Hygroscopic Inertia as a Function of Transient Behavior of Covering Materials

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ABSTRACT

This paper presents recent work on analysis of the importance of hygroscopic inertia in the hygrothermal behavior of buildings. The paper first discusses the role of hygroscopic materials in moderating the inside relative humidity variation in countries of mild climate of which Portugal is an example. Then laboratory tests, aimed at characterizing the behavior of covering materials in transient conditions, are presented, as well as some conclusions provided by these tests.

INTRODUCTION

In countries with a mild climate, of which Portugal is an example, it is not common for dwellings to have continuous heating systems. Usually discontinuous heating takes place, generating strong variations of temperature and, consequently, of relative humidity throughout the day. Under these circumstances the indoor relative humidity assumes high values and the phenomenon of surface condensation takes on large proportions, being a problem for the users and bringing about economic and social consequences.

In our opinion, the hygroscopic behavior of materials covering walls and ceilings, as well as furniture and textiles inside buildings, condition the "hygroscopic inertia," which is an essential parameter for the control of surface condensation.

A mathematical model to estimate the relative humidity variation of a room has already been developed (Ramos 2000; Freitas and Ramos 2002). This model considers envelope configuration, ventilation rate, water vapor production, and outside climate, as well as the contribution of hygroscopic materials to the balance of the humidity of indoor air. Using this model, the computer program RH2000 was developed and the results from simulations lead us to believe that hygroscopic materials can play an important role in moderating the relative humidity variation inside buildings. The need for comparison of the simulation results with laboratory measurements and the characterization of materials' sorption kinetics has motivated a series of tests that are being developed. In this paper, the laboratory tests and results are presented, as well as an overview of the mathematical model that provided the background for those tests. Both simulation and laboratory tests contribute to the definition of the hygroscopic inertia classes proposed in this paper.

HYGROSCOPIC INERTIA

The "hygroscopic inertia" concept is not yet well defined, nor its relation with the variation of relative humidity of the air inside rooms. The understanding of that relation has been part of the motivation for our current work. We aim to demonstrate that there will be a decrease on the peaks of daily relative humidity variation as a function of the hygroscopic inertia class of the room, defined by the hygroscopicity of the materials present in that room. The results obtained in numerical simulations, presented in this paper, have encouraged us to proceed with this work. Although the definition of the hygroscopic inertia classes is not yet fully developed, Figure 1 illustrates the relation between those classes and the smoothing of relative humidity variation. The figure shows how an increasing class of hygroscopic inertia represents a decrease in relative humidity peak values, taking as a reference the room behavior without hygroscopic surfaces.

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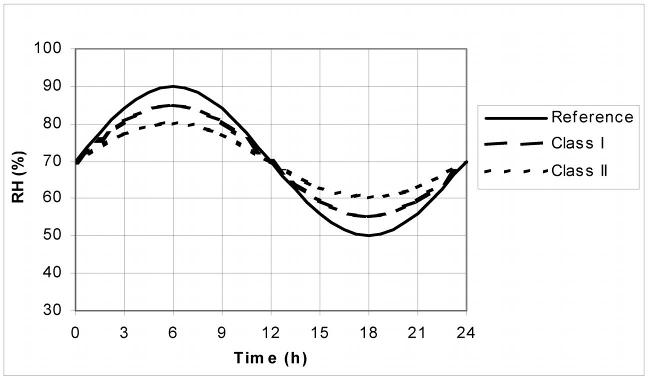

Figure 1 *Idealized relation between hygroscopic inertia classes and relative humidity variation for a daily cycle.*

As a first approach to the concept of hygroscopic inertia classes we present a proposal that would allow an objective definition of those classes. If we consider a room, given its geometry, the inside temperature, the ventilation rate, the vapor production, and the outside temperature and relative humidity, it is possible to define the relative humidity values for the inside air during a certain period of time, such as a day, a week, or a whole season. A statistical analysis of those values allows for the definition of significant values, corresponding to chosen percentiles. As a first idea, we would suggest a percentile of 90% for the definition of the upper characteristic value. Taking that first set of values as the reference, then the hygroscopic inertia classes would be defined as a function of the reduction ability of the upper characteristic value of relative humidity. Table 1 suggests the definition of hygroscopic inertia classes based on this concept.

This is, of course, a first suggestion for the referred classification, and all the numerical values are still being studied. But this principle seems to be a way of transforming the research results in this area into recommendations for practitioners. Those recommendations should be an optimal relation between the hygroscopic inertia, the type of room, and its climatic conditions. The way of achieving the recommended inertia class with the available construction materials should also be part of the information coming from research.

To fulfil these goals, research including numerical simulation and laboratory experiments has been developed in the last few years. The next sections elaborate on these aspects.

NUMERICAL SIMULATION

Proposed Model for Inside Relative Humidity Variation

The model proposed by Ramos (2000) is based on the differential equation given by Equation 1, which represents the humidity variation in time and calculates the vapor fluxes

Table 1. Proposed Hygroscopic Inertia Classes

Class	Reduction (R)	Designation
1	R ≤ 5%	Low Inertia
2	5% < R ≤ 15%	Medium Inertia
3	15% < R	High Inertia

generated by the ventilation (F_V), the vapor production ($F_{G,}$), and the vapor exchanges on the n hygroscopic surfaces in contact with the room's air ($F_{Hj,\, j=1,n}$).

$$\frac{dm_{vi}}{dt} = F_G + F_V + \sum_{j=1}^{n} F_{Hj} \tag{1}$$

If we replace the several components of Equation 1 by the expressions that quantify them, according to hygrothermal parameters, we obtain Equation 2, which defines the differential equation that represents the phenomenon of relative humidity variation in time inside a room, considering the possibility of temperature variation.

$$\begin{aligned}\left(\frac{dP_i}{dt}T_i - P_i\frac{dT_i}{dt}\right)\frac{V}{R_v \cdot T_i^2} &= \frac{G}{3.6\times10^6}\\ -\frac{N\cdot V}{3600}\left(\frac{\phi_i \cdot P_{sat}(T_i)}{R_v T_i} - \frac{\phi_e \cdot P_{sat}(T_e)}{R_v T_e}\right) &- \sum_{j=1}^{n}\frac{\gamma_j \cdot A_j}{3.6\times10^4}(\phi_i - \phi_{mj})\end{aligned} \tag{2}$$

where

A	=	area, m^2
HR, ϕ	=	relative humidity, $\phi = HR \times 0.01$, %
F_G	=	vapor flux resultant from the production of vapor, kg/s
F_H	=	vapor flux resultant from the materials' hygroscopicity, kg/s
F_V	=	vapor flux resultant from the ventilation, kg/s
G	=	vapor production, g/h
m_{vi}	=	mass of water vapor on the indoor air, kg
N	=	air change rate, h^{-1}
P	=	water vapor partial pressure, Pa
P_{sat}	=	saturation pressure, Pa
R_v	=	gas constant, Rv = 461.5, J/(kg·K)
t	=	time, s
T, t_g	=	temperature, $T = t_g + 273.16$ K, °C (K)
V	=	volume, m^3
γ	=	coefficient of moisture flux density, g/(m^2·h·ΔPHi)
i	=	inside
e	=	outside
m	=	material

In the proposed model, the moisture flux density coefficient, γ, allows for the determination of the vapor flux due to the presence in the room of hygroscopic surfaces (F_H)

as a function of the difference between the relative humidity of the air (ϕ_i) and the relative humidity of the material surface (ϕ_m).

Based on the analysis of the behavior in adsorption and desorption of several rendering materials tested, we have looked for a variable that would represent the humidity variation of the various samples (Castro 1998; Freitas 1999). The curves shown on Figure 2 represent the values for the flux density coefficient γ in situations of adsorption or desorption that will be obtained as a function of the relative humidity of the air. Having in mind that these first experiments were made at a steady-state temperature of 18°C, we admit that these curves are an acceptable first approach for this temperature level. The full definition of this coefficient is dependent on more experimental studies, using different materials, submitted to different hygrothermal conditions.

Another difficulty in the calculation of the vapor flux due to the presence in the room of hygroscopic surfaces (F_H) is the determination of the relative humidity of the material surface (ϕ_m). In this model, the Luikov and Phillip-De Vries theory for the combined heat and moisture transfer for a unidirectional flux inside a porous material is applied in the determination of the moisture content at the surface of the materials exposed to the room's air. That theory, as applied by Freitas et al. (1996), can be represented by the simplified mass and energy conservation equations 3 and 4.

$$\frac{\partial w}{\partial t} = \frac{\partial}{\partial x}\left(Dw\frac{\partial w}{\partial x} + DT\frac{\partial T}{\partial x}\right) \tag{3}$$

$$(\rho^* \cdot C^*)\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda^*\frac{\partial T}{\partial x}\right) \tag{4}$$

where

C = specific heat, J/kg·K
Dw = moisture diffusivity coefficient, m^2/s
DT = thermal moisture diffusivity coefficient, $m^2/s \cdot K$
T = temperature, °C (K)
t = time, s
w = moisture content, kg/kg
λ = thermal conductivity, W/m·K
ρ = density, kg/m^3
* = apparent

The solution of Equations 3 and 4 for a given boundary condition allows for the calculation of moisture content (w) at the surface of each material present in the room and, subsequently, from the sorption curve, the relative humidity of the material surface (ϕ_m).

As a final remark in this section, some limitations of the model should be pointed out. The main objective for the development of the proposed model was the analysis of the effect of hygroscopic materials on the moderation of relative humidity variation inside buildings. At its present stage, the model has several limitations that have to be taken into account when we consider the simulation of a real building. For instance, in terms of air exchange, the model only admits the exterior and not other rooms, and the temperature is imposed and not calculated. Also, surface condensation is not yet considered in the model.

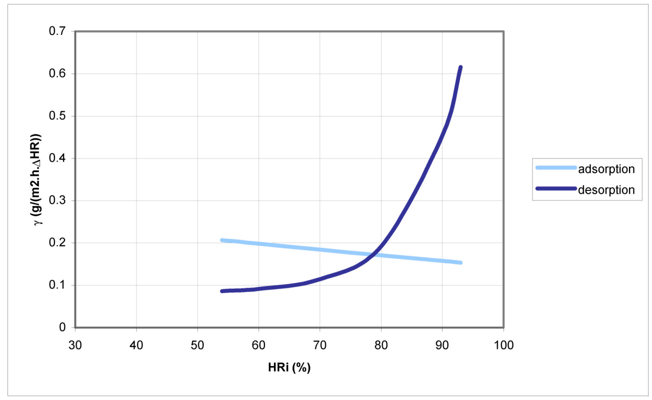

Figure 2 *Moisture flux density coefficient for* T_i *= 18°C (Freitas 1999).*

Simulation Results

The modeling program RH2000 was developed by Ramos (2000) as a simulation tool with the purpose of implementing the variation model of the indoor relative humidity defined in the previous section. The numerical simulations calculated with the modeling program RH2000 analyzed the sensitivity of the model in relation to the various parameters involved in the calculus and explored the program's capacities in general and more embracing simulations. From the several simulations calculated, the set that contains simulations 1 and 2 stands out, referring to the hygrothermal behavior analysis of a small room, during an extensive period, beginning at 0:00 of 1/12/1999 and ending at 24:00 of 13/2/2000. During that period the outdoor temperature and relative humidity values used were provided by our laboratory weather station, as shown in Figures 3 and 4. (Freitas et al. 1999).

In simulations 1and 2, the relative humidity variation was calculated inside a room with a volume of 50 m^3, a constant inside temperature of 18°C, and an initial inside relative humidity of 60%. The conditions of vapor production correspond to daily cycles of 100 g/h during eight consecutive hours (assumed to be the night period from 0:00 to 8:00 a.m.) and 20 g/h during the remainder of the day. Ventilation was assumed to be $N = 0.5\ h^{-1}$ from 0:00 to 8:00 a.m. and $N = 0.8\ h^{-1}$ for the remainder of the daily cycle. Simulation 1 does not present active hygroscopic surfaces, while in simulation 2 a surface of 20 m^2, covered with 2 cm of mortar, was located inside the room. It was imposed that the hygroscopic surfaces did not belong to the envelope walls so that it could be assumed that the temperature of those surfaces was equal to the room's air. No windows were considered for this room, as the focus was not condensation analysis.

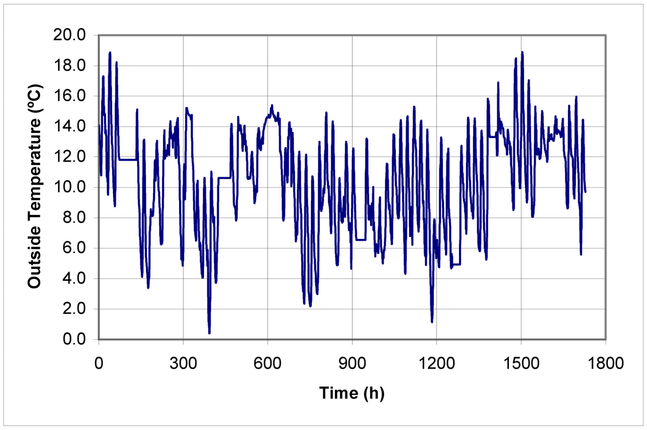

Figure 3 *Outside temperature from 1/12/1999 to 13/2/2000 (Freitas 2000).*

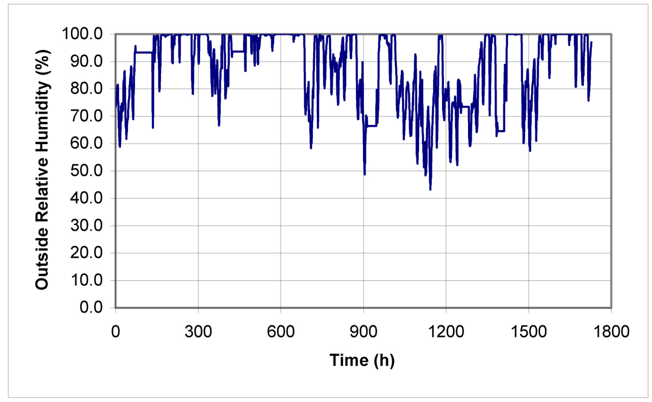

Figure 4 *Outside relative humidity from 1/12/1999 to 13/2/2000 (Freitas 2000).*

The results of these two simulations are shown in Figure 5. In view of a probable use, the program RH2000 showed in a conclusive way the important role that hygroscopic surfaces can play by moderating the inside relative humidity variation. The inside relative humidity peaks of simulation 1 were drastically reduced in simulation 2, that reduction being more evident in the periods during which the gradient between inside relative humidity and the relative humidity of the mortar's surface was higher. In the periods during which the inside relative humidity variation showed higher amplitudes, the hygroscopic effect was also more visible.

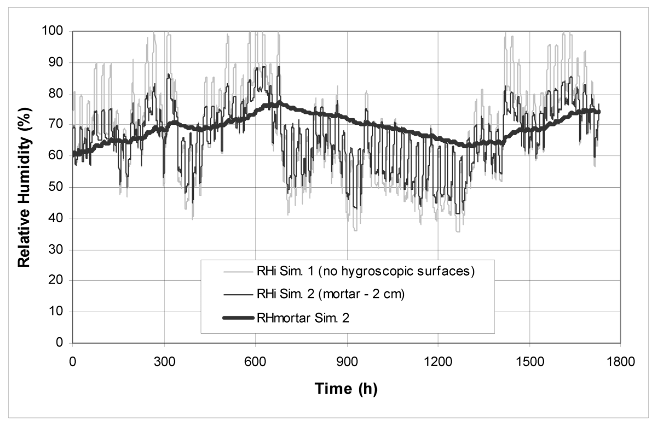

Figure 5 *Relative humidity in simulations 1 and 2 (inside air and mortar surface).*

Application of the Proposed Hygroscopic Inertia Classes Concept

The results from simulations 1 and 2 were used as an example for the application of the proposed concept of hygroscopic inertia classes. A statistical analysis of the results from both simulations revealed that the upper characteristic relative humidity value, corresponding to the 90% percentile, as defined earlier in this paper, would be 88.9% in simulation 1 and 79.5% in simulation 2. This means that the reduction in the upper characteristic value would be R = 9.4%, and, therefore, according to Table 1, the applied hygroscopic material would put us in a situation of medium inertia.

LABORATORY TESTS

Motivation

The proposed hygroscopic inertia classes, as well as the proposed numerical model, require an extensive knowledge of material behavior. We must keep in mind that knowledge of physical properties needed for numerical simulations is important but also that definition of the moisture buffer capacity of materials is desired because of the relation that can be established with the proposed hygroscopic inertia classes. The recent work of several researchers (Padfield 1998; Reick and Setzer 1998; Ojanen and Salonvaara 2003; Mitamura et al. 2001) and the conclusions from the NORDTEST Workshop on Moisture Buffer Capacity (Rode et al. 2003) inspired the specific tests that are presented in this paper. In these tests, several specimens of rendering materials are submitted to transient conditions of air humidity and/or temperature. The results of these experiments will help us to characterize the kinetics of mass exchange between air and materials and also provide a way of comparing different materials in terms of their contribution to the room's hygroscopic inertia.

Experimental Conditions

Based on the suggestions of the NORDTEST Workshop on Moisture Buffer Capacity—Summary Report, a laboratory test was prepared, where a specimen is submitted to a square wave in relative humidity with 12-hour steps and constant temperature. This experiment simulates the cyclic variations in moisture loads and relative humidity levels that can be found in bedrooms, for instance, where during the night there will be an increase in relative humidity due to vapor production by occupants.

The tests carried out at the laboratory tried to explore the importance of some of the variables that can interfere in the final results, such as materials themselves, relative humidity level, temperature level, amplitude of relative humidity variation, and the use of coatings.

The specimens used in the tests were stabilized inside a climate chamber at 20°C and 65% relative humidity. Afterward, each specimen was tested for a six-day period with a square wave of relative humidity, with 12-hour steps and constant temperature. The graphic displayed in Figure 6 exemplifies the cycles applied in these tests. The high value used for relative humidity was 85% in most of the experiments but also 75% was used. Two tests with 65%-85% relative humidity at 15ºC are also presented in this paper.

The option for these values of temperature and relative humidity relate to the reality of Portuguese dwellings. For the reasons stated in the "Introduction," inside temperatures are usually lower than the recommended limits, and as the outside air during winter is very humid and not too cold (average temperature around 10°C), the relative humidity inside dwellings will be high. As we intend to repeat these tests under several conditions, the first set was submitted to the somewhat extreme value of 85%.

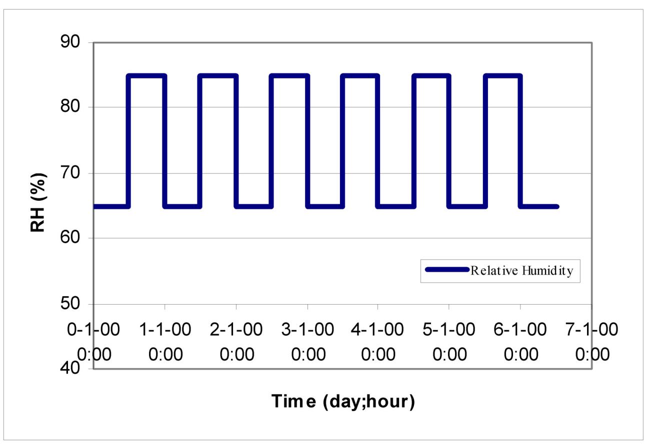

Figure 6 *Cycles of relative humidity variation inside the climatic chamber.*

To perform these experiments, a climate chamber was used, allowing for the control of temperature and relative humidity. A precision balance was located inside the chamber and linked to a computer, where the mass change was registered continuously.

The specimens consisted of 20×20 cm^2 or 15×15 cm^2 squares, with a vitrified back and sealed around the edges, leaving only one open surface.

Materials Tested

In these experiments, one option was using specimens of common materials used in Portugal as coverings on walls and ceilings. Therefore, several specimens were built using cement plasters, gypsum plasters, and gypsum plasterboards. Two of the cement plaster specimens were painted using common interior paints, and on one of the gypsum plaster specimens a pre-paint was applied. The specimens referred in this paper are listed in Table 2.

LABORATORY TEST RESULTS

Previous Data on the Specimens

The gypsum plasterboard and the cement plaster specimens used in these tests had already been used in previous experiments. That work (Freitas and Machado1999) supplied the information presented in Table 3, which consists of the maximum expected moisture adsorption for this variation of relative humidity. The gypsum plaster specimens were not tested at that time so we don't have that same information available.

Looking at these results, we could make the assumption that cement plaster would be a much more hygroscopic material then gypsum plasterboard, but we have to remember that these results refer to a process of stabilization at constant conditions for long periods of time.

Table 2. Materials Used in Experiments

Specimen	Test Material	Thickness (mm)	Density (kg/m^3)
1	Cement plaster (unpainted)	15	1950
2	Cement plaster (paint 1)	14	1950
3	Cement plaster (paint 2)	15	1950
4	Gypsum plaster (unpainted)	8	1340
5	Gypsum plaster (paint 3)	8	1340
6	Gypsum plasterboard	14	750

Table 3. Maximum Moisture Adsorption (85%-65% RH)

Specimen	Test Material	Moisture Content Difference (85%-65% RH) (g/m^2)
1	Cement plaster (unpainted)	148
2	Cement plaster (paint 1)	130
3	Cement plaster (paint 2)	142
4	Gypsum plaster (unpainted)	–
5	Gypsum plaster (paint 3)	–
6	Gypsum plasterboard	39

Tests Results

The series of tests performed on the specimens meant to analyze the response in terms of moisture content variation as a function of several different parameters. Each specimen was subjected to cycles of relative humidity variation similar to the one represented in Figure 6. The cement plaster (unpainted) and the gypsum plaster (unpainted) specimens were also subjected to a set of cycles of the same type as those but where the high relative humidity was only 75%. The temperature was kept constant at 20°C. Some of these tests were also repeated at 15°C, so that the influence of temperature level and vapor pressure level can be determined. For this paper, and apart from the tests performed at 20°C, only the results from cement plaster (unpainted) and gypsum plasterboard at 15°C were ready.

The graphics in Figure 7 show the mass variation registered in specimens of three different materials without coatings: cement plaster, gypsum plasterboard, and gypsum plaster. From the graphics we can see that gypsum plasterboard and gypsum plaster were the "most active" materials since they presented the highest daily mass variations.

The effect of paint was also studied. Regarding the paints applied in the specimens, we can say that paints 1 and 2 are commonly used paints in interior finishes of walls and paint 3 represents the application of a first coating that will prepare the surface for the actual painting. This technique is often applied with certain types of materials where the paint cannot be directly used. The paints' permeability has not been determined yet, but we know that paint 3 represents a much less permeable coating then the other two.

We can conclude from the graphics in Figure 8 that paint 1 does not change dramatically the hygroscopic behavior of the cement plasters in which it is applied. However, the cement plaster (paint 2) specimen showed a growing accumulation of moisture after each daily cycle, which indicates that this type of paint can have a sensible influence on the behavior of this revetment as a moisture buffer when we look at a weekly or

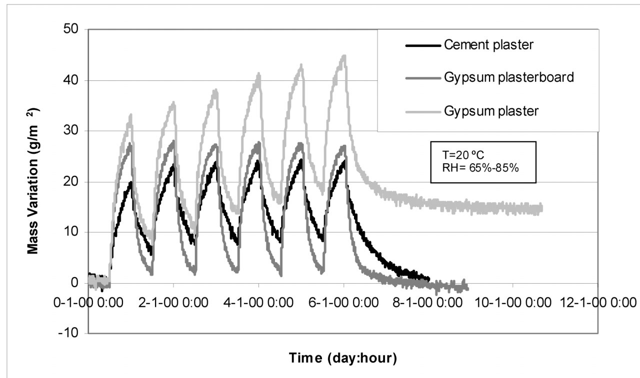

Figure 7 *Mass variation for three different materials.*

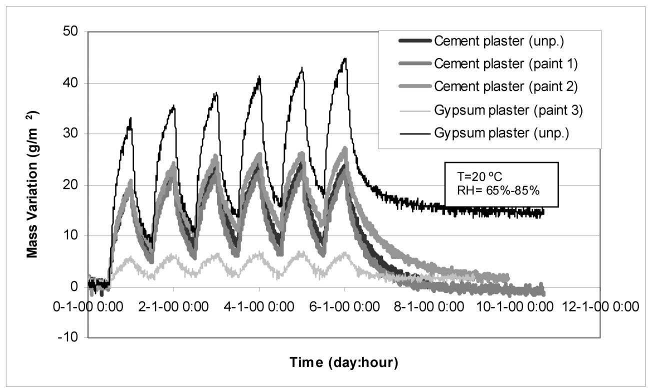

Figure 8 *Mass variation for different surface coatings.*

monthly cycle consisting of a repetition of these daily cycles. A deeper characterization of the vapor permeability of these paints is therefore needed, to set the boundaries for what we could call a "non-affecting paint."

The comparison of the unpainted gypsum plaster specimen with the painted one (paint 3) showed the highest differences. It was possible to see that the paintings applied nowadays in what used to be a material finished with more open pore coatings almost erased the buffer capacity that could be expected from this kind of solution.

Two different amplitudes of relative humidity variation were applied to the unpainted cement plaster and gypsum plaster specimens. The graphics in Figure 9 allow us to compare the behavior of the specimens in those two tests. The results show that the behavior of the specimen could be extrapolated from one test to the other, given a scale factor to multiply the set of values of one of the tests, but that scale factor is not proportional to the relative humidity difference. A reason for this result is the fact that the sorption curve usually has important differences for the slopes at these high relative humidity values (75% and 85%).

Table 4. Moisture Buffering Capacity Evaluation

Specimen	Test Material	Moisture Buffering Capacity (85%-65% RH) for a Daily Cycle (Average) (g/m^2)	Moisture Retention after 6 Daily Cycles (g/m^2)	Moisture Flux Density Coefficient γ ($g/m^2h\Delta Rhi$)
1	Cement plaster (unpainted)	16.1	8.5	0.25
2	Cement plaster (paint 1)	16.3	6.3	0.19
3	Cement plaster (paint 2)	15.3	13.0	0.21
4	Gypsum plaster (unpainted)	27.0	21.3	0.31
5	Gypsum plaster (paint 3)	4.1	2.5	0.03
6	Gypsum plasterboard	25.2	3.0	0.3

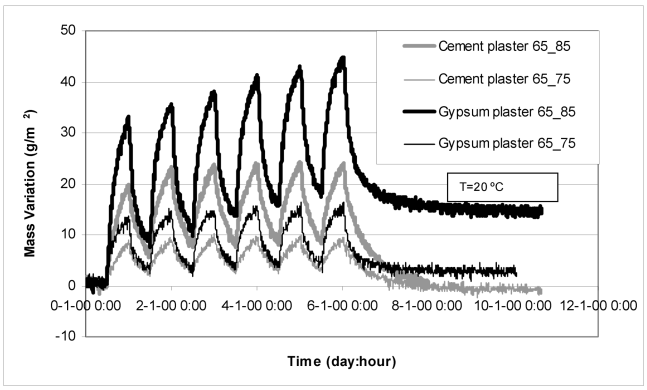

Figure 9 *Mass variation for cycles of different relative humidity amplitude.*

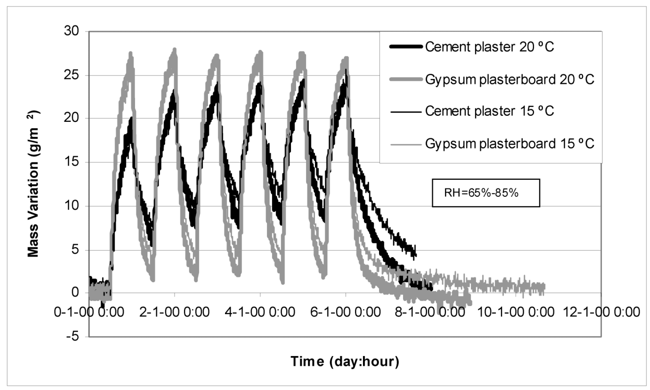

Figure 10 *Mass variation for cycles at different temperatures.*

The cement plaster (unpainted) and the gypsum plasterboard specimens were also tested at 15°C. The behavior of the specimens was not very different in the two tests, as can be seen in Figure 10. However, for the 15°C experiment, the lower peaks have a constant increasing value in both specimens. The reason for these differences can only be determined after more tests.

The results from the several tests presented can also be seen from a different perspective. If we wanted to characterize a material with a single number retrieved from these tests, which would represent its moisture buffer capacity, then the results would be the ones in the third column of Table 4. The moisture retention at the end of six full cycles is also presented. The last column contains the values of the moisture flux density coefficient γ (as defined above in this paper), calculated from the mass variation of the samples during the first hour of the first cycle.

DISCUSSION

The results from the laboratory tests presented above raise the following points of discussion.

1. The adopted test method allows for a comparison of different covering materials, facing a daily cycle of relative humidity variation.
2. If we try to compare these materials using the results summarized in Table 4, we would say that for the conditions of this test, the unpainted gypsum plaster revealed the highest moisture-buffering capacity, closely followed by the gypsum plasterboard. In the case of the gypsum plaster, this could be expected, as traditionally this material is regarded as a good buffer when compared to other renderings, but the gypsum plasterboard, on the contrary, is seen as having a low ability for moisture retention. We must bear in mind that for cyclic variations, such as the ones reproduced in these tests, a material that combines some moisture capacity with a high permeability can compete with others that have a higher moisture capacity but are less vapor permeable.
3. The analysis of the moisture retention after six daily cycles demonstrated that, for the adopted cycles, the gypsum plasterboard showed the closer return to the initial mass value after the tests, and, therefore, if we think of a room where actual cycles of relative humidity would persist thanks to an

effective ventilation system, this material would be very interesting to use as a buffer.

4. By applying the same logic, the unpainted gypsum plaster could then be regarded as a less interesting buffer because the fact that it kept accumulating moisture could be a turnoff for daily cycles if we consider the whole humid season, as from day to day it would see its capacity diminished. But from a different perspective we could say that in a real situation, where the high and low values for relative humidity are not constant, the possibility of buffering moisture during an extensive period or even the whole season could be an advantage.
5. In any case, the importance of the moisture-buffering effect of covering materials was demonstrated by these results. If we consider a bedroom with 12 m^2 area and one of the two more active materials applied in walls and ceiling, resulting in a 40 m^2 area for adsorption, after each "loading" cycle, that material would have buffered 1000 g of water (25×40).
6. The γ values determined from these tests and presented in Table 4 confirm that the average values used in the proposed model for relative humidity variation are valid, but there is still a long way to define the moisture transfer coefficients between the indoor air and the finish materials in a correct way.
7. The tests revealed that small variations of temperature (< 5°C) have a small influence in the overall results.
8. The use of certain kinds of paint can "erase" the buffer capacity of a material, and, therefore, there should be more research on this matter to try to define what is the limit value for the vapor permeability of a coating so that it won't diminish the moisture-buffering capacity of a rendering.
9. The use of a different gradient of relative humidity in the test demonstrated that we cannot easily transform the results of this kind of test in a number that is a function of the relative humidity difference (g/m^2 %RH). The value representing the moisture-buffering capacity has to be associated with the relative humidity difference that originated it.
10. The influence of the "history" of the specimen being tested must also be taken into consideration. The effect of hysteresis must be taken into account for certain materials. If we look at the end of the test with the gypsum plaster specimen, we can see that it stabilized above the departure point. This result stresses that for a possible standardization of this test, the effect of hysteresis should be considered and dealt with so that the number symbolizing the material's moisture-buffering capacity reflects the actual behavior of the material under cyclic loads.
11. As there are many variables involved (relative humidity values, amplitude of relative humidity variation, temperature level, and paints used) we should be careful in transforming these results to a single number that qualifies each material.

CONCLUSIONS

These are the main conclusions for this paper:

- A proposal for the definition of hygroscopic inertia classes was presented, based on the ability of a room's hygroscopic materials to reduce the upper characteristic value of relative humidity observed in a given period of time. These classes make the hygroscopic inertia concept more tangible and can be a way of supplying practitioners with easy-to-use information on this subject.
- The full definition of these classes demands more research, associated with a better knowledge of materials' buffer capacity, so that a relation can be established between the desired hygroscopic inertia class of a room and the technical solution that materializes it.
- A numerical model for relative humidity variation inside rooms had already been developed and, although it has to be tested, its results are encouraging. It demands deeper research on hygroscopic behavior of materials facing transient conditions, especially in the definition of the values for the moisture flux density coefficient used in the model.
- An experience of testing the response of materials under cycles of square variations of relative humidity was applied to typical Portuguese revetments. Although this kind of test is still far from standardization, some conclusions can already be pointed out after the discussion of the results.
- A number (or a few numbers) coming out of cyclic tests similar to the presented ones could be useful for the characterization of the moisture-buffering capacity of rendering materials because it would supply a link between those materials and the proposed hygroscopic inertia classes.
- Other results from the laboratory tests should also be pointed out, such as the low importance of small temperature differences and the great importance of paints and the relative humidity gradient used in the tests.
- As a final remark, we should stress once again that the importance of hygroscopic materials in the moderation of relative humidity variation was demonstrated by numerical simulation and laboratory tests.

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