IMPACT OF RESIDENTIAL NATURAL VENTILATION AND AIR-TIGHTNESS TECHNIQUES ON THE ENERGY LOSS AND INDOOR AIR QUALITY

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ABSTRACT

To better quantify the impact of different window opening models in comparison to ventilation techniques a multizone ventilation model, incorporating the CO_2-production of the inhabitants, was developed, using Comis-Transys. The reference model represents a free-standing dwelling in which infiltration is the only source of fresh air. Through a series of simulations natural ventilation systems (standard, user controlled or CO_2-based demand-controlled), air-tightness techniques and/or window opening models (deterministic or stochastic) are added. The effect of the window opening models on the energy loss, air change rate and the indoor air quality is quantified and compared to the effect of different ventilation and air-tightness techniques.

KEYWORDS

natural ventilation techniques, window opening model, ventilation loss, indoor air quality

INTRODUCTION

This study is part of a research project to create a methodology to assess the energy-saving potential of air-tightness and ventilation techniques on natural ventilated dwellings. In a first step (Maeyens et al. 2003a) the performance of natural ventilation systems (in accordance with the Belgian ventilation standard) is evaluated regarding energy loss and indoor air quality, using a multizone ventilation model (ContamW). A second step studies the possibilities of a stochastic single zone ventilation model regarding air-tightness and user behaviour (Maeyens et al. 2003b). This part focuses on the window opening models, implemented in a multizone ventilation model. It describes how a deterministic and a stochastic model can be built and shows the effect of these models on the air change rate, energy loss and indoor air quality. The final step of the research project will combine a stochastic multizone ventilation model, incorporating a window opening model, with a model to estimate the infiltration heat recovery (Janssens, 2001).

VENTILATION MODEL

The model is built using a Comis-Transys coupling. The basic multizone ventilation model is built in Comis. Transys is used to implement the window opening models and the time dependent ventilation techniques. Annex 23 (Furbringer et al. 1996) concluded that for multizone ventilation models the convergence of measurement and calculated global air change rate is within 25%. Therefore this study, for the moment, relies on simulation results only, without comparison with field measurements. The simulations are transient in time steps of 15 min, from 1th November till 31th March. Thereby, representing the heating season. Climatic data is taken from the Test Reference Year Ukkel, completed by values for wind direction.

The model represents a free-standing, two-storied, single-family house, with an unused attic (Figure 1), surrounded by scattered windbreaks equivalent to half the building height. Terrain constants and wind pressure coefficients are taken from Orme et al. (1994). The dwelling is occupied by a four-headed family. Occupancy schedule and CO_2-production of the inhabitants is based on Maeyens et al. 2003. A simplified occupancy schedule is shown in Table 1.

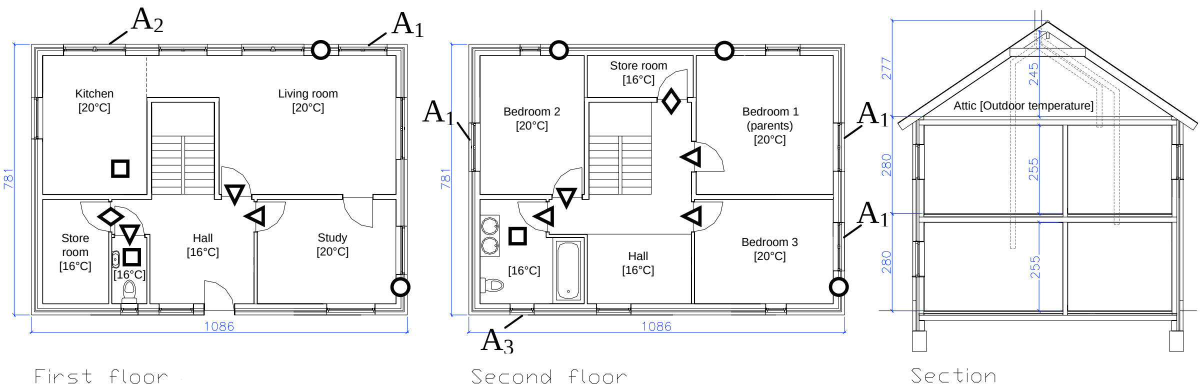
Leakage paths through the weather-stripped windows and doors are given specific values (Orme et al. 1994). The interface between window and door frames with walls is considered uncaulked in the air-open building (9,5 h^{-1}) and caulked in the air-tight building (3,0 h^{-1}). The remaining air leakage is evenly distributed over the whole building façade, making the model correspond with the average n_{50}-value of a freestanding Flemish dwelling (BBRI, 1988: 9,5 h^{-1}). External walls and the upper ceiling have the same leakage value, since this distribution corresponds well with the distribution given by ASHRAE (2001).

TABLE 1

Occupancy schedule and the time a window is possibly opened (T_w) , for weekdays (up) and weekends (below).

Zone	T_w [%]	time [h] 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Living room and Kitchen	31,3																								
Bathroom	16,7																								
Bedrooms	68,8																								
Living room and Kitchen	39,6																								
Bathroom	18,8																								
Bedrooms	77,1																								

Occupied — Possible open window



○ = ventilation inlet □ = ventilation outlet (vertical duct) △ = transfer opening ◇ = store room ventilation

Window opening area in simulation : A_1 = 0,7 m x 1,0 m A_2 = 0,9 x 1,0 m A_3 = 0,7 x 1,0 m

Figure 1: Lay-out of the dwelling and its ventilation system and window openings.

Lay-out and sizing of the ventilation openings (Figure 1) is based on the Belgian ventilation standard, the NBN D50-001 (BIN, 1991). In some simulations the ventilation system is made more efficient by applying a user behaviour or by using CO_2-based demand-controlled ventilation inlets. The user behaviour assumes that the occupants diminish the opening size of all in- and outlets to 25% when they are not at home. The same reduction is applied at night (from 23.00h till 8.00h on weekdays and between 23.00h and 9.00h during the weekend), but only on the first floor. The CO_2-based demand-controlled ventilation inlets are closed at CO_2 concentrations lower than 700 ppm. Between 700 and 850 ppm they are half open and above 850 ppm fully opened.

DETERMINISTIC WINDOW OPENING MODEL

The deterministic model consists out of two fixed window opening patterns, one for weekdays and one for the weekend (Figure 2). It is based on the following data and assumptions:

- The average window use in different chambers, for winter climate (Table 2). Window use is expressed in terms of N_{ow} (Number of open windows per day).
- The open area of an open window is 0,5 m². For an ajar it is 0,1 m² (Dubrul, 1988).
- The percentage of time an open window is wide open is 31%. The remaining time the window opening is an ajar (Dubrul, 1988).
- Windows are never wide open during the night (0:00 till 6:00).
- Windows are not left opened when no person is present in the dwelling (Månsson, 1995).
- The longer the dwelling is occupied the more windows are kept open (Dubrul, 1988).

TABLE 2
Window use (N_{ow}) according to room type, average of Belgian data (Dubrul, 1988).

Dwelling	Living room	Kitchen Apart	Bathroom	Main Bedroom	Bedroom 2 or 3
0.39	0.03	0.05	0.04	0.12	0.075

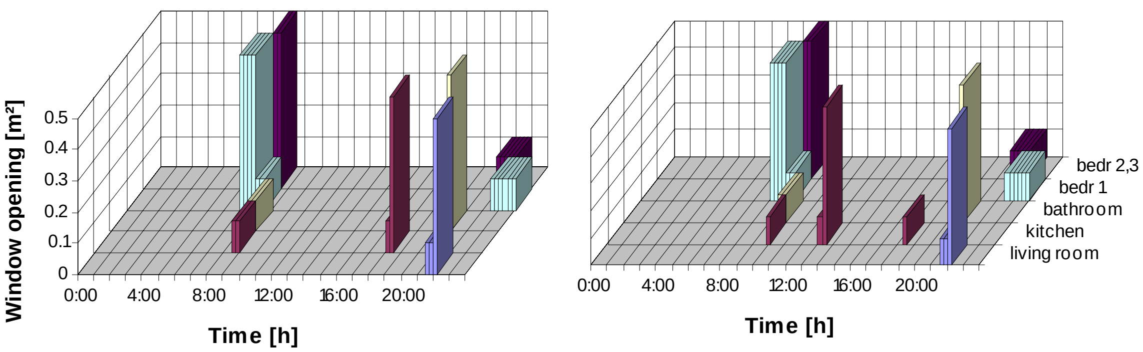


Figure 2: The deterministic window opening model.

STOCHASTIC WINDOW OPENING MODEL

The stochastic window opening model estimates for every time step and for every different room if a window is open or not. The model is based on the following data and assumptions:

- The percentage of open windows is a function of the outdoor temperature and the amount of sunshine (Dubrul, 1988). Irradiation higher than 50000 lux is assumed to represent sunny weather. Further, the percentage of open windows is influenced by the wind velocity. There seems to be almost no correlation at velocities lower than 3m/s. Therefore the model introduced by Erhorn (1986) is slightly adjusted (Figure 3).

- Windows are not left opened when no person is present in the dwelling (Månsson, 1995). Other more detailed time related restrictions are summarized in Table 1.
- Frequency of window opening varies in accordance to room type and is therefore corrected. The correction factors (Table 3) are based on data from Wouters et al. (1986).
- The amount of openable window surface is taken from the Senvivv database (BBRI et al. 1998). Since there is for all room types, except the bathroom, a correlation between the openable window surface and the netto building volume, the openable surface is adjusted to the building volume (Table 3). This surface is converted to the effective free opening area, by taking into account a fixed window frame of 5 cm.
- Most of the time the window opening is just an ajar. Wouters et al. (1986) give estimations for the degree of window opening during wintertime (Table 3). The equivalent opening area of a window in position 'ajar' is about 20% of the opening area of a wide open window (Dubrul, 1988).
- Windows are never wide open during the night (0:00 till 6:00).

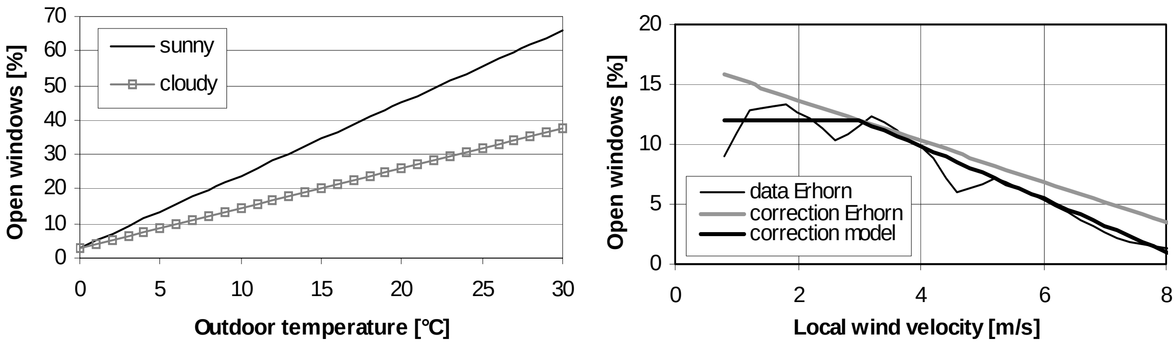


Figure 3: Percentage of open windows as a function of the outdoor temperature and the amount of sunshine (left) and local wind velocity (right).

TABLE 3
Average duration time of window opening and the resulting correction factor, openable window surface and window opening position for different type of rooms.

Room	Living room	Kitchen	Bathroom	Main bedroom	Av. of bedroom 2 and 3
Duration [h/day]	0,4	0,9	1,6	4,0	2,55
Correction = C_1	0,2	0,45	0,8	2,0	1,275
Openable window surface = A_{wtot} [m²]	4,6	1,8	0,7	1,4	1,4
Ajar [%]	67,4	74,6	65,8	62,0	59,1
wide open [%] = w_o	32,6	25,4	34,2	38,0	40,9

By taking into account parameters that correlate with the window use, this stochastic model hopes to result in more realistic air change rates, energy losses and indoor air quality. Nevertheless, due to the lack of detailed data, few parameters are not taken into account:

- The model does not take into account a possible correlation between in the indoor air quality and the probability a window is open. Since 'to remove odour' and 'to get fresh air' are motivation to open a window (Månsson, 1995) this correlation might be important.
- There might be a negative correlation between the amount of openable window surface and the probability a window is opened. When more openable windows are available the probability for a single window to be opened might be lower.

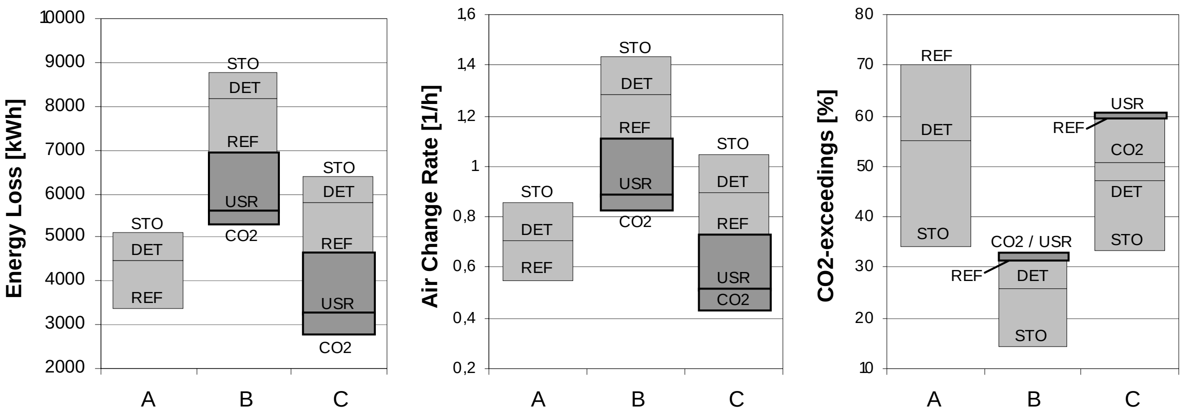
- Auto-correlation of the window opening is not taken into account. Thereby, the opening pattern fluctuates more heavily than it will in reality. This might have a significant influence on the indoor air quality.
- Window opening in relation to wind velocity is only corrected downwards. Thereby, the window opening probalility might be underestimated.

TABLE 4
The stochastic window opening model (u = a uniform random number in the region [0,1[ )

Based on the outdoor temperature and the amount of irradiation the probability a window is opened is determined. If the local wind velocity is higher than 3 m/s it is corrected.	IF $I > 500$ W/m² ELSE IF $v > 3$ m/s	$p = (42/20 \cdot T_{out} + 3)/100$ $p = (29/25 \cdot T_{out} + 3)/100$ $p_v = (1{,}55 - 0{,}183 \cdot v) \cdot p$
This probability is corrected in accordance with the time schedule a window is possibly open (Table 1) and for the average duration time of window opening (Table 3).	$p_{c1} = (p \text{ or } p_v) \cdot 100/T_w \cdot C_1$	
The probability is recalculated from the total window opening surface to one opening area in each room (Figure 1). This is done for reasons of simplification and might lead to chances bigger than 1. In this model this happens during a neglectable amount of time steps (0.1 %).	$p_{c2} = p_{c1} \cdot (A_{\text{openable window}} / A_{wtot})$	
The final probability is used to decide if the window is open or not, using Monte Carlo methods.	IF $u < p_{c2}$ ELSE	the window is open the window is closed
If the window is open, the degree of window opening is set, using Monte Carlo methods.	IF $u < (w_o/100)$ ELSE	the window is wide open the window opening is 'ajar'

RESULTS

For the different scenarios the energy loss, average air change rate and the indoor air quality is shown in Figure 4. Indoor air quality is represented as the percentage the occupied time 1000 ppm CO_2 is exceeded. Values for the stochastic model are based on the average of 10 runs. Standard deviations for energy loss, air change rate and indoor air quality are respectively at most 47 kWh, 0,008 h^{-1} and 0,7 %).



A = air-tightness 9,5 h^{-1}, no ventilation system
B = air-tightness 9,5 h^{-1}, NBN D50-001 ventilation system
C = air-tightness 3,0 h^{-1}, NBN D50-001 ventilation system

STO = Stochastic window opening model
DET = Deterministic window opening model
REF = Reference situation (A,B or C)
USR = User controlled ventilation
CO2 = CO_2-based demand-controlled ventilation

Figure 4: Energy loss, average air change rate and indoor air quality for the different scenarios (IAQ is only shown for bedroom 1. Proportions are the same for other rooms, but values are less extensive.)

For the three different cases controlled ventilation techniques and window opening models have about the same impact on the energy loss and air change rate. The stochastic window opening model has, in absolute values, about the same effect as the applied ventilation techniques. Only regarding CO_2-concentrations the controlled ventilation techniques remain closer to the reference situation. CO_2-based demand-controlled ventilation even gives lower concentrations. Thereby, window airing can by considered much less efficient than the applied ventilation techniques.
The extra energy loss and air change rate due to the deterministic window use are averagely 1170 kWh and 0,166 h^{-1}, respectively about 2/3 and 1/2 of the outcome of the stochastic model (1778 kWh and 0,315 h^{-1}). The energy loss differs less since within the deterministic model heavy airing occurs mainly in the morning, when temperatures are quite low. The increase in average air change rate due to the stochastic model compares well with an estimation of this value for natural ventilated Belgian single-family dwellings during winter: 0,31 h^{-1} (Wouters et al. 1986). The deterministic model seems to underestimate the window use and thereby the air change rate and energy loss.

CONCLUSIONS

Eventhough the stochastic model does not take into account an amount of parameters that might influence the window use, the simulated increase in air change rate due to window use is close to the average for natural ventilated Belgian single-family dwellings during winter. The stochastic model has is, in absolute values, about the same effect on the energy loss and air change rate as the controlled ventilation techniques. The deterministic window opening model seems to underestimate the window use and thereby the extra ventilation losses and air change rates. The effect of the window opening models is almost independent of the applied ventilation and air-tightness techniques.

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