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Moisture Admittance Model: Measurements in a Furnished Dwelling

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1 SYNOPSIS

The BRE method of predicting water vapour conditions in houses is based on two generalised moisture admittance parameters α and β. Previous laboratory experiments suggested that it is possible to determine these coefficients for an unfurnished room with wooden panels, using measurement periods of six hours under dynamic equilibrium conditions. The present study explores the possibility of using such conditions to determine α and β in-situ for the living-room and bedroom of a furnished flat of conventional construction. Dynamic equilibrium conditions were measured and used to calculate the moisture coefficients of both rooms. These were included in a simulation program based on the moisture admittance model developed by BRE, and compared with measurements for different scenarios: constant heat input, constant humidity input, both constant heat and humidity input.

Results show that α and β can be measured in real situations with an accuracy as good as in the laboratory, despite the widely differing materials involved in the process of absorption-/desorption. The mean deviation between measurements and predictions for the admittance model is about 30% lower than for the Loudon model. In addition some guidelines concerning the experiments in-situ are derived from the mathematical theory.

2 LIST OF SYMBOLS

ψ(in)=vapour content of the inside air, kg/kg
ψ(out)=vapour content of the outside air, kg/kg
ψ(svp)=vapour content of the air at saturation vapour pressure, kg/kg
G = rate of moisture input kg/hr
ρ=density of air, kg/m^3
v=volume of the rooms m^3
n=ventilation rate, air changes per hour
α=absorption coefficient
β=desorption coefficient

3 INTRODUCTION

BS5250 [1] and IEA Annex 14 [2] include simplified equations for the calculation of the internal moisture load, taking into account ventilation rates, moisture production rate and vapour pressure difference between indoors and outdoors. The IEA Annex 14 equation also includes the effect of temperature variations. In conformity with the Loudon model, neither equation accounts for any adsorption by the internal surfaces. However, absorption during periods of water vapour production would reduce the moisture load, while desorption at later times would increase the internal air humidity. Therefore, the predictions of the Loudon model would differ from reality both during and after the period of water production.

Many models have been developed which include absorption and condensation in the calculations. An overview of available models until 1988 mainly in Europe can be found in ref [3] and a calculation method is decribed in [4]. Many models have been also proposed from researchers in Canada and the US [5-8]. However, most of the models require the input of hygric properties of materials which are not readily available, especially in combinations usually found in the interior of the buildings. There are experimental results on the hygroscopic capacity of walls, floors, ceiling and furnishing [9-11] and published catalogues [12], but the data are not specific enough for the requirements of most moisture models.

An empirical equation has been developed by BRE [13] which takes into account absorption and desorption of internal surfaces. The equation uses two coefficients α and β to determine the overall rate of absorption and desorption in a room with some general characteristics. Work in a laboratory cell has produced a set of coefficients and a method of determining them for buildings, [13].

This project was initiated with the aim of measuring the coefficients α and β in an unoccupied furnished dwelling as a first step between laboratory and occupied building experiments. The study was intended to show whether the experimental procedure of dynamic equilibrium conditions, described by R. Jones [13], works in a typical furnished house, and whether it can be used to establish coefficients for a range of situations.

4 THE TEST HOUSE

The ground floor flat of a converted early century house in south London was selected as the test house for the following reasons:

- stable conditions need to be maintained for a relatively long time in the rooms of the home
- thick masonry walls have a larger hygric inertia in absorbing/desorbing moisture.

The flat consists of a living room, bedroom, dining area, kitchen and WC in an almost linear arrangement with a total floor area of approximately 55m^2. The construction of the external walls is brick, plastered on the inside, without any insulation, with a total thickness of 0.22m. The sash timber framed windows are single glazed. Heating is provided with a gas fired boiler and conventional radiators in every room. Ventilation is through operable windows and background infiltration. Measurements were taken in the middle of the living room and bedroom. In addition the external conditions were measured. Table 1 summarizes the various characteristics of the two rooms.

Table 1: Characteristics of the test house

	Living-room	Bedroom
dimensions (m)	4.30x4x3	3.65x2.45x3
floor area (m^2)	17.2	9
volume (m^3)	51.5	27
window area (m^2)	3.85 (7.7% of walls)	1.6 (4.4% of walls)
door area (m^2)	1.6 (3.2% of walls)	1.6 (4.4% of walls)
wall finish	emulsion painted wall paper	unpainted wall paper
ceiling	emulsion painted plaster	emulsion painted plaster

5 THE MEASUREMENTS

5.1 Conditioning period

A two weeks conditioning period was set up for both the living-room and the bedroom. During the first week, conditions were maintained as follows (all doors closed):

- living-room: constant temperature of about 17°C from 9am to 6pm, and
- bedroom: constant humidity of about 80%.

The conditions were changed during the second week as follows:

- bedroom: constant temperature of about 17°C from 9am to 6pm, and
- living-room: constant humidity of about 80%.

In addition to the two weeks of conditioning, moisture and heat inputs were performed in both rooms in order to collect data on their humidity performance under various scenarios. These monitored periods are discussed further in section 7. Tracer gas tests were also carried out to measure the air change rate during each dynamic equilibrium experiment.

5.2 Dynamic equilibrium

Throughout the project, a total of twenty four dynamic equilibrium experiments have been performed (twelve in each room) in order to calculate the coefficients α and β using the following equation from [13]:

$$d\psi(in)/dt = G/\rho v - n(\psi(in) - \psi(out)) - \alpha\psi(in) + \beta\psi(svp) \quad (1)$$

These experiments consisted of periods of 4 to 6 hours during which stable conditions of vapour pressure were achieved inside, using fan heaters, and outside weather permitting. Most of them were carried out around mid-day as the outside humidity conditions proved to be more stable at that time. Experiments were generally taking place in both rooms at the same time to optimize the site utilisation.

6 RESULTS AND ANALYSIS

6.1 Presentation of the results

Which conditions are suitable for coupling with the others would depend on the coefficients of the dynamic equilibrium equation. Two equations are needed to solve for α and β as follows:

$$\psi(in)_1\alpha - \psi(svp)_1\beta = -(n(\psi(in) - \psi(out)))_1 \text{ and} \quad (2)$$
$$\psi(in)_2\alpha - \psi(svp)_2\beta = -(n(\psi(in) - \psi(out)))_2 \quad (3)$$

We can solve for α and β provided that the determinant of the system is not zero, which implies:

$$\psi(in)_1 / \psi(svp)_1 \neq \psi(in)_2 / \psi(svp)_2 \quad (4)$$

Therefore one experiment would be suitable for coupling with another if the ratio of internal vapour pressure to internal saturation vapour pressure is different from another experiment. One way of achieving that is to heat the room to high temperatures.

On the other hand, the rooms could not be heated to very high temperatures because this would increase condensation risks on the windows because of desorbed moisture. For this reason, a compromise had to be reached between desirable and practical experimental conditions.

6.2 The coefficients selected

Following the previous remarks, it was decided to divide the experiments into three groups.
Group 1: experiments with a high vapour pressure ratio (about 0.65-0.70),
Group 2: experiments with a medium ratio (0.50-0.60), and
Group 3: experiments with a low ratio (about 0.40).
Each experiment of one group can be coupled with any experiment of another group to produce a set of coefficients.

One set of coefficients was calculated for each coupling of two groups by averaging the coefficients obtained by cross calculation for these two groups: groups 1&2, groups 1&3, groups 2&3. Finally, an average value was calculated from the three averages. The values obtained are presented in Table 2.

The results are similar for both rooms. More importantly the ratio of the two coefficients is the same in both rooms, α/β approximately equal to 1.5. Previous work carried out at BRE in rooms lined with wood panels, found coefficients within a range 0.5-0.66 for α and 0.35-0.45 for β. We can reasonably expect higher numbers for the rooms investigated here as both hygric inertias are higher (due to thick masonry walls, wooden furniture and curtains).

Table 2: The α and β coefficients

	α	β
Living Room	0.76	0.50
Bedroom	0.68	0.45

7 COMPARISON OF MEASURED AND PREDICTED DATA

7.1 Living room

Figs 1-3 present typical cases of increased vapour pressure in a space due to internal conditions rather than the influence of the external conditions. Fig 1 presents the conditions for the case when water vapour and heat were added to the room. Fig 2 is the case when water vapour was added without heat, and Fig 3 presents the case when heat was added without water vapour. In all cases the ventilation rate is 0.6 ach, an average value for the living room.

It can be seen from the graphs that the predictions using the moisture admittance model [13] are closer to the internal measured values than the Loudon model predictions. In particular, the predictions of the moisture admittance model follow very closely the measured values curve in the case 3, where the temperature was increased in the living room but no water vapour was released. This case indicated the necessity of including a desorption coefficient in any equation predicting the moisture load of a space.

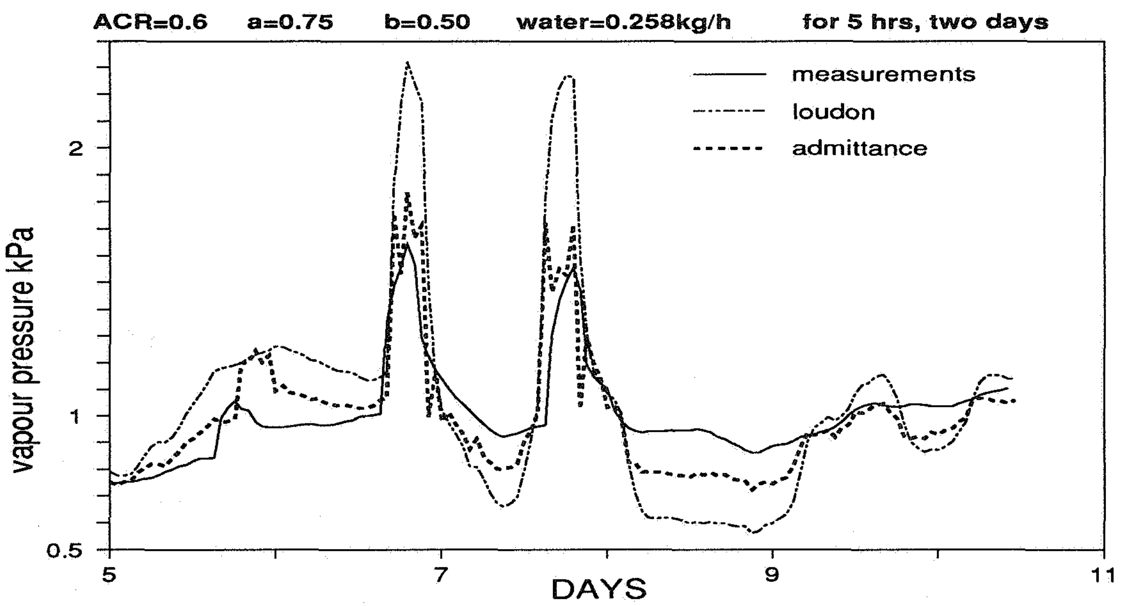

Figure 1: Measured and predicted vapour pressure in an unoccupied living room. Water vapour and heat are added for five hours during the 6th and 7th day.

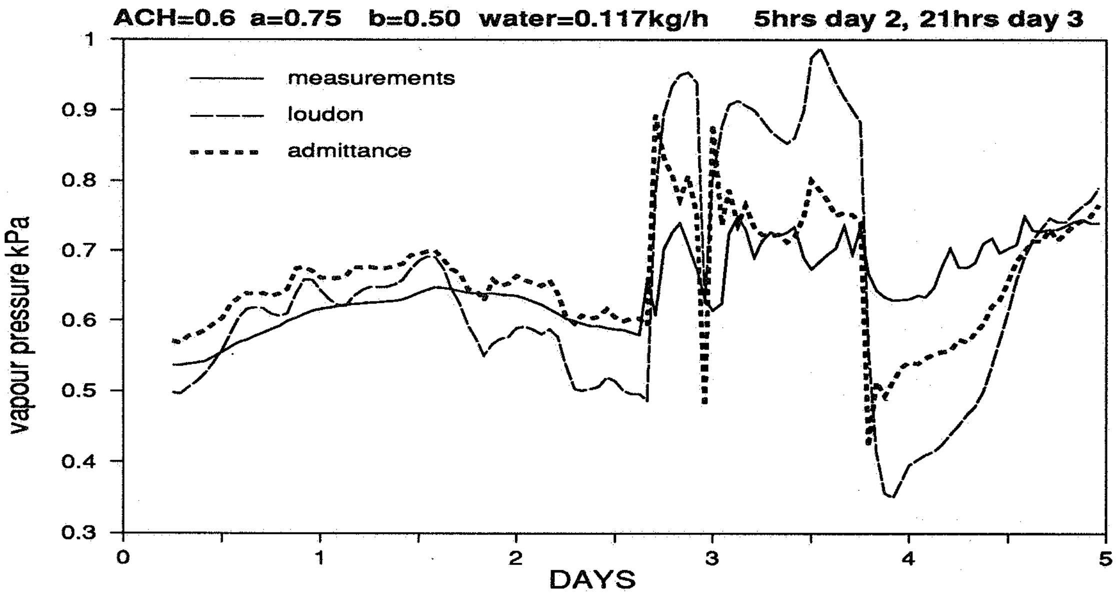

Figure 2: Measured and predicted vapour pressure in an unoccupied living room. Water vapour is added for 5 hours during the 2nd day and 21 hours during the 3rd day.

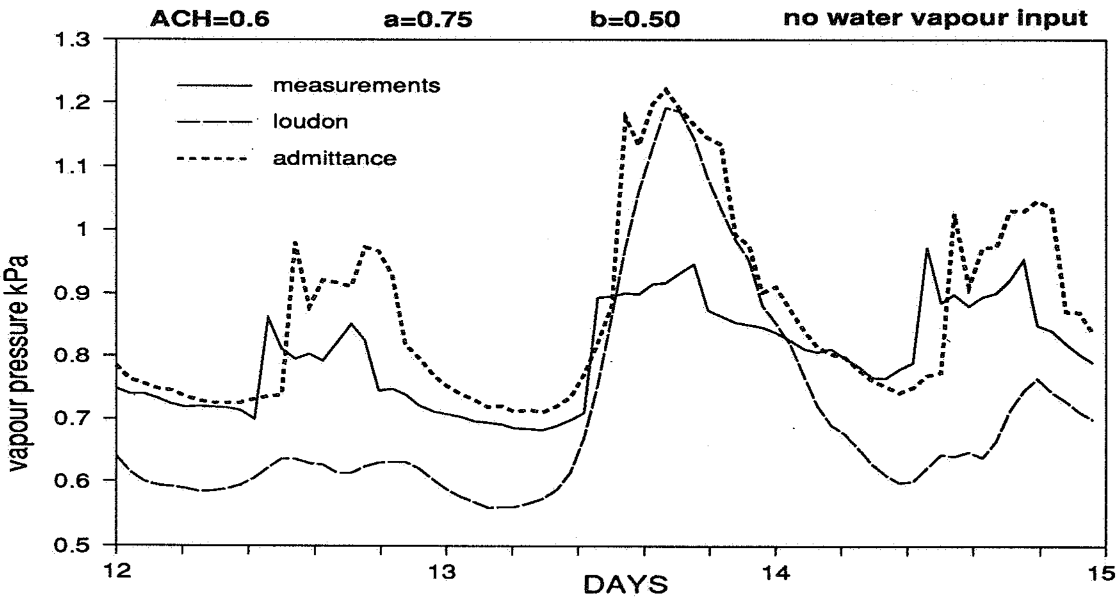

Figure 3: Measured and predicted vapour pressure in an unoccupied living room. Heat is added for 10 hours during the 12th, 13th and 14th days.

A further statistical analysis was carried out to compare the predictions of both the Loudon model and the moisture admittance model to the measured values. This analysis used the same data as those used for cases 1 to 3, in order to treat different situations. In table 3, the mean deviation represents the average absolute difference between either Loudon or admittance predictions and measured values. This gives a figure representative of both over/under estimations of the measurements. The percentage of error is the ratio of this mean deviation to the average of measured values.

Table 3: Mean deviation and percentage of error of predicted values compared to measurements for the living-room

Living-room	Case 1 Loudon	Case 1 Admitce	Case 2 Loudon	Case 2 Admitce	Case 3 Loudon	Case 3 Admitce
Mean deviation (kPa)	0.221	0.109	0.1	0.06	0.143	0.087
% of error	22.5%	10.8%	16.5%	9%	18%	11%

Table 3 highlights the accuracy gained by the use of the admittance model for which the percentage of error is between half and two third of the one achieved with Loudon model. But it should be noted that the statistical analysis was carried out on all the data used for the various figures and not only on the specific periods of production of water vapour or heat. Figures 1 to 3 suggest that the difference of accuracy is much higher for these particular periods.

7.2 Bedroom

Similar results were obtained for the case of the bedroom and are presented in Figure 4.

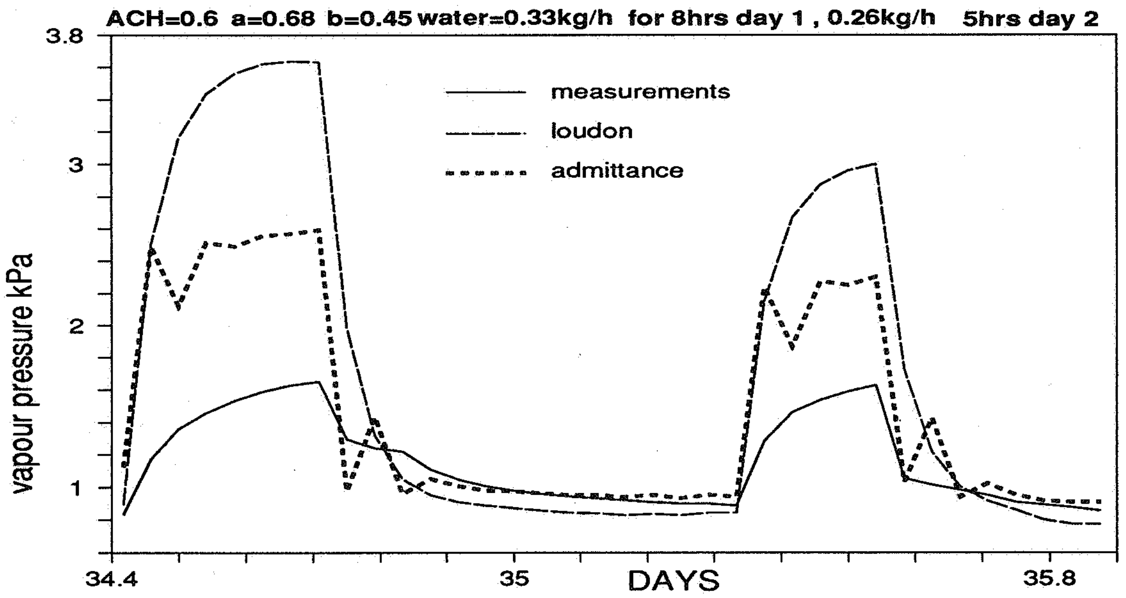

Figure 4: Measured and predicted vapour pressure in an unoccupied bedroom. Water vapour and heat added for eight hours in the first day and five hours during the second day.

The difference between the admittance model predictions and measured values is bigger in the bedroom than in the living room. This is mainly due to condensation occurring more frequently in the bedroom because of the smaller volume and the colder weather during monitoring. It is observed that the moisture admittance model predictions become flat at a certain point in Fig 4. This is the saturation vapour pressure point for the internal conditions. Therefore, the moisture admittance model predicts realistic values unlike the Loudon model. It is suggested that the remaining difference from the measured values is due to condensation on the cold window surfaces.

As expected, the mean deviations are higher for the bedroom than for the living-room. The reason, as explained, might be the condensation which occured on the window. But the percentage of error for the admittance model is still between half and two thirds of the Loudon one. A similar ratio was found for the percentage of error betwen the two models for the living-room, which might suggest that the admittance model reduces the inaccuracy of the Loudon model by 30 to 50%.

Table 4: Mean deviation and percentage of error of predicted values compared to measurements for the bedroom

Bedroom	Case 1 Loudon	Case 1 Admitce	Case 2 Loudon	Case 2 Admitce	Case 3 Loudon	Case 3 Admitce
Mean deviation (kPa)	0.63	0.35	0.5	0.27	0.2	0.13
% of error	55%	30%	42.5%	25.5%	20%	13.5%

8 CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

This study showed that it is possible to determine the coefficients for the moisture admittance model by performing equilibrium condition experiments in unoccupied rooms. The experiments suggested that for the cases of masonry construction with soft furnishing, the coefficients are similar to the wood lined test cell.

The mathematical theory to solve the dynamic equilibrium equations and the accuracy of the equipment, impose different ratios for $\psi(in)/\psi(svp)$. This can generally be achieved by heating the room to higher temperatures during one experiment. However, too much heating could increase the risks of condensation on windows and cold bridges and ruin the results as condensation is not taken into account by the moisture admittance model from which α and β are derived.

Therefore it is recommended that one experiment be carried out with no heating at all, and one with as much heating as possible provided that there is no condensation in the room. This should provide a satisfactorily large difference between the two ratios. Our results suggest that a difference of 0.1 is enough to achieve a relatively good accuracy. Outside conditions were also very important in establishing the dynamic equilibriums. Most of the experiments were conducted around mid-day as outside conditions proved to be more stable at that time. This should be taken into consideration for further work.

The moisture admittance model, being an empirical equation, relies on the availability of a range of coefficients which can be used for various building constructions, operation, heating regimes and moisture production. Monitored data gathered in the unoccupied furnished test dwelling of the present study have shown that the model can be successful in predicting the internal moisture conditions. The results obtained were in all cases a significant improvement on the "Loudon" prediction method. However in some cases the predicted values of vapour pressure were not as close to the measured values as had been hoped for. For this model to be useful as a prediction tool better agreement is required. As an alternative to deriving the coefficients by the dynamic equilibrium technique a method using optimised curve fitting is underway.

Moisture data from various spaces with different adsorption characteristics and different constructions need to be gathered and compared with the predictions of the moisture admittance model so that a complete set of coefficients is created. In addition, it is expected that seasonal variations might affect the adsorption capacity of the surfaces. Work is under way to gather humidity data in various situations. It is anticipated that these will help in the development of a curve fitting model which will assist in determining coefficients for a wide range of available data from many sources. This will help in compiling a complete set of coefficients applicable to situations faced by designers. This approach agrees with the conclusions of similar studies undertaken by EDF [14].

Other spaces apart from the main living spaces of dwellings could be investigated such as crawl spaces, attics, under-stairs storages and garages. The prediction of humidity variations in such rooms could be helpful in determining the required ventilation rates to avoid a build-up of moisture which could lead to structural damage.

The development of more advanced humidity measuring techniques would be beneficial in detecting any problematic areas in large spaces, such as cathedral roofs and attics, or zones which are difficult to reach, such as crawl spaces. Such techniques could consist of equipment to survey wide sweeps and volumes of humidity instead of point measurements.

Finally, work should be carried out to investigate whether the "flywheel" hygric effect of wall surfaces (analogous to the flywheel thermal effect wall-mass), may be used to reduce humidification/dehumidification loads in commercial buildings.

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