HUMIDITY CONTROL IN OFFICES IN THE BELGIAN CLIMATE

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ABSTRACT

In the survey study 'Kantoor 2000' the HVAC-system of several large office buildings in Flanders was monitored. Some of these buildings use air humidity control, most of them not. This triggered the question : why? In this paper the humidity control strategy is studied for some of these offices.

A humidity transport model is developed by using simplified assumptions for the building envelope. This model is validated on a test case, using measured humidity inside a real office building and weather-data logged by the building control system. The model is proven to be sufficiently accurate. The possibility to insert a recovery heat exchanger in the ventilation system was added to the model. Not only recovery of heat was calculated, but also the recovery of moisture.

Two buildings are then evaluated : a smaller size office building and a large office building. In both cases it is shown that the relative humidity drops below 30% for an unacceptable period in time. Adding a recovery heat exchanger is only productive when active humidification is used. These heat exchangers can save about 20 to 25 % of the operation costs of the humidification system.

KEYWORDS

Humidity control, recovery heat exchanger, moisture transport model, ventilation

HEAT AND MOISTURE RECOVERY IN BUILDINGS

The relative humidity of air in buildings is of great importance for the human comfort. Comfort theory shows that relative humidity should be between 30% and 60%. The moisture content of ventilation air is therefore in most office buildings controlled. Especially in mechanically ventilated office buildings this is often the case.

As the outside temperature drops during winter, the water vapour content of it is quite low. When the air is heated the relative humidity drops down, resulting in the delivery of too dry air the building. To solve this problem water can be added to the ventilation air by humidifiers. Two types can mainly be discerned : adiabatic and isothermal. The first type uses the heat included in the air to evaporate water. So no heat has to be added, giving them their name : adiabatic. Main types are water spraying systems and ultrasonic devices. The second type evaporates the water by means of an external heat source and then ads steam to the ventilation air. Thus the air gets slightly heated, resulting in an almost isothermal process. Known types are electrical steam humidifiers and directly fired humidifiers.

The installation of humidifiers is not only an important investment, it also results in a higher energy use of the building and thus in a higher operational cost. It seems therefore interesting to try to recover a part of the water going out of the building and feed it back to the entering air. This can be realised by most recovery heat exchangers. Two main types of heat exchangers are used : plate type heat exchangers and regenerative heat exchangers. This last type consists of two sub types : ratory wheels and stationary matrix types. Only regenerators are able to recover moisture. The recovery potential is expressed by the moisture recovery effectiveness :

$$\eta_X = \frac{x_{22} - x_{21}}{x_{11} - x_{21}} \qquad (1)$$

with : x_{11} moisture content of the extracted air (kg/kg);
x_{21} moisture content of the fresh air (kg/kg);
x_{22} moisture content of the air leaving the exchanger (kg/kg).

The effectiveness of the heat exchanger is different for different types and is strongly influenced by its construction and the working conditions. Figure 1 gives examples of performance curves.

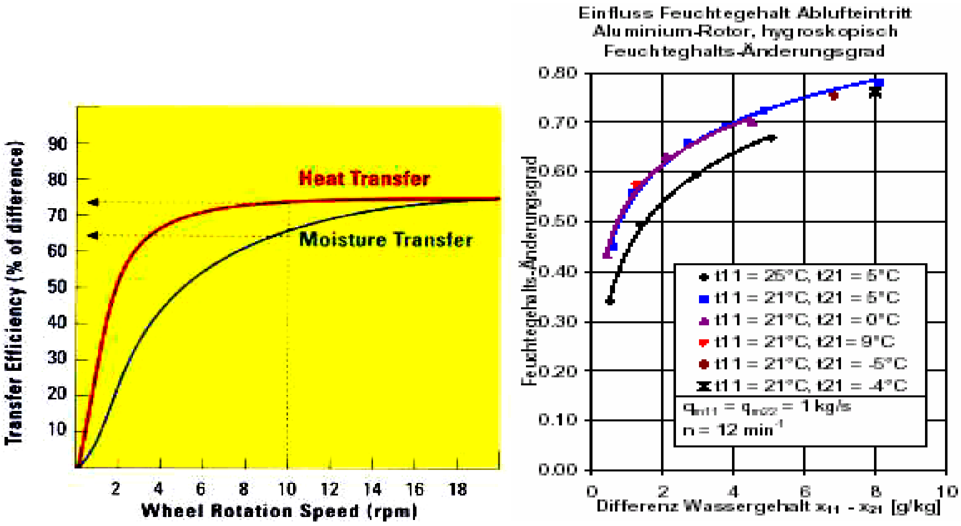

Figure 1 : Effectiveness of recovery heat exchangers
(Harriman et al, (2001). Furter and Keller, (2000).)

HUMIDITY TRANSPORT MODEL

Moisture transport is a specific way of mass transfer. Therefore the law of conservation of mass can be applied to a building :

$$G_p + G_{v,in} + G_n - G_{v,out} - G_d - G_c - G_l = \frac{dm}{dt} \qquad (2)$$

with G_p the water vapour produced inside the building;
$G_{v,in}$ the water vapour supplied by the ventilation system;
G_n the water vapour supplied by wet surfaces;
$G_{v,out}$ the water vapour exported by the ventilation system;
G_d the water vapour exported by diffusion;
G_c the condensation flow rate on cold surfaces;
G_l the water vapour exported through leakage.

Each of these terms can now be further specified.

The water vapour produced (G_p) comes from people and plants inside the building. Typical values for persons doing moderate work are situated between 30 to 60 g/hr/person (Harriman

et al, (2001)). This value for plants can differ a lot depending on type of plant and the environment of the plant. For typical plants in office buildings the value of 0.6 l/day/plant was found (Harriman et al, (2001)).
The water supplied by the ventilation system can be written as :

$$G_{v,in} = G_{a,in} \cdot \frac{\rho_{v,in}}{\rho_{a,in}} = G_{a,in} \cdot \frac{R_a}{R_v \cdot p_{a,in}} \cdot p_{v,in} \approx G_{a,in} \cdot \frac{R_d}{R_v \cdot p_{atm}} \cdot p_{v,in} \tag{3}$$

with $G_{a,in}$ the supplied air flow rate (kg/s);
$\rho_{a,in}$, $\rho_{v,in}$ density of air and vapour (kg/m³);
$p_{a,in}$ pressure of the supplied air (Pa);
$p_{v,in}$ vapour pressure (Pa);
p_{atm} atmospheric pressure (101325 Pa)
R gas constant of vapour (v), supplied humid air (a), dry air (d).

In the same way this gives for :

$$G_{v,out} = G_{a,out} \cdot \frac{\rho_{v,out}}{\rho_{a,out}} = G_{a,out} \cdot \frac{R_a}{R_v \cdot p_{a,out}} \cdot p_{v,out} \approx G_{a,out} \cdot \frac{R_d}{R_v \cdot p_{atm}} \cdot p_{v,out} \tag{4}$$

In porous materials water is transported by means of diffusion. The vapour flux is given by :

$$g_v = \frac{p_{w,i} - p_{w,e}}{\sum_n Z_j} = \frac{p_{w,i} - p_{w,e}}{\sum_n (d_j \cdot \mu_j)/\delta_a} \tag{5}$$

with g_v vapour flux through the wall (kg/s/m²);
$p_{w,i}$ vapour pressure on the inside of the wall (Pa);
$p_{w,e}$ vapour pressure on the outside of the wall (Pa);
μ_j the diffusion resistance of layer j (-);
d_j thickness of the wall layer j (m);
δ_a the vapour diffusivity of air (s)

Condensation on surfaces only occurs if the wall temperature is lower than the dew point of the surrounding air. In the model it is assumed that walls are well insulated, so the wall and air temperature are the same. Condensation is thus neglected. The water evaporation from surfaces is accordingly neglected.

Finally the water vapour transport through leakage can be given as :

$$G_l = \frac{n.V}{3600.R_v.T_i} \cdot (p_i - p_o) \tag{6}$$

with n air tightness (h^{-1});
V volume of the building envelope (m³);
T_i temperature inside the building (K);
p_i vapour pressure inside the building (Pa);
p_o vapour pressure outside the building (Pa).

If the air temperature variation in time is small, the water vapour stored in the air is given by :

$$\left.\frac{dm}{dt}\right|_{air} = \frac{V}{R_v.T_i} \cdot \frac{dp_i}{dt} \tag{7}$$

The moisture storage in a porous material is given by :

$$\left.\frac{dm}{dt}\right|_{porousmat.} = A.d.\frac{\partial w}{\partial t} = A.d.\frac{\partial w}{\partial \varphi}.\frac{\partial \varphi}{\partial t} = A.d.\rho_0.\xi_\varphi.\frac{1}{p_{sat}(T_i)}.\frac{dp_i}{dt} \tag{8}$$

with
- A the contact surface (m^2);
- d the effective penetration depth (m);
- w moisture content of the material (kg/m^3);
- ρ_0 density of the dry porous material (kg/m^3);
- $\rho_0.\xi_\varphi$ the volumetric moisture capacity (kg/m^3);
- $p_{sat}(T_i)$ saturation pressure (Pa).
- φ relative humidity of the surrounding air (-)

Combining all these terms results in a first order differential equation in p_i. This equation was integrated with a finite difference approach, with a time step of 1 hour. In order to be able to evaluate the hygric performance of a building several parameters have to be entered for the building envelope, as to be able to take into account the geometry of the building. This was included in a spreadsheet. More details can be found in Dedoncker (2003). The recovery heat exchanger was added to the model by means of Eqn 1.

VALIDATION

In order to evaluate the performance of the model, the model was used for an existing building. Recent measurement data were obtained for the SD-Worx building in Kortrijk, Belgium. More details of the building can be found in Dedoncker (2003). On the second flour the relative humidity and temperature were measured together with the ventilation rates. A weather station on top of the building also recorded the climate data. Knowing the building construction details and the performance of the recovery heat exchanger the change of relative humidity inside the building could be calculated with the model. Figure 2 shows the comparison between calculations and measurements.

Figure 2 : Validation of the model

The general trend is well predicted and the maximal and minimal values give a good agreement. The model cannot predict the detailed variation. This is mainly caused by the fact that the number of people in the building was not known exactly at every instant in time and also the fluctuation of infiltration was not known. The model shows a slower response to changes. This is caused by a too strong damping in he model. This could be fine tuned if more details were introduced in the calculations. For the purpose of this study the model is satisfactory.

RESULTS

Introduction

The model was used to evaluate the performance of two buildings in Belgium, for which the HVAC-system was studied during the Kantoor 2000 project. The effect of moisture recovery by heat exchangers and the use of humidifiers is evaluated. The studied period is the period over which the inside temperatures were measured during the Kantoor2000 project, being from 18 February to 15 March 1999.

First test case : Sycron, Oostkamp, Belgium

This building has two stories and 92 people work there. The building has a mechanical ventilation system and a protected volume of 12808 m^3. More data can be found in (Kantoor 2000). Figure 3 shows the different test cases. If the building is operated without any humidity control, a period of several days is seen in which the relative humidity is below 30%. If a recovery heat exchanger is added very little amelioration is found. This is caused by the fact that the air leaving the building contains very little water vapour. This reduces the performance of the recovery heat exchanger significantly, as can be seen in Figure 1. So adding a humidifier to the system is necessary. For the studied period an amount of 7096 kg of steam has to be added, resulting in about 19189 MJ of heat. By introducing a recovery heat exchanger, part of the necessary moisture can by recovered. In this case this will give the same curve of relative humidity, but will result in a reduction of 20% humidification costs if an electrical steam humidifier is used.

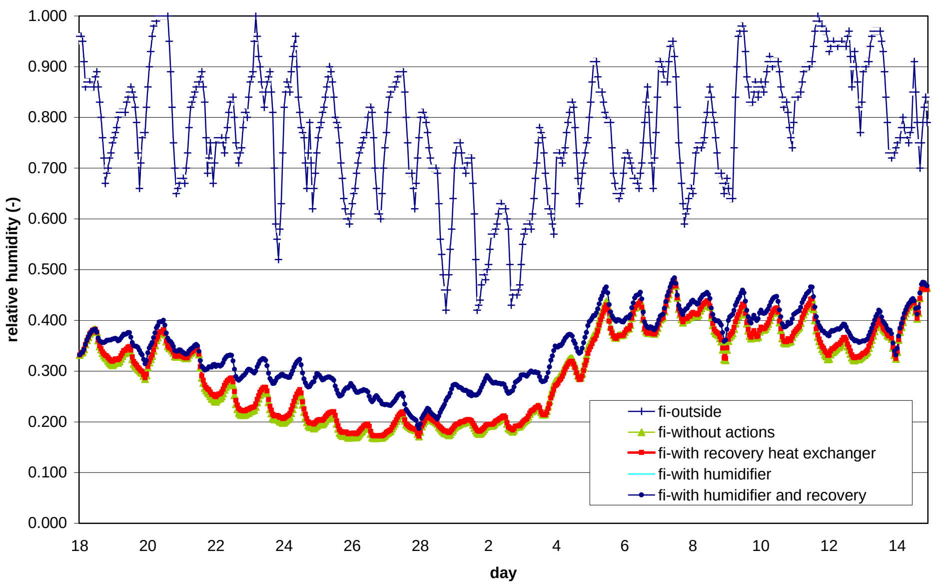

Figure 3 : Test case Sycron, Oostkamp, Belgium

Second test case : City council administration, Ghent, Belgium

This building is a 10-story building, containing the city council administration of Ghent. The total protected volume is 61168 m^3, with 384 people working there on weekdays and Saturday morning. Humidification, is done with electrical humidifiers (Kantoor 2000). Though there is a big difference in size in both buildings, the results for the case with recovery or humidification are quite comparable (Figure 4). This is caused by the fact that the same period, with the same external conditions, was studied. Using only recovery does again not give a significant change in the relative humidity. So humidification is necessary, as is done in the actual building. Using a recovery heat exchanger in this case gives a reduction of energy costs of 26%, as in this large building a gas-fired humidifier could be used instead of an electrical humidifier.

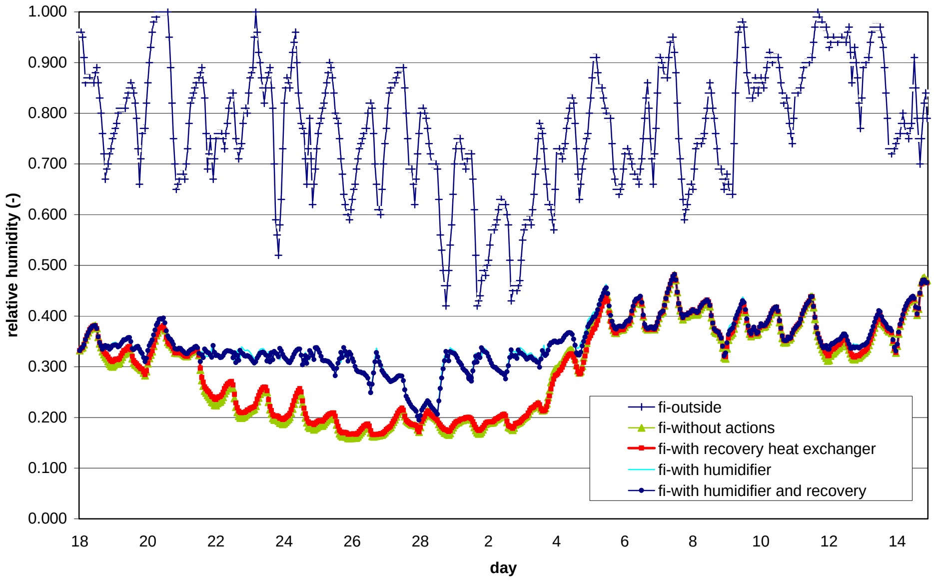

Figure 4 : Test case City council administration, Ghent, Belgium

CONCLUSION

To evaluate the performance of moisture recovery in Belgian office buildings a humidity transport model was developed and validated.

Using the model on two different test cases in Flanders, a large and a small office building, it was shown that the size of the building has a very small influence on the relative humidity pattern of the air in the building. In both cases humidification was necessary. The analysis also showed that moisture recovery does not make sense if the relative humidity of the air is too low, as there is simply nothing to recover.

Combining humidification with recovery though gives the possibility to reduce operational costs with 20 to 25 %.

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