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Experimental Verification of one-dimensional Heat and Moisture Transfer Models

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Summary

Special wall elements allowing the determination of moisture profiles have been tested in hot / cold box tests under winter conditions. The wall elements consist of frames or segments which can be weighed individually and which are stacked together for testing. The measured moisture profiles are compared with calculations using either a Glaser-type program or the Danish MATCH model. A first series of measurements with wall elements containing cellulose insulation has been completed. The maximum difference between calculated and measured moisture changes was −22% in the diffusion experiment (MATCH model, liquid transport not included).

Zusammenfassung

Experimentelle Verifikation von eindimensionalen Wärme- und Feuchtetransport-Modellen

In der vorliegenden Untersuchung wurden spezielle Wandelemente, welche die Bestimmung von Feuchteverteilungen erlauben, getestet und mit GLASTA- und MATCH-Berechnungen verglichen. Die Versuchsreihe umfasste einen Diffusionsversuch im Zweikammer-Prüfstand unter winterlichen Verhältnissen sowie einen Trocknungsversuch. In einer ersten Versuchsreihe wurden Wandelemente mit Zellulose-Isolation geprüft. Die maximale Differenz zwischen den gemessenen und berechneten Feuchtewerten betrug im Diffusionsversuch für das MATCH-Programm −22%, was für Zellulose- und Holzwerkstoffe ein normaler Wert ist.

Introduction

A series of laboratory experiments have been run in order to check the performance of one-dimensional heat and moisture transfer models available at EMPA. The models tested were either GLASTA, a Glaser-type program with modifications allowing simulation of simplified moisture distributions or the Danish MATCH model, a one- dimensional, non-steady state calculation program for full modelling of simultaneous heat and moisture transfer. Both programs are commercially available.

This paper describes a drying and a diffusion experiment with wall elements containing cellulose insulation. The properties of the materials used were measured independently using standard test methods. Care was taken to measure samples from the same board or in case of cellulose insulation from the same bag as was used for the construction of the wall elements.

Wall elements

The wall elements are put together from separate layers which can be weighed individually, thus allowing the determination of simple moisture profiles. They are kept together and sealed by polyester adhesive tape. The wall elements have an overall size of 50 x 50 x 15,2 cm. The construction data is given in Table 1.

No.	Material	No. of layers	Thickness [mm]	λ [W/m K]	μ [-]
1	wood fiber board	1	19	0,104	51
2 to 7	cellulose insulation	6	20	0,040	1,6
8	gypsum board	1	12,5	0,27	7,3

Table 1, Construction of the wall elements

The layers containing cellulose insulation consist of a frame covered on both sides with a thin (0,1 mm) polyester gauze and filled with cellulose insulation with a density of 60 kg/m^3. Fig. 1 shows a picture of an insulation layer and of the assembled wall element.

Special attention was payed to the frame. It has a cross section of 2 x 2 cm. In order to keep moisture flow one-dimensional, the frame material must have low moisture absorption and low moisture diffusivity. The frames were therefore made of a resin bound wood replacement product (CIBA BM 5500) with a low water absorption coefficient ($1{,}7 \cdot 10^{-4}$ kg/m^2 s^{½}). They were also lacquered but the thickness of the coating was too thin (< 0,1 mm) to have a measurable influence.

A first estimation of the edge effects gave following results:

(i) Moisture absorption after 1 month at 20°C and 90% R.H. calculated from sorption measurement data (important for the drying experiment):

moisture content in the cellulose insulation	0,0432 kg
moisture content in the frame	0,0054 kg

(ii) Modification of moisture flow in the diffusion experiment by heat bridge effect of the frame:
The temperature distribution of a wall element during the diffusion experiment was analysed 3-dimensionally using the steady state heat transfer model TRISCO: On the cold side the surface temperature of the insulation will be rised in the middle of the edges by 0,65 °C and in the corners by 0,9°C. Making a Glaser calculation for the edge area and taking the area-weighed mean over the whole area, a decrease of -1,2% in moisture flow was calculated.

(iii) Moisture diffusion in the frame was considered negligible during the diffusion experiment. In the main direction of the temperature gradient, the diffusion in the cellulose insulations is orders of magnitude higher and in the transvers direction, the temperature differences are below 1 K.

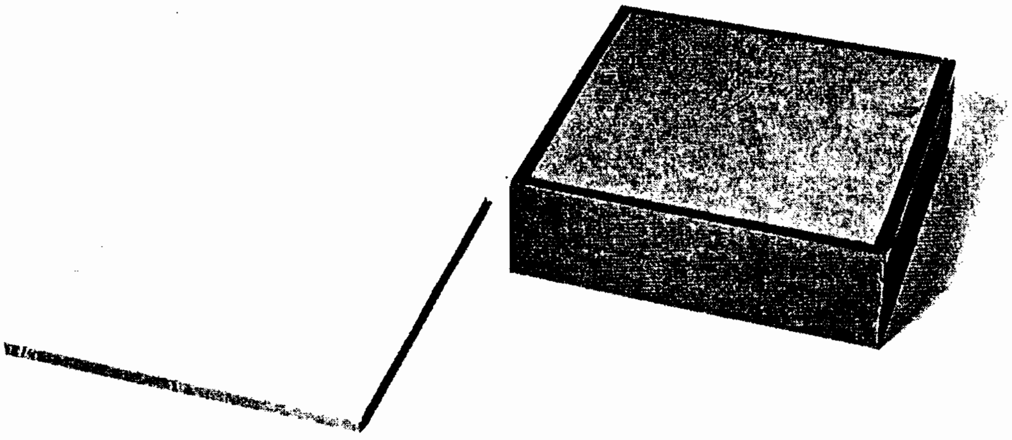

Fig. 1, Picture of a separate insulation layer and of the assembled wall element

The drying experiment

The wall elements were first stored for 1 month at 20 °C and 90% R.H. After preconditioning they were weighed and then brought into a climatic chamber for drying at 20°C and 35% R.H. The change in moisture content was determined by weighing the wall elements at time intervals of increasing length.The drying out of the wall element is shown in Fig. 2 together with the results of the Glaser and MATCH calculations. In addition the measured values have been corrected for the moisture release of the frame (dashed line).

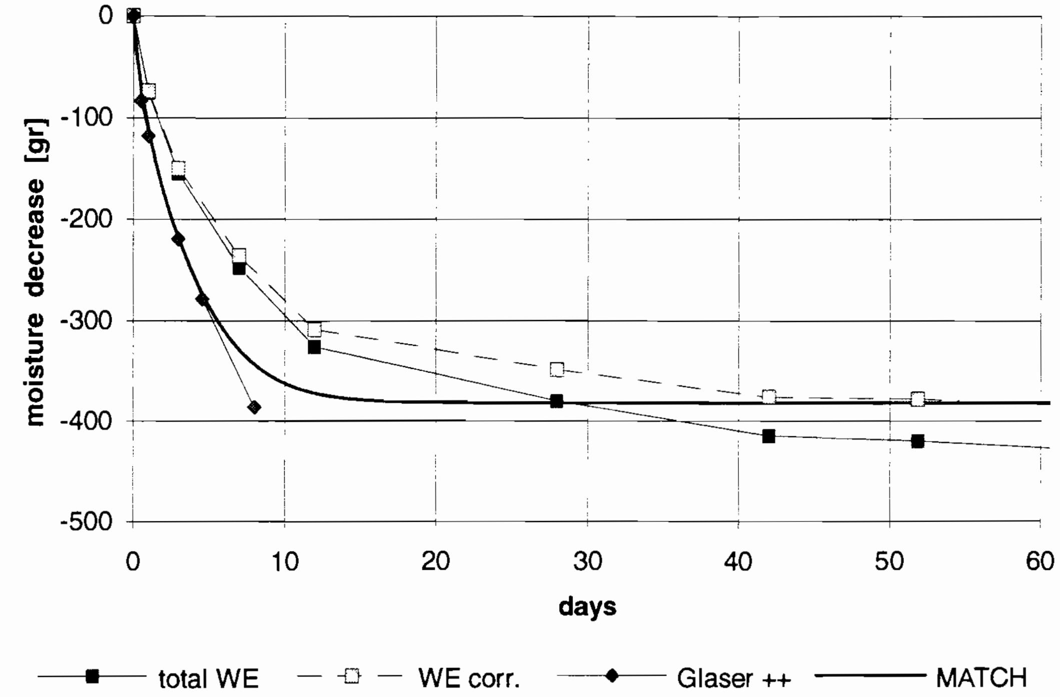

Fig. 2, Drying of the wall element

Glaser programs usually do not allow calculation of drying behaviour. The GLASTA program used has a special calculation mode called GLASTA++ which simulates a very simple moisture distribution and which allows the input of the moisture content of the different layers. For the input the measured moisture content was reduced by the equilibrium value at 35% R.H. Otherwise the program would reduce the moisture content finally to zero because it does not store sorption data.

As can be seen clearly from Fig. 2, the drying of the wall element is in reality slower than in the calculations. In the first 5 days there is little difference between the two calculations. After 5 days the GLASTA calculation dries out the wall at constant rate whereas the MATCH calculation shows a more realistic behaviour.

The moisture content in the different layers can only be analysed with the MATCH program:
The drying of the cellulose insulation layers is in good agreement with the calculation (max$\left(\frac{\Delta m}{m}\right)$ = +19%). On the other hand the gypsum and the wood fiber board show rather large differences bet-between calculated and measured values (max$\left(\frac{\Delta m}{m}\right)$ = +65% for the gypsum board and max$\left(\frac{\Delta m}{m}\right)$ = +50% for the wood fiber board).

In the present case the drying of the wall element is mainly determined by the diffusion of the moisture from inside the wall to the surface. A possible explanation for the differences found would therefore be the use of too low μ values (vapour resistance factors) in the calculations.

The diffusion experiment

The wall elements were first stored for 1 month at 20°C and 60% R.H. and then built in a vertical hot/cold box test apparatus. The climatic conditions on the warm side were 20°C and 60% R.H. On the cold side they were supposed to be 4°C and 80% R.H. but due to a defect in the humidity controller, the climate on the cold side was changing. This was not considered harmful because the climatic conditions were measured troughout the experiment and the input of measured climate data into the MATCH and GLASTA model is easy. Fig. 3 shows the measured climate during the diffusion experiment. The peaks indicate the opening of the chamber for the weighing of the wall elements.

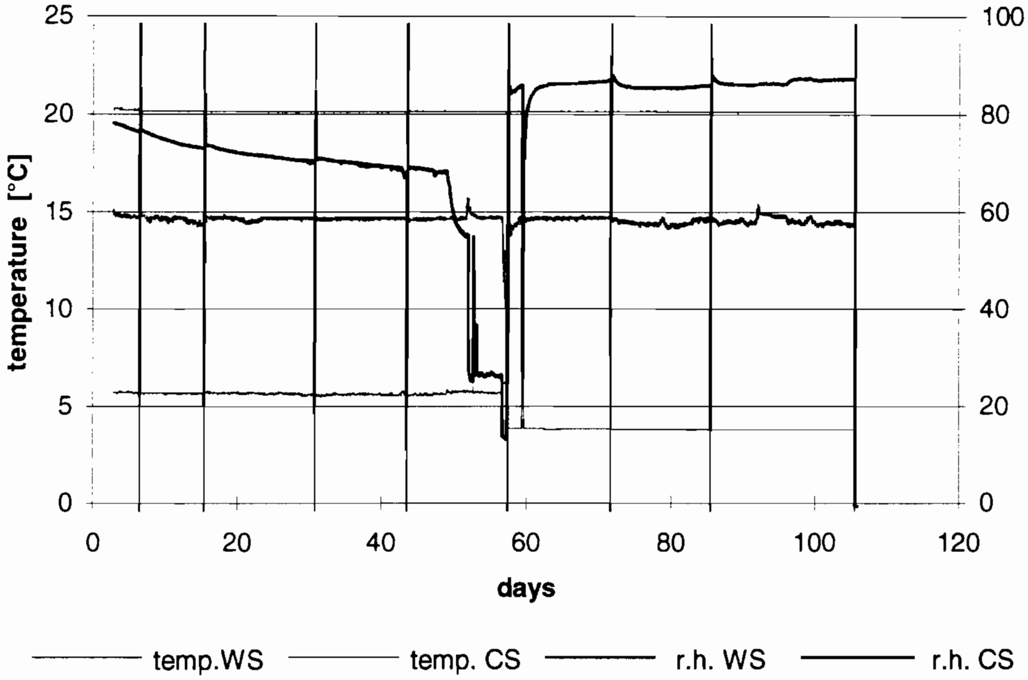

Fig. 3, The measured climate during the diffusion experiment

The diffusion experiment was run for 100 days. Fig. 4 shows the measured moisture accumulation toghether with the results of the corresponding Glaser and MATCH calculations. As can be seen from the figure, the measured moisture accumulation is slightly higher than the calculated values. In contrast to the drying experiment, the μ values used seem now too high. The difference between the two calculations is small as long as MATCH is calculating the diffusion part only. When liquid transport is included in the MATCH calculation, the moisture accumulation is much slower. The large difference between the calculated and measured values may also be partly caused by the construction of the wall elements. It may well be possible that the different layers have interface resistances which reduce capillary moisture transfer in the wall element.

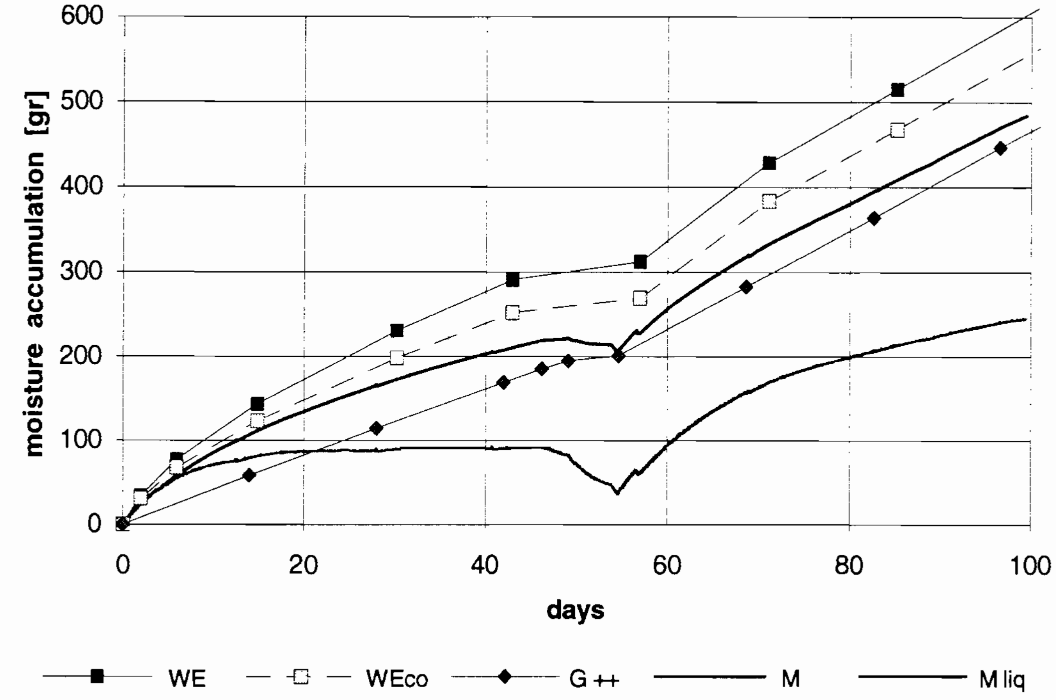

Fig. 4, Moisture accumulation in the diffusion experiment

Conclusion

One-dimensional heat and moisture transfer can be simulated very efficiently with present simulation tools. In the two cases analysed the maximum difference between calculated and measured moisture changes was +45% in the drying experiment (for the whole wall element in the first 7 days) and −22% in the diffusion experiment (full model, liquid transport not included).

Differences in this order of magnitude are not unusual for moisture transfer calculations. For the laboratory experiments the differences found were however larger than expected and the cases are currently being analysed further.