Determination of moisture surface transfer coefficients under transient conditions

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ABSTRACT: Detailed investigations on surface transfer coefficients for indoor environments under nonstationery conditions, like short term airing, are presented in the paper. The measurement method is carefully investigated to minimize the influence of uneven surface temperature profiles. A small (4x4x2 cm³) insulated specimen with a high liquid conductivity is the best probe for determination of the surface transfer coefficients. From the experiments it can be concluded that under winter conditions the moisture transfer coefficient is increased by 180% from its value with closed windows and that it takes two hours after the windows have been closed till it reaches its old value.

1 INTRODUCTION

Determination of Indoor Climate always includes the prediction of thermal and hygral conditions of the indoor air and at the surfaces. Already developed simulation models for the performance of buildings are able to predict those parameters. User behaviour (heat and moisture production, ventilation) and the dynamics of heat and moisture inside materials can be modelled with an acceptable accuracy and input data can be found in literature. Standards recommend different heat transfer coefficients for heat and moisture calculations and neglect surface moisture resistances. Still very rare and incomplete are well documented datasets on the surface transfer coefficients for heat and moisture transport. A documentation of existing models and measurements together with measurements on the dependence of the surface transfer coefficients on the air flow velocity can be found in Worch 2002.

To measure realistic surface transfer coefficients a test room has been developed where different heat and moisture production and/or ventilation strategies can be run. During such non-stationary experiments the sorption of moisture at surfaces, the surface transfer coefficients and the dynamics of the room and the outdoor climate are measured.

2 MEASUREMENT SETUP

The mass loss of a small specimen (4x4x2 cm³) is determined with a balance. Additionally the surface temperature in the centre of the specimen and the temperature and the relative humidity of the indoor air are measured next to the specimen. The test-room has an area of 13.4 m² and a height of 3.5 m. The east facing exterior wall has one window (1.32 x 1.95 m²).
3 MATHEMATICAL MODEL

The evaporation of water from surfaces can be modelled with the following equation.

\[ m = A_{\text{evap}} \cdot \beta' \Delta p \tag{1} \]

where \( m \) = mass loss of specimen; \( A_{\text{evap}} \) = evaporating area; \( \beta' \) = moisture transfer coefficient and \( \Delta p \) = partial vapour pressure difference between room and surface.

The density of heat flow across the surface is determined by the convective and radiative heat transfer and the heat which has to be used for evaporation. As the radiative heat transfer is depending on the geometry and the temperature of all surfaces the equation is simplified using an effective heat transfer coefficient.

\[ q = \alpha \cdot (T_{\text{room}} - T_{\text{surf}}) - h_v \cdot \frac{m}{A_{\text{evap}}} \tag{2} \]

where \( q \) =density of heat flow, \( \alpha \) =effective heat transfer coefficient, \( T_{\text{room}} \) =room temperature, \( T_{\text{surf}} \) =surface temperature and \( h_v \) =enthalpy of liquid-vapour phase change.

To calculate the time-response of a specimen with an insulation ring a three dimensional program has been developed which accounts for the heat flow due to evaporation according to Equation 2. Figure 2 shows the geometry and the network which is used for calculating the heat flows. Not accounted for is the convective heat transport inside the specimen due the liquid water movement or vapour transport.

Figure 2. Geometry of model and network for the calculation of the heat flows

4 SURFACE TEMPERATURE PROFILE

As the evaporation of water depends on the partial vapour pressure at the surface, which itself depends on the surface temperature, a uniform temperature across the evaporating surface is important. Usually the surface temperature is measured at one point of the surface. An uneven distribution would result in a systematic error of the calculated moisture transfer coefficient. Figure 3 shows the measured temperature profile across the evaporating area. The room temperature has been 22.5 °C and the specimen has been insulated with 4cm extruded polystyrene. The specimen had 10 hours to reach equilibrium. The measurement of the surface temperatures has been done with an infrared thermography system SC1000 from Inframetrics calibrated with the temperature at the centre of the specimen measured with thermocouple. As can be seen the temperature profile depends on the material.

![Figure 3. Measured and calculated temperature profile across surface for two different materials. The boundary conditions used for the calculations are \( \alpha = 12.7 \text{W/m}^2\text{K} \), \( \beta' = 18 \cdot 10^{-3} \text{kg/m}^2\text{sPa} \). \( T_{\text{room}} = 22.5^\circ\text{C} \).](image)

With a calcium-silicate fibre board (CaSi, max. moisture content 850 kg/m³), which has a high moisture conductivity, the profile is more uniform comparing to the profile measured with autoclaved aerated concrete (AAC), which has a lower moisture conductivity. The calculated profile agrees very well with the measured profile on the AAC surface. As can be seen the convective heat transport due to liquid transport flattens the profile and using CaSi as the “moisture source” is appropriate.

5 STEP RESPONSE AND ACCURACY

To estimate the accuracy of the measured transfer coefficients the step response of the system is calculated for two different scenarios. In case 1 the transfer coefficients are varied and in case 2 the room temperature is varied stepwise.
In Figure 4 the results for the simulated measurement are presented for case 1. The uneven temperature field leads to a systematic deviation of 3%. As the temperature in the centre of the drying area is a slightly lower than the mean value the vapour pressure difference is underestimated and therefore the “measured” transfer coefficient is overestimated.

Additionally it can be seen that if the specimen starts with an initial temperature equal to the room temperature it takes about 4 hours until equilibrium is reached. Due to the geometry, the additional heat flow across the insulated surfaces increases the surface temperature and the mass flow rate. It has been shown that, increasing the area to 20x20cm², results in a more uneven temperature distribution across the drying surface (Bednar 2002) and therefore the systematic deviation of the measured transfer coefficient increases too.

In Figure 5 the results of case 2 are presented. The stepwise variation of the room temperature results in variation of the surface temperature. As different parts of the surface react in a different way, the relation between the temperature in the centre of the area and the mean temperature changes. If the room temperature increases rapidly the deviation of the “measured” transfer coefficient increases to 5%.

From the calculations above one can conclude that if the mean surface temperature is estimated from the temperature in the centre of the drying area the systematic error is less than 5%, especially if the material has high liquid water conductivity.
6 RESULTS FOR SHORT TERM AIRING

The measurement setup has been used to measure the moisture transfer coefficient during short term airing of the test room. The initial temperature of the test room was 22.5°C. The outdoor conditions during the measuring period were 8 °C, 95% rel. humidity, wind: W, 1km/h, rainfall. The window was opened to an angle of 90° during 30 minutes. The recorded mass loss of the specimen and the measured difference of the partial vapour pressure are shown in Figure 6.

Due to the temperature difference between room and outdoor environment the air flow during the period with the open window influenced the balance in a way that the determination of the time-dependent mass loss during that period was not possible. Therefore only the mass loss over 30 minute intervals was used to determine the mean mass flow rate. The mean partial vapour pressure difference was calculated out of the measured surface temperature and room conditions.

As shown in Figure 7 the moisture transfer coefficient is nearly doubled during intensive airing of a room. After the window has been closed the air flow in the room is still higher and the transfer coefficient is increased. This could be explained with the disturbed temperature fields in the room which induce air movement until equilibrium is reached again.

Already published results for the transfer coefficients (Dreyer et.al. 2002) with closed, tilted and open windows showed lower transfer coefficients for closed (12·10⁻⁵ kg/m² h Pa) and constant open windows (16·10⁻⁵ kg/m² h Pa) under spring weather conditions (outdoor temperature 18°C). This could be explained with the lower temperature differences between indoor air, window surface and outdoor air resulting in lower air flows.

7 CONCLUSIONS

The measurement of the surface transfer coefficients can be done with a small specimen with high liquid moisture conductivity. The systematic error due the uneven surface temperatures is less than 5%.

With closed windows and “still” air the moisture transfer coefficient is around 18·10⁻⁵ kg/m² h Pa. During short term airing under winter conditions the moisture transfer coefficient is increased to 180% and it takes about two hours till it reaches the old value.

REFERENCES


