Moisture Balance in Dwellings

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Summary: *Moisture problems in dwellings are widespread, yet there is no clear understanding of the moisture balance. A balance sheet is produced, based on experimental data. The balance sheet helps to identify conditions with high risk of mould growth and high house dust mite population growth.*

Keywords: *moisture, occupancy*
Category: *healthy housing*

1. Introduction

Damp conditions in houses stimulate the growth of mould and house dust mite, which may lead to allergic reactions of dwellers. Moisture problems in dwellings are widespread, yet there is no clear understanding of the moisture balance: the moisture emission of different sources, the effect of transport to different rooms, the absorption and re-entrainment processes and the removal of moisture by drying, cleaning and ventilation.

The objective is to study the moisture sources, the peak shaving and removal mechanisms and the resulting humidity levels in different rooms. A balance sheet is produced and scenarios lead to different input of data. Outdoor air temperature and humidity are included in the scenarios. The balance study is located in The Netherlands, a country with a moderate and moist sea climate.

2. Research methods

In a model study we investigated daily patterns of moisture production and removal in a single-family house. Moisture in houses originates from the ambient environment (e.g. rain penetration, capillary and diffusive moisture from the crawlspace) and dwellers activity such as cocking, dishwashing, clothes drying and taking showers (Table 1). The latter depends on the number of dwellers in the house and the life style. In this study the life style pattern was modelled on the basis of several field studies in which a total of 300 houses were visited. During these visits a questionnaire was completed on building characteristics, life style and behaviour of dwellers with respect to ventilation.

2.1. Moisture production

Starting point of our study was a family consisting of two adults and three children. The activity schedule was as follows. The man and two children take a shower in the morning, the wife and the youngest child in the evening. The man leaves the house at 8.00 and is back at 17.30, whereas the children arrive from school at 15.30. Preparation of the dinner takes place between 17.30 and 18.00. Between 18.00 and 20.00 the family is at home for dinner, washing dishes and having tea. The members if this model family go to bed between 20.00 (for the youngest child) and 23.00 for the adults. The combination of moisture production (table 1) and this activity schedule resulted in the moisture production schedule (table 2). Moisture production rates per activity were obtained from the literature.

2.2. Moisture removal

Ventilation is the most important way of moisture removal. The rate of moisture removal was estimated from the air exchange rate and the differences in relative humidity between the indoor and outdoor air. The outdoor temperature was set to 6 °C with 85% RH. This represents an average outdoor condition in wintertime in the Netherlands. The indoor temperature varies between 15 and 22 °C, whereas the indoor RH was calculated from the moisture balance. The air exchange rate was approximated from the infiltration rate and the rate of mechanical exhaust. The mechanical exhaust rate was estimated using the rates as prescribed by Dutch building regulations and data on ventilation behaviour of dwellers obtained during the field study. According to Dutch building regulations the rate of mechanical exhaust is equal to 0.9 1/s per square meter floor area. The prescribed exhaust rates in the kitchen and bathroom are 21 and 14 1/s, respectively. Generally, Dutch dwellers can select three fan speed levels of mechanical ventilation controlled by a switch mounted in the kitchen. The field study revealed that dwellers selected the lowest speed level during 23 hours and the highest during 1 hour. At the lowest speed level the ventilation rate is equal to 40% of the level prescribed by the Dutch Building Code. The infiltration rate is approximately equal to 0,56 m^3/h per square meter floor area [2]. Since infiltration and mechanical ventilation rates depend on the dimensions of the building, we used a standard Dutch single-family house with garden faced living room to model these rates (table 3). Then, the exhaust rate φ is given by:

$\varphi = [23*\sqrt{(\varphi_i^2+(0.4*\varphi_{mv})^2)}+\sqrt{(\varphi_i^2+(\varphi_{mv}^2)}]/24$ (1)

in which φ_i is the infiltration rate and φ_{mv} is the mechanical ventilation rate (table 4).

Table 1 Moisture production sources in houses [1]

Moisture source	Production
Adult at rest	40 [g/h]
Adult normal activity	100 [g/h]
Shower	500 [g/shower]
Cocking	1000 [g/h]
Laundry drying	500 [g/kg]
Evaporation, transpiration by plants	10 [g/h]
Evaporation from crawlspace	850 [g/day] *
Capillary transfer from wet foundation	300 g[day] *

* Estimates

Table 2 Moisture production schedule

	Moisture production [g/h]			
Time	Living	Kitchen	Bedroom	Bathroom
1	75	25	80	80
2	75	25	80	50
3	75	25	80	0
4	75	25	80	0
5	75	25	80	0
6	75	25	80	0
7	145	85	0	0
8	145	40	0	370
9	145	55	0	230
10	185	105	0	100
11	145	25	0	50
12	145	25	0	20
13	145	25	0	10
14	145	25	0	0
15	145	25	0	0
16	245	25	0	0
17	245	325	0	0
18	370	225	0	0
19	390	225	0	0
20	370	25	0	50
21	370	25	0	200
22	70	25	0	240
23	70	25	80	200
24	75	25	80	110
Total:	4000	1485	640	1710

Table 3 Dimensions of the main spaces in standard Dutch single-family house with garden faced living room [3]

Space	Floor area [m^2]	Height [m]
Living	26.1	2.5
Kitchen	7.3	2.5
Bedroom	11.4	2.4
Bathroom	4.8	2.4

Table 4 infiltration and ventilation rates [m /h]

Space	φ_i	φ mv		φ
		low	high	
Living	15	37	151	45
Kitchen	4	30	76	32
Bedroom	6	16	41	19
Bathroom	3	20	50	22

2.3. Computational scheme

For the computations an Excel sheet with a simple calculation scheme was used.

It was assumed that equilibrium between moisture production and removal by ventilation was reached instantaneously. Then, the equilibrium concentration C_E [kg/m^3] of water vapour can be calculated by:

$$C_E = C_0 + \frac{Q}{\varphi} \quad (2)$$

in which C_0 [kg/m] is the outdoor vapour concentration and Q [kg/s] is the moisture production rate. Subsequently, the rate of moisture removal was calculated by:

$$\varphi = \varphi *(C_E - C_0) \quad (3)$$

Equations 2 and 3 only hold if the saturated vapour density is not exceeded. This saturated vapour density C_s depends on temperature and was calculated by the formula given by [4]. If C_E was greater than C_s, C_E was set to C_s. Then:

$$\varphi = \varphi * (C_s - C_0) \quad (4)$$

and the moisture removal rate was smaller than the production rate. The moisture surplus was supposed to condensate and removed by ventilation afterwards when the vapour density became unsaturated mainly due to a lower moisture production rate.

2.4. Scenarios

We modelled the water balance in the living, kitchen, main bedroom and bathroom. With respect to indoor temperature we studied two scenarios: a warm and a moderate indoor temperature profile. With respect to ventilation we studied a scenario in which the input air was obtained form outdoors, whereas in the other scenario the input air consisted of indoor air. The latter reflects the situation in which windows and ventilation grids were closed due to dwellers fear of cold draught or risk of burglary.

3. Results

As energy saving strategy, the thermal isolation of houses in the Netherlands strongly improved during the last two decades. The average indoor temperature concomitantly increased. In general, houses built before 1980 have a moderate indoor temperature regime, whereas in modern houses a warmer indoor climate prevails. Figure 1 shows the effect of these two temperature scenarios on the relative humidity in the living room. In both scenarios the living room is ventilated with fresh outdoor air (T = 6 °C; RH = 85%). As expected, higher indoor temperatures give rise to lower RH.

The figures 2 to 4 show the results of two ventilation scenarios at the moderate temperature regime for the kitchen, bedroom and bathroom. In scenario 1 the in coming ventilation flow consists of fresh outdoor air; in scenario 2 it is assumed that the dwellers closed all windows and ventilation grids. In this scenario the ventilation is based on indoor air obtained from adjacent spaces in the building. In our computations for scenario 2 the temperature and relative humidity of in coming indoor air assumed to be equal to the average temperature and humidity prevailing in the living room.

In the figures 2 to 4 RM is equal to the moisture production PR minus the removal by ventilation. RM is positive when PR exceeds the removal, i.e. the RH is 100% and condensation occurs. RM is negative when moisture removal exceeds the production. This can be observed in e.g. the bathroom with the scenario of indoor air ventilation. Then, RM is positive in the time span in which showers were taken and negative in the time span between showers. Ventilation by indoor air (scenario 2) results in higher RH levels which prevail during a longer period compared to ventilation by outdoor air (figures 2, 3 and 4). Especially in the bathroom this is most obvious. This is a result of the higher absolute humidity (vapour density) in the indoor air compared to outdoor air. Thus, ventilation with outdoor air is recommended to avoid dampness in the indoor environment.

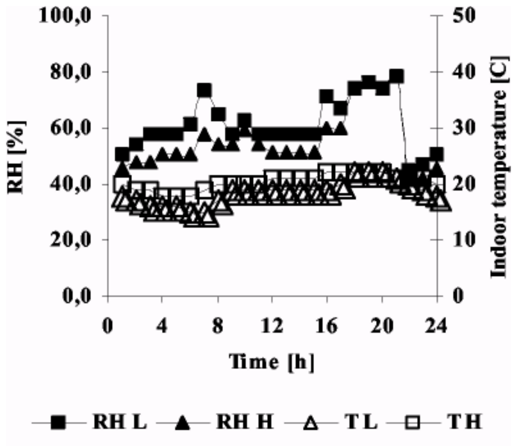

Figure 1. The course of relative humidity RH and temperature T in the **living room** for low L and high H temperature regimes.

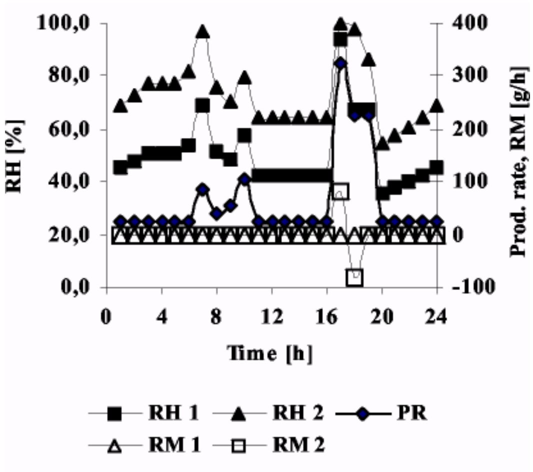

Figure 2. Course of RH, moisture production PR and RM (= PR minus removal) in **the kitchen;** outdoor (1) and indoor air ventilation (2).

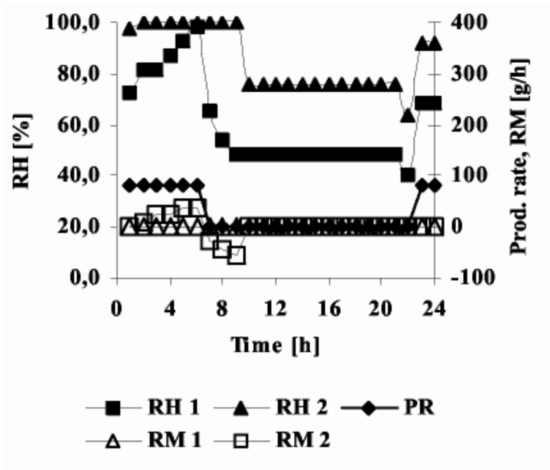

Figure 3. Course of RH, moisture production PR and RM (= PR minus removal) in **the bedroom;** outdoor (1) and indoor air ventilation (2).

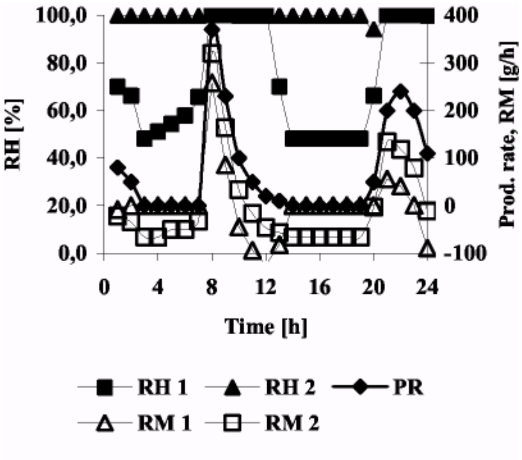

Figure 4. Course of RH, moisture production PR and RM (= PR minus removal) in **the bathroom;** outdoor (1) and indoor air ventilation (2).

4. Discussion and conclusions

On the basis of the results given previously, the general conclusion is that indoor air ventilation leads to high relative humidity, often at saturated level. The question arises how realistic these results are. Saturated vapour conditions in a bedroom will motivate dwellers e.g. to open a window. However, Van Dongen and Steenbekkers [1] found that even with an outdoor temperature of 13 °C 55% of the dwellers sleep with closed windows and grids. Also absorption processes may lower the vapour pressure. These processes were disregarded in our calculations. After taking a shower, dwellers leave the bathroom when damp conditions are considered as normal. Here, no controlling acting of dwellers is expected. Thus, although the computational results may be a bit exaggerated for bedrooms, they seem realistic for bathrooms. This is supported by the observation that mould growth generally occurs in bathrooms. As stated in the introduction, dampness stimulates growth of house dust mites and mould. This may cause allergy with dwellers.

To avoid mould growth, the time of wetness (TOW) should not exceed 0.5. This TOW is defined as the ratio of the period during which the relative humidity exceeds the 80% and the total cyclic wet-dry period [5]. Thus, if the RH is above 80% during more than 50% of the time, mould growth will occur. The results given in previous section show that mould growth can be expected with indoor air ventilation in the bathroom. In this scenario the indoor air in the bathroom is almost constantly saturated with water vapour. Also in the bedroom there is a risk of mould growth with indoor air ventilation. To avoid development of house dust mite the relative humidity should not exceed the 60% for more than 3 consecutive hours [6]. Using this condition growth of house dust mite can be expected in the living room with a moderate temperature regime and in the bedroom and bathroom with indoor air ventilation. Since house dust mite feed on human skin scales, this means that e.g. storing dirty clothes in a basket in the bathroom is a risky habit for dwellers sensible to allergy. In the bedroom both ventilation scenarios lead to conditions favourable to the development of house dust mites, although outdoor air ventilation gives a much dryer indoor climate.

Indoor air ventilation in bathrooms is very common in multi-family houses in the Netherlands. The general floor plans in these houses show a built-in type bathroom. This means that the bathroom has no outer wall and no window or grid that enables the supply of fresh outdoor air. When reconstruction of pre war multi-family houses is at hand or with the construction of new houses, it is recommended that the bathroom will be located at an outer wall to allow for outdoor air ventilation.

References

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