performance of the insulated brick walls for both locations are shown in Figure 3.

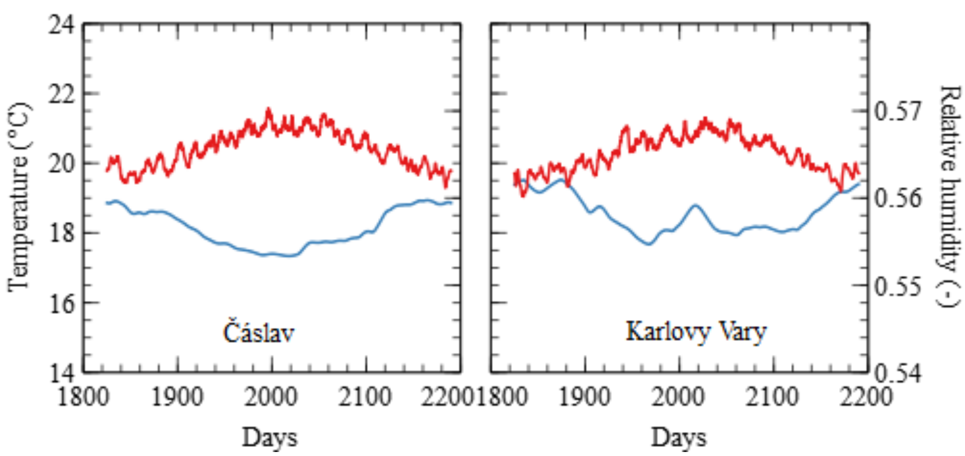

Figure 3. Temperature and relative humidity variations for insulated walls, location Čáslav.

Along with those quantities, the thermal conductivity as a function of moisture content was evaluated in order to obtain as accurate data for the quantification of the heat fluxes. Typical example of temperature and relative humidity variations during last year of the simulation of uninsulated brick wall under studied climatic load are shown in Figure 2. It is obvious how internal thermal insulation system help the construction to increase surface temperature and reduced the fluctuation of both temperature and relative humidity in the surface layer of interior plaster.

The distribution of temperature in the surface layers was used for quantification of heat fluxes on the interior surface of the walls. Along with the temperature data the thermal conductivity as a function of moisture content was used to calculate the energy balances. The results of the energy analysis are shown in Tables 2 and 3.

Table 2. Energy performance of studied building envelopes, location Čáslav.

	Heat transmission per unit area of the wall per year ($kWh \cdot m^{-2} \cdot a^{-1}$)		
	Loss	**Gain**	**Total**
Brick wall, uninsulated	121.156	6.167	127.323
Brick wall, insulated	40.370	1.173	42.143
Sandstone wall, uninsulated	211.456	10.116	221.573
Sandstone wall, insulated	27.002	1.151	28.153

Table 3. Energy performance of studied building envelopes, location Karlovy Vary.

	Heat transmission per unit area of the wall per year ($kWh \cdot m^{-2} \cdot a^{-1}$)		
	Loss	**Gain**	**Total**
Brick wall, uninsulated	146.654	2.203	148.857
Brick wall, insulated	48.926	0.510	49.436
Sandstone wall, uninsulated	257.300	3.394	260.694
Sandstone wall, insulated	32.719	0.319	33.038

The results in Tables 2 and 3 clearly indicate that application of thermal insulation on the interior surface of load-bearing structure has significant impact on energy savings. The brick masonry reduced the heat transmission by 66.7% in both Čáslav and Karlovy Vary. The heat losses through the sandstone masonry were reduced by 87.2%. Interesting fact is that the sandstone masonry after retrofitting exhibits better thermal and energy performance than insulated brick wall. This is obviously because of the thermal parameters of applied thermal insulation layer since mineral wool has almost twice as low thermal conductivity at wood fiber board. This can be easily proved by providing U-value of refurbished walls. The U-value of insulated brick masonry in dry conditions is approximately $U_{CB} = 0.46\ W \cdot m^{-2} \cdot K^{-1}$ while the U-value of insulated sandstone masonry in the same conditions is $U_S = 0.32\ W \cdot m^{-2} \cdot K^{-1}$. This clearly underlines the necessity of proper selection of the material for thermal insulation. Another interesting fact is that boundary condition, i.e. the location of the building has significant impact on thermal performance. Even if Čáslav and Karlovy Vary provide quite similar conditions with only slight difference in temperature and relative humidity distribution, the real performance shows the differences in annual energy performance up to 18% regarding heat losses. Therefore, the location of the building should be always considered when new building is design or some contemporary is being refurbished.

5 CONCLUSIONS

The hygrothermal simulations of historical and contemporary building walls were performed within this research in order to investigate the effect of applied internal thermal insulation on the energy performance of the construction. For that purpose, sandstone and ceramic brick masonries were modelled before and after retrofitting. The results showed that application of interior thermal insulation layer can reduce the annual heat losses by 66.7% to 87.2% depending on the material of thermal insulation and the location of the building. Although the results are promising several other studies should be done, especially regarding the assessment of hygrothermal risks that are associated with practically any application of internal thermal insulation system. For that reason, a two-dimensional simulation would be more appropriate.

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