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Field Experiments on Airborne Moisture Transport

J. Oldengarm TNO Institute of Applied Physics (TPD), Delft, The Netherlands

W.F. De Gids, TNO Division of Building and Construction Research, Delft, The Netherlands*

Introduction

Within the framework of the Dutch participation in the IEA Annex XIV " Condensation" field experiments have been carried out to study airborne moisture transport in realistic circumstances. The experiments were done in an unoccupied 3-storey dwelling in Leidschendam in the Netherlands. Some of the results will be discussed in this paper.

Airborne Moisture Transport

The aim of field experiments was to study the airborne moisture transport from a local moisture source to other areas in the house. Two distinct phenomena have been considered separately:

- The airborne moisture transport from the zone in which the moisture source is located, to other zones in the same house. This is denoted as the interzonal airborne moisture transport.
- The internal airborne moisture transport inside the single zone in which the moisture source is located. This is denoted as the internal airborne moisture spreading.

Interzonal airborne moisture transport is induced by pressure differences between adjacent zones in the building. These pressure differences are influenced by temperature differences (stack effect), wind pressure and the use of ventilation devices. The basic principles of interzonal air transport are quite well understood, although the complex interaction of the influencing factors may result in unpredictable effects. Internal airborne moisture spreading within a single room is much more difficult to understand. The nature of this type of moisture transport is mainly induced by air movement. Water vapour diffusion does not play an important role in dwellings. Many factors influence the indoor humidity levels caused by an internal moisture source, such as

- the air flow patterns in the room and the associated mixing process; air flow patterns are influenced by factors like type and position of heating systems, shape and geometry of the room, the way in which air is supplied or extracted, etc.
- the removal effectiveness of the extract ventilation (if any)
- the amount of dilution by infiltration
- the absorption/desorption process of water vapour at the room surfaces and furniture.

The variety of possible airflow patterns makes it very difficult to predict quantitatively the airborne moisture movement within a single zone.

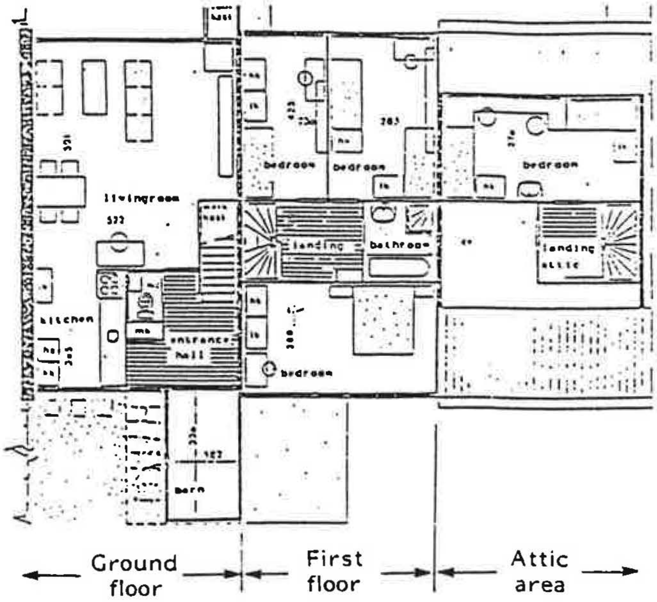


Figure 1 Floor plan of the dwelling used for field experiments

The Experiments

In order to eliminate disturbing influences of occupants the experiments were carried out in an unoccupied house. A floor plan is shown in Figure 1. During these experiments the moisture was generated in a precisely defined and controlled way. Three types of moisture generation experiments have been considered:

a. cooking experiments (800 grams water vapour in 30 minutes);
b. shower experiments in the bathroom;
c. wash drying experiments in the attic;

In this paper only the results of the cooking experiments will be discussed briefly. The full details of all experiments have been reported in a TNO report [1]. The cooking experiments were done for various conditions in order to study the effect of the major influencing factors, like open or closed windows, open or closed interior doors and the use of the ventilation system. A constant evaporation rate was achieved during the chosen moisture generation period of 30 minutes. Only one cooking experiment was done per day to allow the establishment of the moisture equilibrium of the wall surfaces.

Measurement Equipment

Sophisticated equipment was installed to collect the experimental data: a constant concentration gas tracer (N_2O) technique, to monitor air infiltration of all rooms. A constant generation gas tracer (SF_6) technique was applied to monitor the air transport from the moisture source to other ones. Further a 16-channel dew-point sensor system to monitor local water vapour concentrations. Finally, a micro manometer measurement system to monitor air pressure differences.

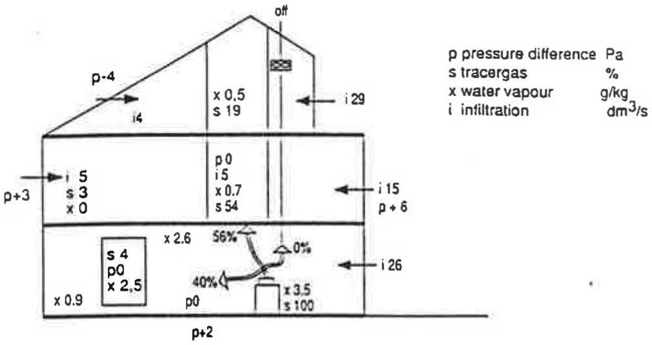
A unique feature of this study was the simultaneous measurement of air transport and airborne moisture transport by using the SF_6 tracer gas and the dew point systems. This feature allowed the study of the moisture storage effects associated with airborne moisture transport. Because SF_6 is an inert non-absorbing gas, the simultaneous measurement of water vapour and SF_6 gas tracer concentration permits to derive quantitative information about the moisture storage effects due to hygroscopic absorption-desorption and condensation-evaporation on wall surfaces.

Results

In Figures 2 and 3 some experimental data are shown for two different cases A and B. Case A can be considered to be the worst case with respect to the moisture load, because the extract ventilation is switched off and the doors and windows are closed. Case B can be considered to be less so as the mechanical ventilation is switched on and the vent lights are open.

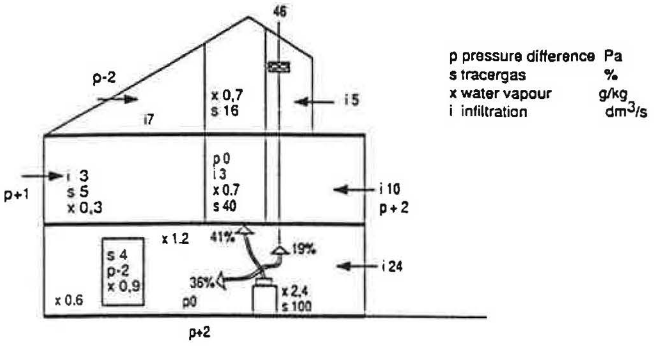
Experimental Decay Curves

In the cooking experiments two kinds of contaminants were released during a period of 30 minutes: water vapour at a constant rate of 27 grams per minute and SF_6 tracer gas at a constant rate of 100 cm^3 per minute. Figure 4 shows the recorded time history of the measured room averaged concentrations for both contaminants for case A. The curves are plotted for an equivalent scale maximum for each of the two contaminants. The scale maximum is computed according to Cmax = M/V, where M is the amount of released contaminant and V is the air volume of the room air.



cooking 30 minutes	yes
door between kitchen/living and hall/staircase	open
vent lights	closed
mechanical extraction ventilation system	off
windspeed	8-10m/s
winddirection	W
outside temperature	11°C

Figure 2 Experimental data from the cooking experiment case A (worst case: fan off, vent lights closed). The data shown refer to: x = water vapour concentration difference (with respect to outdoor air), maximum values are shown as observed after the generated moisture peak at the cooking place.



cooking 30 minutes	yes
door between kitchen/living and hall/staircase	closed
vent lights	open
mechanical extraction ventilation system	on
windspeed	1-3m/s
winddirection	N
outside temperature	10°C

Figure 3 Experimental data from the cooking experiment case B (less worst case: fan on, vent lights open). The data shown refer to: x = water vapour concentration difference (with respect to outdoor air), maximum values are shown as observed after the generated moisture peak at the cooking place.

The example shown in Figure 4 refers to Case A where the air exchange rate is determined by natural ventilation only. The concentrations for both contaminants show a sharp increase during the generation period, as expected. However, there is a significant difference between the maximum concentrations. The SF_6 peak level concentration reached at about 80% of the Cmax = M/V value. This indicates that the other 20% has been removed by ventilation during the generation period. The peak level of the water vapour concentration is much lower: about 40% of Cmax value. Apparently, much more water vapour has been removed with respect to the inert SF_6 gas. This can be explained by the removal of water vapour due to condensation and absorption on wall surfaces. Hence, a comparison of peak values for SF_6 and water vapour concentrations provides information on the moisture storage process that took place during the moisture generation. Figure 4 also gives information on the moisture behaviour by comparing the decay curves. The decay curve of the SF_6 concentration provides reliable information about the real air change rate. This information can be used to predict the decay curve of the water vapour concentration, starting from the time the generation of the contaminants was stopped. The decay curve for water vapour concentration due to ventilation only is indicated by a dotted line. The drawn line represents the observed room averaged water vapour concentration. During the first hours the decay rate of the water vapour concentration is higher compared to the ventilation decay curve. This indicated that additional airborne moisture has been removed by absorption. A few hours later the decay rate becomes lower than the expected ventilation decay rate. This indicates that then moisture is released by desorption. A more detailed analysis showed that absorption and desorption occur simultaneously during the decay time period. During the first few hours absorption is dominating but later desorption becomes dominating.

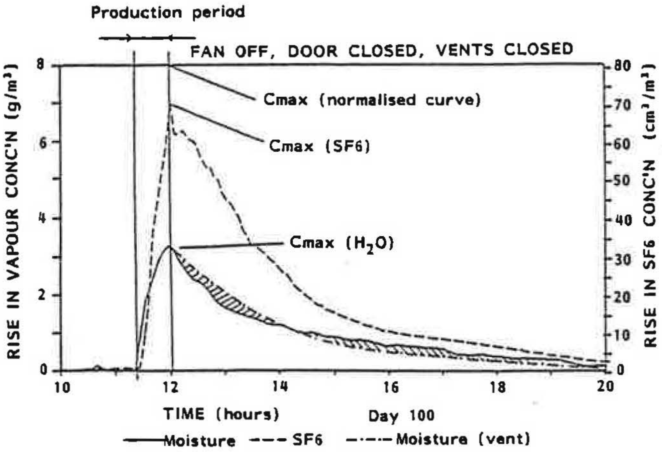


Figure 4 Comparison of water vapour and tracer gas concentration response due to a generation period of 30 minutes.

Moisture Balance And Moisture Removal Effectiveness

The combined gas tracer and water vapour concentration measurements enable us to reconstruct the moisture removal process by deriving the instantaneous moisture balance. The instantaneous moisture balance can be decomposed into the following components:

Mp = amount of moisture released during the generation process
Mv = portion of Mp removed by extract ventilation
Ma = portion of Mp removed by absorption at interior wall surfaces
Me = portion of Mp removed by air transport to other zones
Mi = portion of Mp present in the room air

At any time after the moisture release the following balance is valid:

$$Mv + Ma + Me + Mi = Mp \ [g]$$

or

$$Mv/Mp + Ma/Mp + Me/Mp + Mi/Mp = 1$$

The ratio's Mv/Mp, etc., can be expressed in percentages. The ratio Mv/Mp is of particular interest because it is the figure of merit for the moisture removal effectiveness. Some experimental results for the mass ratios (expressed in percentages) are given in Figures 2 and 3. The percentages shown refer to the instantaneous moisture balance as observed immediately after the moisture generation period. The results have shown that moisture storage certainly is an important factor when considering airborne moisture transport. In case A (Figure 2) 56% of the produced moisture is stored in walls within a very short time during the moisture generation period; 40% is released to the indoor air and 4% is removed by exfiltration. In case B (Figure 3) still 41% is stored in the walls, 36% is then released to the indoor air and 19% is removed by the ventilation system and 4 5 by exfiltration. It was noted that the moisture removal effectiveness Mv/Mp did not exceed 23% in any of the examined cases.

Water Vapour Gradients

The water vapour distribution in the room during and after the cooking experiment was also the subject of study. The moisture distribution was monitored at nine measuring positions located in the kitchen and the living room. During the moisture production large vapour gradients have been observed. Instantaneous differences of up to 5 g/m^3 have been observed between two remote locations in the living room. Data for the observed water vapour concentrations are given in Figures 2 and 3. The water vapour equalization process takes several hours, depending on the ventilation rate. During the equalization period the stored moisture is gradually released again by desorption or evaporation. As noted before moisture storage and moisture release occur simultaneously during the equalization period. This can be explained by the phenomenon that wall areas near to the moisture source have been moistened during the production peak, while wall areas remote from the cooking place are still dry. Apparently, an equalization process of moisture content between wall surfaces occurs: moisture from "wet" areas moves to "dry" areas by airborne transport.

Interzonal Airborne Moisture Transport

In all experiments the effect of interzonal airborne moisture transport was also analyzed. The results showed that interzonal airborne moisture transport appears to be significant only in cases where internal doors between rooms are kept open during or just after moisture production. The interzonal air transport from the kitchen to other zones has been analyzed by comparing the observed peak gas tracer concentrations. It was found that peak ratio varies between 10 to 50% when considering the adjacent hall/staircase. This depends on fan switching and position of the door between living/kitchen and hall/staircase. For the bedrooms this ratio was found to be only a few percent. Comparisons were made to water concentration measurements and it was concluded that a large part of the water vapour is removed by absorption on its way to other zones.

Conclusions

A unique feature in this study was the simultaneous measurement of air transport and airborne moisture transport by using the SF_6 tracer gas measurement technique and a dew point measurement system. This allowed us to study moisture storage effects in association with airborne moisture transport. Interzonal airborne moisture transport was found to be of little importance when considering short term moisture production activities, like cooking. In particular this is true if doors are kept closed in rooms where moisture is produced.

During the cooking experiments large differences between local water vapour concentrations have been observed in the kitchen/living room area. An analysis of the measurement results shows that moisture storage at wall surfaces is a very significant component of the moisture balance. Roughly 40% of the moisture produced is stored at the wall surfaces by absorption and condensation during the 30 minutes period in which the moisture is produced. The stored moisture is gradually released again, but this takes several hours. Moisture storage has an important effect on the ventilation efficiency. Cookerhoods with a proper exhaust capacity and placed on the appropriate distance from the source, will have a positive effect on the internal airborne removal effectiveness. With respect to the internal airborne moisture transport the open kitchen/living room situation is a disadvantage compared to a separated kitchen and living room.

Reference

(1) Elkhuizen, P.A., Oldengarm, J., De Gids, W.F., and Van Schijndel L.L.M., TNO-IBBC report B-90-128, Febr.1990

**Willem de Gids is this year's Vice Chairman of the AIVC Steering Group.*

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