HUMIDITY CONTROL THROUGH THE MODULATION OF VENTILATION FLOWRATES BY MICROPROCESSOR

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1. Introduction

In recent years, as new buildings in Canada are made more airtight to reduce energy consumption, the traditional need for humidification during the heating season is eliminated. More and more buildings experience problems because of high, rather than low, levels of interior relative humidity. At best, the only effect is visual due to condensation on the cold window surfaces. At worst, high humidity can cause moulding of furniture, wallpaper, etc. or even rotting of the wood structure.

Low infiltration flowrates also have an adverse effect on indoor air quality since they result in higher concentrations of contaminants such as CO_2 and other gases. Their effect on the occupants' comfort and health can not be overstated.

In order to compensate for these unwanted side effects of energy-saving reduced-infiltration construction practices, mechanical ventilation is necessary in airtight buildings. Its rate should not however be fixed but it should be adjusted, taking into consideration indoor and outdoor conditions, in order to satisfy the often contradicting requirements of comfort and energy conservation. This paper presents the theoretical foundations and experimental results of such a variable ventilation strategy.

2. Analytical basis

The principle of mass conservation applied to the water vapor within a building enveloppe is

$$M \frac{d\omega_i}{dt} = H + m\,(\omega_o - \omega_i) \qquad (1)$$

where M is the air mass in the building, ω the absolute humidity (subscripts i and o refer to indoors and outdoors conditions respectively), H the rate of vapor generation (including human activity, mechanical humidification and dehumidification, absorption and desorption by all matter within the enveloppe, etc.) and m the rate of air substitution including infiltration and ventilation. Assuming constant values for H, m and ω_o (an approximation which is certainly appropriate for small time intervals) the solution of Eq. 1 is:

$$\omega_i = \omega_o + \frac{H}{m} + \left[\omega_i - \left(\omega_o + \frac{H}{m}\right)\right]_{\text{initial}} \cdot \exp\left(-\frac{m}{M}t\right)$$

This result shows that ω_i varies monotonically from its initial value towards the steady state condition ω_o + H/m. It can be made to increase or decrease by adjusting the ratio H/m to meet any chosen target humidity level. When H > 0 (no dehumidification) the achievable indoor humidity levels are higher than outdoor values.

The following considerations are used to establish target values for indoor humidity. In order to avoid condensation on windows, the value of ω_i must not exceed the saturation value ω_g corresponding to the inside surface temperature of window glazings. This temperature depends on T_i, T_o, the overall heat transfer coefficient for the window and the indoors convection heat transfer coefficient. It is shown in Fig. 1 as a function of T_o for single, double and triple glazed windows together with the highest and lowest values of ω_i recommanded in the ASHRAE Fundamentals Handbook (1981, p. 8.21) for comfort. The figure also shows outdoor absolute humidity for typical conditions in autumn-winter (relative humidity of 80%) and spring (relative humidity of 60%). The shaded area defines the acceptable possible indoor humidity conditions for double glazed windows, typical winter conditions (ϕ_o = 80%) and internal vapor generation (H > 0). Ideal target conditions can be set as follows for a building with double glazed windows:

- ω_i = 0.075 kg vapour per kg air (ϕ_i = 50%) for $T_o > -6$ °C

- $\omega_i = \omega_g$ for $T_o < -6$ °C

The following example illustrates that it is possible to approach these target humidity conditions by adjusting the air change ratio as a function of outdoor temperature, assuming that T_i and H are constants. For a typical bungalow at T_i = 21°C, necessitating m > 10 ℓ/s and incorporating a ventilation system with a maximum capacity of 75 ℓ/s, Figures 2 and 3 show the calculated results corresponding to average diurnal measured outdoor temperatures for a period of nine months. In September, when ω_o and T_o are high, the required air substitution rate is 75 ℓ/s for most of the time and the resulting ω_i is between ω_g and ω_o. In October and November, values of ω_o and T_o are lower and it is possible to maintain ϕ_i = 0.50 for all three values of H by adjusting accordingly the air substitution rate. In December, January, February and the first half of March, ω_o and T_o are even lower: for H = 0.2 kg/h the air substitution rate is 10 ℓ/s (i.e. equal to its minimum value) and ω_i is below the condensation limit, while for H = 0.5 and 0.8 kg/h the air substitution rate is higher to avoid condensation and $\omega_i = \omega_g$. Finally, as temperatures start increasing during spring, target internal conditions (ϕ_i = 0.50) are met once again for all values of H by appropriate modulation of the air substitution rate.

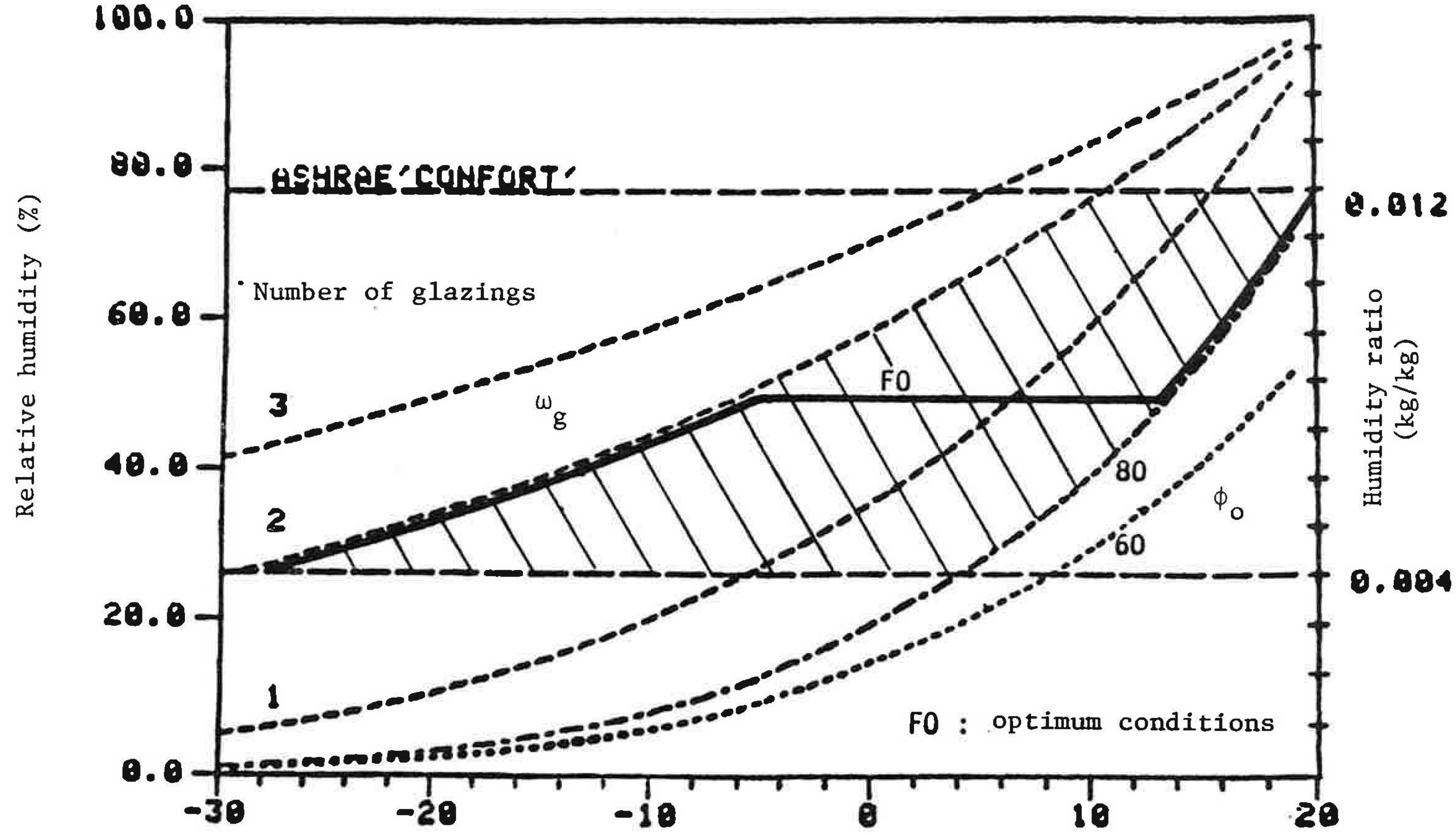

Fig. 1. Acceptable indoor humidity levels for $T_i = 21^oC$.

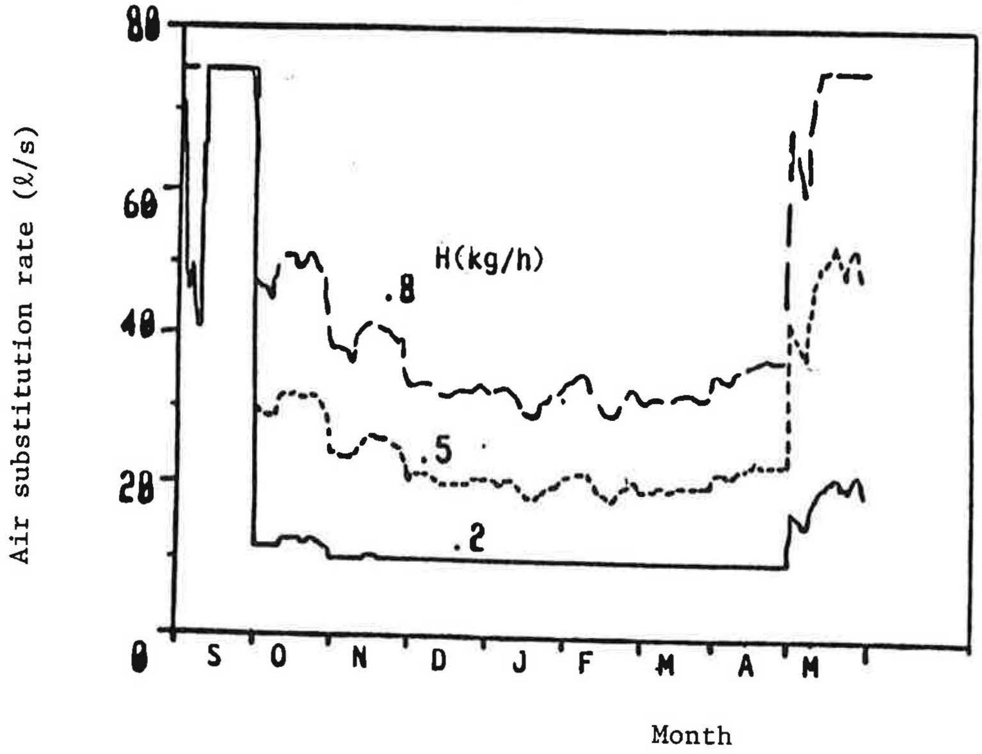

Fig. 2. Air substitution rate necessary to achieve optimum conditions for average outdoor conditions.

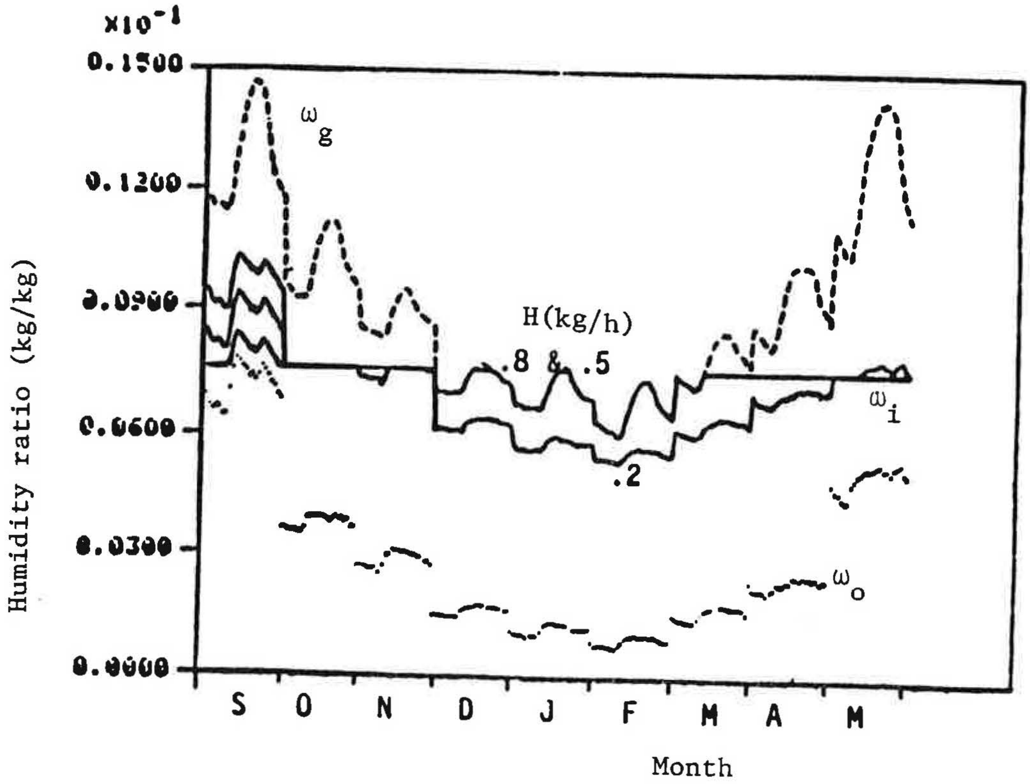

Fig. 3. Humidity ratio corresponding to conditions specified in Fig. 2.

These results are particularly interesting since they show that the control of indoor humidity by modulating air substitution rates is possible and at the same time compatible with energy conservation measures. Indeed, lower air substitution rates are required during winter than in spring and autumn.

3. Implementation and results

The previous results and discussion were based on assumed constant values of the rate of vapor generation H. This term is in reality variable and quite difficult to measure or predict in view of the diverse physical phenomena that influence its magnitude. Therefore, it is not easy to realize a control strategy based on equation 1. It is however quite possible to base a control strategy on the difference between measured values of ω_i and the corresponding target value calculated from a simultaneous measurement of T_o. Since without dehumidification H is positive and $\omega_i > \omega_o$, the two terms on the right hand side of Eq. 1 have opposite signs. Therefore, if the target value is higher than the measured ω_i, the air substitution rate must be small in order to retain in the building as mush as possible of the generated humidity. On the other hand, if the target value is lower, than the measured ω_i, the air substitution rate must be large to evacuate the excess humidity.

Such a simple strategy has been implemented in a bungalow in which the mechanical ventilation can be varied by adjusting the position of a damper in the air intake duct. The damper can be in one of six positions giving ventilation rates equal to 0, 20, 40, 60, 80 and 100 percent of the rated capacity (32 ℓ/s). The corresponding positions of the damper are identified as 0, 1, 2, 3, 4, and 5. The bungalow is equiped with thermocouples measuring indoor and outdoor temperatures as well as an indoor relative humidity meter. Simultaneous measurements of these three variables are taken every 12 minutes and fed to a microprocessor which calculates the target indoor humidity corresponding to T_o. In this experiment the target values have been defined in terms of indoor relative humidity (see Table 1). If the measured value of ϕ_i is within the limits corresponding to the simultaneously measured value of T_o, the damper is set to the position identified as normal in Table 1. If however the measured ϕ_i is higher than the corresponding target, the microprocessor activates a motor which increases the opening of the damper so as to increase the ventilation rate and thus remove excess humidity. On the other hand, if ϕ_i is lower than the corresponding target, the ventilation rate is decreased by partially closing the damper.

Typical measured results are shown in Fig. 4. For most of the day, outdoor temperatures were quite stable and the corresponding indoor target humidity range was therefore constant (47% to 56%). Between midnight and 7 a.m., measured indoor humidity was within the target range so that the damper setting was normal (see Table 1). Shortly after 7 a.m., human activity resulted in an increase of measured indoor humidity and the microprocessor increased the ventilation rate to eli-

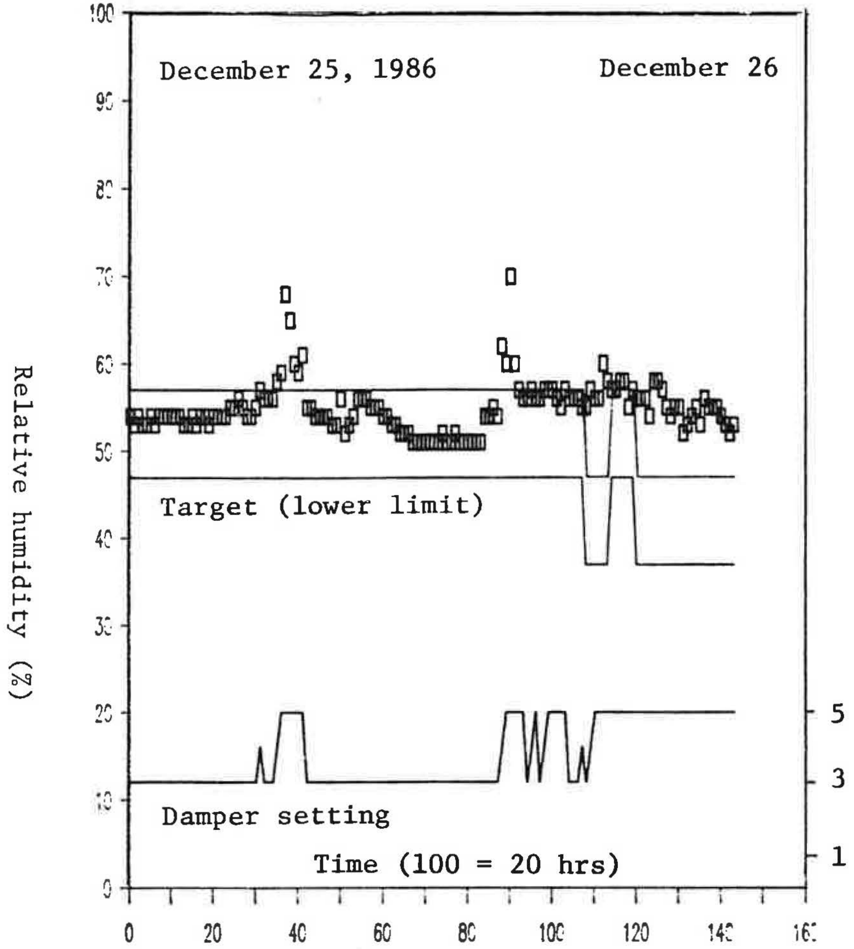

Fig. 4. Evolution of measured indoor humidity and damper setting.

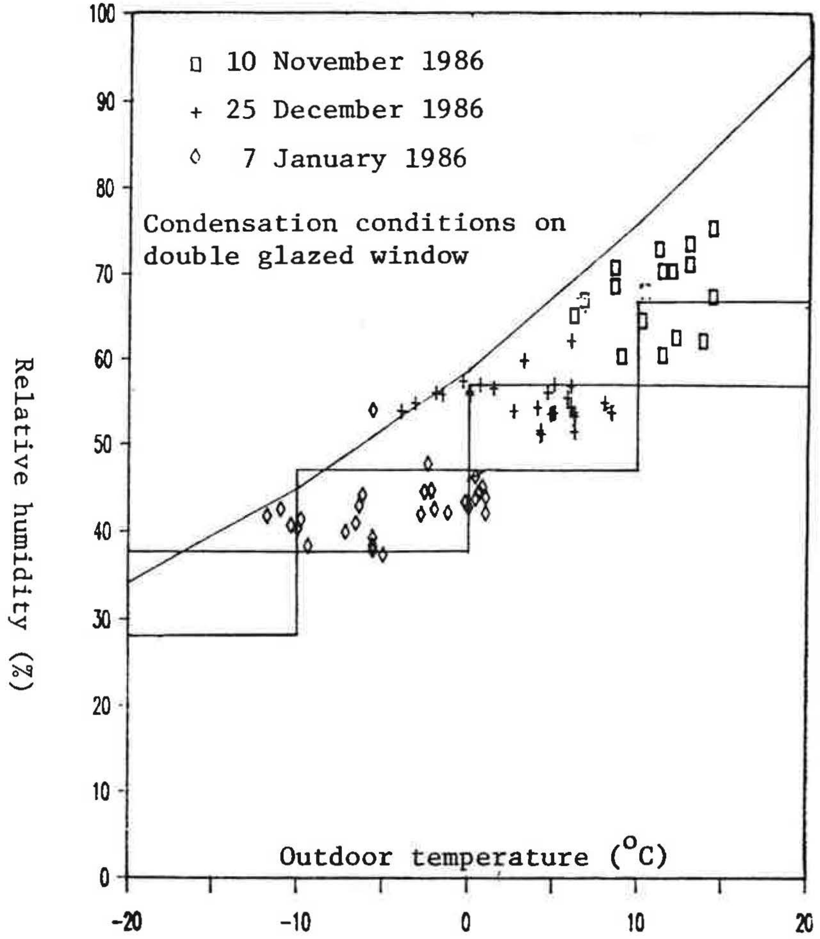

Fig. 5. Comparison of measured hourly average conditions with target values.

Outdoor temperature (°C)	indoor humidity (%)	normal damper setting
$T_o > 30$	$\phi_i > 0.77$	0
$30 > T_o > 20$	$0.77 > \phi_i > 0.67$	5
$20 > T_o > 10$	$0.67 > \phi_i > 0.57$	4
$10 > T_o > 0$	$0.57 > \phi_i > 0.47$	3
$0 > T_o > -10$	$0.47 > \phi_i > 0.37$	2
$-10 > T_o > -20$	$0.37 > \phi_i > 0.27$	1
$-20 > T_o$	$0.27 > \phi_i$	0

Table 1. Target indoor relative humidity and corresponding normal damper setting.

minate the excess water vapor. By approximately 8 a.m., the measured humidity was back within the target range. The same phenomenon was repeated shortly after 5 p.m. and once again the increase of the ventilation rate achieved the reduction of ϕ_i to the upper limit of the target range. After approximately 9 p.m., the outdoor temperature dropped and the indoor target humidity range shifted accordingly. The damper remained completely open thereafter and the indoor humidity level responded as required, although rather slowly.

Figure 5 shows hourly averages of measured indoor relative humidity and corresponding outdoor temperatures for three different days. Also shown is the higher limit of ϕ_i corresponding to condensation on double glazed windows and the target areas defined in Table 1. The results are quite encouraging for the entire range of outdoor temperatures which includes values from approximately - 12°C to almost + 15°C. On the whole, the control seems most effective at low outdoor temperatures for which the drying potential of substituted air is greatest.

4. Conclusions

The results presented in this paper indicate that it is possible to control the indoor humidity in a building by varying the ventilation rate. The control is achieved by a simple strategy implemented by a microprocessor. The occupants of the instrumented bungalow indicate that comfort conditions have improved since the controls have been installed and are quite satisfied with the operation of the system.