NUMERICAL SIMULATIONS OF ENERGY PERFORMANCE OF A VENTILATION SYSTEM CONTROLLED BY RELATIVE HUMIDITY

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ABSTRACT

High levels of indoor relative humidity are one of the main causes of moisture damage in buildings. That cause can be removed by an appropriate ventilation system. Relative humidity controlled ventilation systems were designed to increase energy performance of buildings without exposing them to moisture damage. The study of the performance of such a system in terms of energy savings and maximum relative humidity is proposed here using numerical simulations with an appropriate whole building heat, air and moisture modelling approach that is developed in the frame of IEA Annex 41. In the studied dwelling the benefits of relative humidity controlled ventilation system were found only in terms of indoor climate (relative humidity) and not in terms of energy savings. Moreover the study showed that for the predictions of global energy consumption some simplifications, such as using monozone calculations and neglecting moisture buffering effect of materials can be admitted. However for estimations of the indoor climate in each room (temperature and relative humidity) multizone simulations and modelling of moisture interactions between air and materials are necessary.

KEYWORDS

Energy, Relative humidity, Ventilation, Numerical Simulation, Moisture buffering, Multizone

INTRODUCTION

High levels of indoor relative humidity are one of the main causes of moisture damage in buildings. They stimulate mould growth on surfaces and condensation problems inside the building envelopes. Indoor moisture is mainly due to human presence and activities, and can be removed by an appropriate ventilation system. Ventilation has a considerable impact on the energy performance of the building, especially in modern, very well insulated dwellings, where the heat loss due to the air renewal can account for as much as half of the total heat loss. It seems then, that the reduction of the amount of new cold air introduced into the building contributes to bringing down the energy consumption. However, in order to avoid long term damage due to moisture problems caused by insufficient ventilation this type of solutions must be carefully studied. The performance of a ventilation system in terms of energy savings and of maximum relative humidity can be analysed using numerical simulations with an appropriate modelling approach.

A comparative study of two ventilation systems, one with the airflow controlled by relative humidity (called RHC in the following) and one with a constant airflow rate is proposed in this paper. A second objective of the work was to analyse the impact of different simplifying hypothesis on the numerical simulations results.

HUMIDITY CONTROLLED VENTILATION SYSTEM

Ventilation systems with the airflow controlled by relative humidity were designed in order to increase the energy performance of buildings without exposing them to moisture damage. The special feature of these systems is their air outlet or sometimes their air inlet equipped with a humidity sensitive membrane acting on the cross section of the vent. The airflow increases for high indoor humidity values and decreases when the indoor air gets drier. An additional advantage of these systems, used in dwellings in France, is a good correlation between relative humidity and most of the air pollutants.

Former studies (Woloszyn et al. 2000, Enache et al. 2002), already showed that energy savings can be insignificant. Anyhow, the real energy performance of such a system should not only depend upon moisture production in the dwelling but also upon moisture buffering capacity of all materials in contact with the indoor air.

WHOLE BUILDING MODELLING APPROACH

Numerical simulations of a ventilation system controlled by relative humidity must be carefully conducted using the whole building heat, air and moisture approach. In this case the energy (used to heat the dwelling), the air (ventilation system) and the moisture (controlling parameter of the ventilation system) have very strong interactions that must be taken into account. Such models are being developed now in the frame of the international collaboration in the Annex 41 project from ESBCS program of IEA (Rode et al. 2005).

In the following study, Clim2000 software was used to perform the numerical simulations (Guyon and Rahni, 1997, Plathner and Woloszyn, 2002). The model library of this modular open code includes more than hundred elements representing various building components such as the layer of a wall, a window, an electric heater, different vents, moisture buffering capacity of furniture, etc. Numerical resolution is done by simultaneous solving of a system of algebraic-differential equations generated by the assembly of the global model. The dynamic behaviour is assessed by using an implicit solver with auto-adaptative time step. This method allows for true representation of all the interactions described in the physical model.

CASE STUDY

Building

The BESTEST building from the Common Exercise 0 of the Annex 41 of IEA (Rode et al. 2005), originally proposed by Judkoff and Neymark (1995) in Annex 21, is used as a support for this study. The indoor space of about 50 m² is divided into one big living room with a separated bathroom and kitchen, as showed in Figure 1. The building has heavyweight structure (see Table 1). The heaters are situated in the living room and are controlled by the indoor air temperature (set point temperature: 20°C). Internal loads represent 2 persons, equipments, lighting and moisture production due to human activity (showers, cooking, etc.) with the scenario of Table 2 over a typical day. The building is situated in Trappes in northern France. The simulations were run over one cold month (February) and some results are focusing on the 3 first days of this month.

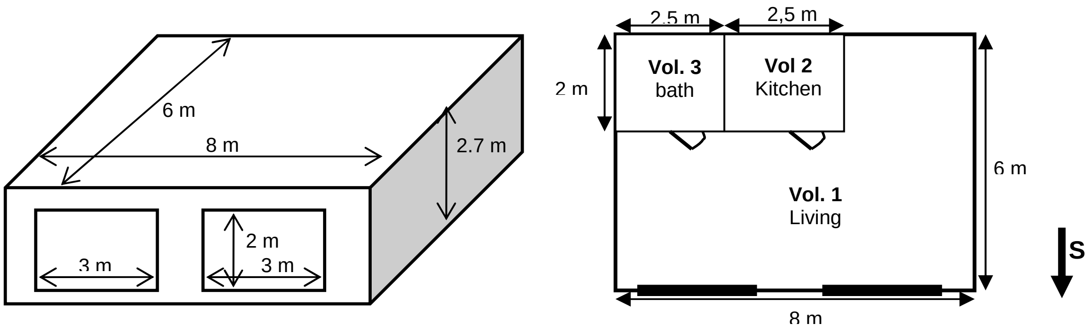

Figure 1: Test building

TABLE 1
Description of the envelope of the test building

Wall	Materials	Area [m²]	U [W/Km²]
Vertical walls	Concrete block (0.51 m) + Foam insulation (0.04 cm) + Wood siding (0.14 m)	63.6	0.512
Floor	Concrete slab (0.08 m) + Insulation (1.007 m)	48	0.039
Roof	Plasterboard (0.16 m) + fibreglass (0.04 m) + roofdeck (0.14 m)	48	0.318
Windows	Double-pane	3	12

TABLE 2
Total daily internal loads

	Load [kWh/day]	Moisture production [kg/day]
Occupants	1,2495	1,575
Bathroom	0,12	3,12
Cooking	1,85	3,7
Equipments + Lighting	1,077	
TOTAL	4,2965	8,395

Ventilation system and indoor moisture content

Two ventilation systems are compared:

- A first with the airflow controlled by relative humidity (RHC), with a minimum flow rate of 80 m^3/h (RH_{indoor} < 30%) and a maximum of 160 m^3/h (RH_{indoor} > 70%) and with linearly interpolated airflow rate in between.
- A second with a constant airflow of 120 m^3/h.

The values of the flow rates were determined by preliminary simulations in order to keep the indoor relative humidity at a suitable level. In both systems the inlet is situated in the living room and the exhausts equally distributed in the bathroom and the kitchen.

Moisture interactions between air and indoor materials are represented using the hygroscopic buffer model proposed by Duforestel et al. (1994), and successfully used by Plathner et al. (2002). The model represents all materials as a lumped capacity with an internal moisture content found by preliminary simulations in order to keep a good balance on a long time period. Here, for the ventilation rate used, the internal moisture content of the hygroscopic buffer was found to be 9.1 g/m^3.

Numerical simulations

The parameter study was conducted to compare the performance of the two ventilation systems but also to define the level of detail necessary to conduct the study. The simplifications concerned both the geometry and physical representation. The compared cases include:

- RHC and constant ventilation,
- Neglecting or not the moisture buffering capacity of indoor materials,
- Using one-zone (whole dwelling = one zone) or multi-zone (whole dwelling = 3 rooms = 3 zones) approach.

In the case of a multi-zone approach the 3 air zones (bathroom, kitchen and living room) are separated by doors. The doors can be opened (air recirculation is possible) or closed (air is passing only in one direction).

RESULTS AND DISCUSSION

Mono-zone vs. multi-zone approach

The results of relative humidity and of energy use showed that when the doors remain open the difference between the two representations is insignificant. Because of the recirculation flow through the doors, the air in the whole apartment is well mixed. A typical situation is presented in figure 2. The net dry air flow follows the ventilation principle and goes from the living room to the kitchen but the net vapour flow goes the opposite way. This situation happens when the moisture content in the kitchen is higher than in the living room.

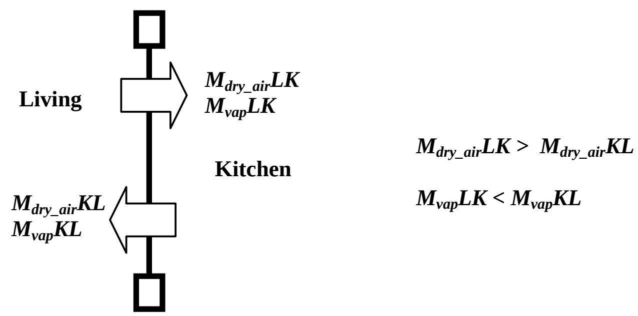

Figure 2: Typical recirculating air flow through the kitchen door during peak vapour production in the kitchen.

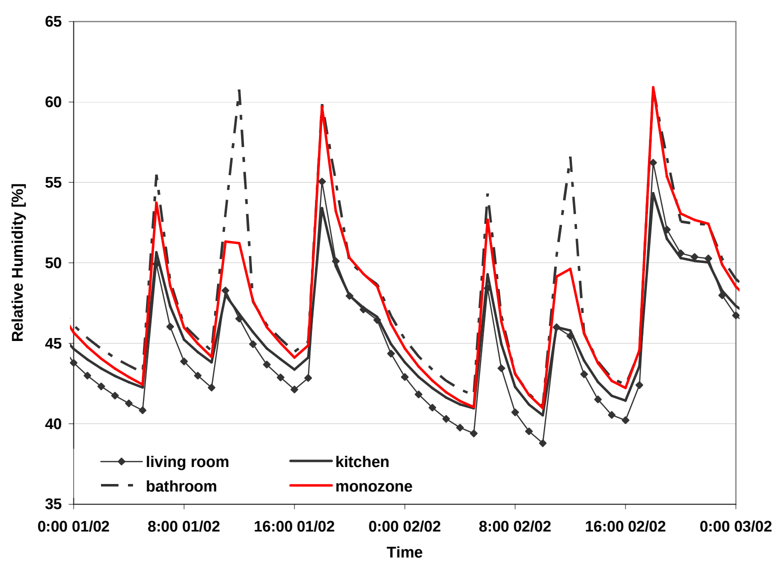

Figure 3: Indoor relative humidity in case of RHC ventilation for both modelling approaches: mono- and multi-zone (doors closed).

On the opposite, when the doors are closed some differences in the indoor climate can be seen. The temperatures in the kitchen and bathroom vary from 18 to 22°C and the peaks of relative humidity are much higher in the kitchen and the bathroom than in the living room (figure 3).

Moisture interactions between air and constructions

The figure 4 shows indoor relative humidity computed, neglecting or not, moisture buffering capacity of materials. As expected, neglecting this phenomenon results in much higher amplitude of relative humidity variations and in peak values overestimated by about 10%.

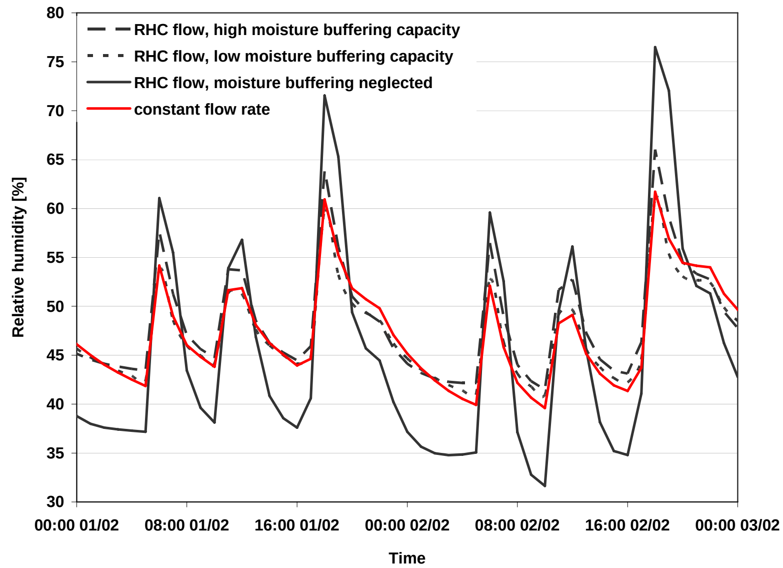

Figure 4: Indoor relative humidity for different moisture buffering representations of indoor materials

RHC vs. constant flow ventilation systems

The energy use for space heating for the most significant cases is given in table 3. As mean ventilation rates in both systems are similar, all results are comparable and RHC ventilation has no real impact on the energy consumption of the studied dwelling. A constant rate ventilation performs even better in terms of energy consumption than RHC ventilation, but the difference is only about 4% (case 2 vs.1 and 5 vs. 4). Moreover the differences between the energy uses estimated by mono- or multi-zone modelling are less than 1% (case 2 vs. 5 and case 1 vs. 4). Also neglecting moisture buffering capacity of materials gives still a correct estimation of the global energy use: no difference was found for constant ventilation (cases 2 and 3) and a small difference of about 2% in case of RHC system (case 4 vs. 6).

TABLE 3
Energy use for heating in February for different cases

Case	Number of zones	Moisture buffering	Ventilation system	Energy use [kWh]	Difference [%]
1	3 (closed doors)	Yes	RHC	767	0
2	3 (closed doors)	Yes	Constant	736	-4.05
3	3 (closed doors)	No	Constant	735	-4.07
4	1	Yes	RHC	773	+0.78
5	1	Yes	Constant	737	-3.92
6	1	No	RHC	757	-1.25

Figure 5 shows the differences in the indoor relative humidity for the two ventilation systems. In the living room the differences are lower than 4% when the moisture buffering effect of indoor materials is represented.

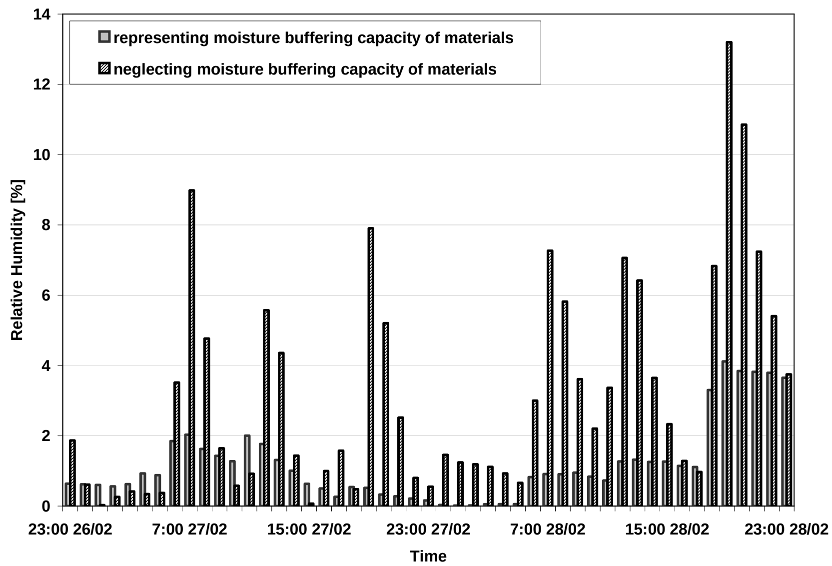

Figure 5: Differences in relative humidity in the living room between the two ventilation systems for two modelling possibilities: neglecting or not moisture buffering capacity of materials.

CONCLUSIONS

In the studied dwelling no energy savings were found due to the use of relative humidity controlled ventilation system. Concerning the indoor climate, when a good mixing of the air can be assumed (open doors) a constant flow ventilation system is enough to ensure correct conditions. However, when the doors are closed RHC system helps to maintain adequate climate in rooms with high moisture production. It seems though that the benefits of RHC system should be estimated in terms of indoor climate (relative humidity or risks of moisture damage…) and not of energy savings.

For predictions of global energy consumption some simplifications, such as using mono-zone calculations and neglecting moisture buffering effect of materials, can be admitted. However these simplifications are not allowed when correct estimations of the indoor climate (temperature and relative humidity) are the objective. When the doors are often kept closed, multizonal simulations are necessary and for correct estimations of indoor relative humidity the moisture interactions between air and materials must be taken into account.

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