"Environmental Engineering" 10th International Conference
Vilnius Gediminas Technical University
Lithuania, 27–28 April 2017
http://enviro.vgtu.lt

eISSN 2029-7092 / eISBN 978-609-476-044-0

Article ID: enviro.2017.254
DOI: https://doi.org/10.3846/enviro.2017.254

Moisture Buffering Potential of Plasters for Energy Efficiency in Modern Buildings

Jan Fořt[1], Magdaléna Doleželová[2], Robert Černý[3]

Czech Technical University in Prague, Faculty of Civil Engineering,
Department of Materials Engineering and Chemistry
E-mails: [1]jan.fort.1@fsv.cvut.cz (corresponding author); [2]magdalena.dolezelova@fsv.cvut.cz;
[3]cernyr@fsv.cvut.cz

Abstract. Moisture level significantly affects durability of constructions, their thermal performance and quality of indoor air. Since building envelopes are subjected to a moisture gradient, additional ventilation systems are employed to maintain relative humidity on the desired level. Although modern advanced ventilation systems provide sufficient air exchange rate, their wider application is in conflict with sustainability development principles due to high energy demands. Moreover, according to the European legislation related to the Nearly Zero Energy Buildings (European Directives 2002/91/EC and 2010/31/EU), air tightness of building envelopes in order to provide high thermal resistance leads to large moisture loads in building interiors. Among other factors, a high level of relative humidity has negative effect on the work efficiency and health of building inhabitants. A detailed insight into building materials behavior during cyclic moisture loading was accessed within this study. The moisture buffering values of three interior plasters were investigated in order to describe influence of plasters on moderation of indoor environment. Particular materials were loaded according to the NORDTEST protocol by 8/16 h loading schema at 70/30% RH. Here, the excellent moisture buffer classification was obtained for lightweight perlite plaster (PT) with the highest total open porosity. However, contrary to the higher total open porosity of renovation plaster (PS), the core plaster (CP) achieved higher moisture buffer capacity than PS. This discrepancy refers to the influence of the pore size distribution which is, besides the total open porosity, essential for a detailed characterization of moisture buffering potential of building materials. Based on the results of Mercury intrusion porosimetry, a correlation between pore size distribution and moisture buffer value was revealed.

Keywords: moisture buffering, plaster, sorption isotherm, pore size distribution.

Conference topic: Energy for buildings.

Introduction

Nowadays, the energy efficiency and moderation of buildings indoor environment became important topic in the field of building physics. High energy demands assigned to the building sector connected with substantial portion of exhausted greenhouse gases point to the importance of energy savings in this area. The discussion during several last decades was focused mainly on thermal stability of buildings closely related to the energy consumption. Associated thermal regulations and further increase of thermal resistance of building materials result in large moisture loads due to the air tightness of applied building envelopes. A negative influence of the low or high level of relative humidity is most obvious in modern passive houses with limited air exchange with outdoor environment (Osanyintola, Simonson 2006). According to various measurements, the relative humidity level can drop even below 30%, especially during winter period (Korjenic *et al.* 2010). Consequences of the undesirable level of relative humidity on building occupants consist in irritation of eyes, dryness of skin and throat, reduced work efficiency and respiratory problems. Moreover, the higher risk of condensation is related to material defacement and proliferation of microorganisms (Toftum *et al.* 1998). Nevertheless, the additional equipment used for the moderation consists mostly in mechanical ventilation devices, so utilization of employed devices in order to handle water vapor peaks is connected with considerable costs and energy demands. A proper and detailed understanding of the relation between ambient climate and applied building materials is crucial for energy sustainability in building sector and also for the comfort of building inhabitants (Ge *et al.* 2014).

The summary of ventilation strategies proposed in (Koffi *et al.* 2011) recapitulates mostly applied ventilation systems including extract-only mechanical ventilation, balanced mechanical ventilation, relative-humidity sensitive ventilation and natural ventilation. The air permeability of building envelope has a crucial impact on the efficiency of air exchange rate. Here, utilization of elements with high moisture buffer capacity was found as beneficial for reduction and moderation of internal moisture loads and therefore operational costs. Since the importance of moderation of indoor relative humidity was recognized, the research aiming at the increase of moisture buffering of conventionally used building materials became relevant (Vieira *et al.* 2014). The impact of external weather conditions was revealed in relation to the number of commonly used materials and objects placed inside of buildings. Indoor humidity control materials were firstly studied in Japan for cultural heritage protection and subsequently expanded to the chemical, textile and building industry. Lately, according to the performed studies based on measurements (Cerolini *et al.* 2010) or simulations (Steeman *et al.* 2009) several authors refer to the beneficial properties of buildings materials such as bricks, aerated autoclaved concrete, wood, and plasters for moderation of interior humidity.

The Nordtest method represents one of the most used testing procedure for evaluation of material ability for adjusting the internal moisture variations. Unfortunately, simplified buffer models applied by many authors (Silva *et al.* 2010) for comparison of building materials unfortunately do not reflect the real moisture loadings with nonlinear sorption isotherms. The ultimate moisture buffer testing (Wu *et al.* 2015) proposed for more complex testing of building materials in order to reflect moisture proofing and desorption capacity of tested materials in realistic application situations. Here, a detailed relationship between adsorption ability and interior performance of materials can be accessed.

In order to moderate interior climate, three types of interior plasters with different characteristics were studied to access their hygric properties related to moisture buffering.

Experimental

Studied materials

Four different types of plasters, which are widely used in the Czech Republic were studied, namely a plaster with pozzolanic admixture (PP), lightweigted lime-cement plaster with perlite (PT) and a restoration lime-cement plaster (PS). The samples were prepared according to the instructions of the plasters producer (Baumit). All studied plasters contained silica aggregate with dimension to 2 mm. Characterization of studied plasters is given in Table 1.

Table 1. Characterization of studied plasters

Material	Characteristic	w/ds
CP	Baumit GrobPutz Maschinell – core plaster	0.17
LP	Baumit Thermo Putz – lightweight plaster with perlite	0.4
RP	Baumit Sanova – renovation plaster	0.34

Basic material properties

Basic physical properties of studied plasters were characterized by measurements of the bulk density, matrix density, and total open porosity. Performed measurement of the bulk density was done on five cubic samples of 50 mm side and determined from the measurement of sample sizes (using digital caliper) and its dry mass. The matrix density was accessed by helium pycnometry using apparatus Pycnomatic ATC (Thermo Scientific). The accuracy of the gas volume measurement using this device is ±0.01% from the measured value, whereas the accuracy of used analytical balances is ±0.0001 g. The measurement of bulk density uncertainty was 5.3% and 3% for matrix density.

Pore size distribution

The pore structure characterization of studied materials was performed by Mercury Intrusion Porosimetry Analysis (MIP). For the pore size distribution measurement, mercury porosimeters Pascal 140 and Pascal 440 (Thermo Scientific) were used. Mercury provides in liquid state a high contact angle with the solid surface of commonly tested silicate porous materials. Tested samples were firstly dried at 105 °C to constant mass and thereafter placed into a glass container which was filled with pure mercury. During the measurement, pressure was gradually increased from 100 kPa up to 400 MPa to force mercury penetration into the pore structure of studied materials.

Water vapor storage properties

For measurement of sorption and desorption isotherms, dynamic vapor sorption device DVS-Advantage was used, whereas the measurements were done at 21 °C. Before the measurement, the sample of studied material was dried at first and maintained in desiccator during cooling. Then, the sample was put into the climatic chamber of the DVS-Advantage instrument and hung on the automatic balances in the special steel tube. The instrument measures the uptake and loss of vapor gravimetrically, using highly precise balances having the resolution of 1.0 μg. Such a high resolution is obtained by hanging samples on the end of a beam where the position of the beam is measured by an optical sensor. The particular samples were exposed to the following partial water vapor pressure profile: 0; 20; 40; 60; 80; 90; and 98% of relative humidity (RH). Each step in RH during the DVS measurement is incremented either when a stable mass is achieved with mass change less than 0.00004% /min or a maximum time interval of 400 min is reached. Because reaching of sample mass equilibrium at high RH was problematic, the maximum time interval of samples exposure to RH of 80% was 4000 min, and for RH of 98% it was extended up to 7000 min. The sample mass was 5–10 g (Pavlík *et al.* 2012).

Moisture buffer value

The heat-mass transfer analogy was employed for the theoretical description of moisture buffer capacity on the material level. Well known from heat transport theory is the thermal effusivity which expresses the rate of heat transfer over the surface of a material when the surface temperature changes. The description of the material ability to absorb or release moisture can be done by introducing the moisture effusivity b_m [kg/m²Pas^{½}] in a similar way to the definition of thermal effusivity

$$b_m = \sqrt{\frac{\delta_p \cdot \rho_0 \cdot \dfrac{\partial u}{\partial \phi}}{p_s}} \; . \tag{1}$$

In Eq. (1), δ_p [kg/msPa] is the water vapor permeability, ρ_0 [kg/m³] the dry density of material, u [kg/kg] the moisture content, φ [-] the relative humidity, and p_s [Pa] the saturation vapor pressure at the temperature of the experiment.

The experiment for determination of the moisture buffer values is based on the step-response method. This method records the mass variation during RH cycles of a specimen with a known exposed surface area. The particular specimens were vapor proof insulated on lateral sides in order to get accurate information on exposed surface area. A DVS (Dynamic Vapor Sorption) device was used to set cycles of 8 hours at high RH (70%) and 16 hours at low RH (30%). The sample mass variation during adsorption and desorption phases was continuously monitored during 4 cycles in order to reach dynamic equilibrium where the final mass at the end of the cycle and initial mass vary by less than 5%. The practical Moisture Buffering Value ($MBV_{practical}$) was calculated using the maximum moisture uptake (g/m^2) after 8 hours of adsorption phase divided by the RH interval, which, in this case was 40%. We adopted similar procedure as in (McGregor *et al.* 2014), where moisture buffering capacity of unfired clay masonry was studied.

From the point of view of the theory of moisture transport, was used the definition of Ideal Moisture Buffer Value MBV_{ideal} (Rode, Grau 2008). The formulated equation predicts the surface moisture flux vs. time $g(t)$ for sample exposure to relative humidity cycles as given above. The accumulated moisture uptake $G(t)$ [kg/m^2], respectively moisture release that both happen within the time period $t_{p,}$ is found by integrating the moisture flux over the surface $g(t)$ as in Eq. (2)

$$G(t) = \int_0^t g(t)dt = b_m \cdot \Delta p \cdot h(\alpha)\sqrt{\frac{t_p}{\pi}} \; , \tag{2}$$

where

$$h(\alpha) = \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{\sin^2(n\pi\alpha)}{n^{3/2}} \approx 2.252\left[\alpha(1-\alpha)\right]^{0.535} \tag{3}$$

α [-] is the fraction of the time period where the humidity level is high. For the 8/16 hours' scheme, $\alpha = 1/3$, which makes $h(\alpha) = 1.007$, and the accumulated moisture uptake can be expressed in a simpler form

$$G(t) \approx 0.568 \cdot b_m \cdot \Delta p \cdot \sqrt{t_p} \; . \tag{4}$$

MBV [g/m^2 %RH] is expressed based on the moisture exchange from Eq. (4) normalized with the change in surface relative humidity, ΔRH. *MBV* is proportional to the moisture effusivity b_m times the square root of the time period, t_p½ [s^{½}]. Thus the defined theoretical, or ideal, value of MBV_{ideal} is given by Eq. (5)

$$MBV_{ideal} \approx \frac{G(t)}{\Delta RH} \approx 0.00568 \cdot p_s \cdot b_m \cdot \sqrt{t_p} \; . \tag{5}$$

On the basis of above given experimental and computational procedure, moisture effusivity can be determined from the steady state experiments. On the other hand, the *MBV* represents a dynamic characteristic. Additionally, the ideal conditions of experiment rarely exist, and thus Eq. (5) is only an approximation. Therefore, we calculated $MBV_{practical}$ [g/m^2 %RH] exactly from the DVS experiment as presented by Rode (Rode, Grau 2008). The measurement uncertainty of $MBV_{practical}$ was 5.9% a MBV_{ideal} 3.1%.

Results and Discussion

The results obtained from the measurement of the bulk density, matrix density and total porosity of studied plasters are given in Table 2.

Table 2. Basic physical properties of studied plasters

Material	Bulk density, kg/m^3	Matrix density, kg/m^3	Total open porosity, %
PP	1555	2833	45.1
PT	592	2743	75.8
PS	1262	2666	46.6

Looking at the data, the bulk density of the PT is distinctly lower compared to PP and PS, due to the incorporated lightweight aggregate in plaster dry mix. The matrix density of all studied plasters exhibited similar values which influenced the total open porosity of examined materials. The highest total open porosity results were obtained for PT, namely about 75%, while PP and PS had total open porosity in the range of 45–47%. Information about the total open porosity are often used as one of the most important factors influencing moisture buffering efficiency of porous building materials whereas materials with higher porosity are widely considered as more prospective materials from this point of view (Polat *et al.* 2010). Table 3 shows the parameters obtained by MIP, where besides the information on the total open porosity, also the cumulative pore volume and average pore size of the plasters are given. The total open porosity values calculated on the basis of knowledge of the bulk density and matrix density are very similar to the results delivered by MIP analysis.

Table 3. Pore space description

Material	Total open porosity, %	Cumulative pore volume, cm^3/g	Average pore size, μm
PP	42.3	0.29	0.79
PT	71.1	1.325	7.31
PS	44.5	0.349	5.73

Incremental pore size distribution curves are given in Figure 1, where MIP curves clearly point to the differences in the porous structure of studied plasters. The MIP curve of PP shows smaller pores than PS although their total open porosity is similar. This is reflected also in the difference in average pore diameter (Table 3). The relationship between pore size distribution and the water vapor transmission properties was described, e.g., in (Collet, Pretot 2012); they concluded that cumulative pore volume plays an important role for moisture absorption.

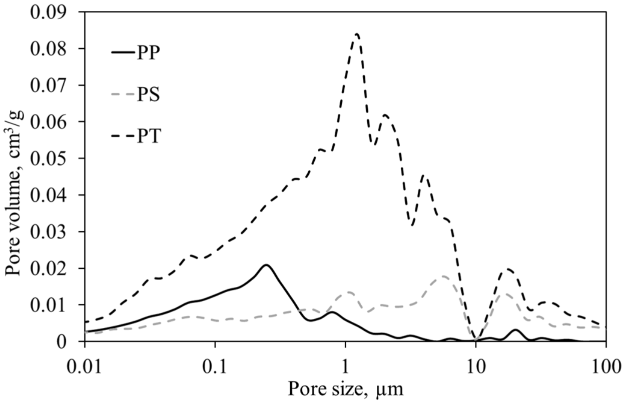

Fig. 1. MIP curves of studied plasters

The obtained differences of sorption and desorption isotherms of studied plasters given in Figure 2 are related to the changes in pore systems. The moisture storage capacity of PT was significantly higher than PP and PS, in line with the results of mercury porosimetry. Therefore, the overall higher moisture storage capability of PT can be assigned to the increase in total open porosity, as well as to the changes in pore distribution. The obtained results refer to the better capability of PT to moderate indoor relative humidity variations, where the higher volume of the porous space allows better adsorption of water molecules. On the other hand, sorption isotherms of PP exhibited slightly higher ability to adsorb water vapor compared to PS, despite the lower total open porosity. To be specific, maximum hygroscopic equilibrium moisture content (EMC) was increased by about 9% (PP) and 350% (PT), respectively, in comparison with EMC value of PS. These findings can be assigned not only to the differences in the total open porosity, but also to the higher specific surface of the porous space of subjected materials. A similar relationship between the total open porosity and EMC was described in detail in (Abadie, Mendoca 2009) where the dependence of moisture buffering on EMC was revealed in order to access the moisture performance of building materials.

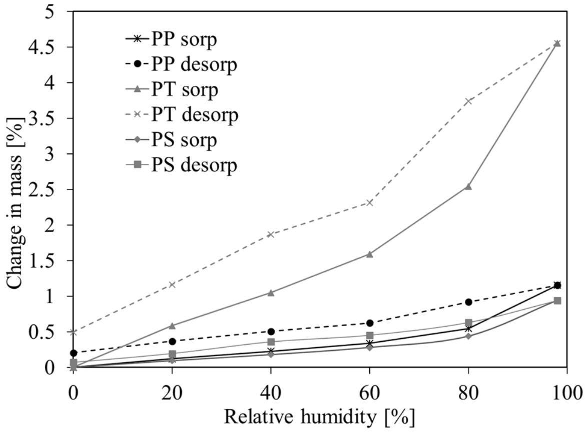

Fig. 2. Sorption and desorption isotherms of studied plasters

The record of the dynamic moisture buffer experiment is showed in Figure 3. $MBV_{practical}$ was calculated on the basis of the performed moisture buffer experiment (Rode, Grau 2008). Looking at the results, the best ability to moderate indoor relative humidity fluctuations, namely of about 2.21 g/m^2 % RH can be assigned to PT plaster. Although obtained results for plasters PP and PS exhibited similar total open porosity, even for PS plaster slightly higher, better moisture buffer performance was revealed for PP. Attained results of $MBV_{practical}$ correspond with the observation obtained within the evaluation of sorption and desorption isotherms. According to the conclusion formulated in (Yang *et al.* 2012) and (Janssen, Roels 2009), these apparently contradictory findings can be explained by the differences in the pore size distribution, where smaller pore diameter of PP has higher surface area and therefore, better capability to bind molecules of water vapor. Compared to the MBV_{ideal} results (see Fig. 4), where the difference between PP and PS was not obvious, the attained results refer to the underestimation of dynamic experiments related to the hygric behavior of building materials. Considering the widely adopted moisture buffer classification (Rode, Grau 2008) for transparent classification of porous building materials, PS and PP plasters can be labeled as good moisture buffering materials, while PT belongs to the group of materials with excellent ability to moderate indoor humidity variations. Taking into account the findings presented in a study considering more realistic loading scheme (Wu *et al.* 2015), the applied classification disregards variations of temperature affecting the response of the material and does not respond to the natural varying weather conditions. Therefore, it requires further and more detailed investigations. For example, the study by (Wu *et al.* 2015) focused on the correlation between moisture buffer capacity and moisture effusivity concluded, that different loading schemes influence the moisture buffer potential of hygroscopic materials.

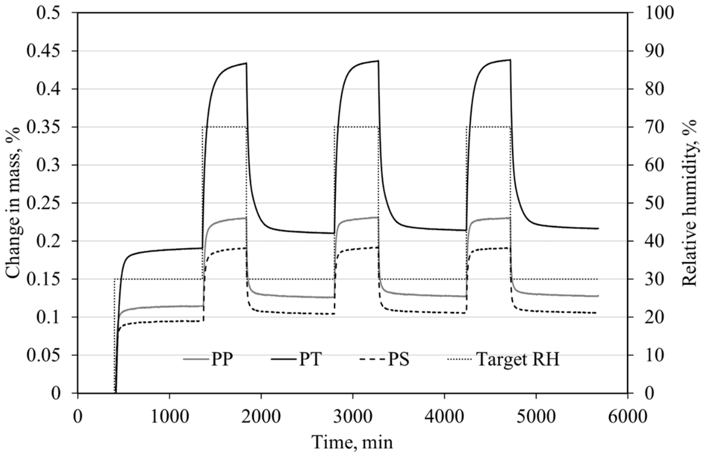

Fig. 3. Record of the moisture buffer value measurement

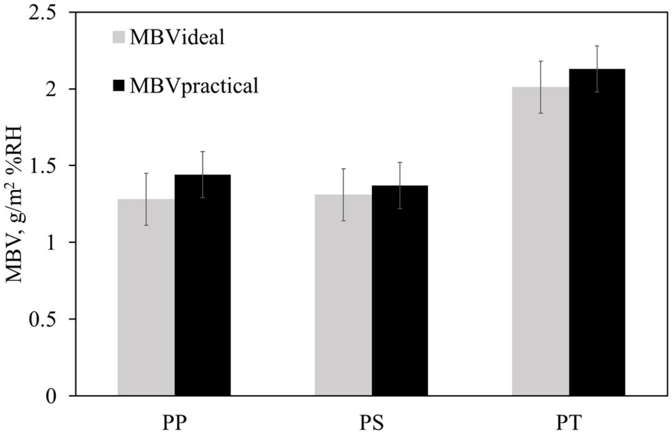

Fig. 4. Comparison between $\mathrm{MBV}_{\mathrm{practical}}$ and $\mathrm{MBV}_{\mathrm{ideal}}$ of studied plasters

Conclusions

The presented study dealt with the characterization of properties of three different types of plasters. The plasters were firstly analyzed from the point of view of basic physical properties, the information about pore size distribution and sorption isotherm was obtained. Within the measurement of moisture buffering potential of subjected materials, samples were loaded according to the NORDTEST protocol by 8/16 h loading schema at 70/30% RH. Here, the excellent moisture buffer classification was obtained for PT plaster with the highest total open porosity. However, contrary to the higher total open porosity of PS, the PP plaster achieved higher moisture buffer capacity than PS. This discrepancy refers to the influence of the pore size distribution which is, besides the total open porosity, essential for a detailed characterization of moisture buffering potential of building materials. A proper understanding of the hygroscopic properties of building materials is essential for moderation of the indoor environment without excessive energy demands. Moreover, a directed design of building materials aimed on the utilization of this currently underestimated ability of building materials can bring significant improvements in the field of building energy sustainability. Influence of the excessive relative humidity may be considered also as a consequence of changes in the indoor air enthalpy. Therefore, a further research focused on the moisture penetration depth and subjecting of materials to testing in varying weather conditions should be done in order to determine the potential impacts of hygroscopic materials on energy consumption related to the buildings maintenance.

Acknowledgement

This research has been supported by the Czech Science Foundation, under project No GBP105/12/G059.

Disclosure statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial, professional, or personal interests from other parties.

References

Abadie, M. O.; Mendoca, K. C. 2009. Moisture performance of building materials: from material characterization to building simulation using the moisture buffer value concept, *Building and Environment* 44(2): 388–401. https://doi.org/10.1016/j.buildenv.2008.03.015

Cerolini, S.; D´Orazio, M.; Di Perma, C.; Stazi, A. 2010. Moisture buffering capacity of highly absorbing materials, *Energy and Buildings* 41: 385–394.

Collet, F.; Pretot, S. 2012. Experimental investigation of moisture buffering capacity of sprayed hemp concrete, *Construction and Building Materials* 36: 58–65. https://doi.org/10.1016/j.conbuildmat.2012.04.139

Ge, H.; Yang, X.; Fazio, P.; Rao, J. 2014. Influence of moisture load profiles on moisture buffering potential and moisture residual of three groups of hygroscopic materials, *Building and Environment* 81: 162–171. https://doi.org/10.1016/j.buildenv.2014.06.021

Janssen, H.; Roels, S. 2009. Qualitative and quantitative assessment of interior moisture buffering by enclosures, *Energy and Buildings* 41: 382–394. https://doi.org/10.1016/j.enbuild.2008.11.007

Koffi, J.; Allard, F.; Akoua, J.-J. 2011. Numerical assessment of the performance of ventilation strategies in a single-family building, *International Journal of Ventilation* 9: 337–49. https://doi.org/10.1080/14733315.2011.11683892

Korjenic, A.; Teblick, H.; Bednar, T. 2010. Increasing the thermal indoor humidity levels in buildings with ventilation systems: Simulation aided design in case of passive houses, *Building Simulations* 3: 295–310. https://doi.org/10.1007/s12273-010-0015-2

McGregor, F.; Heath, A.; Shea, A.; Lawrence, M. 2014.The moisture buffering capacity of unfired clay masonry, *Building and Environment* 82: 599–607. https://doi.org/10.1016/j.buildenv.2014.09.027

Osanyintola, O. F.; Simonson, C. J. 2006. Moisture buffering capacity of hygroscopic building materials: experimental facilities and energy impact, *Energy and Building* 38: 1270–1282. https://doi.org/10.1016/j.enbuild.2006.03.026

Pavlík, Z.; Žumár, J.; Medveď, I.; Černý, R. 2012. Water vapor adsorption in porous building materials: experimental measurement and theoretical analysis, *Transport in Porous Media* 91: 939–954. https://doi.org/10.1007/s11242-011-9884-9

Polat, R.; Demirboga, R.; Karakoç, M. B.; Turkmen, I. 2010. The influence of lightweight aggregate on the physico-mechanical properties of concrete exposed to freeze-thaw cycles, *Cold Regions Science and Technology* 60: 51–56. https://doi.org/10.1016/j.coldregions.2009.08.010

Rode, C.; Grau, K. 2008. Moisture buffering and its consequence in whole building hygrothermal modeling, *Journal of Building Physics* 38: 333–360. https://doi.org/10.1177/1744259108088960

Silva, L. M.; Ribeiro, R. A.; Labrincha, J. A.; Ferreira, V. M. 2010. Role of lightweight fillers on the properties of a mixed-binder mortar, *Cement and Concrete Composites* 32: 19–24. https://doi.org/10.1016/j.cemconcomp.2009.07.003

Steeman, H. J.; Janssen, A.; Carmaliet, J.; De Paepe, M. 2009. Modelling indoor air and hygrothermal wall interaction in building simulation: Comparison between CFD and well-mixed zonal model, *Building and Environment* 44: 572–583. https://doi.org/10.1016/j.buildenv.2008.05.002

Toftum, J.; Jorgensen, A. S.; Fanger, P. O. 1998. Upper limits for indoor air humidity to avoid uncomfortably humid skin, *Energy and Buildings* 28: 1–13. https://doi.org/10.1016/S0378-7788(97)00017-0

Vieira, J.; Senff, L.; Gonçalves, H.; Ferreira, V. M.; Labrincha, J. A. 2014. Functionalization of mortars for controlling the indoor ambient of buildings, *Energy and Buildings* 70: 224–236. https://doi.org/10.1016/j.enbuild.2013.11.064

Wu, Y.; Gong, G.; Yu, C. W.; Huang, Z. 2015. Proposing ultimate moisture buffering value (UMBV) for characterization of composite porous mortars, *Construction and Building Materials* 82: 81–88. https://doi.org/10.1016/j.conbuildmat.2015.02.058

Yang, L.; Fazio, P.; Rao, J. 2012. An investigation of moisture buffering performance of wood paneling at room level and its buffering effect on a test room, *Building and Environment* 47: 205–216. https://doi.org/10.1016/j.buildenv.2011.07.021