Performance Evaluation of Humidity Controlled Ventilation Strategies in Residential Buildings

ABSTRACT

A high-performance low-energy ventilation system needs to combine two opposite demands: an adequate air flow rate for a satisfactory IAQ and a minimal air flow rate to reduce ventilation heat loss. This research highlights Indoor Air Quality (IAQ) and energy use in residential buildings where humidity controlled ventilation is applied. How does moisture buffering affect the performance, and how much energy can be saved by using this control strategy? The savings in heating energy associated with humidity controlled ventilation and the exposure to pollutants are benchmarked with the multizone airflow network model CONTAM. These simulations are carried out on a detached residential building with extraction ventilation and selfregulating air inlets.

This study determines the potential energy savings due to humidity controlled ventilation while the IAQ is compared to the mandatory standards concerning carbon dioxide and relative humidity.

***Keywords**: Air Pollution Control Equipment, Energy Recovery, Building Automation & Controls*

INTRODUCTION

Nowadays the natural habitat of humans is the 'indoor environment' at home, at work or in the car. The perception of the indoor air quality in these spaces as 'fresh and pleasant' depends mainly on temperature, humidity ratio, carbon dioxide and the level of thousands other chemicals in the air (Fanger, 1998). Unfortunately most chemicals, although above an odour threshold, are difficult to measure and therefore impracticable as control parameter. The energy savings possible with carbon dioxide Demand Controlled Ventilation (DCV) systems have well been established (10-80%) (Persily, 2003; Emmerich, 1997), but on the other hand questions have risen concerning IAQ if only CO_2 is taken into account (Afshari, 2003). Unlike CO_2, the humidity in a building is not solely dependent on the presence of occupants, but also on ventilation with outdoor air, cooking, showering, washing and drying laundry. Furthermore high indoor humidity levels often lead to health related concerns and building damage. Possibly humidity DCV can overcome some of the flaws of CO_2-based DCV.

Furthermore the economic viability is at stake: carbon dioxide sensors are a lot more expensive than humidity sensors, and tend to have a bigger drift. A cheaper control mechanism may possibly result in a rather moderate energy saving potnetial, but on the other hand it will have a larger consumer market. The performance evaluation of ventilation systems has to consider both CO_2 as well as humidity. According to EN 13779 (Ventilation for non-residential buildings – Performance) the relative humidity has to lie between 30% and 70% (also Harriman, 2001) and the IAQ concerning CO_2 is commonly expressed by IDA-classes.

MODEL

To assess the performance of humidity DCV simulations were carried out with the multizone airflow network model CONTAM on a designed detached residential building. The design was based on a statistical analysis of the newly built dwellings in Belgium. Figure 1 shows the floor plans: the surface area is 162m² and the compactness is 1.33. The indoor air temperature is 18°C troughout the whole year because CONTAM cannot calculate the effect of different air temperatures inside the ducts. The temperature also has an important influence on the extraction rate, because the ventilation system uses the relative humidity as control parameter. The constant indoor temperature may cause some uncertainty in the stack effect and hence in the total airflow rate in the building. On the other hand pressure differences are primarely dependent of the fan of the ventilation system. Next to that, the influence of the overall temperature is of very little importance if the objective is to compare different ventilation systems. Simulations point out that the effect of local temperature differences (for example in the bathroom when it's used) is more important. Because the building is detached, the terrain roughness is set to 0,20 (country with scattered wind breaks), and the AIVC Wind Pressure Coefficient data for lowe-rise buildings surrounded by obstructions equivalent to half the height of the building were used.

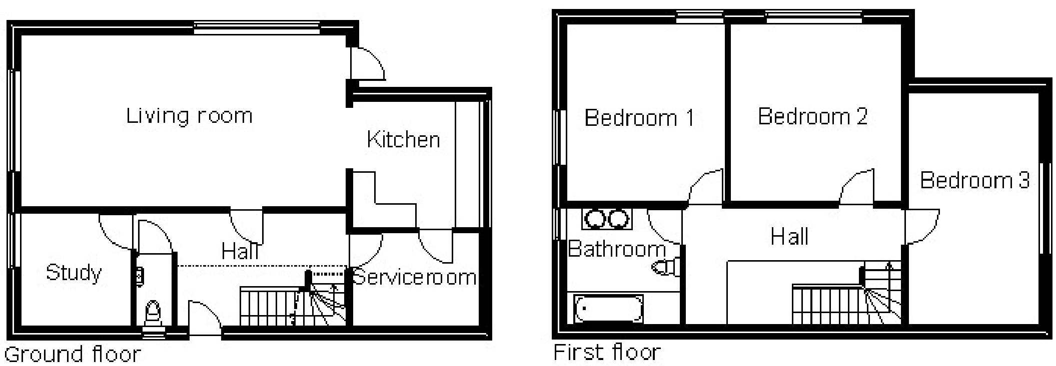


Figure 1: Floor plans of simulation model

Airtightness

The airtightness is expressed by the n_{50}-value: the number of air changes per hour while there is an indoor-outdoor pressure difference of 50 Pa. In the simulations we use 4 different values: $n_{50} = 0.6\ h^{-1} – 1\ h^{-1} – 3\ h^{-1} – 11.2\ h^{-1}$. N_{50}= 0.6 is the passive house airtightness standard. The Belgian ventilation standard NBN D50-001 demands a n_{50}-value of maximum $3h^{-1}$ for balanced ventilation and $1h^{-1}$ for balanced ventilation with heat recovery, and n50 = 11.2 is the compulsatory value for energy loss calculation in absence of measurement for new houses (other quantity converted for this model). In order to properly model leakage due to stack effect the façades are subdivided into horizontal strips for each room, with two cracks per storey. The airtightness of the inner walls is simulated by cracks in the walls and apertures along the doors.

Selfregulating air inlets

The living room, study and bedrooms have selfregulating air inlets above the windows. A pressure difference of 2Pa results in an air flow rate of 3.6m³/h (for length inlet 1m), and only increases a little if the pressure difference is higher. The fresh air flows through transit openings from the living areas to the kitchen, toilet, bathroom and serviceroom. In CONTAM it is not possible to model the inlet according to measured data: the bicubic spline forces us to use a simplified model with a constant air flow rate when pressure differences exceed 6.5 Pa (see Figure 2). The influence of this change is not te be neglected: during 5% of the time the difference in air flow rate lies between 4% and 20% (pressure difference > 6.3 Pa), during 1% of the time the difference can rise up to 50% (pressure differences up to 20 Pa). The total average air flow rate through the selfregulating air inlets is about 1% higher because of this. On the other hand the simplified model that was used in CONTAM can be seen as a general air inlet of the type P3 of P4.

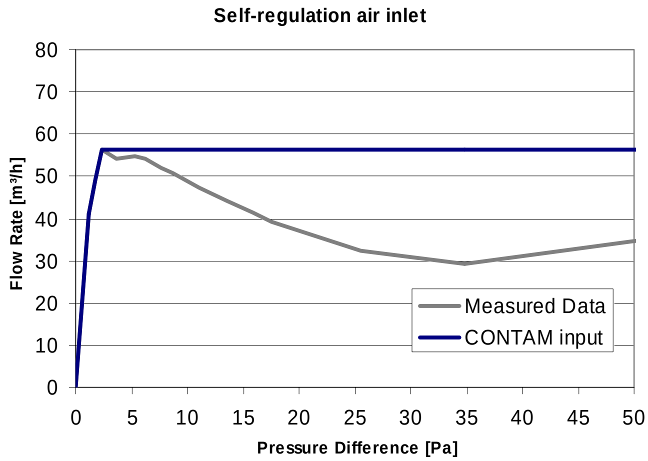


Figure 2: Self-regulating air inlet

Contaminant generation

In the simulations two parents and two children produce H_20 and CO_2 according to their level of activity. The level of CO_2 in the outdoor environment is fixed, but the relative humidity varies according to the data from the Test Reference Year in Uccle (TRY).

Moisture buffering

In CONTAM a boundary layer diffusion model was used to simulate the effect of moisture buffering. The walls and ceiling have gypsum plaster, other materials like wood and textile are not present in the standard model but the influence of additional buffering is analysed further on.

VENTILATION

The house is equipped with an extraction ventilation system that extracts 50m³/h in the kitchen, serviceroom and bathroom, and 25 m³/h in the toilet (nominal flow rate according tot NBN D50-001). We distinguish two types of control strategies: System C is not demand controlled and maintains a constant extraction flow rate as decribed above, System C+ varies the extraction flow rate according to the measured relative humidity and presence detection.

There are motion detectors installed in the bathroom, kitchen and toilet. In the bathroom and kitchen the ventilation period is extended with half an hour after the last presence detection, in the toilet it's extended with 20 minutes. Whenever the motion detectors have observed presence the nominal flow rate will be extracted, otherwise humidity sensors will control the extraction rate. The humidity sensors are installed in the kitchen, bathroom and serviceroom. The minimal air flow rate is 20% of the nominal flow, and from 30 tot 100% RH the flow rate rises in a linear way from 20 tot 100% of the nominal air flow rate (Figure 3).

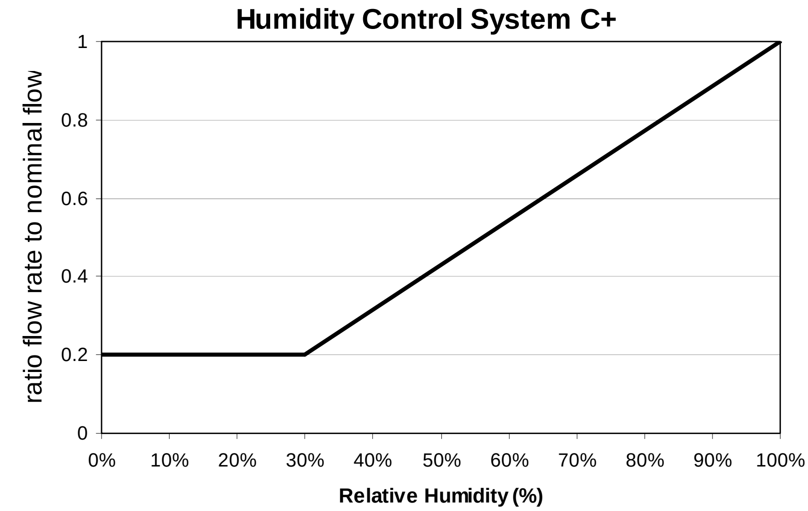


Figure 3: Humidity Control mechanism System C+

The control signals only act on the extraction points, and not on the fan. The fan curve is specifically chosen because fluctuating pressure differences result in a steady air flow rate. That way the behaviour of one extraction point will only have a moderate effect on the other extraction points.

INDOOR AIR QUALITY

To evaluate the indoor air quality there are different criteria which are used in different countries. It's interesting to compare those different possibilities and select the most efficient one to compare ventilation systems.

IDA-classes

Following diagram (Figure 4) shows the indoor air quality in the living room for system C and system C+ for different degrees of airtightness. The left side represents the system with a constant extraction flow rate, the right side shows the results for the system with humidity control and motion detection.

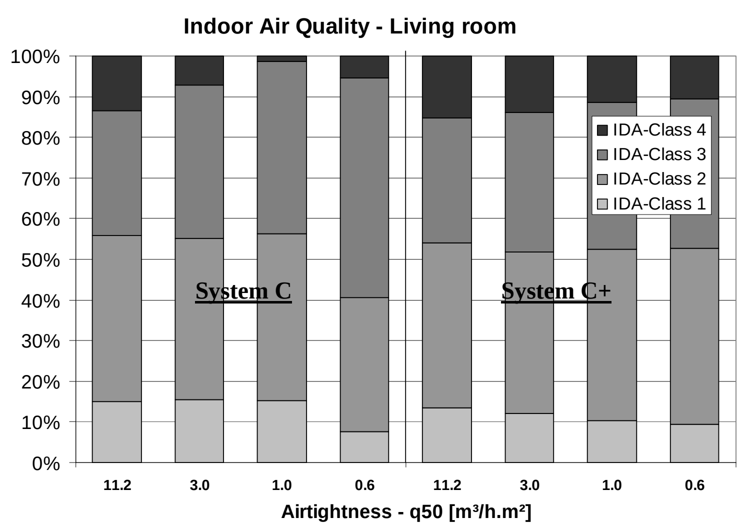


Figure 4: Indoor Air Quality Living Room – IDA

The influence of the airtightness on the IAQ in the building is ambiguous. The fraction of IDA-class 1 as well as the fraction of IDA-class 4 decrease when the airtightness of the building improves. For one thing the in- and exfiltration rate are reduced, so less fresh air will enter the building. On the other hand the ventilation system will function better because the actual air flows will correspond better to the theoretical design.

So based on Figure 4 one could come to the conclusion that the indoor air quality might be similar for the two systems, but the mere subdivision in IDA-classes can be misleading: in fact two systems with identical percentages of IDA-classes can differ remarkably in IAQ.

French Standard

According to the French standard “Modalités d’instruction des Avis Techniques sur les systèmes de ventilation asservis » one has only got to look at the carbon dioxide levels above 2000 ppm to evaluate the indoor air quality. For every hour the carbon dioxide level exceeds 2000 ppm that concentration is cast up throughout a whole year. The standard states that the total amount needs to be less than 500.000 ppmh. Allthough this method takes the dose-effect-relation into account it’s not clear whether there are very high concentrations over a small period of time, or rather moderate concentrations during the whole year. The fysical meaning of this criterium is less explicit, but on the other hand it’s very practical to compare different ventilation systems to each other.

Belgian Standard

The Belgian ventilation standard NBN D50-001 is very ‘*prescriptive*’: there are a lot of regulations for the ventilation system, but no criteria for indoor air quality at all. It’s more desirable to define clear performance criteria for indoor air, in stead of defining the ventilation systems by prescriptions.

Dutch Standard

NEN 5128 (Dutch standard energy-use in buildings) defines a ‘low ventilation index’ (LVI) which gives expression to both the extent as the duration of the ventilation deficiency (dose-effect-relation). The LVI can be derived from the histogram of the standardized effective ventilation (Q_{en}). The Q_{en} is defined as the proportion of the concentration limit (for instance 800ppm above outdoor concentration) to the actual concentration:

$$Q_{en} = \frac{C_{Limit}}{C_t}$$

The LVI is the total percentage of the time that the indoor concentration exceeds the concentration limit (the area below the curves in Figure 5 for $Q_{en} < 1$).

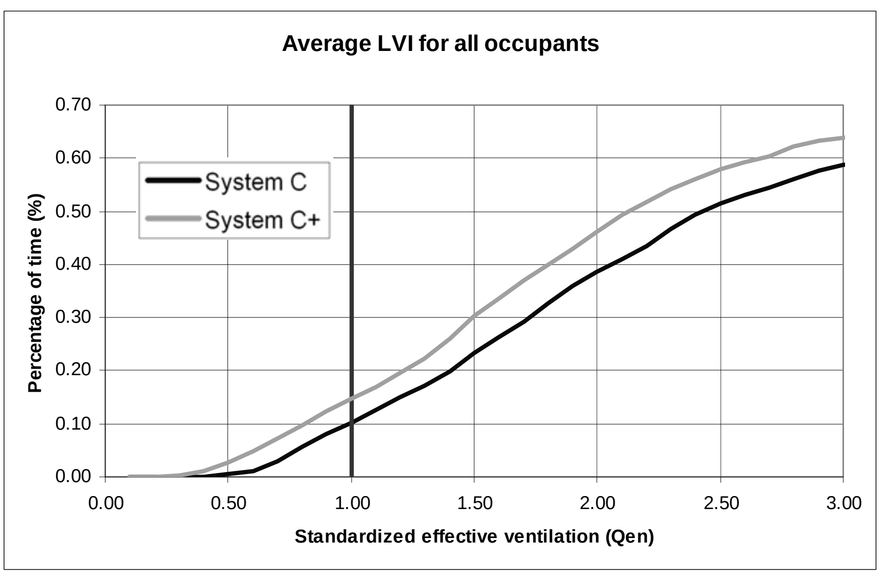
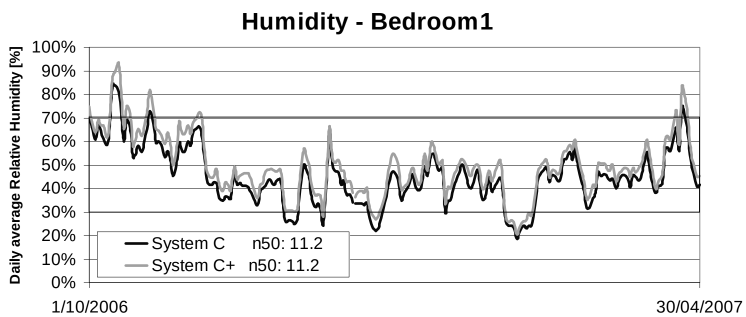


Figure 5: Low Ventilation Index

This one curve gives the opportunity to limit the maximal indoor concentration, limit the LVI and allow an objective analyses of two systems, without any arbitrary constraints. In this case the IAQ of the two systems are clearly not equivalent. Currently we use monte-carlo analyses to develop correct values and concentration limits to benchmark new ventilation systems.

Humidity

The indoor air humidity level depends on a number of different factors, including the level of humidity in the outdoor air that is brought indoors by ventilation, human respiration and activities such as showering, cooking, washing and drying laundry. For a good IAQ the RH should fall in the range of 30-70%.



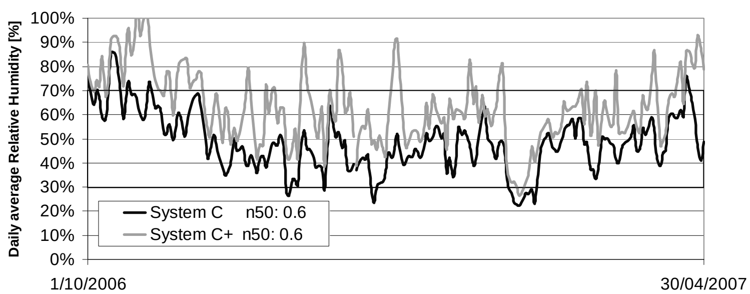


Figure 6 & 7: Relative Humidity in Bedroom 1

As can be seen on the figures above, the difference between systems C and C+ concerning relative humidity is clearly more distinct for airtight buildings. However, the effect is less explicit for the living room and the kitchen. System C results in an IAQ that for 86 to 88% of the time (in the living room, bathroom and bedroom) the daily average relative humidity falls in the range of 30 to 70%. System C+ will perform worse for the bathroom and the bedroom, particularly if the building is airtight.

Airtightness n50-value		11.2	3	1	0.6
LIVING	C	0.88	0.88	0.87	0.87
	C+	0.87	0.87	0.88	0.88
BATHROOM	C	0.88	0.88	0.87	0.90
	C+	0.84	0.75	0.68	0.67
BEDROOM	C	0.86	0.87	0.88	0.89
	C+	0.87	0.77	0.71	0.67

Table 1: Perc. of time indoor air falls in RH-range

Energy use

The ventilation heat losses of system C and system C+ show a similar correlation with the airtightness of the building (Figure 8). System C+ allows to increase the energy savings up to 27% for very airtight buildings, and 14% for buildings with an average aitightness. However, the absolute energy saving potential of 1100 to 1200 kWh is independent of the airtightness: the curves on figure 7 are only translated vertically.

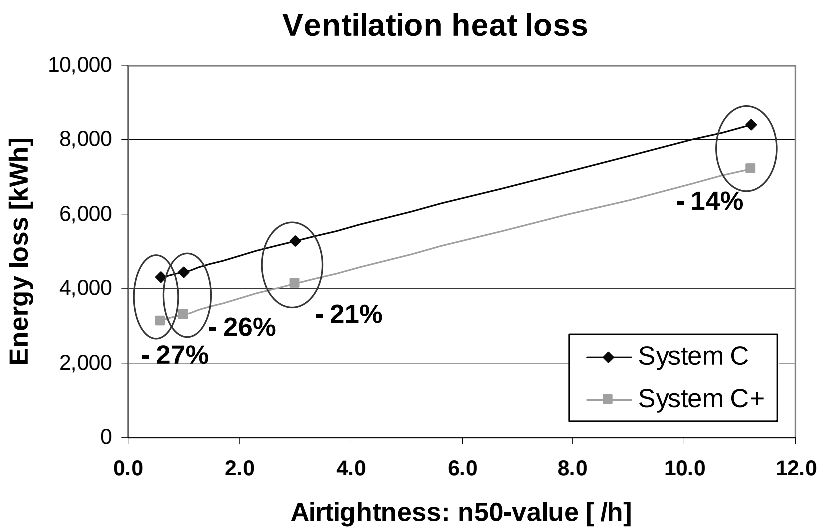


Figure 8: Energy loss - airtightness

One should bear in mind that these two models have different performances concerning IAQ. Furthermore simulations point out that while the indoor air quality is maintained at the same level, more energy can be saved if the peak extraction rate is higher than the nominal airflow rate.

MOISTURE BUFFERING

In CONTAM a Boundary Layer Diffusion Sink/Source Model (Figure 9) is used to model moisture buffering in different materials. This model has been compared to other buffering models (TRNSYS, Annex41 simulations). The source/sink model in CONTAM corresponds well to the other models, but aparently it buffers a little bit more than the other models.

In the basic model only the gypsum plaster of walls and ceilings was entered in the boundary layer diffusion model. To evaluate the significance of moisture buffering for humidity controlled ventilation two other simulation models are developped. In addition the comparison of these three degrees of buffering will tell us more about how thorough the buffering capacity has te be modelled.

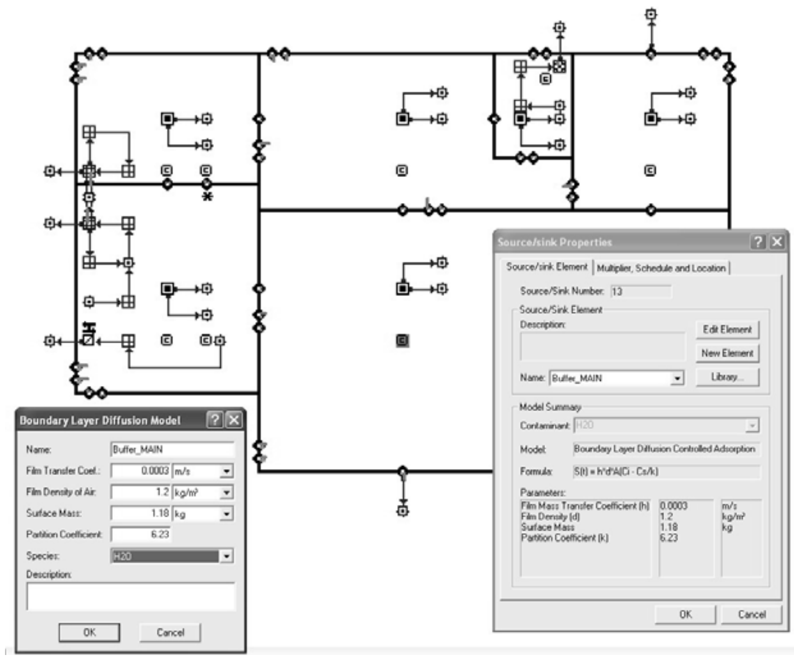


Figure 9: Boundary layer diffusion model in CONTAM

The first model (minimal buffering) has no buffering capacity at all. The second model (medium buffering) takes the gypsum plaster of walls and ceilings into account, and the third model (maximal buffering) has the biggest buffering capacity because next to the gypsum plaster also textile and wooden surfaces were added to the model.

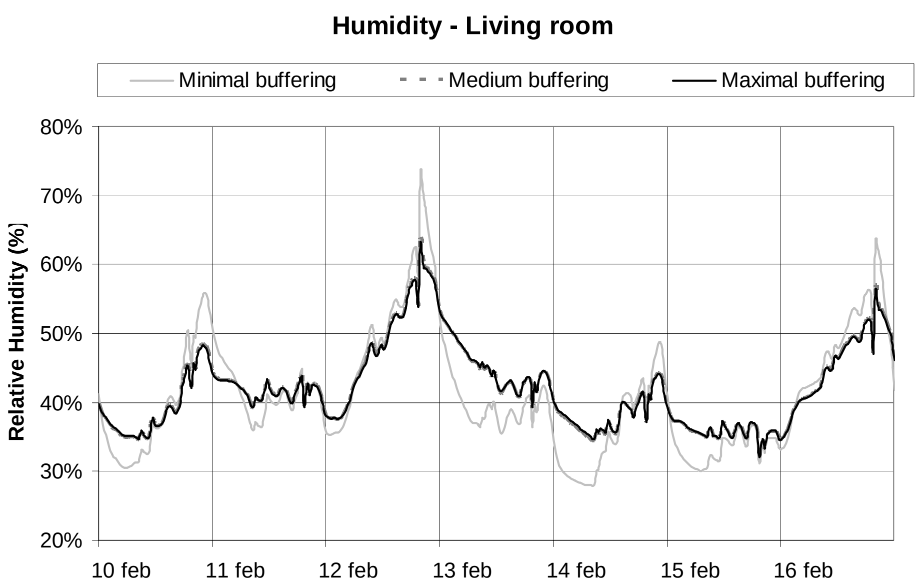


Figure 10: Relative Humidity – Living room

The difference between the minimal and medium buffering is clearly visible: the gypsum plaster dampens out peaks in relative humidity both for high as low values (Figure 10). The effect of additional buffering (textile and wood) is practically none, even in the bathroom. In terms of energy use for system

C+ the influence is rather small, because the average humidity is about the same for the different models and the humidity controlled air flow rate is linear to the RH. The simulations point out that system C+ will have an energy demand that is 0,75% higher if moisture buffering is modelled. The influence of the airtightness on the effect of buffering is very small: in terms of energy consumption for system C+ it makes no difference.

CONCLUSIONS

The analysis of simulations of indoor air quality should be done with great care. A simplified evaluation method can lead to a misinterpretation of the results.

There is a big difference in IAQ between the two systems if one looks at the relative humidity. These difference are perhaps more pronounced than those in CO_2-levels. However, more research has to be carried out on this matter.

System C+ allows to increase the energy savings up to 27% for very airtight buildings and 14% for buildings with an average airtightness.

There is a clear influence of moisture buffering in the model on the relative humidity, but the effect on humidity-controlled ventilation in energy-use is rather small. The results demonstrate it's important to add moisture buffering in the simulation model, though it is not necessary to add an elaborate list of buffering materials and surfaces. In this model the walls and ceilings have enough buffering capacity to define the influence on indoor humidity.

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REFERENCES

[1] Fanger P. O., Clausen G., Fang L.1998. Impact of Temperature and Humidity on the perception of Indoor Air Quality. Indoor Air 1998; 8: 80-90. ISSN 0905-6947

[2] Persily A., Musser A., Emmerich S., Taylor M. 2003. Simulations of indoor Air Quality and Ventilation Impacts of Demand Controlled Ventilation in Commercial and Institutional Buildings NISTIR 7042. NIST.

[3] Emmerich S.J., Persily A.K. 1997: A literature review on CO2-based demand controlled ventilation, ASHRAE Transactions., Atlanta, GA, 1997.

[4] Afshari A., Bergsøe N.C. 2003: Humidity as a Control Parameter for Ventilation, Indoor en Built Environment 2003; 12:215-216

[5] Harriman, L., Brundrett, G., Kittler, R. 2001. Humidity Control Design Guide for Commercial and Institutional Buildings. ASHRAE. ISBN 1-883413-98-2.

BIBILIOGRAPHY

BIN. 1991. Ventilatie voorzieningen in woongebouwen, Belgian Institute for Standardisation, NBN D50-001, Brussels.

NBN EN 13779:2004 ‘Ventilatie voor niet-residentiële gebouwen - Prestatie-eisen voor ventilatie- en kamerbehandelingssystemen’

Technische Voorlichting 192 – Ventilatie van woningen – Deel 1 Algemene Principes. Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf

Technische Voorlichting 203 – Ventilatie van woningen – Deel 2 Uitvoering en prestaties van ventilatiesystemen. Wetenschappelijk en Technisch Centrum voor het Bouwbedrijf

prCEN/TR 14788 Final Draft – Ventilation for buildings - Design and dimensioning of residential ventilation systems

prEN 15251, Draft 2005. Criteria for the Indoor Environment including thermal, indoor air quality, light and noise

CONTAM 2.4 Userguide and Program Documentation. George N. Walton, W. Stuart Dols. NIST. National Institute of Standards and Technology. Last Revision November 14, 2004.
Dols, W., Walton, G., & Denton, K. 2000. CONTAM 2.4

Nist Multizone Modeling Webite. http://www.bfrl.nist.gov/

Axley, J.W. 1991. Adsorption Modeling for Building Contaminant Dispersal Analysis. Indoor Air, 1: 147-171

A guide to energy efficient ventilation. 1996, Annex V - Air Infiltration and Ventilation Centre, International Energy Agency

Demand Controlled Ventilation Systems – Summary of International Energy Agency Annex 18

ASHRAE. 2001. Infiltration and Ventilation in Handbook of Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta GA.

Maeyens J., Janssens A. 2004. Air exchange rates, energy losses and indoor air quality due to the application of the Belgian ventilation standard. Department of Architecture and Urban Planning, Ghent University, Belgium

Andrew K. Persily 1997. Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide. ASHRAE Transactions 1997

Humidity Control Options. Interim Report for ASHRAE 1121-RP

H. Hens. Impact of water vapor buffering on the indoor partial water vapor pressure and relative humidity: a simple evaluation test. International Energy Agancy-EXCO. Energy Conservation in Building and Community Systems. Annex 41 Moist-Eng

T Leephakpreeda, R Thitipatanapong, T Grittiyachot, V Yungchareon, 2001. Occupancy-Based Control of Indoor Air Ventilation: A Theoretical and Experimental Study. ScienceAsia 27 (2001) : 279-284

H. Breesch 2006. Natural Night Ventilation in Office Buildings - Performance Evaluation Based on Simulation, Uncertainty and Sensitivity Analysis. Doctoral thesis

Steve Emmerich, Andrew Persily and Steven Nabinger, 2002. Modeling Moisture in Residential Buildings with a Multizone IAQ Program. Proceedings, Indoor Air 2002, 9th International. Conference on Indoor Air Quality and Climate in Monterey, California. June 30-July 5, 2002

Orme, M., Liddament, M. & Wilson, A.1994. An analysis and data summary of the AIVC's numerical database, IEA, AIVC, Oscar Faber Partnership, UK.