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ON CONTROLLING INDOOR THERMAL AND MOISTURE CONTENT FOR AN OCCUPIED BUILDING

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ABSTRACT

The focus of this paper is on controlling ventilation rate to provide acceptable temperature and relative humidity in the space being ventilated. To this end, a system of heat and moisture balance equations for building indoor and components is described. The system is solved numerically. Based on a series of indoor temperature and moisture measurements for our experimental house and well-mixed air distribution in room, moisture generation rate is estimated. The model is validated by simulating the experimental house. Good agreement between the simulated and measured results is obtained. The effects on ventilation controlling and indoor relative humidity of the moisture generation rate and surface moisture resistance of building material are also demonstrated by simulation.

KEYWORDS

Heat, moisture, mathematical model, indoor temperature, indoor relative humidity, ventilation control.

INTRODUCTION

Indoor temperature and relative humidity are important parameters which can greatly affect indoor's comfort as well as occupants' health. If not controlled, the capacity of air within the building to accommodate water will be exceeded which causes condensation within or on the surface of the building structure. This condensation is the most serious and can result in severe structural damage Huovinen et. al. (1998) and health problem. High relative humidity (more than 80%) may develop mould Viitanen (1997), while low relative humidity, by contrast, may cause infection of the respiratory tract Awbi (1995). Hence the control of indoor temperature and relative humidity is essential.

Indoor temperature and relative humidity are variables and dependent on many building physical parameters. In building where there is no temperature and humidity control, the indoor temperature and relative humidity depend on the balance between heat and moisture gains and losses. They mainly follow the outdoor trends if the ventilation rate is big. Ventilation is commonly used in building to reduce discomfort from over heating in summer and to prevent excessive relative humidity in winter.

Indoor temperature and relative humidity are also influenced by internal heater and occupants' moisture generation rate. Hence to validate the model, moisture generation rate has to be deduced from the measurement data.

The objective of this paper is to control ventilation to ensure indoor temperature and relative humidity varying within allowable ranges. In the next section, a model work is briefly presented. The model is validated by our experimental house. For the applications of the model, we are attempting to focus on ventilation-controlling of indoor relative humidity level. Simulation results are reported also.

MODEL WORK

Model Equations

The detailed discussion of heat and moisture balance equations for indoor air and each component of building system can be found in Viljanen et. al. (1999). Some simplifications have been introduced, considering the complexity of mathematical expression of the balance equations, for example, air temperature and moisture content are uniformly distributed within indoor room.

The heat and moisture balance equations therefore can be written in the following:

$$V\rho_{air}C_p^{\ air}\frac{dT_{in}}{d\tau} = nV\rho_{air}C_p^{\ air}(T_{out} - T_{in}) + Q \tag{1}$$

$$V\frac{dc_{in}}{d\tau} = nV(c_{out} - c_{in}) + G + M \tag{2}$$

where τ is time (s), ρC_p is thermal mass ($Jm^{-3}{}^{\circ}C^{-1}$), V is volume of the room (m^3), T is temperature (°C), n is air ventilation rate (s^{-1}), Q is sum of heat quantities contributed by building components (W), c is water vapour content (kgm^{-3}), G is moisture generation rate (kgs^{-1}) and M is sum of moisture quantities contributed by building components (kgs^{-1}). Superscript and subscript 'air', 'in' and 'out' indicate indoor air, indoor and outdoor.

To have a closed system of heat and moisture equations for indoor air and building components, surface heat and moisture transfer coefficients and all material property data, isothermal absorption curve for example, have to be taken into account. These data are taken from RIL 117 (1979).

The model partial differential equations are discretized using an implicit finite difference technique. The resultant system of algebraic equations is then solved, see Viljanen et. al. (1999).

Calculation of Moisture Generation Rate

The occupants' moisture generation rate is calculated numerically. Eqn. 2 gives the moisture generation rate as:

$$G = V\frac{dc_{in}}{d\tau} - nV(c_{out} - c_{in}) - M \tag{3}$$

To deduce G, the derivative, $\frac{dc_{in}}{d\tau}$, is approximated numerically by interpolation polynomial, Eqn. 3 produces time dependent G+M. With the simulation and measurement data of c_{in} and c_{out}, G and M are then estimated.

COMPARISON OF SIMULATED AND MEASURED RESULTS

To validate the above-discussed model for simulating indoor temperature and relative humidity, the simulated indoor relative humidity in a heated one-storey house is compared with the measured value. Figure 1 shows the cross-section view of the experimental house, see Lehtinen et. al. (1998). The floor is about 109 m^2. The walls, roof and floor are mainly composed of plywood, wood and mineral wool with thickness 200 mm, 300 mm and 300 mm respectively. The total area of the interior surfaces is about 324.7 m^2 and the volume is about 266.3 m^3.

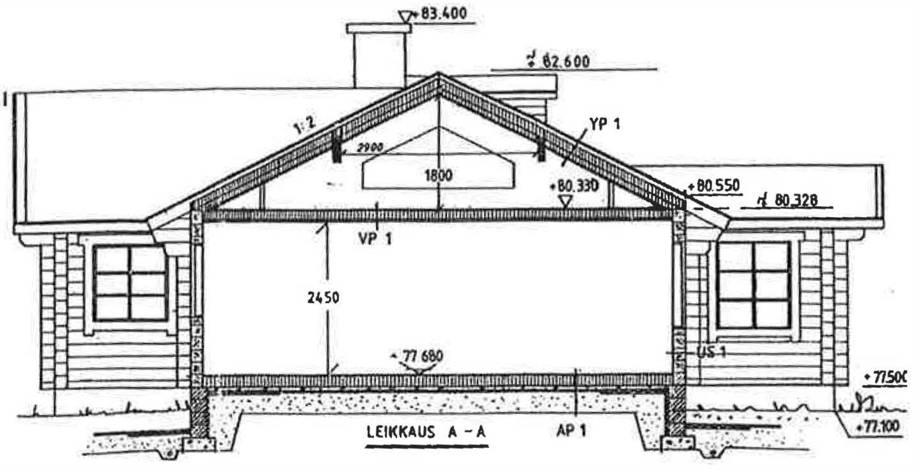

Figure 1: Cross-section view of the experimental house

Temperature inside the experimental house is controlled by directly heating. Its measured data are illustrated in Figure 2. Outdoor temperature and relative humidity are measured for 9 months and indoor temperature and relative humidity are measured for about one week. All measured data are recorded at 30 min intervals.

The surface heat transfer coefficient of the inner surface of walls is derived from empirical equation from RIL 117 (1979) as:

$$h^{in} = 2|T_{in} - T|^{0.25} \qquad (4)$$

The moisture transfer coefficient of the inner walls is assumed as 0.001 ms^{-1} and air ventilation rate 0.3 h^{-1}. The average moisture generation rate is calculated by Eqn. 3 as $G = 124.6\ gh^{-1}$.

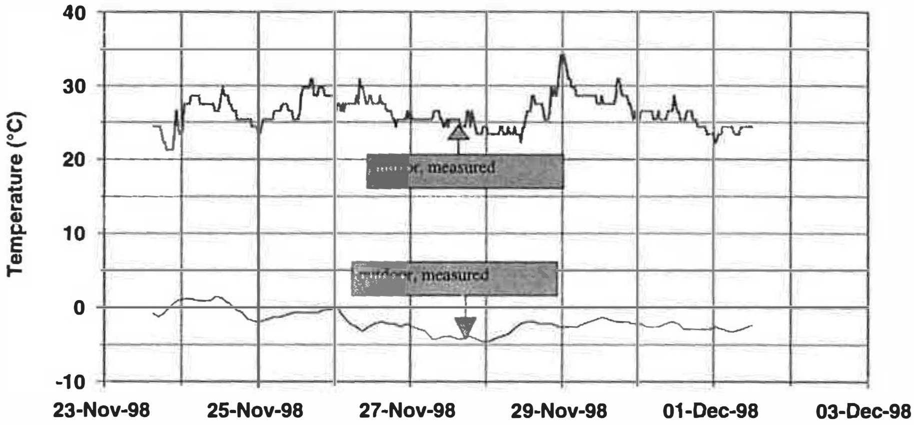

Figure 2: Indoor and outdoor temperatures measured for experimental house

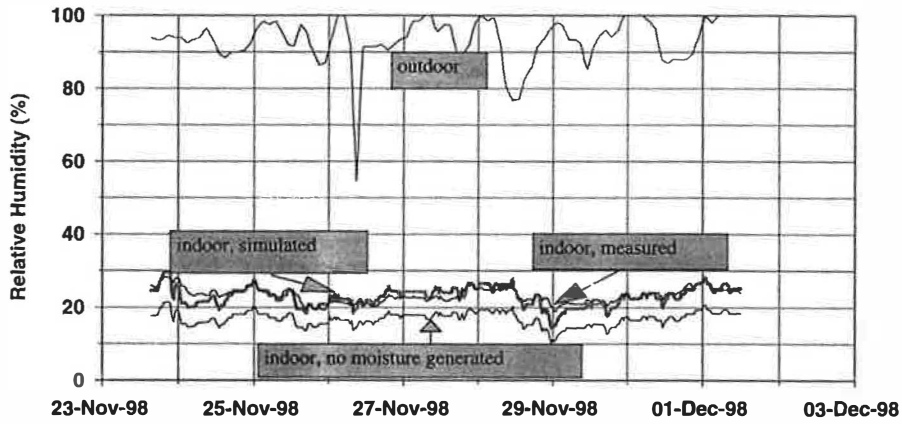

Figure 3: Comparison of indoor relative humidity measured and simulated with moisture generation rate124.6 gh^{-1}. Indoor relative humidity simulated without moisture generation is also presented

Figure 3 shows the comparison of the simulated and measured results of indoor relative humidity. The simulation result is in good agreement with the measurement result.

RESULTS AND DISCUSSION

In order to study the ventilation controlling on indoor temperature and relative humidity, simulation is carried out for the experimental house when indoor temperature is kept at relatively steady value. Here we assume that indoor temperature can be controlled by internal heaters. Simulation examples of controlling indoor temperature can be found in Viljanen et. al. (1999). Therefore, to simplify our calculation, we focus on the controlling of indoor relative humidity.

Assume that the indoor temperature is 22°C and the desired indoor relative humidity is 65%. The indoor relative humidity is allowed to vary within [55 %, 75 %]. Suppose the ventilation system can be supplied with several outputs either by natural air flow or by mechanical fans with on/off cycling for period of 30 min. Then the ventilation rate n ensuring the above condition is estimated from Eqn. 3 as

$$n = \frac{V\frac{dc_{in}}{d\tau} - G - M}{V(c_{out} - c_{in})} \qquad (5)$$

Therefore, the ventilation-controlling logic is to select that ventilation rate n which is close to the value numerically computed from Eqn. 5.

Result of applying the above ventilation controlling technique to Figure 3 for as long as half year is displayed in Figure 4. Here the occupants' average moisture generation rate is assumed as before 124.6 gh^{-1} and the outputs of the ventilation rates are assumed to be 0 h^{-1}, 1 h^{-1} and 10 h^{-1}.

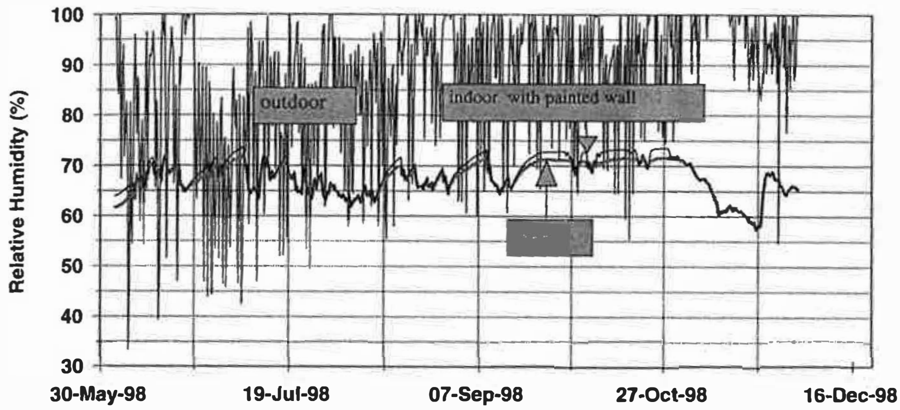

Figure 4: Ventilation controlled indoor relative humidity. Result of painted wall is also displayed

It can be seen that the indoor relative humidity of the experimental house is well controlled by ventilating the outdoor air. The highest indoor relative humidity is 73% and lowest 57%. For the period from Nov. 24 to Dec. 2 presented in Figure 3, the highest indoor relative humidity is 69% and lowest 64% and its average indoor relative humidity is 65%. Note that the average indoor relative humidity is 20% in Figure 3.

Results of the effects on indoor relative humidity of moisture generation rate patterns and surface moisture resistance of building walls are presented in Figure 4 and Figure 5. In Figure 5, it is assumed that a daily moisture generate rate is 373.8 gh^{-1} from 9:00 am to 5:00 pm during the working hours and 0 gh^{-1} otherwise. So the daily average moisture generation rate is still 124.6 gh^{-1} as in Figure 3. We can see from Figure 5 that the difference in indoor relative humidity is within a very small range.

CONCLUSIONS

From the results discussed above it can be concluded that it is possible to control ventilation to ensure indoor temperature and relative humidity varying within desired ranges under different building material properties, moisture generation products and outdoor conditions. The simulation method is useful to further find optimised ventilation for controlling indoor environment. In ventilation-controlling applications, the effects of both the moisture generation rate and the material moisture properties must be taken into account. A constant moisture generation rate model is generally not valid, but the associated error may be negligible as we can see in Figure 5. This has important implication for simplifying our future simulation model.

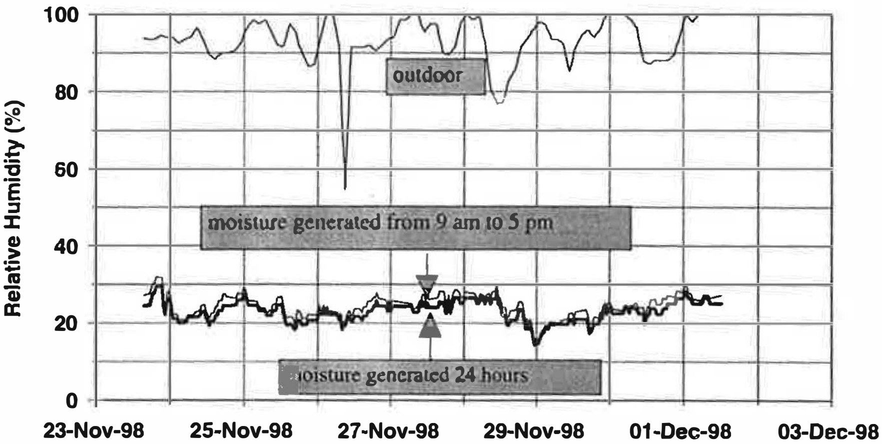

Figure 5: Comparison of the effects on indoor relative humidity of the moisture generation patterns

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