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MODELLING WATER VAPOUR CONDITIONS IN AN ENCLOSED SPACE

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INTRODUCTION

In the U.K. the usual method for calculating inside vapour pressure is the mass transfer equation where the mean moisture generation rate is equated to the mean outside vapour pressure and the ventilation rate, so;

p(gen) = n (p(in) - p(out)) ;
where: p(gen) = vapour pressure generation rate.
n = ventilation rate.
p(in), p(out) = inside and outside vapour pressures.

This equation was used by Loudon in his 1971 paper on condensation and mould growth, and as shorthand it will be refered to as the Loudon equation. When the moisture behaviour in a building was monitored in detail, this model proved unsatisfactory in both the equilibrium and dynamic cases. It was necessary to allow for the fact that building materials absorb and desorb moisture. Here, this effect will be termed 'moisture admittance' because it is useful to draw attention to the similarity between this and thermal admittance. Additional terms to account for absorption, desorption and condensation are required for this equation, and the following proposes such an equation and sketches in the method whereby the various coefficients used were derived.

MOISTURE ADMITTANCE MODEL

In order to study the moisture admittance effect, two experimental rooms were arranged at BRE which enabled the temperatures, vapour pressures, ventilation rates and moisture inputs to be measured. One room had all surfaces covered with metallic foil so it would behave as the 'Loudon' model, and the other room had the four walls and ceiling lined with pine matchboarding to give a high moisture admittance.

Experiments in the wood lined room with no moisture input, showed that the relative humidity of the air tended to remain constant if the temperature was varied slowly. Thus at low temperatures, water was absorbed into the material and at high temperatures water was desorbed from it.

If the extreme case of a small sealed test chamber is considered, where there is a large volume of material and a small volume of air, the relative humidity of the air is determined by the amount of moisture held in the material. Much work has been done on the subject of sorption isotherms, particularly in Denmark, which link the moisture content and equilibrium relative humidities for a wide variety of materials. In real buildings however, the relative humidity cannot be defined so readily since, (1) the limiting case of material to air volume ratio does not apply and (2) the ventilation to outside has a considerable effect.

If the Loudon model is extended to describe the dynamic situation, the equation would be;

$$\frac{d\,(p(in))}{dt} = n\,(\,p(in) - p(out)\,) + p(gen);$$

To account for the moisture movement into and from the materials of the room and the condensation on a window the following equation is proposed;

$$\frac{d(p(in))}{dt} = n(p(in)-p(out)) - a\,p(in) + b\,p(svp) + p(gen) - g(p(in)-p(win))$$

$p(svp)$ = inside saturation vapour pressure.
$p(win)$ = vapour pressure at the surface of the window.
a = absorbtion coefficient.
b = desorbtion coefficient.
g = condensation factor.

The method adopted to solve for the inside vapour pressure was to use a finite difference computer program which derived values of p(in) calculated from the measured values of values of n, p(out), p(gen) and p(svp), which is derived from the inside air temperature. Measured and simulated profiles of the inside vapour pressure for periods of up to 6 days were produced and compared with each other. The values of 'a', 'b' and 'g' which produced the best fit were adopted.

As already mentioned, when the temperature is varied slowly, the relative humidity tends to stay constant. In order to decouple the effect of ventilation and determine the RH associated with moisture content of the wood, a small metal cone was fixed around the temperature and humidity sensors and the wide, open end was sealed against the wood surface. The RH values given by this instrument proved to be remarkably steady.

In the equilibrium state when p(in) is steady, and there are no moisture inputs,

$$n(p(out) - p(in)) - a\,p(in) + b\,p(svp) = 0;$$

and when the ventilation rate is zero,

$$\frac{p(in)}{p(svp)} = \frac{b}{a}$$

i.e. this leads to the relative humidity.

When conditions in the wood room were steady it was assumed that the area sampled by this cone has equilibriated with the rest of the wood in the room, i.e. there were no significant moisture content gradients across the surfaces. Thus measurements made from a small sample of wooden surface could be applied to all the wood in the room. Since the b/a ratio found in this way depended on the moisture content of the wood, it was influenced by the immediate past history of the conditions in the room. Experiments involving humidification in the room subsequently increased the moisture content of the wood giving an a/b ratio of about 0.7, whilst periods of drying out gave a ratio of about 0.55.

When the value of the ratio b/a obtained by this method was used in simulations of dynamic situations with varying temperature and moisture inputs the results proved consistant. In the three examples which follow, all the measurements were made in the centre of the room and the ventilation rates were measured using SF6 decay techniques.

Case (1). The desorption of water vapour under cyclic changes of temperature.

When the temperature is cycled the vapour pressure profile follows the temperature profile very precisely. Fig (1) shows an example of the measured and simulated profiles of vapour pressure obtained when a fan heater was run for 8 hours a day in the wood lined room. The ratio b/a was given from previous cone experiment, and it was found that any value of 'a' from about 0.002 to about 1.5 gave good agreement for the max and min of the observed values. However the absolute values of 'a' and 'b' affected the shape of the simulated vapour pressure profile. In this case the most satisfactory simulation was obtained using values for a = 0.1. and b = 0.057, i.e. b = (b/a)/10.

Also shown in this figure is a comparable simulation using the 'Loudon' model, here the small variation of the vapour pressure is due to air exchange with outside.

Case (2). The absorption of cycling moisture input at steady low temperature.

Water vapour was introduced into the wooden room using an evaporator humidifier which was weighed before and after each input period of six hours. There was no heating and there was virtually no condensation observed. Fig (2) shows the measured vapour pressure profile and the simulations obtained by the two models, here the 'Loudon' simulation gave an exaggerated response to the vapour input. In this case the admittance model profile proved to be sensitive to the absolute values of 'a' and 'b' but again the value of a = 0.1 gave the best fit.

Case (3). The combined absorption, desorption and condensation effects.

In this experiment the heating was cycled and produced high maximum temeratures of about 30 C, water vapour was input from the evaporator at the same time as the heating, and because of the resulting high humidities and cold outside temperatures there was considerable condensation produced on the window surface.

The processes of condensation and evaporation can be modelled with some complexity, but for this relatively simple situation with single glazing, it was assumed that the inside window surface temperature was the same as the outside air temperature. The term p(win) was thus equal to the outside saturation vapour pressure, which was derived from the measured values of outside temperatures. The condensation function (g), applicable to the particular window was found by doing simulation runs in the foil room where the terms 'a' and 'b' were zero, in this case the value of 'g' was found to be 0.03.

Fig (3) gives the three profiles for vapour pressure; measured, moisture admittance and 'Loudon' simulations. In this situation the Loudon simulation is not as far out as in the previous cases, because the absorption and condensation effects are compensated by the desorption effect.

These examples show the scope of the proposed moisture admittance model, but if it is to be taken further the values of 'a' and 'b' need to be explored. Here the coefficients have been derived empirically for an unfurnished test room lined with wood and heated with a fan heater placed near the centre of the room. That is, there was little variation of the surface temperatures around the room. In practice, surface temperatures will vary widely, and the surfaces will be made up of a variety of materials, consequently, one area could be acting as a moisture source and another area could be acting as a moisture sink.

The vapour exchange between surfaces may be likened to the radiant energy exchanges between six surfaces modelled in thermal analysis. The environmental temperature seen at the centre of the room is derived from a summation of the thermal admittance factors AY, and it is suggested that the vapour pressure at the centre of the room can be predicted using an integrated moisture admittance function.

In order to calculate the 'a' and 'b' values a summation is required which needs the sorption properties of the various materials, their respective areas, their average water contents, and surface temperatures. For general use this calculation is unmanagable and needs to be simplified. For most practical purposes, categories of high, medium and low moisture admittances applicable to summer and winter conditions could be defined, and values for these cases evaluated.

To conclude, consideration should be given to the use of this admittance model and its advantages over the previous Loudon type model. The examples have shown that the moisture admittance model gives consistent agreement with measured results over a wide range of situations, but the Loudon model only applies when conditions are such that the condensation and absorbtion balance the desorption.

Clearly for dynamic modelling the moisture admittance model is a significant improvement. Accurate dynamic modelling of buildings can be important for example, when conditions for mould growth are considered. One important parameter is the 70% index, this is the percentage of time that the room air is at a relative humidity at or above 70%. The moisture admittance functions could be incorporated into many of the building humidity prediction programs to give such an index at a design stage. Some steady state models such as recent versions of BREDEM use the 'Loudon' model to predict humidity levels. In spite of the inherent smoothing of the data because mean values are used, there are some circumstances such as cases (1) and (2) considered here, where the accuracy of the modelling may be improved if moisture admittance terms were included. It would be worthwhile to investigate the sensitivity of such models to the inclusion of the additional terms.

FIG.1 CYCLING TEMPERATURES ONLY, NO MOISTURE INPUT.

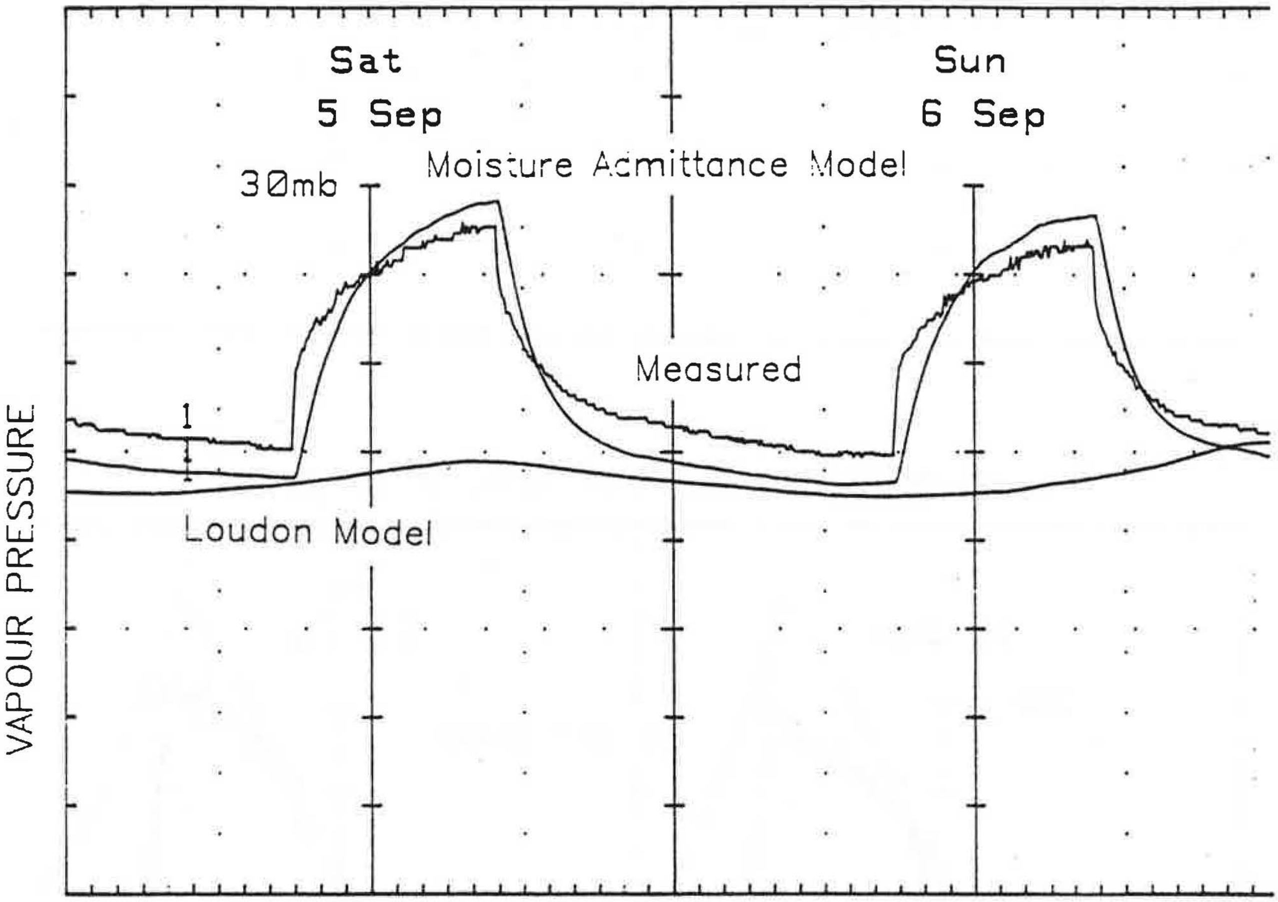

FIG.2 CYCLING VAPOUR INPUT AT CONSTANT TEMPERATURE.

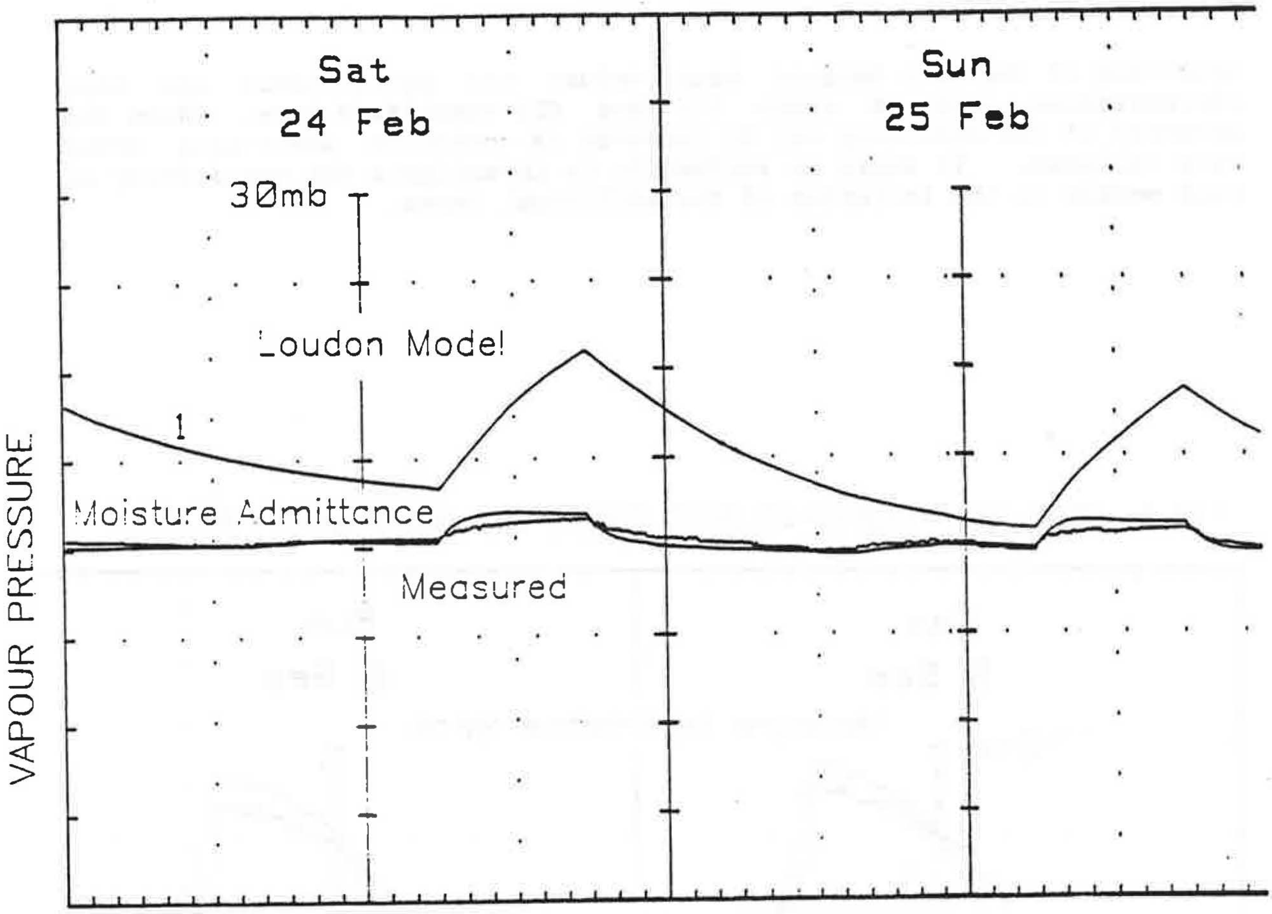

FIG.3 CYCLING TEMPERATURES WITH VAPOUR INPUT.