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# A MODEL FOR THE PREDICTION OF INDOOR AIR HUMIDITY

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## 1. INTRODUCTION

A model for the prediction of air humidity is an important tool for the study of humidity related problems. Examples of such studies are: - The influence of hygroscopic material on the indoor climate; - The influence of ventilation strategy on air humidity; - The number of hours a certain water activity at a surface is exceeded. From these examples it is clear that a dynamic model is needed. A rigorous computer model that contains the full complexity of the moisture transfer equations would require a lot of accurate data which are not available. The accuracy of the result will depend completely on the estimates for the data at the input. This is even true for the simplified model we developed. So there is a practical reason for the simplified approach. Moreover, the advantage is the physical transparancy of the model. One can easily deduce analytic solutions which give insight in the problem. It is a great support of experimental programmes in the field. The model can also be used for parameter-identification: the components of the model can be found by correlation techniques from field measurements and with the calibrated model the measurements can be extrapolated.

The model we developed is more or less the same as used by e.g. Kusuda (1) and Cunningham (2). The main difference is the way the components of the model are determined. This is fully described in (3) and (4).

A first step towards an experimental appraisal of the model was made in the climate room of FAGO. In the room was a sinusoidally varying vapour source. The experiments are described in (3). In this paper the measurements of the vapour flow rate into hygroscopic material are reported. For the prediction the measured indoor vapour pressure was used.

## 2. THEORY

It is assumed that a zone has one air temperature and one vapour pressure. This complete mixing is never observed in reality (5). There is however no simple alternative. With this assumption the mass conservation equation of the air in zone i can be written as:

$$G_{int} + G_{ae} (p_e - p_i) \ 0.62 \times 10^{-5} + \sum_j G_{aj} (p_j - p_i) \ 0.62 \times 10^{-5} -$$

$$\sum_k G_k + m_a \ 0.62 \times 10^{-5} \ \frac{dp_i}{dt}$$

where $G_{int}$ = vapour production rate (kg/s); $G_{ae}$ = air mass flow rate from outside (kg/s); $p_e$ = outside vapour pressure (Pa); $p_i$ = vapour pressure in zone i (Pa); $G_{aj}$ = air mass flow from zone j (kg/s); $G_k$ = vapour mass flow to material k (kg/s); $m_a$ = air mass of the zone (kg); t = time (s).

By air mass flows from one zone to another, zones are linked (multizone-model). For the calculation of these flows a number of models is available e.g. (6).
The main problem is the calculation of the vapour flow to the material. We only considered two cases:
- condensation on non-hygroscopic material (e.g. glazing)
- vapour flow to hygroscopic material with no condensation.
As the calculation of air humidity is the objective condensation on glazing can sometimes be of interest. The severe case that there is so much condensation on hygroscopic material that the air humidity is effected, is not considered yet.
Condensation occurs when the saturation pressure of the glazing temperature is below the room air vapour pressure. As the release of latent heat changes the surface temperature we corrected for that effect. If for 1 W/m² the surface temperature increases $\Delta T$ then:

$$g = h \left[ p_i - p_s(\theta_w) - gL\Delta T \ \frac{dp_s}{d\theta} \right] \quad (kg/m^2 s)$$

$$g = \frac{h}{1 + gL\Delta T dp_s/d\theta} \left[ p_i - p_s(\theta_w) \right]$$

where: g = vapour flow density (kg/m²s); h = surface vapour transfer coefficient (s/m); $p_s(\theta_w)$ = saturation pressure at glazing temperature $\theta_w$; L = latent heat ($\approx$ 2500 kJ/kg).

The condensate is assumed to disappear.
The assumptions for the vapour flow to the hygroscopic material are:
- The vapour diffusivity $a_v$ and the vapour permeability value ($\delta$) are constants. In fact they are dependent on moisture content of the material, temperature. The values for a low relative humidity (< 20%) and a very high one (> 80%) are very different. Within this range, considering the inaccuracy of values found in literature, the assumption seems reasonable. If the air humidity is but seldom above 80%, the inaccuracy with this model will not be a problem. Only for very humid situations the model will be unreliable.
- Vapour transfer through the material is neglected.
The diffusion resistance of constructions is in general so large, that the vapour flow is much smaller than the vapour flow by ventilation.
- Temperature gradients in the material are neglected.

The surface layer responsible for the hygric storage for daily swings in the indoor air humidity is very small (maximum 10 mm). The corresponding thickness for temperature swings is about 100 mm. So the gradients in the small layer will be very small.

With these assumptions the equations for each layer in a construction are:

$$\frac{\partial p_v/p_s}{\partial t} = \frac{a_v}{p_s} \frac{\partial^2 p_v}{\partial x^2}$$

and $G_k = - A_k \delta \left( \dfrac{\partial p_v}{\partial x} \right)_w$ at the boundary

and at the surface: $G_k = A_k h (p_i - p_w)$

where: $p_v$ = vapour pressure in the material; $p_s$ = saturation pressure at the temperature of the surface; $a_v$ = vapour diffusivity ($m^2/s$).

As the surface temperature can vary with time $p_s$ is a function of time. These equations could be discretized and solved by known methods. We choose to simplify this further to a first order differential equation:

$$\Sigma G_k = L_m (p_i - p_m) = C_m p_s \frac{d}{dt} p_m/p_s$$

The components $L_m$ and $C_m$ are determined in such a way that the solution for $\Sigma G_k$ with a sinusoidally varying indoor vapour pressure calculated with the partial differential equations equals the solution of the first order equation. The method has been applied before (4). A good compromise for the period time which gives reasonable results for both 24-hour variations and 1-hour variations turns out to be 12-hour. The fact that the result for 1-hour variation is still reasonable can be explained by the large air capacitance in the model which is the main cause of the dampening at this frequency.

Note that the hygric storage depends on the relative humidity at the material surface. So the (average) surface temperature is needed: the hygric model should be combined with a dynamic thermal model and an air flow model (7).

## 3. EXPERIMENTS

The indoor vapour pressure in the climate room was varied sinusoidally by a sinusoidal vapour source. The vapour flow to blocks of aerated concrete was measured by continuous weighing (see Fig. 1). In order not to disturb the measurements the air flow velocities in the room were kept low.
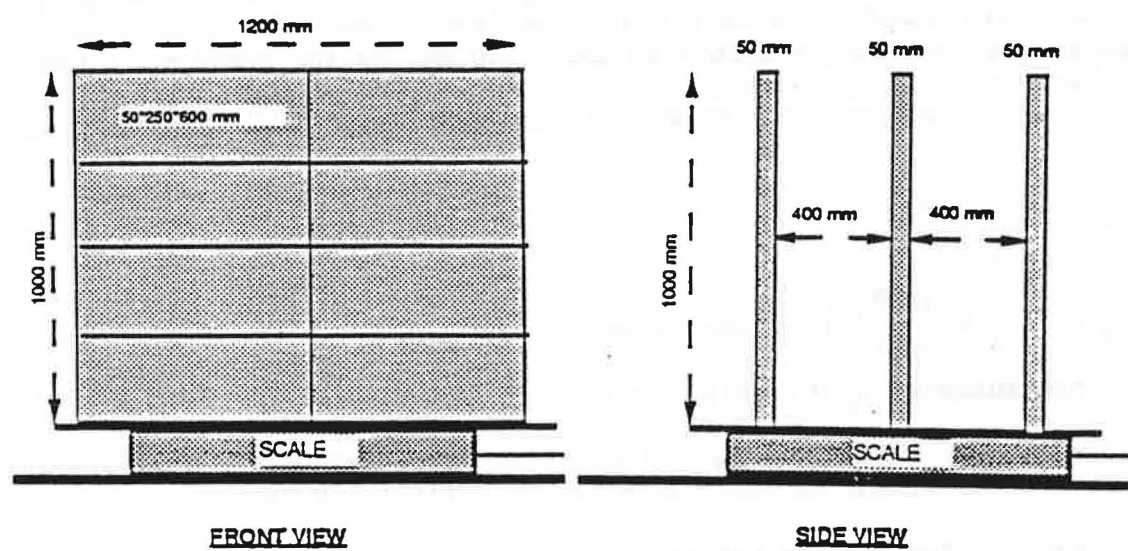
FIGURE 1. Determination of the vapour flow rate.

For the determination of the vapour diffusivity of the blocks the vapour resistance factor ($\mu$) and the sorption curve have to be measured as:

$$a_v = \frac{\delta_a}{\mu} \frac{p_s}{\mu\xi} \quad (m^2/s)$$

where: $\delta_a$ - vapour permeability of air, $\xi$ - derivative of sorption curve (kg/s).

The vapour resistance factor was determined with the cup method (KCl-$NH_4NO_3$): $\mu = 9.4 \pm 0.4$. The derivative of the sorption curve caused some troubles due to hysteresis effect. Within the range 20% and 80% relative humidity we found: $\xi = 25 \pm 11$ kg/m$^2$. With these values the vapour diffusivity at 20°C is in the range: $12 \times 10^{-10} < a_v < 34 \times 10^{-10}$ m$^2$/s. The penetration depth for a cyclic variation is given by: $d* = \sqrt{(a_v t_0/\pi)}$ so for $t_0 = 24$ h the thickness is about 7.1 mm. The blocks have a thickness of 25 mm. So this can be considered as infinite thick for 24 h variations. In that case it can be shown that the vapour capacitance is:

$$C_m = A \ d* \ \xi/p_s = A \ b_v \sqrt{(t_0/\pi)} \quad (kg/Pa)$$

where $b_v = \sqrt{(\delta \ \xi/p_s)}$ the vapour effusivity. This quantity turns out to be the most important one for hygroscopic storage and it would be interesting to develop measuring methods to determine this quality directly. For aerated concrete this property is within the range: $3.4 \times 10^{-7}$ - $5.7 \times 10^{-7}$ (kg$^{0.5}$s$^{0.5}$/J$^{0.5}$). The vapour conductance to the material is:

$$L_m = A/\left[ 1/h + \sqrt{(t_0/\pi)}/(2b_v) \right] \quad (kg/Pa.s)$$

The surface vapour transfer coefficient is unknown. We made two calculations: h = 0.25 $h_{ref}$ and h = 0.5 $h_{ref}$ with $h_{ref}$ = 2 x 0.62 x $10^{-8}$ (s/m).

The theoretical mass flow to the material is calculated by:

$$\hat{G} = p_i/\sqrt{((1/L_m)^2 + (1/\omega C_m)^2)} \qquad (kg/s)$$

$$\Delta t = (1/\omega) \text{ Atan } (L_m/\omega C_m) \qquad (s)$$

where: $\hat{G}$ = the amplitude of the variation $\Delta t$ the time shift (compared with $p_i$) of the variation; $\omega = 2\pi/t_o$ where $t_o$ = 6, 12 and 24 h.

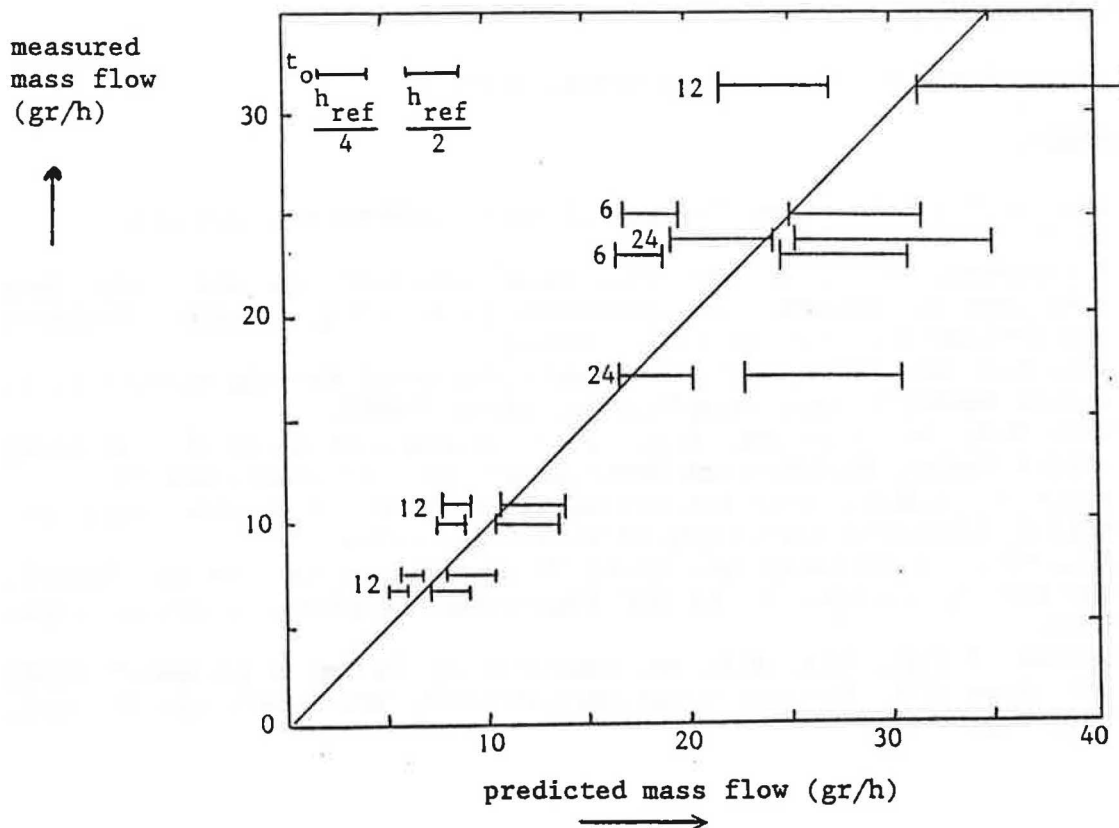The results of the different measurements are given in the figure  below.



FIGURE 2.  Comparison of measured and estimated mass flow rates.

CONCLUSIONS

- The results indicate that 0.25 $h_{ref}$ < h < 0.5 $h_{ref}$. This can be explained by the low air velocities. A problem is that for such a low value the vapour transfer in the boundary layer is for an important part caused by diffusion. So the coefficient will depend on the vapour pressures and not be a constant. This can explain that no h can be found

for which both amplitude and phase shift correspond with measured data. The effect of h on the storage is very large. More research on surface coefficients will be necessary in order to be able to validate the model.
- The determination of the vapour effusivity is very inaccurate. This can be done better but there remains the problem of the hysteresis. A direct measurement method to determine this coefficient would be of great interest.

In view of the inaccuracy of both the estimate of the surface coefficient and the vapour effusivity a physically more correct model can hardly give more correct results.
- The results do not falsify the model. They reveal the problems one can encounter and which steps have to be taken next.

ACKNOWLEDGEMENTS

REFERENCES

(1) Kusuda, T., Indoor humidity calculations, ASHRAE-transactions DC-83-12 no. 5 (1983).
(2) Cunningham, M.J., A new analytical approach to the long term behaviour of moisture concentrations in building cavities. Building and Environment, vol. 18 (1983) 109-116.
(3) Wit, M.H. de, Donze, G.J., A second order model for the prediction of indoor humidity. Rep. Woon/Energie, Gouda (1990).
(4) Wit, M.H. de, Driessen, H.H., ELAN, a computer model for building energy design. Building and Environment, vol. 23 (1988) 285-289.
(5) Weersink, A.M.S., Distribution of water vapour in a room. FAGO-rep. 8823.K. Eindhoven University of Technology (1988).
(6) ASL, ESP, A Building and Plant Energy Simulation System. Manuel, Version 7, Release 2, ABACUS Simulations Limited, Glasgow, Sept. 1989.
(7) Pernot, C.E.E., Wit, M.H. de, Combined modelling; A parameter study IEA Annex XIV. Working Group FAGO-TNO-TUE, TPD-report no. 915.053, Eindhoven (1990).