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THE DYNAMIC BEHAVIOUR OF THE WATER VAPOUR PRESSURE IN BUILDINGS DURING THE YEAR

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1. ABSTRACT

This paper presents an analysis of the average water vapour pressure difference during the year under the influence of the outdoor climate, the moisture production, the ventilation rate and the hygroscopicity of the building materials and furniture.
A dynamic model is described and results of calculations are given.
It appeared that the average water vapour pressure difference between indoor and outdoor is related to the average outdoor temperature in such a way that the water vapour pressure difference increases with decreasing outdoor temperature.
The variations in outdoor water vapour pressure leads to moisture absorption by the indoor hygroscopic materials during summer followed by desorption during winter. Moisture production will lead to a more or less constant increase in water vapour pressure for a constant ventilation rate. When the ventilation rate varies linear with the average outdoor temperature the water vapour pressure difference due to moisture production increases linear with decreasing outdoor temperature.

2. INTRODUCTION

The water vapour pressure in a room is relevant to the study of problems due to surface condensation, the causes of mould growth on building materials and the presence of allergen generating organisms(such as mites). To study in which way the water vapour pressure variates in time a model has been developped.
With this model calculations have been made to study the yearly course of the water vapour in a room under the influence of the moisture production, the ventilation rate and the hygroscopic behaviour of the materials and furniture.
The results will be summarized in this article.

3. BASIS OF THE MODEL

The water vapour pressure in a room is determined by the moisture production in the room, the vapour diffusion through the roompartitions, the ventilation of the room, vapour transport by air flow from other rooms, condensation on windows and the accumulation of water vapour in building materials, furniture and furnishings.
Assuming ideal mixing of water vapour takes place, vapour diffusion through the room partitions is negligible and no air flow from other rooms exist the moisture balance can be described as:

$$\frac{V}{R.T_i}\frac{dp_i}{dt} = \frac{p_e}{R.T_i}\frac{dq_e}{dt} - \frac{p_i}{R.T_i}\frac{dq_i}{dt} + \Phi - \beta.A_h(p_i - p_s) - \beta.A_g(p_i - p'_g)$$

where:
- V is the volume of the room, im m^3
- p_i is the water vapour pressure in the room, in Pa
- p_e is the water vapour pressure of the outdoor air, in Pa
- p_s is the water vapour pressure at the surface of the hygroscopic materials, in Pa
- p'_g is the maximum water vapour pressure at the inner surface of the glazing,in Pa
- q_i is the air flow out of the room, in m^3/s
- q_e is the air flow from outside into the room, in m^3/s
- R is gasconstant of water vapour (= 462 J/(kgK)
- T_i is the temperature in the room, in K
- Φ is the moisture production, in kg/s
- β is the surface coëfficiënt of mass transfer, in s/m

The term $\beta.A_g(p_i-p'_g)$ only counts when condensation occurs.

Because no air flow from others rooms is assumed $q_e = q_i$; when however air is transported from other rooms to the concerning room an extra term must be added which takes into account the transport from water vapour from these rooms. Besides that the air flow q_i must be adjusted.
The vapour transport in the hygroscopic material is considered to be 1-dimensional. The material is divided into a number of elements of finite thickness (mostly 1 mm). The vapour pressure of each element is assumed to be constant during the time-interval Δt and the vapour transport between the elements is then calculated and adjusted on the basis of this.

3. CALCULATIONS

In order to analyse the influence of the different parameters on the indoor air humidity calculations with the model have been made.
The parameters were choosen as follows:
- roomvolume : 100 m^3
  (because ideal mixing is assumed the dimensions of the room play no role)
- hygroscopic materiaal : 100 m^2
  diffusion resistance factor : 30
  hygroscopic moisture content : see figure 1a and 1b

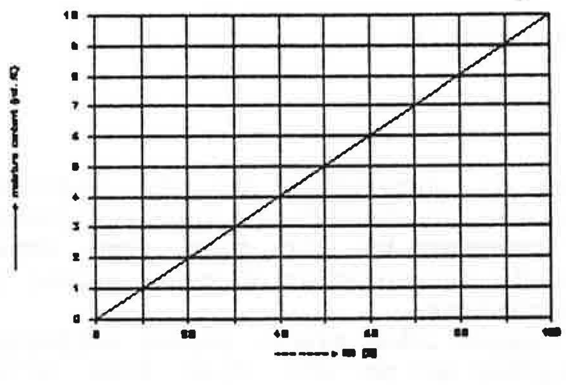

FIGURE 1a

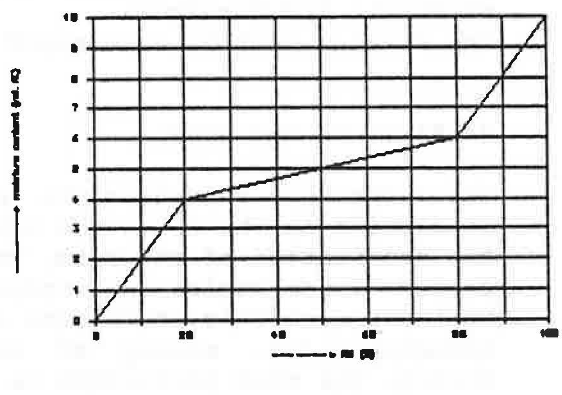

FIGURE 1b

- course of air-temperature in the room
  a daily course : figure 2a (for january)
  monthly increase during the year : see figure 2b

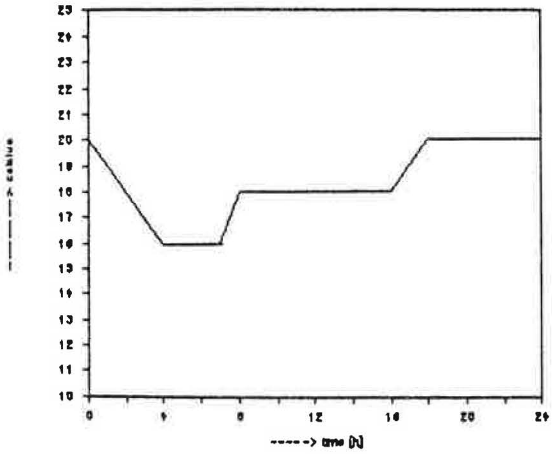

FIGURE 2a : Daily course of the air temperature in the room (january)

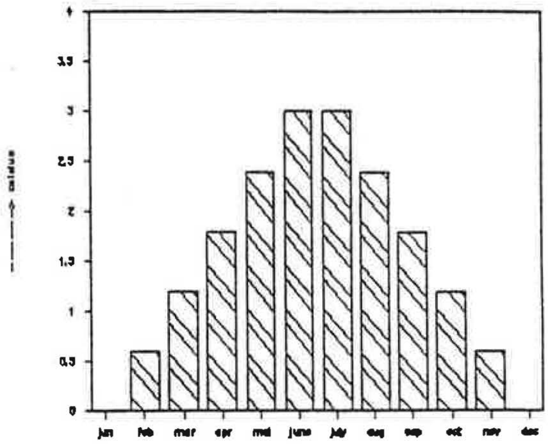

FIGURE 2b : Monthly variation of the roomtemperature

- the outdoor climate : the hourly values of air-temperature and RH at the K.N.M.I-station Airport Rotterdam for the year 1985, 1986 and 1987. Only the results of the calculations for 1987 are used for analyses.
- moisture production : see figure 3

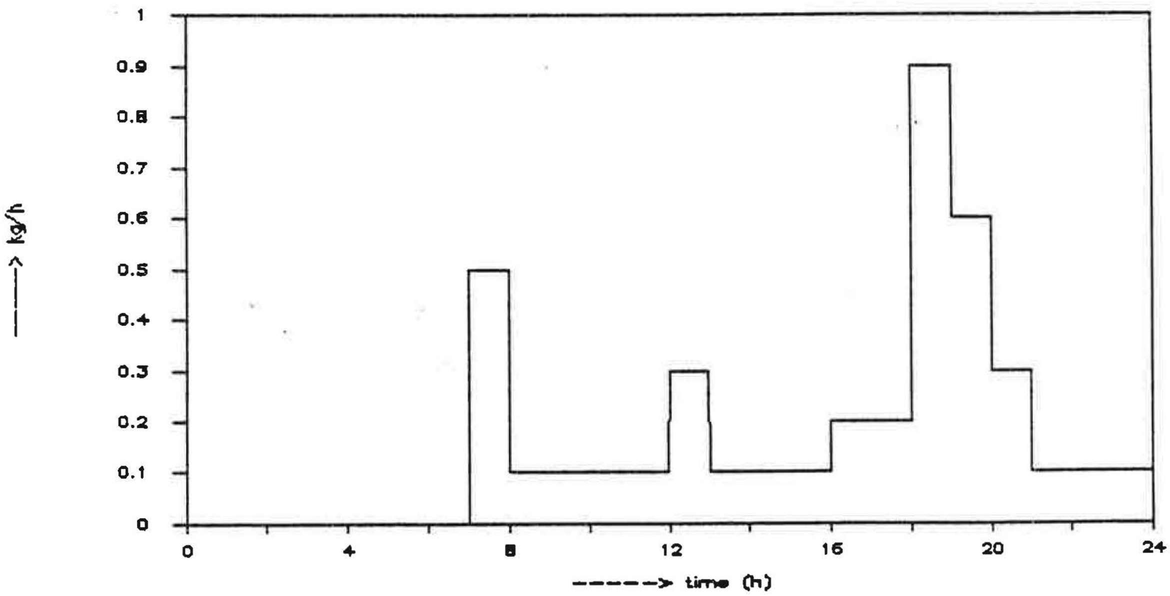

FIGURE 3 : Moisture-production during a day

- ventilation regime : a constant ventilation rate or a ventilation rate depending on the outside air-temperature.

4. RESULTS

The results of the calculations are presented as the weekly average vapour pressure difference between indoor and outdoor ($\Delta\bar{p}_{i,e}$). The individual values of $\Delta\bar{p}_{i,e}$ are related to the weekly average outdoor temperature ($\bar{\theta}_{i,e}$) by means of regression expressed as the function $\Delta\bar{p}_{i,e}(\bar{\theta}_e)$.

4.1 The outdoor climate

First of all calculations were made to determine in which way $\Delta\bar{p}_{i,e}$ variates under the influence of the outdoor climate. This means no moisture production in the room. Further more the ventilation rate was assumed to be constant; the hygroscopicity was taken according to figure 1a.
In figure 4 the individual values of $\Delta\bar{p}_{i,e}$ are given related to the average outdoor temperature $\bar{\theta}_e$ for a ventilation rate of 25 m³/h.

The regression line is also drawn.

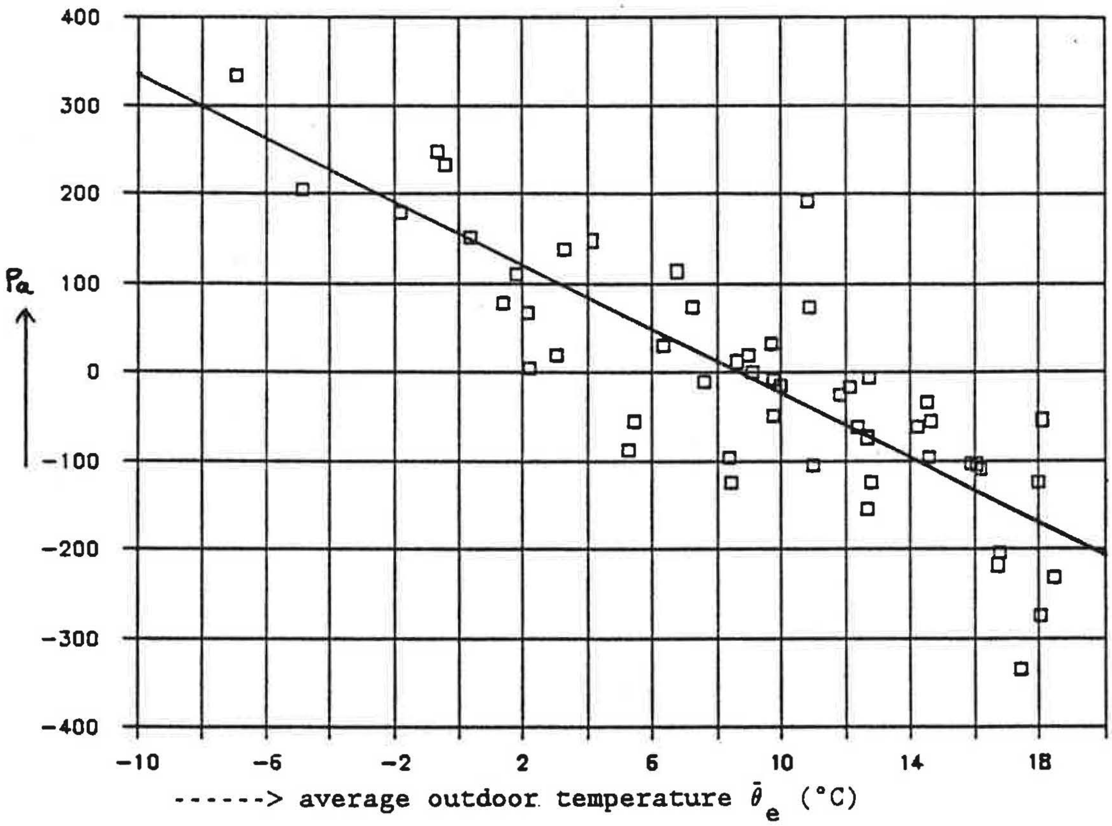

FIGURE 4 : $\Delta\bar{p}_{i,e}(\bar{\theta}_e)$ for a constant ventilation rate of 25 m³/h; no moisture production.

In figure 5 the regression lines for 5 different ventilation rates are drawn. In table 1 the functions and the corresponding correlation coëfficiënt are given.
As can be seen in figure 5 the crossing of the lines with the x-axis occurs at about 9 °C (the yearly average outdoor temperature).

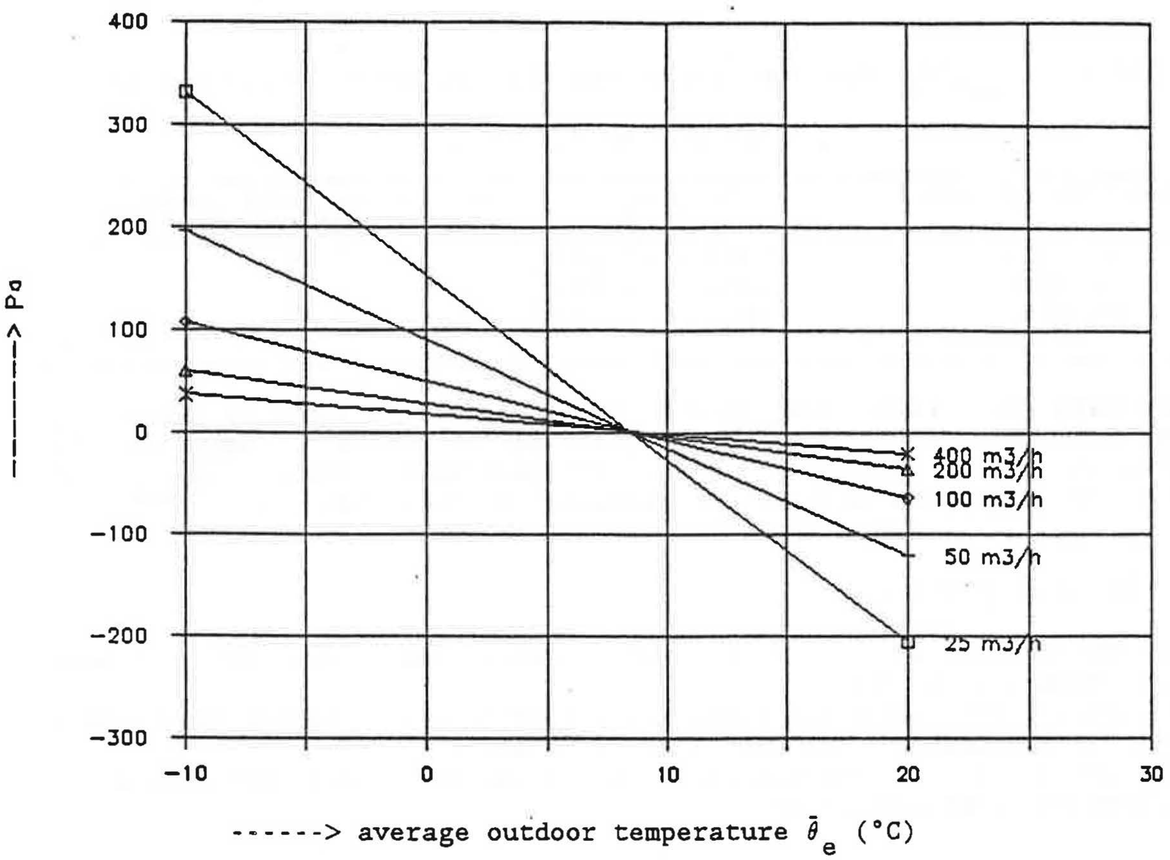

FIGURE 5 : Regression lines for 5 different ventilation rates; no moisture production

TABLE 1 : $\Delta\bar{p}_{i,e}(\bar{\theta}_e)$ for 5 different ventilation rates, no production

Ventilation rate	$\Delta\bar{p}_{i,e}(\bar{\theta}_e)$	Correlation coëfficiënt
25 m^3/h	$152.5 - 17.85\ \theta_e$	0,83
50 m^3/h	$90.6 - 10.53\ \theta_e$	0,75
100 m^3/h	$49.4 - 5.72\ \theta_e$	0.69
200 m^3/h	$28.3 - 3.19\ \theta_e$	0.66
400 m^3/h	$17.7 - 1.91\ \theta_e$	0.66

It can be concluded that:
- the yearly average vapour pressure difference will be equal to zero when no moisture production takes place;
- during summer moisture is absorbed by the hygroscopic materials followed by desorption during winter;
- the amount of absorption/desorption decreases with increasing ventilation rate.

4.2 Hygroscopicity

In table 2 the regression lines for 3 different ventilation rates are drawn related to the hygroscopic curve as given in figure 1b.

TABLE 2 : $\Delta\bar{p}_{i,e}(\bar{\theta}_e)$ for 3 different ventilation rates, no production, hygroscopicity according to figure 1b

ventilation rate	$\Delta\bar{p}_{i,e}(\bar{\theta}_e)$	correlation coëfficiënt
25 m^3/h	$109.5 - 12.60\ \theta_e$	0.78
50 m^3/h	$60.4 - 6.95\ \theta_e$	0.71
100 m^3/h	$31.7 - 3.65\ \theta_e$	0.66

Comparing this regression lines with the regression lines in table 1 it appeared that a decrease in hygroscopicity means a decrease in accumulation of moisture. However the individual values of $\Delta\bar{p}_{i,e}$ will show more variation (compare the correlation coëfficiënts).

4.3 Moisture production

When moisture production in the room takes place the water vapour difference will increase.
In figure 6 the regression lines for 3 different ventilation rates and a moisture production according to figure 3 are drawn.
Also are drawn the 3 regression lines for the same ventilation rates but without moisture production.

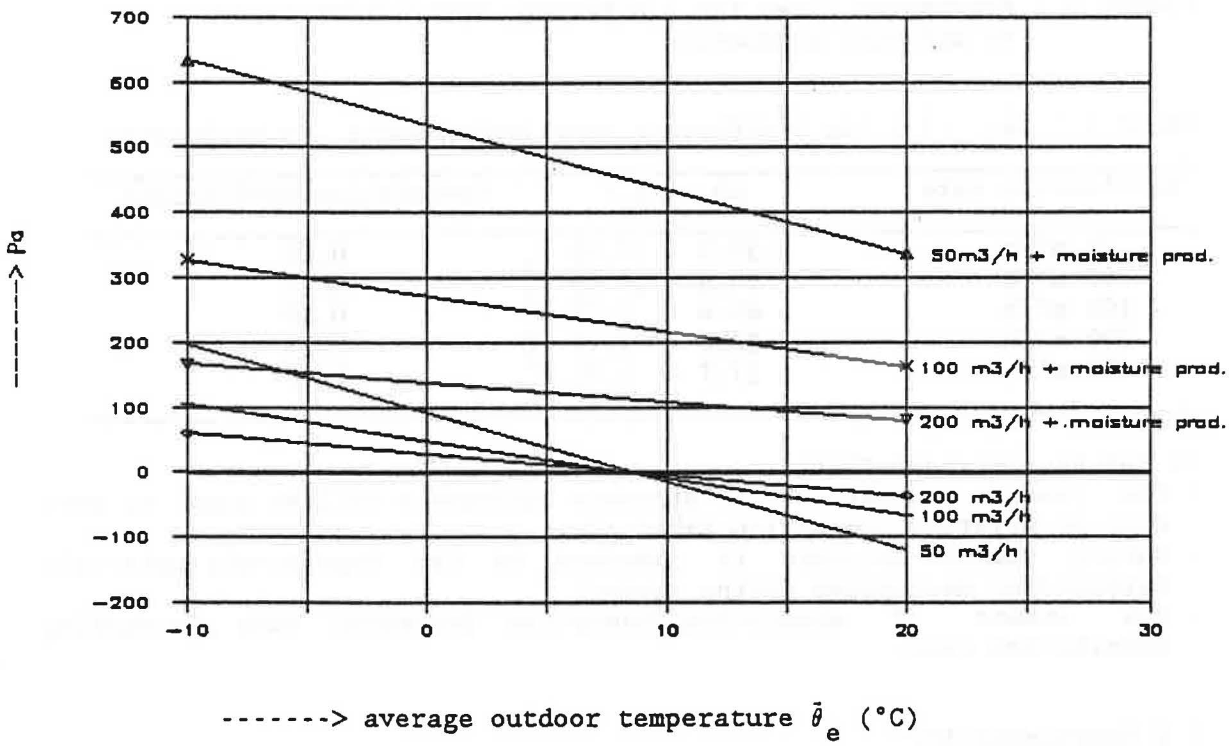

FIGURE 6 : Regression lines for 3 different ventilation rates and a moisture production according to figure 3.

As can be seen from the regression lines the distance between two lines that differ only in moisture production is more or less constant. The difference between two lines for the same ventilation rate equals the difference calculated from the relation:

$$\Delta p = \frac{\Phi . R . Ti}{q_i} \qquad (1)$$

where:

Δp is the water vapour difference, in Pa
Φ is the average moisture production, in kg/s
R is the gasconstant of water vapour, in J/(kgK)
Ti is the temperature in the room, in K
q_i is the ventilation air flow, in m^3/s

Using this relation the water vapour difference due to the moisture production of 4 kg/day amounts to about 451 Pa for a ventilation rate of 50 m^3/h, 226 Pa for 100 m^3/h and 113 Pa for 200 m^3/h.

4.4 The ventilation regime

Untill now it was assumed that the ventilation during the year remains constant. It is however known from research in practice that for instance the opening of windows and doors by inhabitants depends on the outdoor climate. In [1] a relationship is given between the use of windows and doors and the average outdoor temperature. This relationship is given in figure 7. It appeared that the percentage open windows and doors is next to linear with the average outdoor temperature.

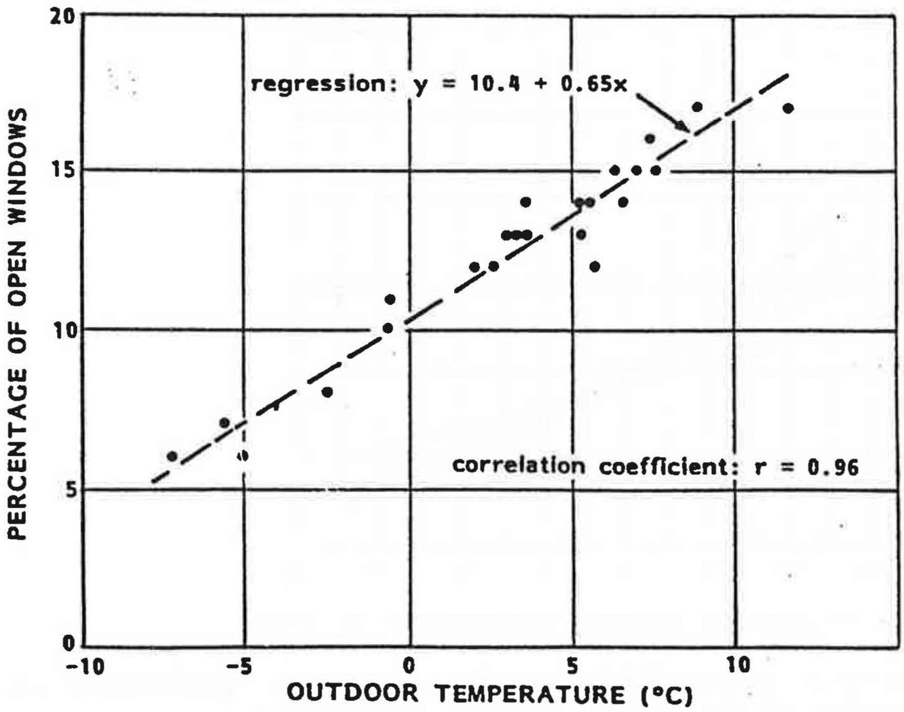

FIGURE 7 : Relationship between the average use of windows and doors and the average outdoor temperature (Schiedam project [1])

Calculations are made assuming that the ventilation rate varies linear to the percentage open windows and doors and that at -10 °C the ventilation rate is only 50 % of the yearly average ventilation rate.
In table 3 the regression lines are given for 3 different ventilation functions related to 3 different moisture production levels. The relation between moisture production and yearly average ventilation rate is kept constant. This means that at a yearly average ventilation rate of 25 m³/h the moisture production amounts to 2 kg/day (50 % of the production given in figure 3), at 50 m³/h the moisture production is 4 kg/day (as given in figure 3) and that at 100 m³/h the moisture production is 8 kg/day (twice as much as given in figure 3).

TABLE 3 : $\Delta\bar{p}_{i,e}(\bar{\theta}_e)$ for 3 different ventilation functions related to 3 different moisture production levels

Ventilation function	Moisture production	$\Delta\bar{p}_{i,e}(\bar{\theta}_e)$
$19.0 + 0.65\ \theta_e$	2 kg/day	$523.0 - 6.16\ \bar{\theta}_e$
$37.9 + 1.30\ \theta_e$	4 kg/day	$553.0 - 9.76\ \bar{\theta}_e$
$75.8 + 2.60\ \theta_e$	8 kg/day	$571.6 - 11.59\ \bar{\theta}_e$

To eliminate the influence of the outdoor climate and its accumulation by the hygroscopic materials the regression lines in table 3 are corrected. These corrected lines are drawn in figure 8.
Also is drawn the water vapour difference calculated with relation (1), that means when no absorption/desorption in taken into account.

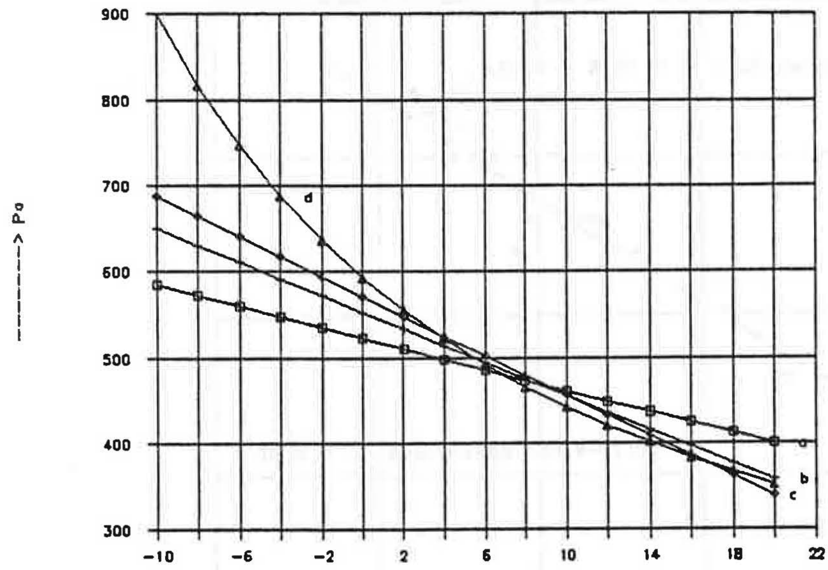

FIGURE 8 : The water vapour difference due to moisture production as a function of the average outdoor temperature.
line a : yearly average ventilation rate of 25 m³/h; production 2 kg/day
line b : yearly average ventilation rate of 50 m³/h; production 4 kg/day
line c : yearly average ventilation rate of 100 m³/h;production 8 kg/day
line d : constant relation between moisture production and ventilation rate (2 kg/day for 25 m³/h)
no absorption/desorption by hygroscopic materials

It appears that at relative high outdoor temperatures (relative high ventilation rates) no significant absorption/desorption occurs.
At relative low outdoor temperatures however some absorption must occur. Further more a constant relation between moisture production and ventilation rate shall not lead to a equal increase of water vapour pressure under the given circumstances.

5. CONCLUSIONS

Under the influence of the variation in water vapour pressure of the outdoor climate and due to absorption/desorption of moisture by the hygroscopic building materials and furniture moisture is absorbed during summer and desorbed during winter.
The amount of absorption/desorption depends among others on the ventilation rate and the hugroscopic capacity.
At a constant ventilation rate and moisture production during the year the increase of the water vapour pressure difference is constant and determined by the ventilation rate, the moisture production and the volume of the room.
When however the ventilation rate varies with the outdoor temperature especially during winter when relative low ventilation rates will occur part of the moisture production will be absorbed by the hygroscopic materials.

6. LITERATURE

[1] AIVC : Inhabitant behaviour with respect to ventilation - a summary report of IEA Annex VIII. Technical note aivc23. Air Infiltration and Ventilation Centre. Berkshire RG12 4AH, Great Britain (1988)