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IN SITU DETERMINATION OF THE MOISTURE BUFFERING POTENTIAL OF ROOM ENCLOSURES

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ABSTRACT

Moisture buffering by the room enclosure can have an important influence on the variation in interior relative humidity. A characterisation to qualify and quantify this moisture buffering effect is given in a complementary paper (Janssen and Roels, 2009a, 2009b). Starting from this methodology, this paper proposes a method to determine the hygric inertia of an entire room in situ. To do so, a humidifier is placed in the room and a moisture production scheme is imposed over an interval of some days. The moisture buffer capacity is determined inversely from the resulting variations in interior relative humidity. The methodology is validated in well controlled climatic chamber experiments and afterwards applied to a real room.

INTRODUCTION

Air quality (Mudarri and Fisk, 2007), occupant comfort (Fang et al., 1998; Toftum and Fanger, 1999), durability of building parts and energy performance (Li et al., 2006; Osanyintola and Simonson, 2006; Pavlovas, 2004) are highly connected with the interior relative humidity (RH). Recently more and more attention goes to the ability of finishes and objects to passively control the RH. Indeed, interior finishes (gypsum plaster, wooden floor,…) and interior objects (books, carpets, furniture,…) are able to absorb moisture when the RH increases and release moisture when the RH decreases, which makes a passive dampening of the RH possible. Consequently, this phenomena should be taken into account to come to a more integrated approach in which more accurate constraints are used to determine the risk on condensation, moulds (Sedlbauer, 2002) and fungi (Passanen et al., 2000) and to develop healthy and comfortable buildings. Therefore, an assessment of the moisture buffering by the entire room enclosure is necessary. The moisture exchange between indoor air and hygroscopic materials is however a very complicated problem and until now, a comprehensive simulation of moisture transport and storage in interior elements remains unrealistic. Recently, Janssen and Roels introduced, based on the Moisture Buffer Value of a single element described by Rode et al. (Rode et al., 2007), a production-adapted moisture buffer potential and demonstrated that the hygric inertia of an entire building zone can be determined from its different contributing components, independent of the boundary conditions considered (Janssen and Roels, 2009a, 2009b). Furthermore, they showed that the determined hygric inertia of a building zone can be used for a qualitative comparison, but also as a quantitative design value, since it is easily implementable in existing building energy simulation tools by means of an effective capacitance model or a buffer storage model.

Though, due to the abundance of finishes and objects in a room, the determination of the buffer potential of all the separate finishes/objects is also a time-consuming or even unrealistic job. Therefore, in this study, starting from the methodology presented by Janssen and Roels (2009a, 2009b), a method is proposed to determine the moisture buffer potential of room enclosures in situ. To do so, a humidifier is placed in the room, imposing a moisture production scheme. Both the evaporated water and the temperature and RH in the room are continuously logged. Based on the measured RH-increase and decrease during the experiment, the ventilation rate and hygric inertia of the room can be inversely determined by solving the moisture balance of the room with the effective capacitance model. Using the effective moisture penetration depth model, based on the measured RH-course an effusivity and adjustment thickness factor can be determined with which the exact RH-course can be predicted.

An introductory section reiterates the characterisation of the single-element and room-enclosure moisture buffer potential and their implementation in the moisture balance. The second section presents a methodology for the in situ determination of the moisture buffer potential of room enclosures. In the third section, the methodology is validated by well controlled experiments in a large climatic chamber. To do so, the hygric inertia of the room (HIR) is determined based on the moisture buffer value of the separate finishes and objects and is afterwards compared to the hygric inertia obtained following the above mentioned methodology. In a fourth section, the methodology is applied to a real room.

IMPLEMENTATION OF HYGRIC INERTIA IN MOISTURE BALANCE

Moisture balance for room air and enclosure

The evolution of the vapour pressure, vapour concentration or dew point in the inside air can be predicted with the moisture balance. Assuming ideal convective mixing and no surface condensation, supposing air exchange with the exterior environment only, and neglecting the temperature dependency of the air density, the moisture balance for the room air can be written as:

$$\frac{V}{R_v T_i} \cdot \frac{\partial p_{vi}}{\partial t} = (p_{ve} - p_{vi}) \frac{nV}{3600 R_v T_i} + G_{vp} - G_{buf} \quad (1)$$

with V (m³) the volume of the zone, T_i (K) the indoor air temperature, $V/(R_vT_i)$ (m³.kg/J) the moisture capacity of the zone air, $p_{vi/e}$ (Pa) the partial vapour pressure of indoor/outdoor air, n (1/h) the air change rate per hour, G_{vp} (kg/s) the indoor vapour production and G_{buf} (kg/s) the moisture exchange between indoor air and room enclosure.

Single-element and room-enclosure Moisture Buffer Potential characterisation

Recently, several proposals to characterise the Moisture Buffer Potential (MBP) of single finishes and objects have been presented. One of these proposals is to use the amplitude of the moisture accumulation in a finish/object exposed to cyclic step changes in ambient RH (Japanese Industrial Standard A 1470-1; Draft International Standard 24353; Nordtest Moisture Buffer Value protocol (Rode et al., 2007)). In the Nordtest cyclic steps of 8 hours 75% RH followed by 16 hours 33% RH are imposed and the 'Moisture Buffer Value' (MBV) of a finish is defined as:

$$MBV_{8h} = \frac{m_{max} - m_{min}}{A.(\varphi_{high} - \varphi_{low})} \quad \text{(kg/(m².\%RH))} \quad (2)$$

with $m_{max/min}$ (kg) the maximum/minimum moisture mass of the sample, A (m²) the exposed surface of the sample and $\varphi_{high/low}$ (-) the high/low RH level applied in the measurements (here respectively 75% and 33%). For an object the definition becomes:

$$MBV'_{8h} = \frac{m_{max} - m_{min}}{\varphi_{high} - \varphi_{low}} \quad \text{(kg/\%RH)} \quad (3)$$

Analogue to Eq. (2) and (3) also a $MBV^{(')}_{1h}$ can be defined, this time with m_{max} the moisture mass of the sample after one hour high RH.

Illustratively, Figure 1 shows for wood-wool cement board and a bookshelf with books the first two cycles of the measurements of the $MBV_{1h}^{(')}$ and $MBV_{8h}^{(')}$ (Vereecken, 2008). Based on these values a production-interval adapted Moisture Buffer Value (MBV^*) can be determined (Janssen and Roels, 2009a, 2009b):

$$MBV^{(')}* = \alpha.MBV^{(')}_{8h} + (1-\alpha).MBV^{(')}_{1h} \quad (4)$$

with α (-) a weighting factor:

- 0 h < production interval $\leq$2 h: $\alpha = 0.0$;
- 2 h < production interval $\leq$6 h: $\alpha = 0.5$;
- 6 h < production interval $\leq$10 h: $\alpha = 1.0$;

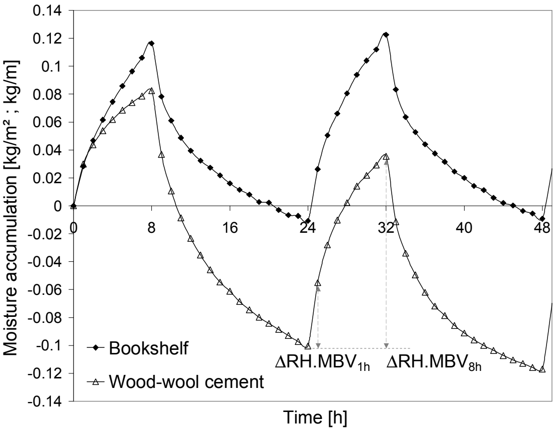

Figure 1 $MBV^{(')}$ characterisation of wood-wool cement board and of a bookshelf (1m)

Furthermore, Janssen and Roels (2009a, 2009b) showed that using the $MBV^{(')*}$-values of all the finishes and objects in a room a production-interval adapted HIR^*-value can be determined, which characterise the moisture buffer potential of the room:

$$\begin{aligned} HIR^* &= \frac{\sum A_k.MBV_k^* + \sum MBV_l^{'*}}{V} \\ &= \alpha.HIR_{8h} + (1-\alpha).HIR_{1h} \end{aligned} \quad (5)$$

with A_k (m²) and MBV_k^* (kg/(m².%RH)) respectively the area and moisture buffer value of finishing material k , $MBV_l^{'*}$ (kg/%RH) the equivalent moisture buffer value of element l, V (m³) the volume of the room, α (-) a weighting factor (see above) and $HIR_{1h/8h}$ (kg/(m³.%RH)) respectively the short and long term hygric inertia of the room given by:

$$HIR_{1h/8h} = \frac{\sum A_k.MBV_{k,1h/8h} + \sum MBV'_{l,1h/8h}}{V} \quad (6)$$

Implementation of HIR* in the EC-model

The moisture exchange between room air and room enclosure in Eq. (1) can be simplified using the Effective Capacitance (EC-) model. The EC-model assumes the mass of moisture buffered in the hygric inertia of the room M_{buf} (kg) in equilibrium with the room humidity and proportional to the HIR^*-value of the room enclosure. That allows to write the moisture exchange G_{buf} of Eq. (1) as:

$$G_{buf} = \frac{\partial M_{buf}}{\partial t} = \frac{100.HIR^*.V}{p_{v,sat}(T_i)} \frac{\partial p_{vi}}{\partial t} \qquad (7)$$

with 100 a unit conversion factor to bring the kg/(m³.%RH) unit of HIR* back to kg/m³. Eq. (7) transforms Eq. (1) into:

$$\left(\frac{V}{R_v T_i} + \frac{100.HIR^*.V}{p_{v,sat}(T_i)} \right) \frac{\partial p_{vi}}{\partial t} \qquad (8)$$
$$= (p_{ve} - p_{vi}) \frac{nV}{3600 R_v T_i} + G_{vp}$$

Note that the exact RH-course can not be determined using the EC-model. This is an inherent shortcoming of the EC-model, due to the assumption that the material humidity is the same as the RH in the room.
To predict the exact RH-course, the EMPD-model could be used. A discussion of this model can be found in (Janssen and Roels, 2009a, 2009b).

PROPOSED METHODOLOGY FOR IN SITU DETERMINATION OF HIR

Determining the hygric inertia of a room based on the moisture buffer potential of the different contributing components is due to the abundance of finishes and objects in a room still a time-consuming or even unrealistic job. Therefore, a methodology to determine the hygric inertia of a room in situ is proposed. Applying this methodology, a humidifier is placed in the room and during a period of some days a moisture production is imposed. The amount of evaporated water is continuously logged together with the RH and temperature. Consequently, knowing the outdoor conditions during the experiment, the hygric inertia can be determined by inversely fitting the moisture balance (Eq. (8)).

Due to the imposed moisture production a rise of interior RH is obtained, followed by a fall of interior RH during the period without moisture production (Figure 2). The amplitude of the RH-increase and RH-decrease can be plotted for different HIR*-values in function of the ACH, as shown in Figure 3a. The curves which represent the theoretical total RH-increase in function of air change rate (dotted lines) show a descending course. On the other hand, the curves corresponding to the theoretical RH-decrease (continuous lines) first show a rising course. With an ACH = 0 no decrease would occur. So increasing the ACH first results in an increase of the RH-amplitude since a larger ACH corresponds to a lower RH at the end of the period without moisture production. However as an increasing ACH also affects the RH-increase during the moisture production period, from a certain moment this feature will be more important than the extra decrease in the period without moisture production. Assuming that the ACH remains constant during the experiment, the measured RH-increase and decrease (Figure 3b) have to intersect the predicted RH-changes for the same HIR*-value and ACH (indicated by the dots in Figure 3c). Note that the graphs (so also the methodology) is not valid when condensation occurs (e.g. light coloured part of the curves of HIR*= 0.0 and HIR*= 0.2 g/(m³.%RH)).

The implemented moisture production scheme can be chosen based on the most typical moisture production scheme in the room. However, a more all-embracing method is to determine the HIR_{1h} and HIR_{8h} of the room, exploring respectively a short term (cycli of 1 hour humidity followed by 5 hours inactivity) and a long term (8 hours humidifying followed by 16 hours inactivity) production scheme. Knowing HIR_{1h} and HIR_{8h}, the hygric inertia of the room in case of other production schemes can be determined as described in (Janssen and Roels, 2009a, 2009b). As an alternative, the HIR_{1h}-value - or other HIR*-values corresponding to a production scheme smaller than 8 hours humidifying - could be determined based on the long term experiment. To do so, the curves for the RH-increase during the first hour – or during the implemented moisture production – should be drawn in function of the ACH and the curve which intersects the measured RH-increase by the ACH as found in the determination of HIR_{8h} should be searched.

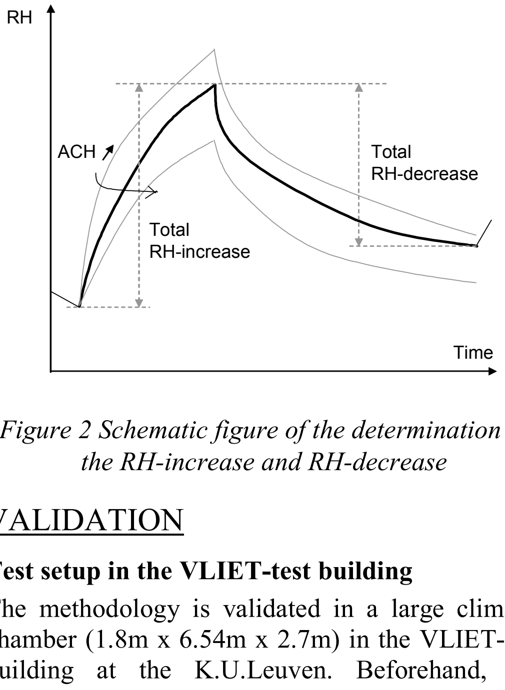

Figure 2 Schematic figure of the determination of the RH-increase and RH-decrease

VALIDATION

Test setup in the VLIET-test building

The methodology is validated in a large climatic chamber (1.8m x 6.54m x 2.7m) in the VLIET-test building at the K.U.Leuven. Beforehand, the moisture buffer potential of the different finishes and objects placed in the room was determined. Figure 4 shows the setup of the finishes and objects in the large climatic chamber. Table 1 gives the finishes and objects, together with their moisture buffer potential determined using the methodology

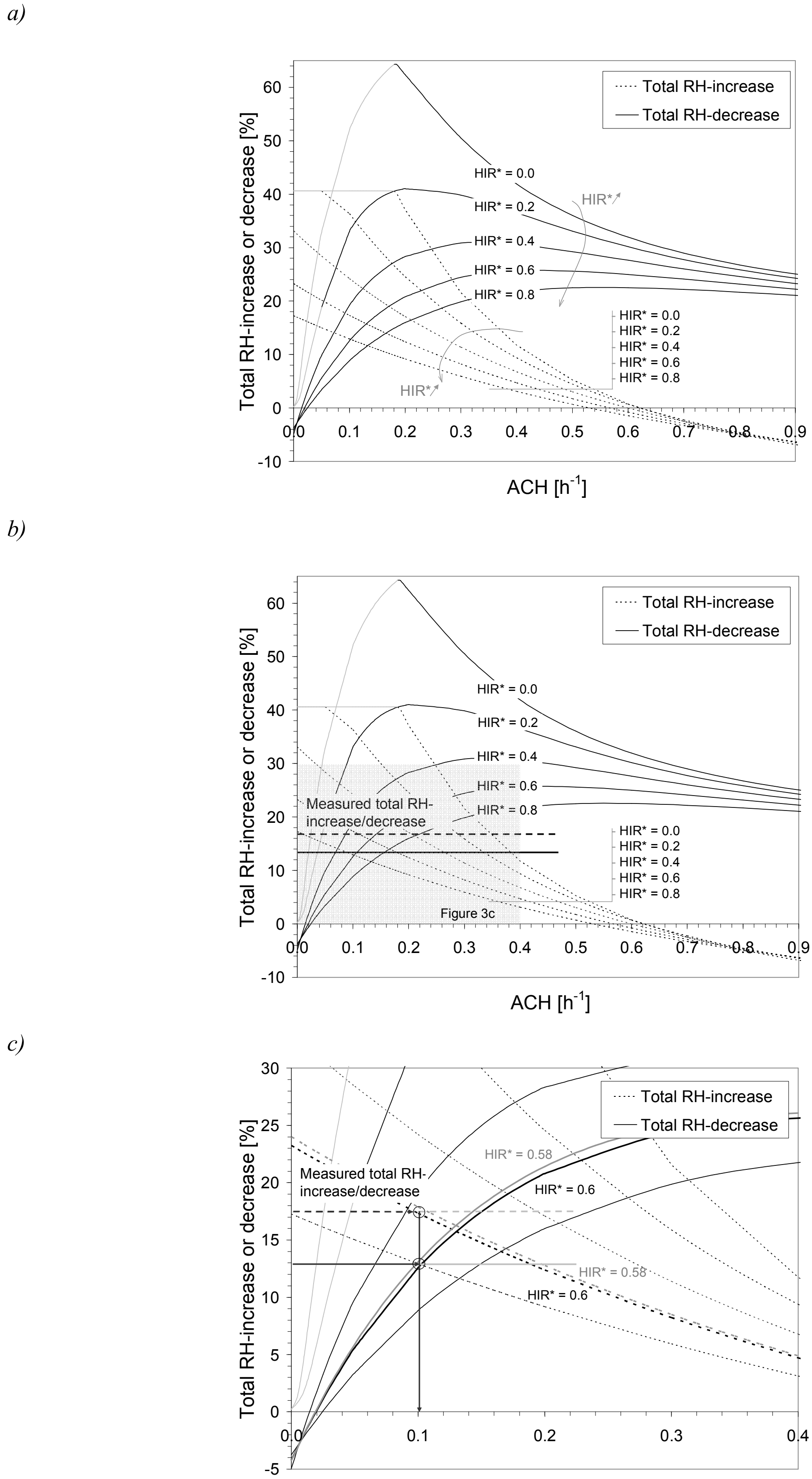

Figure 3 Schematic figure of the determination of the HIR-value: a) draw the theoretical curves of the total RH-increase and decrease, b) draw the measured total RH-increase and decrease, c) look for the curves which intersect the measured RH-increase and decrease at the same HIR*-value and ACH. In this case a HIR*-value of 0.59 g/(m³.%RH) is obtained

described in (Roels and Janssen, 2006). Using Eq. (5), these values result in a HIR_{8h} of 0.51 g/(m³.%RH) and a HIR_{1h} of 0.16 g/(m³.%RH) for the considered enclosure.

In the climatic chamber a humidifier was placed, which imposed a moisture production over a certain period. Behind the humidifier, a small ventilator was placed to mix the moisture in the room air. The evaporated amount of water was continuously logged, together with the temperature and RH. The influence of the outdoor conditions was minimised since the chamber was fairly air and vapour tight. To stabilize the conditions in the room, the experiment was starting one day after entirely locking the room. To have only moisture exchange with the in reality to moisture exposed sides, the back and the edges of the finishes were sealed with respectively plastic foil and aluminium tape.

Figure 4 Test setup in the climatic chamber in the VLIET-test building

Results

The experiment was explored for a long (8 hours humidification followed by 16 hours without humidification) as well as a short (cycli of 1 hour humidification followed by 5 hours without humidification) moisture production scheme. Executing a long term experiment resulted in a HIR_{8h}-value of 0.59 g/(m³.%RH) (see Figure 3 for the determination), which is in close agreement with the calculated value of 0.51 g/(m³.%RH) based on the moisture buffer values of the different elements. A small ACH (0.1 h^{-1}) was obtained, which is in agreement with the expectations since the precise air and vapour tight sealed construction. Using this ACH, a HIR_{1h}-value of 0.04 g/(m³.%RH) was obtained, which is far below the calculated value of 0.16 g/(m³.%RH).

When executing a short term moisture production scheme a HIR_{1h}-value of 0.07 g/(m³.%RH) was obtained, which is still an underestimation of the calculated value.

The smaller agreement of the HIR_{1h}-value can be due to some experimental facts as a lower surface transfer coefficient in the room than in the small climatic chamber, the fact that the water vapour will rise while most elements were placed on the ground, the difference between the RH-level in the room and the small climatic chamber, etc. Note also that the HIR_{1h}-value is especially important for zones with a short production scheme, which is for example the case in bathrooms. During occupation of this rooms a large moisture production can be observed, while in the in situ experiment the HIR_{1h}-value was determined for a small moisture production. To have a more accurate prediction of the HIR_{1h}-value, a larger moisture production should be provided.

Figure 5 compares the measured and in situ determined RH-course for both experiments. As can be seen the measured and the in situ determined hygric inertia are in the same order of magnitude.

The exact course can not be determined using the EC-model. This is an inherent shortcoming of the EC-model. To predict the exact RH-course, the Effective Moisture Penetration Depth (EMPD-) model should be used. Therefore, the equivalent effusivity b_{eq} and adjustment factor a_{eq} can be determined based on the HIR_{1h} and HIR_{8h} as described in (Janssen and Roels, 2009a, 2009b) or with for example the solver in Excel, making the difference between measured and predicted course as small as possible. Figure 6 shows the with the

Table 1

Dimensions and beforehand determined MBV_{1h} and MBV_{8h} of the hygric elements placed in the test room

MATERIAL	AREA ; LENGTH	MBV_{1H}	MBV_{8H}
	m² ; m	g/(m$^{(2)}$/%RH)	g/(m$^{(2)}$/%RH)
Wood-wool cement board	0.834	1.17	3.32
Wood-fibre board	9.375	0.36	1.15
Pile of journals (20 x 29 cm²)	0.225	0.84	2.64
Pile of newspapers 1 (20 x 29 cm²)	0.180	0.91	3.23
Pile of newspapers 2 (20 x 29 cm²)	0.175	0.91	3.23
Pile of books (17.5 x 25 cm²)	0.300	0.71	2.45
Books in rack (17.5 x 25 cm²)	0.305	0.71	2.45

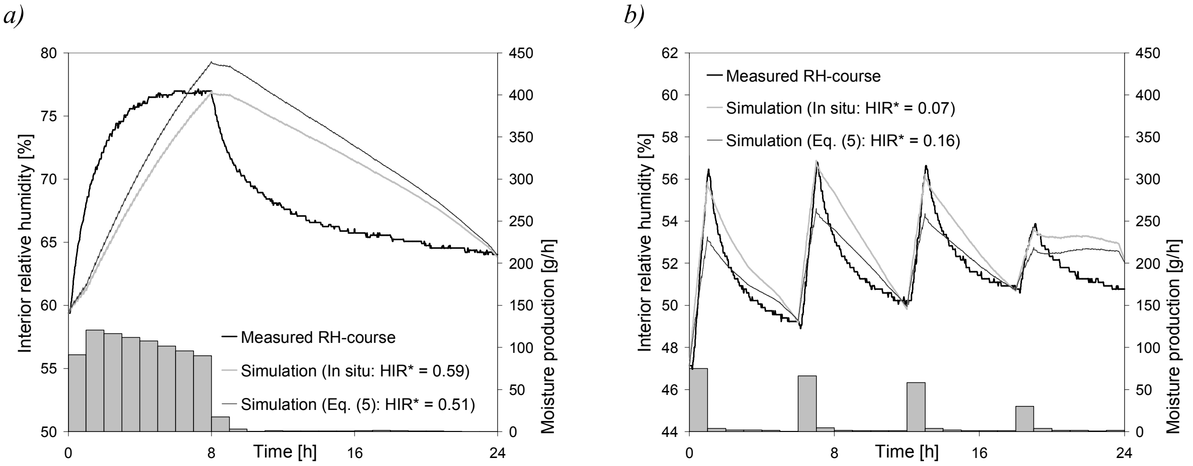

Figure 5 Measured and predicted RH-course (EC-model) in the large climatic chamber during the a) long term and b) short term experiment

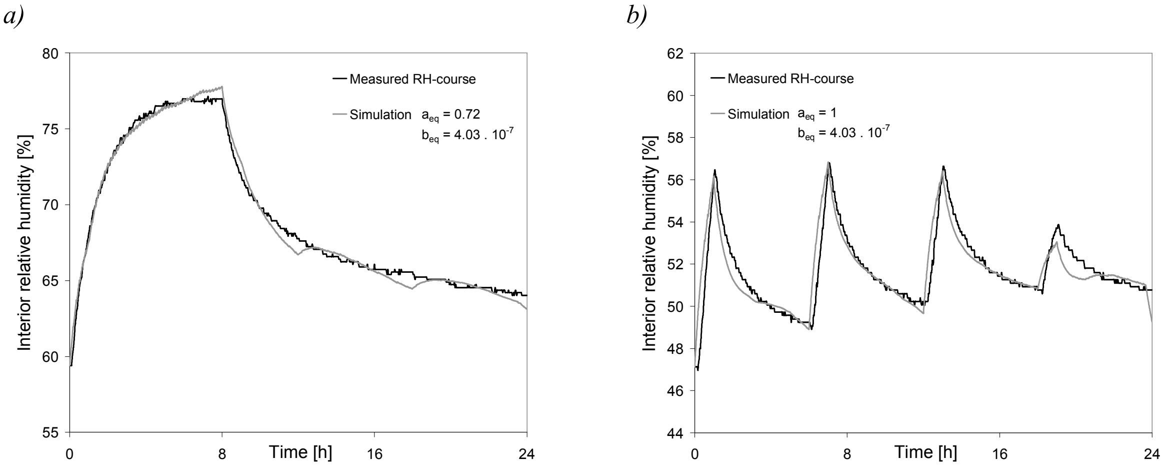

Figure 6 Measured and predicted RH-course (EMPD-model) in the large climatic chamber during the a) long term and b) short term experiment

EMPD-model predicted RH-course. The parameters b_{eq}, a_{eq} and the ACH (constant per 6 hours) were determined by fitting the RH-course. As can be seen, using the EMPD-model the exact RH-course can be predicted. Details of applying the EMPD-model for in situ determination of the moisture buffering potential can be found in (Vereecken et al., 2009). Note however that knowing the peaks in RH is in most studies the most important, so the more simplified EC-model will often be sufficient to analyse most problems.

APPLICATION ON A STUDENT'S ROOM

Test setup in a student's room

In a second step, the proposed methodology was used to determine the hygric inertia of a student's room (5m x 2.8m x 2.5m). Figure 7 gives an inside view of the room. The walls of the room were constructed with autoclaved aerated concrete finished with a coated gypsum plaster. Floor and ceiling consisted of a concrete slab finished with a coated gypsum plaster at the bottom.

Before starting the experiment, to increase the accuracy, possible air gaps around windows and door were sealed with plastic foil. The indoor conditions in the room were stabilized during one day, after which the experiment was started. During a period of three days a moisture production scheme consisting of 8 hours humidification followed by 16 hours without humidification was implemented. The amount of evaporated water was continuously logged together with the temperature and RH.

Figure 7 Inside view of the student's room

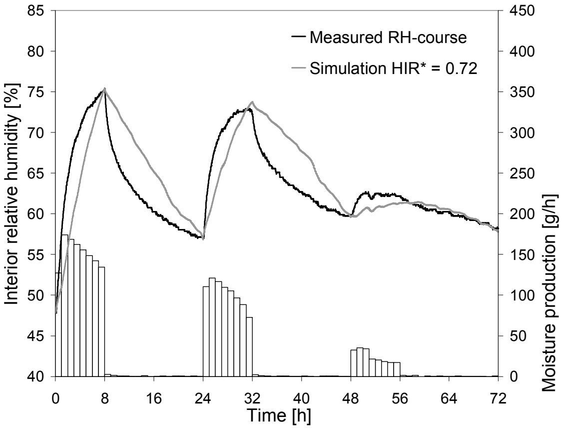

Figure 8 Measured and predicted RH-course (EC-model) in the student's room

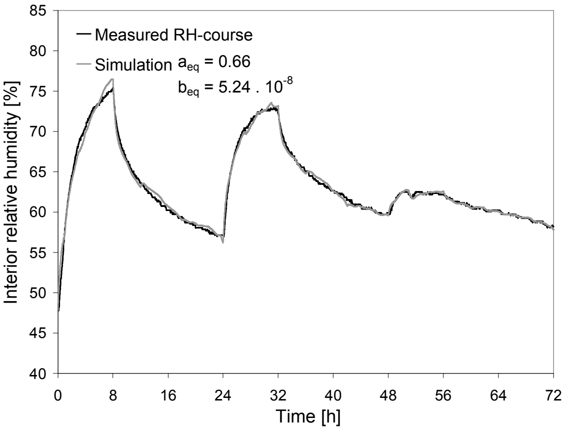

Figure 9 Measured and predicted RH-course (EMPD-model) in the student's room

Results

The first day of the experiment (after the day to stabilize the indoor conditions) was used to determine the hygric inertia of the room, resulting in a HIR_{8h}-value of 0.72 g/(m³.%RH). Using the results obtained during the long term experiment, also the HIR_{1h}-value was determined, resulting in a value of 0.18 g/(m³.%RH). In the determination, assumption was made that all the infiltration air was coming from outside. The measured and predicted RH-course is shown in Figure 8, together with the implemented moisture production. As can be seen the predicted minimum and maximum RH during the first day agree with the measured minimum and maximum RH determined with the HIR-value. Indeed, this was the condition in the determination of the HIR-value. Furthermore, when using the HIR-value determined during the first day, also a good agreement for the minimum and maximum RH of the second day is found. Using the EMPD-model the RH-course can be more accurate predicted. Figure 9 compares the real RH-course with the RH-course determined with the EMPD-model. A rough estimation of the exposed surface (in this case an estimation of 166 m² is used) is sufficient (Janssen and Roels, 2009a, 2009b).

DISCUSSION AND CONCLUSION

Interior relative humidity (RH) plays an important role in the air quality, the occupant's comfort, the appearance of building parts and the energy performance. Objects and finishes in a room are able to absorb and release moisture and as a consequence dampen the peaks in RH. Several authors stress the importance of the room enclosure, especially hygroscopic objects as books etc., to dampen the peaks in RH. These effects can be expressed with the HIR-value (Janssen and Roels, 2009a, 2009b), which can be determined based on the moisture buffer potential of the different elements/finishes separately. However, the abundance of elements and finishes in a room makes the determination of the moisture potential of all the elements a time-consuming or even unrealistic job. Therefore, in this paper, a methodology was proposed to determine the hygric inertia in situ. To do so, a humidifier was placed in the room, implementing a moisture production scheme. The hygric inertia was determined by inversely fitting the moisture balance.

In a large climatic chamber at the K.U.Leuven the proposed methodology has been validated for a short and long moisture production scheme. The in situ determined hygric inertia in the long term experiment showed to be in close agreement with the calculated value based on the moisture buffer potential of the different elements separately. On the other hand, the agreement between the calculated and in situ determined hygric inertia in the short term experiment was less and the short term hygric inertia determined with the long term experiment was even in less agreement with the calculated value. This can be due to some experimental facts as a larger volume of the room compared to the chamber, a different surface transfer coefficient in the room and the climatic chamber, the small variation in RH during the in situ experiment, the fact that the water vapour will rise while most elements were placed on the ground, the fact that the minima and maxima obtained with the EC-model are not entirely the same as the measured values,…

In a second step, the methodology has been applied on a student's room with unknown hygric inertia. Here, a HIR_{8h}-value of 0.72 g/(m³.%RH) and a HIR_{1h}-value of 0.18 g/(m³.%RH) were obtained. Applying these values to predict the response of the room for the next days also a good prediction was observed. As an inherent feature of the EC-model it is however not possible to simulate the exact RH-course. To do so, the EMPD-model can be used. A more detailed discussion of this model is given in (Vereecken et al., 2009).

It should be noted that in the proposed methodology a few assumptions are made. To determine the hygric inertia a constant ACH during the entire day is assumed. Although during the experiment the ventilation system is closed and the windows or other air gaps are sealed, the construction will not be entirely airtight. Therefore, to reduce the influence of outdoor conditions, the experiment is preferably performed on a day without much wind. The in situ determined value will also be slightly different from experiment to experiment. This is not only due to the variety of the influence of the outdoor conditions, but also to the variety in starting conditions, the implemented moisture production in the experiment, etc. Though the scope of the proposed methodology is to get a rough idea of the hygric inertia of the room using an easy experiment.

It can be concluded that the proposed methodology, although some simplifications are made, forms an easy and fast tool to come to a good estimation of the hygric inertia of a room. Main advantage of the methodology is that the HIR*-approach – compared to the standard methodologies – makes a comprehensive characterisation of the hygric inertia of an entire building enclosure possible, since also multilayered interior finishes and multidimensional interior objects as furniture, carpets, drapes, books, etc. can easily be taken into account. Furthermore, the determined HIR*-value can easily be implemented in the EC-model.

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REFERENCES

Fang, L., Clausen, G., Fanger, PO. 1998. Impact of temperature and humidity on the perception of indoor air quality, Indoor Air, 8: 80-90.

ISO/DIS 24353. 2006. Hygrothermal performance of building materials and products – determination of moisture adsorption/desorption properties in response to humidity variation.

Janssen, H., Roels, S. 2009a. Qualitative and quantitative assessment of interior moisture buffering, Proceedings of ‘Building Simulation 2009’, Glasgow, United Kingdom.

Janssen, H., Roels, S. 2009b. Qualitative and quantitative assessment of interior moisture buffering by enclosures, Energy and Buildings, 41: 382-394.

JIS A 1470-1. 2002. Test method of adsorption/desorption efficiency for building materials to regulate an indoor humidity – part 1: response method of humidity.

Li, Z., Chen, W., Deng, S., Lin, Z. 2006. The characteristics for space cooling load and indoor humidity control to residences in the subtropics, Building and Environment, 41: 1137-1147.

Mudarri, D., Fisk, WJ. 2006. Public health and economic impact of dampness and mold, Indoor Air, 17:226-235.

Osanyintola, OF., Simonson, CJ. 2006. Moisture buffering capacity of hygroscopic building materials, Energy and Buildings, 38: 1270-1282.

Passanen, A-L., Kasanen, J-K., Rautiala, S., Ikäheimo, M., Rantamäki, J., Kääriäinen, H., Kalliokoski, P. 2000. Fungal growth and survival in building materials under fluctuating moisture and temperature conditions, Interior Biodeterioration & Biodegradation, 46: 117-127.

Pavlovas, V. 2006. Demand controlled ventilation: A case study for existing Swedish multifamily buildings, Energy and Buildings, 26: 1029-1034.

Rode, C., Peuhkuri, R., Time, B., Svennberg, K., Ojanen, T. 2007. Moisture buffer value of building materials, Journal of ASTM International, 4.

Roels, S., Janssen, H. 2006. A comparison of the Nordtest and the Japanese test methods for the moisture buffering performance of building materials, Journal of Building Physics, 30: 137-161.

Sedlbauer, K. 2002. Prediction of mould growth by hygrothermal calculation, Journal of Thermal Envelope and Building Science, 25: 321-336.

Simonson, C., Salonvaara, M., Ojanen, T. 2002. Humidity, comfort and air quality in a bedroom with hygroscopic wooden structures, Proceedings of the 6th Symposium on Building Physics in the Nordic Countries, Trondheim, Norway, Vol. 2, 743-750.

Toftum, J., Fanger, PO. 1999. Air humidity requirements for human comfort, ASHRAE Transactions, 105: 641-647.

Vereecken, E. 2008. How important are interior finishing materials to reduce relative humidity variations in indoor spaces, Master Thesis (in Dutch), K.U. Leuven, Belgium.

Vereecken, E., Roels, S., Janssen H. 2009. In situ determination of the moisture buffer potential of room enclosures, Submitted to Journal of Building Physics.