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Influence of liquid absorption coefficient on hygrothermal behaviour of an existing brick wall with Lime–Hemp plaster

A. Evrard [a,*], C. Flory-Celini [a], M. Claeys-Bruno [b], A. De Herde [a]

[a] Architecture et Climat, Université catholique de Louvain, Louvain-la-Neuve, Belgium
[b] Aix Marseille Université, LISA EA4672, 13397 Marseille Cedex 20, France

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ABSTRACT

The study of the hygrothermal parameters and performance of permeable materials is being expanded; however, there is a lack of guidelines or regulation regarding the level of liquid water migrations associated with existing materials. Even if some existing recommendations demand the installation of materials that are increasingly permeable to vapour, the liquid water absorption coefficient is often neglected. This study analyses the influence of six material parameters, such as the liquid absorption coefficient and vapour diffusion resistance, on the hygrothermal behaviour of an existing brick wall insulated on the inside surface with a Lime–Hemp plaster. A specific methodology is developed combining hygrothermal simulations, sensitivity analysis and an experimental planning method. This reproducible methodology allows recommendations to be proposed to help designers choose an appropriate combination of material parameters. The paper demonstrates that the water liquid absorption coefficients of brick and of insulation have a greater influence than the vapour diffusion resistance of those materials in the studied cases. Water liquid absorption coefficient should thus be one of the parameters systematically considered in the hygrothermal analyses of wall components.

1. Introduction

Experimental aspects of composite or porous materials [1–8] have been frequently studied and a lot of recommendations on the vapour diffusion resistance factor, (written as μ [-]) of successive layers [9,10] were given. However, very few references are devoted to the study of the risks of condensation through the analysis of the liquid water absorption coefficient (written as A [kg/m^2 s$^{-1/2}$]), which can characterise the transfer of liquid water [11]. Wilson et al. [11], analysed the absorption of water in the case of two vertically superimposed layers. Their results showed that water absorption in the composite is controlled by the properties of second material (i.e. the lower layer in this case where the water is absorbed from upper layer). Moreover, the only case considered was where the first material had a high water sorption coefficient and the second had a very low one. Salonvaara et al. [12] proposed a stochastic building envelope model with which they analysed the influence of material properties on water content distribution through building components. They showed that the transport properties have a less pronounced effect on the moisture content than the storage parameters.

These parameters may not have a significant impact within the framework of classical modern building techniques, but related phenomena, and in particular the liquid transport and the sorption capacity under dynamic conditions, have a strong impact with so-called sustainable materials as Lime–Hemp, straw bale or daub. These materials can thus be of great interest when refurbishing existing buildings where urban constraints often lead to the use of interior insulation. Indeed, adding non-capillary insulation materials in association with vapour barriers can induce damage to the existing walls due to a reduction of their drying potential. For wall components made of multiple layers, it is generally admitted that the resistance to vapour diffusion of each layer should decrease from the interior towards the outside [9,10]. Is this recommendation still valid when considering liquid transfer or when using insulation material with a high absorption coefficient?

The wall type considered in this paper is an existing brick wall insulated on the interior surface with a Lime–Hemp (LH) plaster. Almost half of existing walls in Belgium were built before 1945 of

* Corresponding author. Architecture et Climat, UCL/SST/LOCI – Faculté d'architecture, d'ingénierie architecturale, d'urbanisme, Place du Levant, 1 bte 5.05.02 B-1348-Louvain-la-Neuve, Belgium. Tel.: +32 (0)10 47 21 60; fax: +32 (0)10 47 21 50.
E-mail address: arnaud.evrard@uclouvain.be (A. Evrard).

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Table 1
Methodology of optimisation to combine materials in a composite wall.

	Steps	Example
1	Identification of the influential hygrothermal parameters	Density, thermal conductivity, specific heat, porosity, vapour diffusion resistance, liquid water absorption coefficient, orientation, climatic conditions inside and outside
2	Choice of the values the parameters can take by a preliminary study	Perform a sensitivity analysis with several levels
3	Selection of the relevant outputs from simulation	Temperature, heat flow, heat loss, moisture flow, quantity of transferred vapour
4	Application of experimental planning method	Choice of a suitable software for experimental planning method
5	Choice of the optimal combination of parameters	

plain masonry with a thickness of around 35–40 cm. Lime–Hemp materials appeared 30 years ago in France. Since then, they are steadily developing throughout Europe. The hygrothermal properties of this material have been analysed in many publications [13–22]. The material has a high vapour permeability, a high liquid water transfer coefficient and a high capacity of moisture storage. These specificities are appreciated when insulating existing walls from inside, even if the thermal conductivity of this material is not very low (between 0.07 and 0.14 W/mK).

Simulation results such as temperature, heat loss, moisture flow, relative humidity and water content are calculated using the WUFI® Pro software. As a sensitivity analysis (SA)is too limited in this case because of the strong interactions between considered parameters, experimental planning method (EPM) was used. EPM is a statistical method that allows a more rigorous analysis. It is chosen in order to identify an appropriate combination of material parameters and to optimize the simulation results. The SA approach produced important results with which to start the EPM. This paper presents how the EPM was applied in this case of inside insulation of a brick wall with LH materials and defines a reproducible methodology to optimise the hygrothermal behaviour of multilayer walls.

Table 2
Main parameters of studied bricks.

Designation	Type of brick	ρ	P	c	λ	μ	A
Brick A	High absorption	1700	0.35	850	0.6	10	0.3
Brick B	Average absorption	1700	0.35	850	0.6	10	0.15
Brick C	Low absorption	1700	0.35	850	0.6	10	0.05

2. Methodology

The present study focuses on two materials: clay brick and LH plaster. The LH plaster is covered with a lime render on the inside surface. Three types of bricks are modelled according to their water sorption coefficients.

The SA approach is used to analyse the influence of the vapour diffusion resistance and the water sorption coefficient of the LH plaster on the hygrothermal behaviour of the component. A first step assumed that A varies independently of μ. The second step assumed that μ varies independently of A. This approach allows the identification of some tendencies and shows the complexity of the combined phenomena.

The EPM allows the statistical evaluation of the influence of different parameters on the simulation results. Based on a preliminary analysis and the SA approach, the relevant hygrothermal parameters, some realistic values they can take and the outputs from simulations that should be studied were defined. Table 1 presents the five steps of this reproducible methodology.

3. Models used in the study

3.1. Hygrothermal parameters and software

Simulations are performed using the WUFI® Pro software developed in the PhD thesis of H. Künzel [23]. WUFI® is hygrothermal software based on the dynamic modelling of heat and mass transfer. Three types of moisture transfer are distinguished: vapour diffusion, liquid transfer by absorption and liquid transfer by redistribution. Liquid transfer coefficients are calculated here based on the absorption coefficient following Künzel's exponential law [24].

The software allows the analysis of the distributions of heat and moisture in the walls (broad database of materials) under

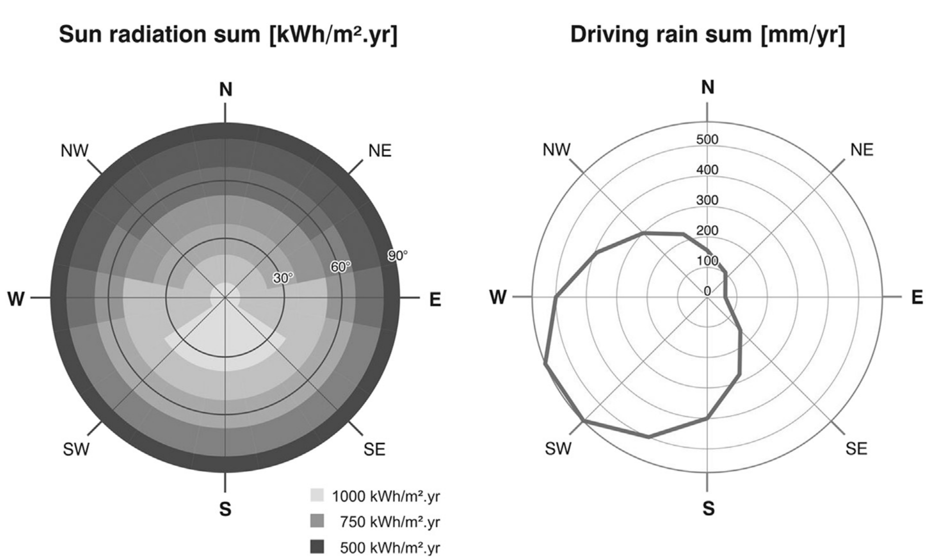

Fig. 1. Belgium climate reference analyses.