Materials and Structures/Materiaux et Constructions, Vol. 31, Mars 1998, pp 99-103 Effect of interior and exterior insulation on the hygrothermal behaviour of exposed walls

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<u>A B S T R A C T</u>

Massive walls exposed to the natural climate without special rain protection show a dynamic moisture equilibrium governed by the alternating events of rain and sunshine. The moisture further reduces the rather low insulation level of the wall. Therefore, thermal insulation measures have to be taken in order to improve the hygienic conditions and the thermal performance of the building. The influence of interior and exterior insulations on the hygrothermal behaviour of such walls can be determined with the aid of a recently developed Computer program which has been experimentally validated by comparison with field tests. The results show that an exterior insulation leads to the drying of the wall, with the drying rate depending on the vapour permeability of the insulation system. An interior insulation, however, results in a rising water content of the wall due to the decreasing masonry temperature. This effect is almost independent of the vapour permeability of the insulating material. While an exterior insulation also improves the thermal resistance of the masonry, an interior insulation has the opposite effect and increases the frost damage risk. Therefore, the interior insulation of exposed walls should be combined with rain protection measures at the facade.

<u>RÉSUMÉ</u>

Des murs massifs exposés au climat naturel sans protection particulière démontrent un équilibre hygrique dynamique gouverné par l'alternance de pluie et d'insolation. L'humidité réduit la résistance thermique déjà peu élevée des murs. Des mesures d'isolation sont nécessaires pour améliorer les conditions hygiéniques et la qualité thermique du bâtiment. L'influence de l'isolation par l'extérieur et par l'intérieur sur le comportement hygrothermique de ces murs peut être déterminée au moyen d'un nouveau programme informatique validé par une comparaison expérimentale. Les résultats montrent qu'une isolation par l'extérieur facilite le séchage du mur, le taux de séchage dépendant de la perméabilité à la vapeur du système isolant. Cependant, l'isolation par l'intérieur mène à une teneur en eau plus élevée à cause de la réduction de la température de la maçonnerie. Cet effet est presque indépendent de la perméabilité à la vapeur du matériau isolant. Contrairement à l'isolation par l'extérieur, qui améliore la résistance thermique de la maçonnerie, l'isolation par l'intérieur a l'effet et accroît le risque de dégradation par le gel. Pour cette raison, on doit joindre à l'isolation par l'intérieur des murs exposés de mesures de protection contre la pluie sur la façade.

1. INTRODUCTION

Elevated moisture due to the impact of driving rain on exposed walls can lead to frost damage or accelerated decay of the facade. Additionally, in the case of monolithic exterior walls, which are often encountered in historical buildings, a high water content reduces the already low thermal resistance of the wall, thus leading to poor hygienic indoor conditions. Therefore, insulation measures have to be envisaged in order to bring such buildings up to modern standards. The best way of insulating a wall is to apply the insulation to the exterior of the facade. However, this may be too costly or undesirable because the original facade should remain unaltered for aesthetic reasons. In such cases, the only possible alternative is an interior insulation of the wall. Besides aggravating the thermal bridge problem, the decrease in temperature of the masonry caused by this type of insulation will reduce the drying of precipitation moisture. With the aid of experimentally-validated heat and moisture transport calculations, the effect of different insulation measures on the hygrothermal behaviour of monolithic brick walls will be studied in this paper. First, the uninsulated exposed wall is considered, and then the influence of an exterior insulation system and of interior insulation measures both with and without the combination of a facade impregnation is assessed.

2. FUNDAMENTALS AND VALIDATION OF THE CALCULATION MODEL

Disregarding the vapour and liquid convection caused by total pressure differences or gravitation, as well as enthalpy changes by liquid flow which only have a negligible effect on the heat balance, the main heat (resp. moisture) transport mechanisms in building components are heat conduction and heat transport by vapour diffusion with phase changes (evaporation, condensation) resp. vapour diffusion and liquid (capillary) transport. The driving potential for heat conduction is the temperature. For moisture transport, two potentials are necessary: the vapour pressure for diffusion and the relative humidity (derived from the capillary pressure) for liquid transport [1]. Since the vapour pressure is a function of temperature and relative humidity, the coupled transport equations can be written as follows [2]:

$$\frac{\mathrm{d}\mathbf{H}}{\mathrm{d}\vartheta} \cdot \frac{\partial\vartheta}{\partial t} = \nabla \cdot \left(\lambda \nabla \vartheta\right) + \mathbf{h}_{v} \nabla \cdot \left(\delta_{p} \nabla \left(\varphi \mathbf{p}_{\mathrm{sat}}\right)\right) \tag{1}$$

 $\frac{\mathrm{d}\mathbf{w}}{\mathrm{d}\boldsymbol{\varphi}} \cdot \frac{\partial \boldsymbol{\varphi}}{\partial t} = \nabla \cdot \left(\mathbf{D}_{\boldsymbol{\varphi}} \nabla_{\boldsymbol{\varphi}} + \delta_{\mathbf{p}} \nabla \left(\boldsymbol{\varphi} \mathbf{p}_{\mathsf{sat}} \right) \right)$ (2) where:

whole.	
dH/dT [J/m³K]	heat storage capacity of the moist building material
dw/dφ [kg/m³]	moisture storage capacity of the building material
λ [W/mK]	thermal conductivity of the moist building material
D _φ [kg/m³]	liquid conduction coefficient of the building material
δ _p [kg/msPa]	water vapour permeability of the building material
h _v [J/kg]	evaporation enthalpy of the water
p _{sat} [Pa]	water vapour saturation pressure
ϑ[℃]	temperature
φ[-]	relative humidity

On the left hand side of both equations are the storage terms. The fluxes on the right hand side are in both equations affected by heat and moisture. The conductive heat flux and the enthalpy flux by vapour diffusion with phase changes in equation (1) are strongly influenced by the moisture field resp. fluxes. The liquid flux in equation (2) is only slightly influenced by the temperature effect on the liquid viscosity and consequently on D_{ω} . The vapour flux however is simultaneously governed by the temperature and moisture fields due to the exponential changes of the saturation vapour pressure with temperature. Due to this close coupling and the strong nonlinearity of both transport equations, a stable and efficient numerical solver had to be designed for their solution; this is the basis of the computer program WUFI described in [2]. This computer program has been experimentally verified for many different building components [2]. For the investigation in this paper, an unrendered monolithic brick wall, which has been studied in [3] is chosen.

Table 1 - Hygrothermal parameters of brick masonry and the insulation materials. The insulating plaster consists of lime-cement mortar and expanded polystyrene particles which are premixed. After water has been added at the construction site, the plaster can be applied

manually or by machines

Material	Brick masonry	Expanded polystyrene	Mineral wool	Insulating plaster
Density [kg/m ³]	1900	15	60	310
Thermal conductivity [W/mK]	0.6	0.04	0.04	0.07
Moisture related increase of λ [%/M%]	15	-	_	1
Vapour diffusion resistance factor [-]	10	30	1.3	8
Sorption moisture at 80% R.H. [Vol%]	1.8	-	-	1.3
Capillary saturation [Vol%]	19	-	-	20



Fig. 1 - Liquid diffusivity of the brick masonry for water absorption during rain periods and the redistribution resp. drying process.

All hygrothermal material parameters, necessary for the calculation, are listed in Table 1 with the exception of the liquid diffusivities, which are plotted in Fig. 1. From the liquid diffusivities D_w the conduction coefficients D_ϕ can be derived by multiplying by the derivative of the moisture storage curve according to the following equation:

$$D_{\varphi} = D_{w} \cdot \frac{\mathrm{d}w}{\mathrm{d}\varphi} \tag{3}$$

The comparison between the measured and the calculated results of the considered brick wall with and without water-repellent impregnation is shown in Fig. 2.



Fig. 2 - Comparison of the calculated and the measured variation in water content of 24 cm thick brick masonry under natural conditions. The initial water content (marked with an arrow) was reached by artificial spray wetting of the facade elements.



Fig. 3 - Annual mean profiles (solid lines) and annual variation range (hatched areas) of the water content in a western-oriented brick wall assuming a driving rain load which amounts to 75 % resp. 50 % of the driving rain, measured in Holzkirchen in 1991.



Fig. 4 - Measured moisture profiles at periodic intervals (dotted lines) during one year in an exposed natural stone facade sample situated in the westernoriented wall of a test hall. The annual mean profile (solid line) is derived by averaging the individual profiles (snapshot recordings) in the figure.



Fig. 5 - Courses of the area-related water content of the brick wall after the application of exterior insulation systems with polystyrene slabs and synthetic resin rendering (μ d = 0.5 m) resp. with mineral wool slabs and mineral rendering (μ d = 0.2 m).



The good correspondence of calculation and experiment prove the suitability of the calculation model and material parameters for the assessment of the hygrothermal behaviour of massive walls.

3. NUMERICAL STUDY

An unrendered brick wall with interior plaster and a total thickness of 40 cm serves as an example for the following calculations. The material parameters are the same as mentioned above. As climate data, the hourly values of air temperature, humidity and solar radiation on a western-oriented facade and the driving rain recorded during an average year in Holzkirchen (near Munich) are used. Since the driving rain load in Holzkirchen is very high, unrendered monolithic wall structures are not used in this area. In regions where this kind of structure is used, the precipitation load is about half that of Holzkirchen. Therefore, in order to make the study meaningful, the rain load of Holzkirchen is divided by two. The interior temperature and relative humidity are approximated by sine waves with mean values of 22°C and 50% R.H. and amplitudes of 2 K and 10% R.H. respectively. The maximum values are reached in July. The surface transfer coefficients are taken from [2]. The shortwave absorptivity of the facade is 0.6, and the

Fig. 6 - Annual mean profiles (solid lines) and annual variations (hatched areas) of the water content in the masonry of a western-oriented wall without and with different types of interior insulation.

driving rain absorptivity (i.e. the amount of water clinging to the surface divided by the amount hitting the surface) is 0.7 which seems to be a good assumption according to [2]. The calculations are carried out over several years by repeatedly applying the same meteorological data until a dynamic equilibrium been has reached. which means that there are no further changes in the transient temperature and moisture profiles from one year to the next. The dynamic moisture equilibrium, assuming 75% resp. 50% of the driving rain load measured in Holzkirchen, can be represented as shown in Fig. 3 for the unin-

sulated wall by the annual mean distribution (solid line) and the annual variation range of the transient profiles (hatched area).



Fig. 7 - Drying behaviour of unrendered brick walls without and with different types of interior insulation after impregnation. The initial water content in the walls corresponds to the respective condition at the beginning of July without impregnation.

The moisture variations are highest at the facade's surface and rapidly diminish towards the interior until the point when more or less constant annual conditions can be found in the interior half of the wall. However, the highest average water content does not lie at the facade's surface but several centimetres beneath it. This somewhat unexpected result has also been found experimentally for natural stone facades by repeated NMR-moisture profile measurements [4], as can be seen in Fig. 4. This can only be explained by the strong non-linearity of the moisture transport equations caused mainly by the moisture dependence of the liquid diffusivities. The following calculations are based on a driving rain load of 50% of the recorded data from Holzkirchen.

3.1 Effect of exterior insulation systems

An exterior insulation system with non-hygroscopic insulation Materials forms a very effective rain protection for walls. The application of such a system will therefore dry out the wall. The courses of the drying process of the considered exposed brick wall after the installation of an exterior insulation in July are shown in Fig. 5 for different insulation materials and thicknesses. While the wall dries out within two years after applying an insulation system with mineral wool, it takes about twice as long with polystyrene (EPS). The insulation thickness, however, has hardly any influence. This may be due to the fact that a higher insulation thickness increases the mean masonry temperature, which seems to compensate the higher diffusion resistance of the additional insulation.

3.2 Effect of interior insulation

In contrast to an exterior insulation system which also serves as an effective rain protection for the wall, the application of insulation layers on the inside of a building does not affect the water absorption of the facade. By lowering the temperature level in the masonry, It reduces, however, the drying capacity of the wall which leads to higher average moisture levels in the wall, as can be seen in Fig. 6. The annual mean moisture profile and variations in the masonry with 60-mm thick insulating plaster, mineral wool and expanded polystyrene (EPS) are compared in this figure to the situation in the uninsulated wall. Almost independent of the insulation material, the interior insulation leads to a higher average water content in the masonry. In order to improve the moisture situation provoked by the interior insulation, a water-repellent impregnation may be applied to the facade. Assuming that this impregnation reduces the precipitation water absorption to zero while only slightly affecting the vapour diffusion resistance of the facade, the drying process of the wall can be calculated. Fig. 7 shows the courses in masonry moisture of the insulated walls after an effective impregnation in July, compared to the uninsulated wall. While the water content of the uninsulated wall drops within less than two years below the practical moisture content for brick walls

(1.5 Vol.-% according to DIN 4108), it takes more than five years for the insulated walls to dry out. Due to the higher vapour diffusion resistance, the EPS insulated wall dries somewhat more slowly than the wall insulated with mineral wool, but the effect is not significant because the main moisture flux is directed to the outside of the wall.

4. CONCLUSIONS

Modern calculation methods are a valuable tool to assess the hygrothermal behaviour of wall constructions. The results show that the best kind of insulation is an exterior insulation. Compared to the influence of the type of insulation material, the insulation's thickness does not affect the drying process to a large extent. A mineral wool insulation system leads to a faster drying of the masonry underneath than do insulation systems with polystyrene foam. There may be, however, one danger: a frost damage risk if a thermal insulation system with mineral wool is applied to a rather wet wall during a period when frost is imminent. Due to the almost unhindered vapour diffusion through the mineral wool, moisture can accumulate behind the surface rendering, especially if this rendering has an elevated vapour diffusion resistance [5]. This risk can be avoided by using polystyrene resp. other more vapour-tight insulation materials or by installing a cladding instead of a renderina.

In cases where an exterior insulation cannot be installed, a water-repellent impregnation or paint coat should be applied to the facade prior to the interior insulation; otherwise, there will be an increase in the risk of frost damage due to the influence of the insulation on the drying capacity of the masonry, along with a slight decrease in thermal resistance of the masonry. It is recommended to improve the rain protection of the facade some time before installing the interior insulation. If the vapour diffusion resistance of the exterior wall surface is negligible, any insulation material can be used inside, as long as convection of the room's air beneath the insulation layer can be safely avoided. A vapour barrier is basically not necessary.

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