

Summary This paper proposes a 'moisture admittance' model which accounts for the moisture absorption and desorption processes for predicting humidity levels in buildings. The experimental method whereby the required coefficients were derived is described and some examples of the results are given. The approaches to real buildings, as opposed to test rooms, and possible modifications to BREDEM are briefly discussed.

Modelling water vapour conditions in buildings

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List of symbols

- A Surface area (m^2)
 g Absolute humidity of air ($kg\ m^{-3}$)
 G Rate of moisture input ($kg\ h^{-1}$)
 k Humidity or mass transfer coefficient ($kg\ m^{-2}\ h^{-1}$) ($kg\ kg^{-1}$)
 m Mass of water transferring between a material surface and air (kg)
 n Ventilation rate (ach^{-1})
 p Vapour pressure of air ($1\ mb = 100\ Pa$) ($kg\ m\ s^{-2}\ m^{-2}$ or $kg\ s^{-2}\ m^{-1}$)
 RH Relative humidity (%) $p/p_{svp} \times 100$ or $\Psi/\Psi_{svp} \times 100$
 RH_s Surface relative humidity or surface activity
 U Moisture content (humidity ratio) of a material ($kg\ kg^{-1}$)
 v Volume of the room (m^3)
 Ψ_{in} Vapour content (humidity or mixing ratio) of the inside air ($kg\ kg^{-1}$)
 Ψ_{out} Vapour content of the outside air ($kg\ kg^{-1}$)
 Ψ_s Vapour content of the air layer adjacent to a surface ($kg\ kg^{-1}$)
 Ψ_{svp} Vapour content of the air at saturation vapour pressure ($kg\ kg^{-1}$)
 ρ Density of air ($kg\ m^{-3}$), the value of 1.2 is normally used.

1 Introduction

The current recommended method of evaluating indoor humidity is based on the mass balance between the humidity generation rate and humidity loss due to ventilation. No account is taken of moisture absorption and desorption by the interior surfaces and furnishings. However, as much as one third of the water vapour generated in a room can be absorbed by its surfaces, so ventilation rates necessary to control humidity levels can be considerably over estimated.

The theoretical modelling of moisture absorption rapidly becomes very complex, involving assumptions and uncertainties which are impractical to assess. Such sophisticated models are not useful when quick 'rule-of-thumb' estimates of humidities are required. A model was sought which had the practicality of the thermal admittance procedure, which is a simple method for predicting indoor temperatures. The thermal admittance factors account for the thermal energy going to storage in the building fabric, so in the same way the term *moisture*

admittance is proposed to account for moisture going into or coming from storage. The term moisture admittance is also useful when referring to either the absorption or desorption effect.

As a result of a great many experiments in test rooms at BRE a simple model was evolved which satisfactorily predicted the humidity levels for a wide range of temperature and moisture regimes. This model, its theoretical background, and methods for evaluating the coefficients necessary for its implementation are described here.

In this paper the following terminology is used: water is water in the liquid state; water vapour is water in the strictly gaseous state; moisture refers to water in either state, or a mixture of both. The term sorption covers both the absorption and desorption processes.

The humidity formulae and conversion factors which have been used in this study are given in Appendix 1.

2 Fundamental humidity equations

This section gives the humidity theory and equations which justify the simple absorption/desorption model which was adopted. Various other equations were explored but the one described here gave the best results when used to compare the experimental measurements with theoretical predictions.

The basic model that Loudon used⁽¹⁾ assumes a steady-state mass balance between the water vapour being generated within a space and water vapour ventilated to outside. The mean inside vapour pressure is derived from the following equation,

$$\bar{G} = n\rho v(\bar{\Psi}_{in} - \bar{\Psi}_{out}) \quad (kg\ h^{-1}) \quad (1)$$

where $\bar{\Psi}_{in}$ is the mean inside air vapour content ($kg\ kg^{-1}$), and $\bar{\Psi}_{out}$ is the mean outside air vapour content ($kg\ kg^{-1}$).

The equation for dynamic conditions is as follows:

$$\frac{d\Psi_{in}}{dt} = \frac{G}{\rho v} - n(\Psi_{in} - \Psi_{out}) \quad (kg\ kg^{-1}\ h^{-1}) \quad (2)$$

To account for the absorption or desorption of water vapour between the air and materials a term is introduced which defines the mass of water transferring per unit time:

$$\frac{dm}{dt} \quad (kg\ h^{-1})$$

Assuming a net absorption of water vapour into the surfaces, equation 2 becomes

$$\frac{d\Psi_{in}}{dt} = \frac{G}{\rho v} - n(\Psi_{in} - \Psi_{out}) - \frac{(dm/dt)}{\rho v} \quad (3)$$

Water vapour will transfer to or from a material if there is a difference in vapour concentration between the air layer at the surface of the material and the bulk of the air. The rate of transfer per unit area is determined by the mass transfer coefficient k . The absorption/desorption rate is therefore:

$$\frac{dm}{dt} = kA(\Psi_{in} - \Psi_s) \text{ (kg h}^{-1}\text{)} \quad (4)$$

The values of k and Ψ_s prove difficult to evaluate. The term k is defined in text books by the Lewis relationship, and is usually assigned a value of $3 \text{ kg m}^2 \text{ h}^{-1} \text{ (kg kg}^{-1}\text{)}^{(2)}$. However, because it is dependent on the air flow rates across the surface and the type of surface, the value appropriate for a ventilated, heated room is likely to be different from a value measured in a sealed environmental test chamber.

The usual method of deriving a value for the vapour pressure at the surface layer Ψ_s makes use of sorption isotherms. The vapour pressure at the surface of a given material is determined by the moisture content of that material, U . Sorption isotherms relate the moisture content U to the relative humidity of the air in equilibrium with it. An example for pine wood is shown in Figure 1⁽³⁾. These curves are determined experimentally by weighing samples of material in atmospheres of controlled humidity. It follows that if the moisture content of the material is known, the relative humidity at the surface RH_s can be found using the appropriate isotherm. The surface relative humidity is also referred to as the surface activity.

In the particular case when the surface temperature and the air temperature are equal, the surface vapour pressure is

$$\Psi_s = RH_s \Psi_{svp} \quad (5)$$

where Ψ_{svp} is the saturation vapour pressure of the bulk air.

Under these conditions of equal air and surface temperatures, the dynamic equation for the inside vapour pressure, equation 3, may be written as follows:

$$\frac{d\Psi_{in}}{dt} = \frac{G}{\rho v} - n(\Psi_{in} - \Psi_{out}) - \frac{kA}{\rho v} (\Psi_{in} - RH_s \Psi_{svp}) \quad (6)$$

This equation models the vapour pressure in terms of the following parameters: the moisture transfer coefficient k , which can vary with air flow rates; the ratio of surface area to room volume A/v ; the relative humidity at the surface of the material RH_s ; and the saturation vapour pressure of the indoor air Ψ_{svp} .

It should be noted that the saturation vapour pressure Ψ_{svp} is a function of room temperature, see the Magus formula in Appendix 1, so the absorption/desorption rate is fundamentally temperature-dependent.

3 Experimental investigation of moisture admittance

To study the moisture admittance effect, two experimental rooms were arranged so that the internal temperatures, internal and external vapour pressures, ventilation rates and moisture input rates could be measured. One room was used to demonstrate conditions of zero moisture admittance, i.e. the conditions predicted by the Loudon model. This room had all the surfaces covered with metallic foil. The other room had walls and ceiling uniformly lined with pine match-boarding to give

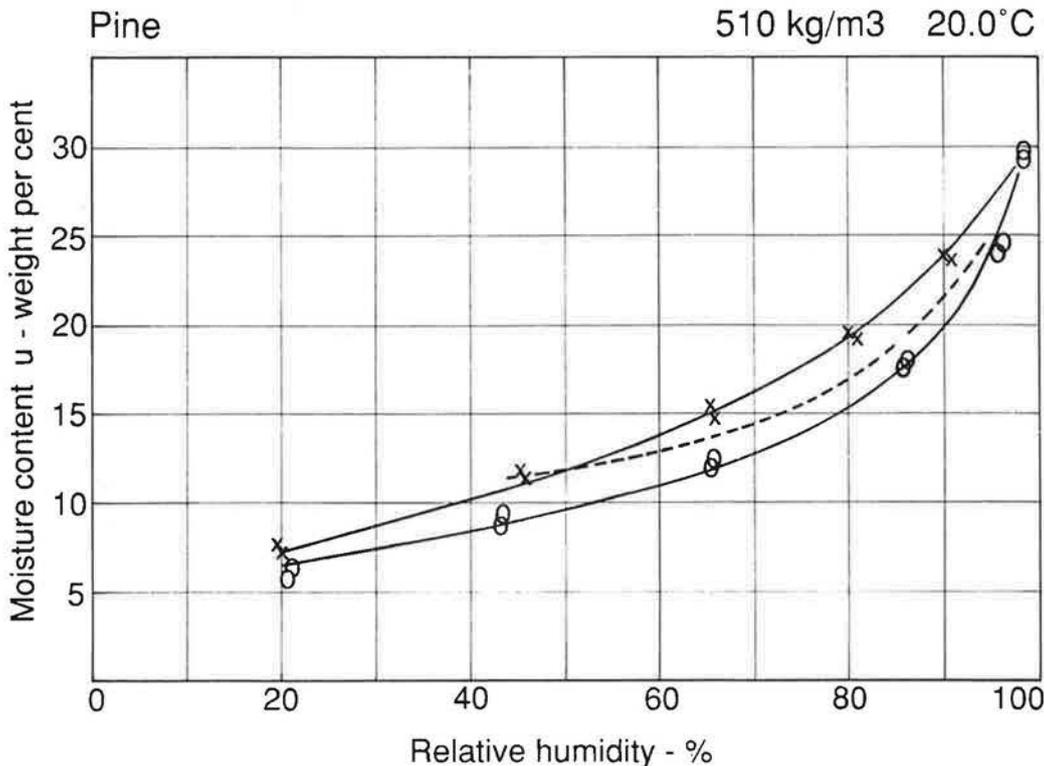


Figure 1 Sorption isotherm for pine wood from the Sorption isotherm catalogue, Technical University of Denmark⁽³⁾.

high moisture admittance. The results quoted in this section were produced in the wood-lined room. The details of the room are listed in Appendix 2.

At the time the experiments were designed it was decided to measure the vapour pressures in millibars, so the results quoted in this paper are expressed in these terms. Where conversion factors were required, those given in Appendix 1 were used.

The following types of experiments were made in the rooms:

- maintaining constant temperature at various levels
- changing the temperature slowly (i.e. about 5°C per day)
- steady moisture input at constant temperature
- cycling the temperatures (8 hours heating, 16 hours cooling down)
- cycling moisture input at constant temperature
- cycling moisture input together with cycling temperature.

As a result of these experiments the moisture admittance behaviour of the rooms became known empirically, but this needed to be modelled theoretically. To do this a finite-difference computer program which incorporated equation 6 was written to predict indoor humidities under dynamic conditions. The inputs to the program were:

- the measured values of outside vapour pressure
- the ventilation rate
- the moisture generation rate
- the inside temperature.

The time interval was five minutes and the maximum simulation period was five days.

The program was used to predict the humidity levels using equation 6 and also the Loudon model, with zero moisture admittance (equation 2). These were compared with the experimentally determined values.

Examples and results from the six types of experiment are now discussed.

3.1 Maintaining constant temperature

When the temperatures were held constant in the wood-lined room (with no moisture input and low ventilation rates), the vapour pressure of the air tended to remain remarkably constant for periods as long as a week. These periods were considered to be conditions of dynamic equilibrium because the moisture gains or losses due to the finite ventilation rate were balanced by moisture absorption or desorption from the fabric. Two examples measured when the external vapour pressure was around 10 mb are:

- inside temperature 6°C, equilibrium vapour pressure 5 mb
- inside temperature 35°C, equilibrium vapour pressure 28 mb.

This demonstrated that there was an overall absorption effect at low temperatures and a desorption effect at high temperatures. It also showed that the absorbant room had a large moisture capacity. Although ventilation rate was low, around 0.2 ach⁻¹, over the extended period of an experiment several litres of water were lost or gained

without making a significant difference to the equilibrium vapour pressure.

3.2 Changing the temperature slowly

As the temperature was raised slowly, at a rate of about 5°C per day, there was a steady increase in vapour pressure. A plot of vapour pressure against temperature produced a continuous line showing a tendency to maintain a constant relative humidity. An example is shown on a psychrometric chart, Figure 2. Here, a rise in temperature from 11°C to 28°C produces a change in relative humidity from 50% to 40%. Without the desorption of moisture, the change in relative humidity can be deduced by moving horizontally across the psychrometric chart from 11°C, 50% RH to 28°C. The change in relative humidity would be from 50% to 20%.

Such a trace was considered to be a locus of the equilibrium states described in experiment 1 above. When the room was cooled slowly after it had been heated, the cooling line was not significantly different from the heating line.

3.3 Steady vapour input at constant temperature

The experiments when water vapour was introduced at steady rates into the foil-lined room and the wood-lined room at constant temperatures demonstrated empirically the absorption effect of the wood decreasing the humidity level and holding it constant for a number of days. Problems with condensation on the windows and the rapid onset of mould growth precluded the use of this type of experiment to collect useful data.

3.4 Cycling the temperature

When the room was heated for 8 hours with a fan heater and allowed to cool down for 16 hours, i.e. daily cycling

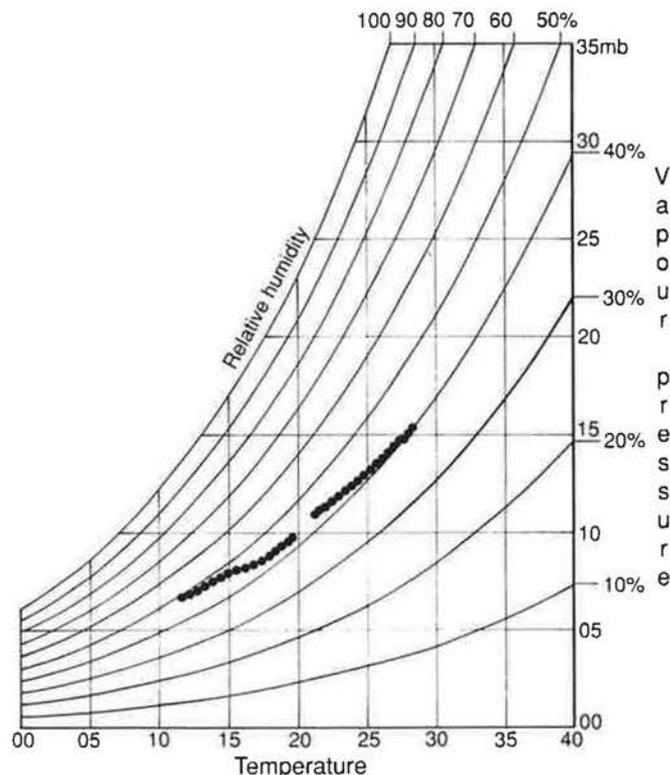


Figure 2 Psychrometric chart showing the locus of the equilibrium states for the wood-lined room

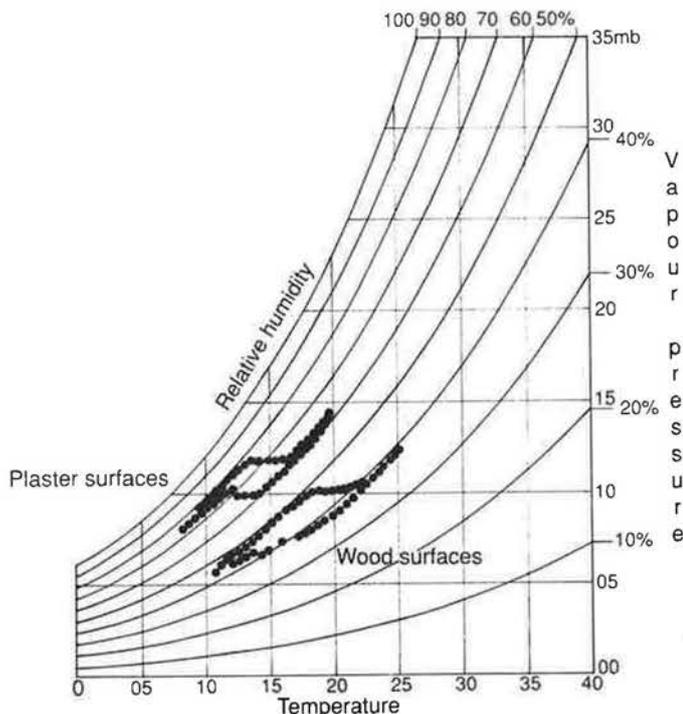


Figure 3 Psychrometric chart showing the hysteresis loops for temperature cycles in the wood-lined and plaster rooms

temperature conditions, the changes of vapour pressure followed the temperature changes very precisely. Figure 4 shows an example of the measured and simulated profiles of vapour pressure. The moisture admittance model gives results which coincide with the measured values, in contrast to the Loudon model. The trace given by the Loudon model should in theory be a horizontal line but the variation seen here is due to the variation of the outside vapour pressure. When the measured temperature and vapour pressure values were plotted on a psychrometric chart the resulting plot was invariably some form of hysteresis loop. Examples of these are given in Figure 3. One loop was obtained in the wood-lined room and the other in a plaster-lined room of similar dimensions. The lower portion of the loop shows the temperature rising; the vapour pressure is lower than

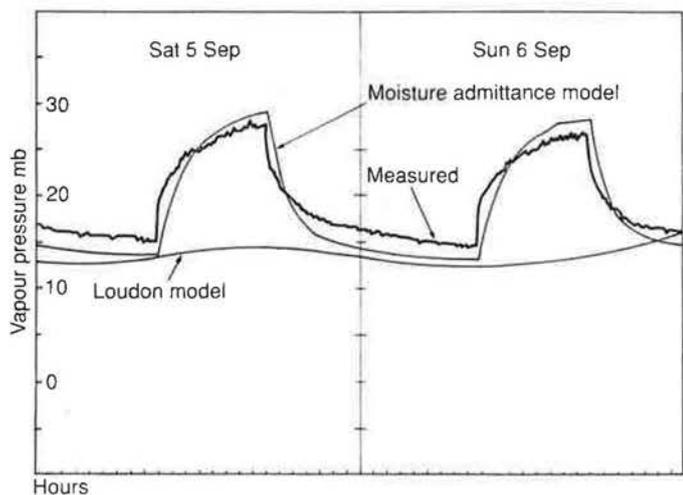


Figure 4 Comparison between the measured vapour pressure and the predictions by the Loudon and moisture admittance models for conditions of cycling temperatures

when the temperature is falling, which is the upper part of the loop. The shape of such loops depends principally on the rate of temperature change, the ventilation rate and the materials in the room.

All hygroscopic materials exhibit some degree of hysteresis but this would not account for the considerable differences observed. It is suggested that the rate of moisture absorption/desorption via the surface layer is greater than the moisture diffusion rate inside the material. When the room conditions change rapidly the absorption/desorption rates also change. During the desorption process the surface layer is soon stripped of moisture and there is a time delay before more moisture diffuses from the interior of the material to the surface. In a similar way when the surface layer becomes saturated during absorption, there is a delay before the excess moisture diffuses into the material and further moisture can be absorbed. These lags would account for the variation in rates which causes the hysteresis effect. When the conditions in the room change more slowly, as in experiment 2, the hysteresis is not so evident because the diffusion rate is closer to the absorption/desorption rate.

3.5 Cycling vapour inputs at constant temperature

Water vapour was introduced into the wood-lined room at constant temperature using a wheel evaporator type humidifier. Although there was no heating in some of the experiments, condensation and mould growth problems did not occur. Figure 5 shows a measured vapour pressure profile and the simulations obtained by the two models. The attenuation of the humidity by the absorption effect is seen by comparing the Loudon simulation with the other two traces.

3.6 Cycling vapour input together with cycling temperatures

In these experiments the temperature was cycled, with high maximum temperatures of about 30°C. Water vapour was input from an evaporator during the heating period. Figure 6 gives the three profiles for vapour pressure: the measured, moisture admittance and Loudon simulations.

For these conditions the overall moisture admittance effect becomes minimal because as the temperature

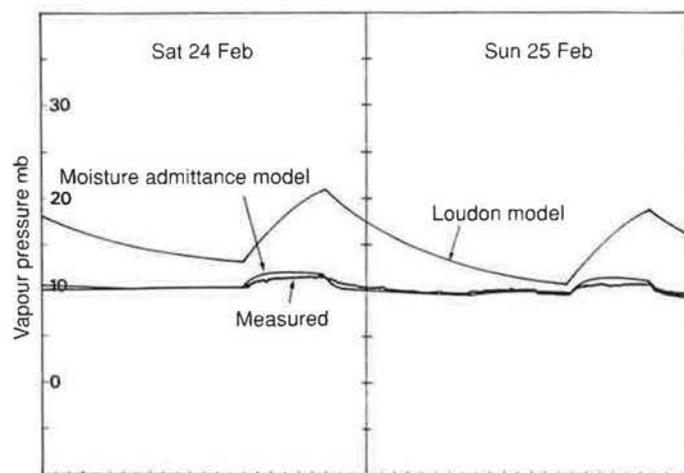


Figure 5 Comparison between the measured vapour pressure and the predictions by the Loudon and moisture admittance models for conditions of cycling moisture inputs with steady temperatures

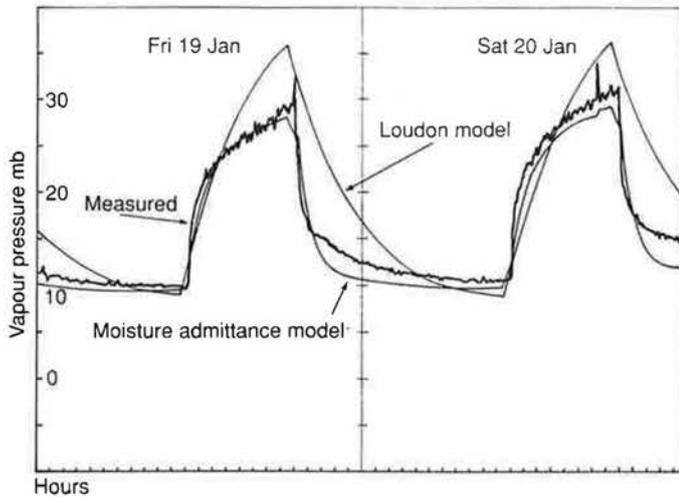


Figure 6 Comparison between the measured vapour pressure and the predictions by the Loudon and moisture admittance models for conditions of cycling temperatures and moisture inputs

increases the desorption rate also increases while the absorption rate decreases. Consequently the Loudon simulation is not so far away from the measured trace as in the previous two cases.

4 Evaluation of the admittance terms

To generate the dynamic simulations with the computer program using equation 6 values of RH_s and k were required. Because of the particular conditions in the wood-lined room the following assumptions were made:

- all the moisture absorbing surfaces were the same uniform material
- the surfaces were at a uniform temperature
- the air and surface temperatures were equal.

It followed that the moisture admittance performance of the whole room could be defined by single values of RH_s and k .

The range of the surface activity RH_s is 0 to 1.0, but the range expected in a room under normal conditions might be 0.3 to 0.8. In practice it proved possible to obtain the value of the surface relative humidity RH_s using a device known as a surface or floor hygrometer⁽⁴⁾. This measures the relative humidity of a pocket of air in equilibrium with the surface. The instrument used was a humidity sensor fixed inside a metal cone which was sealed with Blu-Tack[®] against the surface to be measured. After a few hours the humidity reading became steady and this stayed constant during the period of the experiment.

This left the parameter k , the vapour transfer coefficient, to be evaluated. Two methods were used:

- (a) running the *dynamic simulation* computer program with a range of values of k to get a best fit with the measured data
- (b) using data from the *dynamic equilibrium* conditions to derive k from the steady state equation.

4.1 Dynamic simulation

The simulation program calculated values of the inside vapour pressure every five minutes for a period of up to

five days and this was compared directly with the measured data for that period. Maximum and minimum values of vapour pressure were readily compared, but it was also important to compare the rates of absorption or desorption (given by the slopes and shape of the vapour pressure trace) during the temperature or moisture input cycles.

Figure 7 gives an example of this procedure. It shows the vapour pressure trace measured during four heating cycles with no vapour input, ventilation rate = 1.0 ac h^{-1} and $RH_s = 0.50$. Simulations of vapour pressure traces with k assigned values of 0.5, 0.7 and 1.0 are shown alongside the measured trace. Here the most appropriate value of k is 0.7 when judged by eye. Analysis of further cycles using different ventilation rates and varying temperature and moisture inputs gave an average value for k of 0.7.

4.2 Dynamic equilibrium conditions

This method required a period of about six hours when the outside vapour pressure was reasonably steady.

As mentioned in the previous section, when the room was maintained at constant temperature, with a steady ventilation rate, no moisture input, and no condensation, the vapour pressure stayed virtually constant. Equation 6

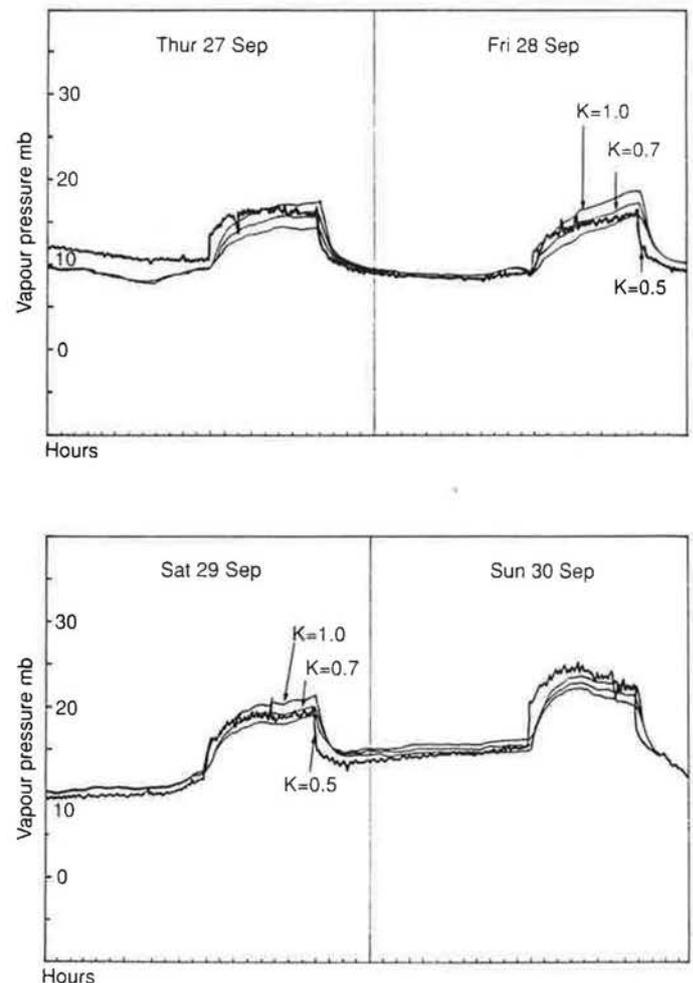


Figure 7 Comparison between the measured vapour pressure and that predicted by the moisture admittance model for values of $k = 0.5$, 0.7 and 1.0

for this dynamic equilibrium becomes:

$$\frac{d\Psi_{in}}{dt} = 0 = -n(\Psi_{in} - \Psi_{out}) - \frac{kA}{\rho v} (\Psi_{in} - RH_s \Psi_{svp}) \quad (7)$$

that is:

$$n(\Psi_{in} - \Psi_{out}) = \frac{kA}{\rho v} (RH_s \Psi_{svp} - \Psi_{in}) \quad (8)$$

If the ventilation rate n and the surface water activity RH_s are measured then one equilibrium case provides a value for k . If only n can be measured then two equilibrium cases provide simultaneous equations which give values for both RH_s and k . The inevitable accumulation of inaccuracies in the measurements and small changes in the ventilation rate and outside conditions during the measuring periods must preclude the use of three equilibrium cases to obtain the three unknowns.

This calculation procedure depends on finding periods of steady outside conditions coinciding with the periods of inside equilibrium conditions. The length of these periods is a function of the ventilation rate; for example, at least 4 hours steady outside vapour pressure is needed when the ventilation rate is 1 ach^{-1} . The accuracy of k can be only as good as that of the ventilation rate, and it is also dependent on three measurements of vapour pressure, and since the humidity sensors can be some 2% out from each other, the accuracy of k must be expected to be significantly less than that of the measured ventilation rate.

An example of a dynamic equilibrium experiment is shown in Figure 8. The temperature is raised to 20°C (point C) and maintained at this level for half a day, then increased again to 34°C , when it is held steady (point D). The trace from A to B is the surface hygrometer plot, which shows the surface relative humidity RH_s to be around 70%. In this example the ventilation rate is high, between 1.1 and 1.2 ach^{-1} , so the equilibrium points are not spectacularly constant. However the results obtained in these cases of high ventilation rates proved better than those when the ventilation rates were low, say under 0.1 ach^{-1} .

Appendix 3 shows the calculation procedure for k when RH_s is measured and Appendix 4 shows the calculation when RH_s is unknown.

Steady state conditions were also achieved after a few hours of steady input of water vapour. A moisture generation term is added to equation 8, thus

$$n(\Psi_{in} - \Psi_{out}) - \frac{G}{\rho v} = \frac{kA}{\rho v} (RH_s \Psi_{svp} - \Psi_{in}) \quad (9)$$

These runs, an example of which is given in Appendix 5, demonstrated the validity of the equation, but it proved more difficult to get good equilibrium conditions because of the added complication of maintaining steady evaporation rates.

The results from experiments using the dynamic equilibrium technique gave an average value for k of 0.5. This is within the range of values found using the dynamic simulation method, although on the low side.

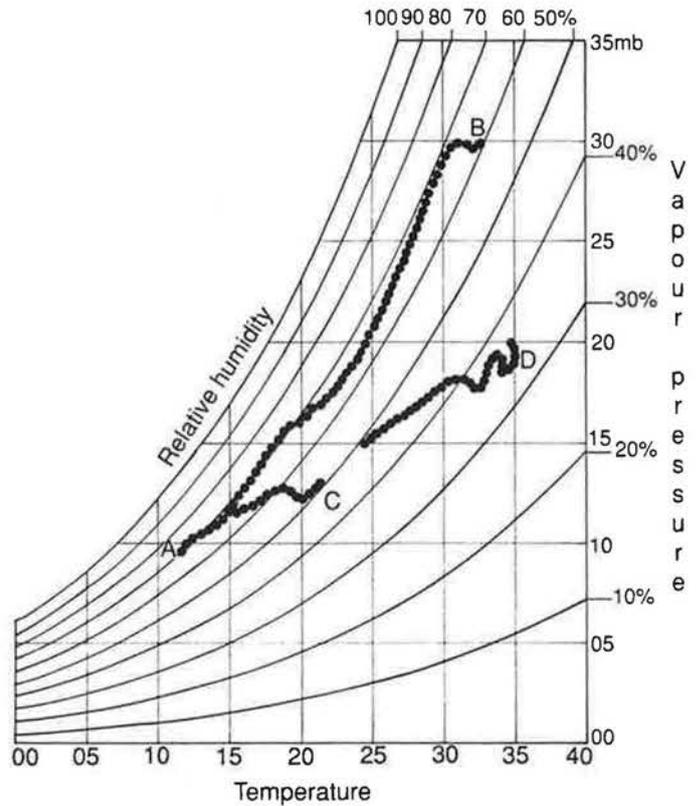


Figure 8 Psychrometric chart showing two equilibrium cases (C and D) and the surface hygrometer plot for steady temperature conditions in the wood-lined room

The advantage of the procedure using two simultaneous equations is that it provides a method of deriving moisture admittance values in situations where the special conditions of the laboratory test room, with uniform values of k and RH_s , do not apply. Thus a move away from the laboratory situation is possible.

5 Move from experimental room to real situation

The typical domestic room contains widely differing materials with varying moisture contents invariably at different surface temperatures. The prospect of gathering sufficient data to calculate the moisture admittance performance of such a room is daunting, so the modelling must necessarily become more empirical as it is difficult to measure the active surface areas and their characteristics.

If the simplification is made that the air and surface temperatures are the same, then moisture admittance values, which could be called α and β , are defined as:

$$\alpha = \frac{\sum (k_N A_N)}{\rho v} \quad (10)$$

$$\beta = \frac{\sum (k_N A_N RH_{sN})}{\rho v} \quad (11)$$

where k_N , A_N and RH_{sN} refer to areas of like materials.

The equation for the simple humidity model of a room is written

$$\frac{d\Psi_{in}}{dt} = \frac{G}{\rho v} - n(\Psi_{in} - \Psi_{out}) - \alpha\Psi_{in} + \beta\Psi_{svp} \quad (12)$$

Because the coefficient α is a negative function, which implies a loss of water vapour, it is called an absorption coefficient and is a conglomerate term of the active surface areas and the humidity transfer coefficients. Similarly the β term implies a gain of water vapour to the room so it is called a desorption coefficient and is a conglomerate of the active surface areas, humidity transfer coefficients and surface activities.

It is argued that any daily domestic humidity cycle will have periods of overall moisture absorption and desorption, so over a day and over a season the average moisture content of the materials will not change dramatically. Thus the surface activities can be considered to be constant. However a change in the values from summer to winter could be expected.

It is suggested that values for α and β be determined for average-sized domestic rooms using the dynamic equilibrium experimental method for categories of high, medium and low moisture admittance under summer and winter conditions. Thus six pairs of terms, together with appropriate surface area and volume weightings could well be sufficient to model vapour conditions in most normal buildings.

6 Moisture admittance impact on the BREDEM model

The significance of the moisture admittance terms has been demonstrated and should be included in all but the most simple models. In the BREDEM energy model which includes some vapour pressure calculations⁽⁵⁾ the algorithm from British Standards⁽⁶⁾, which is essentially the Loudon steady-state equation, is used.

$$\bar{\Psi}_{in} = \bar{\Psi}_{out} + \frac{\bar{G}}{n\rho v} \quad (13)$$

With the proposed admittance terms defined here it could be amended to

$$\bar{\Psi}_{in} = \frac{n\bar{\Psi}_{out} + (\bar{G}/\rho v + \beta\bar{\Psi}_{svp})}{n + \alpha} \quad (14)$$

Typical values of the admittance terms for the wood-lined room are $\alpha = 0.6$, $\beta = 0.4$, see calculation in Appendix 6. Numbers of this order of magnitude could be expected to apply to normal types of buildings. (High admittance values of the wood lining would be expected to be offset by the greater surface area of material due to furnishings etc.)

Comparison of the two last equations shows that the impact of the moisture admittance terms becomes increasingly significant as the ventilation rate becomes low, i.e. 0.5 ach^{-1} or less. Thus it may be argued that the inclusion of the moisture admittance terms would be particularly useful in calculations when evaluating cases of low energy buildings, which necessitate low ventilation rates, and also rehabilitation situations where low ventilation rates are achieved by draught stripping and double glazing.

7 Conclusion

The experimental work in the BRE test facility has demonstrated the importance of including the moisture

admittance effect in all but the most simplistic hygro-thermal analyses.

A practical moisture admittance model has been derived which describes the humidity performance in the test rooms very satisfactorily. Also a number of methods of obtaining the coefficients required in the model have been evaluated.

One method in particular, the 'dynamic equilibrium method', provides a potential method of obtaining generalised coefficients for a real furnished building without too much difficulty. As yet the application of this model to complex buildings is untried but clearly this is where further work needs to be done if the moisture admittance model proposed here is to become generally used. To the extent that the coefficients are reasonably constant for a particular situation they can be incorporated into the BREDEM model.

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Appendix 1

The saturation vapour pressure is expressed as a function of the air temperature ($T^{\circ}\text{C}$) by the Magnus formula⁽⁷⁾.

$$p_{svp} = 6.108 \times \exp[(17.245 \times T)/(237.3 + T)](\text{mb})$$

To convert absolute humidity to vapour pressure, Gay-Lussac's ideal gas law is used, thus when g is in units of kg m^{-3} , the vapour pressure is given by the following⁽⁷⁾:

$$p = (gT_{abs})/0.217 (\text{mb})$$

or⁽⁸⁾:

$$p = (gT_{abs}) \times 4.62 (\text{mb})$$

A conversion frequently used is vapour content Ψ (kg kg^{-1}) from vapour pressure p (mb)⁽⁶⁾.

$$\Psi = (p \times 0.622)/(1013.25 - p) (\text{kg kg}^{-1})$$

An approximate conversion is

$$\Psi = p \times 0.0062 (\text{kg kg}^{-1})$$

since vapour pressures of 13 mb are in the middle of the range at normal room conditions and the standard atmospheric pressure is 1013 mb.

The moisture generation rate is normally quoted as G (kg h^{-1}), and this is converted to mb h^{-1} using the above

approximation, thus:

$$p_{gen} = G/(\rho \times v \times 0.00062) \text{ (mb h}^{-1}\text{)}$$

Appendix 2: Details of the wood-lined room

Dimensions:	3.66 m × 4.5 m × 2.45 m
Volume of room:	39 m ³
Mass of air:	48 kg
Area of wood:	55 m ²
Volume of wood:	0.66 m ³
Density of wood:	510 kg m ⁻³
Mass of wood (dry):	336 kg

Appendix 3: Calculation of *k* under dynamic equilibrium conditions with RH_s measured

Figure 8 shows the experimental data used for the calculations, line AB is the data from the floor hygrometer which gives the measured value of RH_s, and points C and D are the conditions of dynamic equilibrium of the room.

Calculation 1 (Run 73)

The following calculation uses 4-hour mean values when the temperature was constant at 20°C (point C). The saturation vapour pressure at this temperature, *p*_{svp}, is read from a psychrometric chart.

<i>p</i> _{out}	= 10.0 mb
<i>p</i> _{in}	= 12.2 mb
<i>p</i> _{svp}	= 23.3 mb
RH _s	= 0.7
<i>n</i>	= 1.1 ac h ⁻¹
<i>A</i>	= 55 m ²
<i>ρv</i>	= 48 kg

Rearranging equation 8,

$$k = \frac{\rho v n (p_{in} - p_{out})}{A(RH_s \times p_{svp} - p_{in})}$$

or:

$$\frac{48 \times 1.1 (12.2 - 10.0)}{55 \times [(0.7 \times 23.3) - 12.2]}$$

which gives

$$k = 0.51 \text{ kg m}^{-2} \text{ h}^{-1} \text{ (kg kg}^{-1}\text{)}$$

Appendix 4: Calculation of *k* and RH_s under dynamic equilibrium conditions

Calculation 2 (Run 73)

Equilibrium points C and D are used for two simultaneous equations.

Point C:

<i>p</i> _{out}	= 10.0 mb
<i>p</i> _{in}	= 12.2 mb
<i>p</i> _{svp}	= 23.3 mb
<i>n</i>	= 1.1 ac h ⁻¹

Point D:

<i>p</i> _{out}	= 12.8 mb
<i>p</i> _{in}	= 20.0 mb
<i>p</i> _{svp}	= 51.0 mb
<i>n</i>	= 1.2 ac h ⁻¹

Using the same equation for points C and D gives *k* in terms of RH_s: for point C

$$k = \frac{\rho v}{A} \times \frac{1.1 (12.2 - 10)}{(23.3 RH_s - 12.2)}$$

and for point D

$$k = \frac{\rho v}{A} \times \frac{1.2 (20 - 12.8)}{(51 RH_s - 20)}$$

Equating these,

$$2.42 (51 RH_s - 20) = 8.64 (23.3 RH_s - 12.2)$$

$$77.9 RH_s = 57$$

$$RH_s = 0.73$$

and putting RH_s into the equations for *k*,

$$k = 0.44 \text{ kg m}^{-2} \text{ h}^{-1} \text{ (kg kg}^{-1}\text{)}$$

Appendix 5: Calculation of *k* under conditions of dynamic equilibrium with vapour input

Measurements made during relatively steady conditions whilst there was a vapour input from an evaporator.

<i>p</i> _{out}	= 8.0 mb
<i>p</i> _{in}	= 9.7 mb
<i>p</i> _{svp}	= 12.9 mb
RH _s	= 0.6
<i>G</i>	= 0.079 kg h ⁻¹
<i>p</i> _{gen}	= 2.65 mb h ⁻¹
<i>n</i>	= 1.0 ac h ⁻¹

Using equation 9,

$$k = \frac{(\rho v/A)[n(p_{in} - p_{out}) - p_{gen}]}{(RH_s p_{svp} - p_{in})}$$

$$k = \frac{(48/55)[1 \times (9.7 - 8.0) - 2.65]}{(0.6 \times 12.9) - 9.7}$$

$$k = 0.58 \text{ kg m}^{-2} \text{ h}^{-1} \text{ (kg kg}^{-1}\text{)}$$

Appendix 6: Calculation of *α* and *β* for the wood-lined room

Using values *k* = 0.5 and RH_s = 0.7, the equations 10 and 11 give:

$$\alpha = \frac{0.5 \times 55}{48} = 0.57$$

$$\beta = \frac{0.5 \times 55 \times 0.7}{48} = 0.4$$