

Influence of occupants on the energy use of balanced ventilation

Karin Soldaat and Laure Itard

Delft University of Technology, Research Institute OTB, The Netherlands

Corresponding email: L.C.M.Itard@tudelft.nl

SUMMARY

In this paper we give an overview of the ways occupants use ventilation systems and describe the results of interviews conducted in households equipped with balanced ventilation. An attempt is made to quantify the effects of occupant behaviour on the final energy use of the household for heating. This energy use is studied for several behaviour scenarios, leading to the conclusion that occupant behaviour may easily reduce the predicted savings to zero, or even may increase the energy use when compared to natural ventilation.

INTRODUCTION

In the Netherlands the energy use of new buildings is subject to legislation and should not exceed a certain value, calculated by using the Energy Performance Coefficient (EPC, [17]). The lower the EPC, the more energy efficient the building. Ever since its introduction in 1996, the EPC-value has become stricter. This has led to an increase in the implementation of heat-recovery balanced ventilation systems in newly built dwellings. In 1996-1997, when the EPC-value was 1.4, almost all ventilation systems applied used a natural air inlet and a mechanical air outlet. In 2000-2001, when the EPC-value was 1.0, 40 percent of all new residential buildings were equipped with heat recovery balanced ventilation systems [1]. The recent lowering of the EPC to 0,8 will probably enhance this percentage even further, because balanced ventilation is one of the most cost-effective ways to achieve the prescribed EPC-value. However, occupant behaviour may have a considerable influence on the yearly energy efficiency of the balanced ventilation systems in dwellings. This energy efficiency depends among others on the flow-rate settings chosen by the occupants and on the way they use natural ventilation openings. This paper aims at a first evaluation of the energy efficiency of heat-recovery balanced ventilation systems when actual use is taken into account.

METHODS

Occupant behaviour

First, a literature study was conducted. There are indications that occupant behaviour often plays a considerable role [2,3,4] in the effectiveness of sustainable building options that have a user component. When occupants use certain techniques in a way that differs from the intentions of the designer, the minimisation of environmental impacts might be counteracted. A post-occupancy evaluation (PoE) of mechanically ventilated heat recovery systems showed that the real CO₂-production was higher than the calculated optimum and also higher than the base case with only natural ventilation [4]. Jeeninga found in [3] that the actual energy use of households living in dwellings with the same EPC-value can vary up to a factor two. Four main factors play a role on ventilation behaviour [5, 6]. These factors are occupant

characteristics, characteristics of the dwellings and of its environment and finally the characteristics of the ventilation system itself.

Occupant's characteristics: the size and the composition of the households has an influence on the ventilation behaviour [5,7,8], an particularly the presence of children and the age of occupants. The older the occupants, the less ventilation. The presence of occupants is related to the duration of window-opening [9] as well as household activities like cooking, tumble drying, washing clothes or dishes, showering and smoking [5]. Thermal comfort preferences of occupants play also a role. People who have a preference for high temperature open the windows less [5]. The preferred temperature in the bedrooms is lower than in the living room [5,10], which is one of the reasons why windows are opened more often in bedrooms than in living rooms. Ventilation behaviour is strongly correlated to perceived fresh/stuffy air, dry/humid air, cooking odours and other strong odours ([6], [11]). Knowledge about the ventilation system is another important actor. Occupants may not use the system on the right way, because of inadequate operation instructions [8]. From [8] it appears that there is no difference in the frequency and duration of opening of the windows between occupants using different mechanical and natural ventilation systems. However, a difference is noticed in [10] where it appeared that occupants with mechanical ventilations systems tend to use the windows less. The differences between both studies may arise from differences in knowledge or in poorly working systems. Pulmonary diseases may also play a role in the ventilation behaviour. Occupants with lung diseases ventilate longer and more often [12]. Finally some studies show that less conscious occupants and occupants paying a collective energy bill may open the windows longer ([5],[10]). *Characteristics of the dwelling:* The type and design of dwellings influences the opening of windows [9]. In ground-bounded dwellings windows are less often open in the living room and the kitchen than in apartments. For bedrooms, the inverse is observed. In apartments, the windows are more often ajar and in ground-bounded dwellings wide open. Thermal insulation, air tightness and noise insulation of the dwelling may also influence the use of the windows and of the mechanical ventilation. Occupants tend to ventilate less through mechanical system or windows when the air tightness of the dwelling is low (high infiltration rates) or when the rooms are small ([5],[6]). South orientated rooms tend to be more ventilated than other rooms when the sun shines [5]. The use of the rooms itself may influence the ventilation behaviour. Also the location of furniture or the use of decoration stuffs or plants on the windowsill are of importance [13]. Finally, the type of heating system plays a role. In dwellings with central heating windows are less often open than in other dwellings [9]. *Characteristics of the environment:* The weather plays a main role in opening or not the window. The use of windows is linearly correlated with the outside temperature for temperatures between -10 °C and 25 °C and inversed correlated with wind velocities.

When it is raining or snowing, windows are less often used. Next to weather, noise nuisance is an important factor ([9], [13]). In about 30 % of Dutch dwellings, occupants close the windows to avoid noise from outside. Odours from industry, traffic or agriculture produce the same effect [10]. Finally, occupants close their windows when they leave the house or at night as protection against burglary [5]. *Characteristics of the ventilation system:* The ventilation system consists in infiltration trough cracks, ventilation through windows and ventilation through a mechanical system if present. The way the window hangs up in the window frame is important as well as the direction of opening. Windows that are fixed on the bottom of the frame and that open inwards are more often open than other types of windows [9]. Upper windows are open twice more often than windows opening outwards. If the window in open stand cannot be fixed at several positions through a grip, it is possible that the window will

never be used [10]. If a mechanical ventilation system is used, the location of the switches may be of importance. If the system is not cleaned regularly, which is the case in half of the households with balanced ventilation in the Netherlands [6], the capacity of the system may be reduced strongly. Occupants of dwellings with balanced ventilation report fewer burdens from draught from windows and grilles, but report draught from supply air inlets [12]. If the air inlets don't fit with the esthetical preferences of occupants they may remove them [10]. Finally, noise produced by the mechanical ventilation system plays a main role ([10], [14]). In 28 % of dwellings equipped with balanced ventilation occupants are "always" or "often" annoyed by noise and 37 % of the occupants "sometimes". Because of this noise nuisance, 17 % of the occupants ventilate less with the mechanical system than they would like [6].

Based on this literature study and on 18 qualitative interviews with occupants in their houses, combined with an inspection, different user scenarios are established. All occupants rent their houses from a housing association. The aim of the in-depth interviews is to get insights into the relationship between the technical characteristics of the balanced ventilation system and its use by occupants. In a following phase of this research, these interviews will be used as basis for a large survey in order to gather statistical data. The results of these interviews are summarized hereafter. Most of the occupants are not aware of the energy saving aims of balanced ventilation. They do not know that they can save energy by closing the windows in the winter. They do know that the system is needed to supply continuous ventilation. To control the system they use the switch, in all cases placed in the kitchen, but are not aware of other possibilities like the use of the bypass in summer situation. This is because of the poor quality of the use instructions from the producer (no difference in instructions for servicemen and for occupants) and of the housing associations. The design of the switches plays an important role in the use of the system. Balanced ventilation systems run almost always in the lowest stand. When the system is equipped with a two-stand switch the lowest stand has a capacity about 50 %. Systems with a three-stand switch have a capacity of only 30 % in the lowest stand. The location of the switch is important too. 22 % of the interviewees are lacking a switch in the bathroom. Because of this the bathroom is less ventilated than needed. The design of the control display on the system itself is not adapted to occupants. Most of them do not understand the function of the comfort temperature and of the bypass. Most of the interviewees are aware of the necessity of cleaning the inlets and the filters and also clean them regularly. Occupants have relatively often the impression that the system does not supply fresh air, whereas the window does. They have doubts whether the system provides enough fresh air and open therefore the windows. Some odours from outside, like barbecue odours are smelled inside. When this is the case, some occupants shut the ventilation system down by disconnecting the plug. The air exhaust in the kitchen is perceived as insufficient. As a reaction some occupants placed a supplementary cooker hood on the existing system. As a result the whole system is disturbed. The supply air is often perceived as being too dry. In this case, they would open the window or use humidifiers on the radiators. Some of the occupants close the air inlet when they feel draught. Mostly the air inlets then remain closed. Avoiding noise from the ventilators is a reason why the system works in a lower stand than the maximal one. For the same reason some occupants shut the supply ventilator down. The use of the switch is linked to specific activities like cooking, showering, using the toilet, using a tumble dryer en receiving visit, but in most cases, the switch remains continuously in the same low stand.

Characteristics of the studied dwelling and ventilation scenarios

For the calculations we used a typical Dutch terraced house with three bedrooms and an attic. It is a three storey house with a gross floor area of 124 m² and a gross storey height of 2.8 m. The use area as defined in the building decree is 63 m². Facades, roof and ground floor have a Rc value of 2.5 m²K/W. The south and north façades have an area of 46 m², with a window percentage of 30%. Roof and ground floor have an area of 52 m². The west and south facades are outer separation walls with other dwellings. High efficiency glazing is used (U-value= 2.1 W/m²K). The dwelling is heated by a high efficiency boiler (efficiency of 0.83 on yearly basis).

The Dutch Building Decree prescribes the minimum flow rates given in table 1 [15]. The floor areas and the minimum ventilation flow rates for this dwelling calculated according to the Dutch building decree are summarized in table 2. At the level of the dwelling the minimum required air flow rate is therefore 259 m³/h.

Table 1: Minimum flow rates.

	Living area (bedrooms and living room)	Kitchen	toilet	Bathroom
Flow rate (m ³ s ⁻¹)	0,9x10 ⁻³ per square meter with a minimum of 7 x10 ⁻³ total	21x10 ⁻³ total	7 x10 ⁻³ total	14 x10 ⁻³ total

Table 2: Areas and minimum flow rates for a typical Dutch house.

	Living room + kitchen	Bedroom 1	Bedroom 2	Bedroom 3	Bathroom
Area (m ²)	37,1	9,9	9,7	6,0	6,6
Flow rate (m ³ h ⁻¹)	120.2	32.0	31.3	25.2	50.4

To limit costs, balanced ventilation systems in the Netherlands are mostly designed to meet the requirements on the minimum ventilation rates, but not more. Furthermore, the legislation prescribes that these minimum ventilation flow rates must be achieved when the system runs at its highest level (level 3). The systems installed in the inspected dwellings were designed this way. Balanced ventilation systems in dwellings are mostly

equipped with switches that can be put in levels 1, 2 or 3. The interviews showed that the systems are running most of the time in level 2 in which only 50 % of the capacity is available. At night time, the system mostly runs in level 1 due to noise pollution from the ventilator, with only 30 % of the capacity. Furthermore, studies have shown [16] a reduction of the capacity of 10% a year, due to a too low level of maintenance (cleaning). After 5 years, the maximum capacity is reduced to 65 % of the original capacity. The total amount of fresh air supplied to the dwelling is also dependent on the air-tightness of the construction. The air-tightness of Dutch new dwellings should not exceed 200 dm³/s per 500 m³ building volume. For the reference dwelling studied, the air flow rate should be lower than 200 dm³/s. In the calculations we used this value as the upper limit of the infiltration flow rate. This is to take into account the possible opening of windows to ventilate. In the Dutch mandatory energy performance norm [17], it is assumed that an air infiltration flow rate lower than 0.4 dm³/sm² cannot be achieved. We used this value as the lower limit for the infiltration rate.

Five ventilation scenarios, depending on occupant behaviour are. For each scenario, a variant is calculated with low infiltration rate (variant a), high infiltration rate (variant b) and with low infiltration rate and supply ventilator shut down (variant c). In this case, the heat recovery

doesn't work. In variant a) en c) the infiltration flow rates are 91 m³/h and in variant b) 720 m³/h. The five scenarios' are:

- 1 Use of a 5 years-old system with a 3-stands switch. The filters have never been cleaned or not often enough, thus the maximum capacity of the ventilation system is 65 % of the mandatory capacity as given in table 1. The system runs continuously in stand 1, thus 30 % of the maximum capacity is available. The mechanical ventilation flow rate is therefore 50.4 m³/h, which is far below the mandatory value.
- 2 Use of a 5 years-old regularly cleaned system with a 3-stands switch. The system runs continuously in stand 2, thus 50 % of the mandatory ventilation capacity is available, which is 129 m³/h.
- 3 Optimal use of the system: 100% of the mandatory capacity is available, that is 258 m³/h.
- 4 The occupants shut the whole system down and only use natural ventilation. The ventilation flow rate is 258+91=349 m³/h.
- 5 The occupants shut the whole system down and only use natural ventilation. There is a high infiltration flow rate of 720 m³/h.

Calculation model

The calculations are conducted using the software h.e.n.k. [18]. The energy demand for heating is calculated using a heat balance within the dwelling envelope, based on hourly calculations taking into account transmission losses, infiltration and ventilation losses and heat load through sun entering the building and electrical appliances. We assumed that the heat load from lighting was maximum 4 W/m² and for appliances 3 W/m². Maximum 4 people are present in the dwellings. We developed and used occupancy and heat load profiles as shown in figure 1. These profiles give the fraction of maximum occupancy and heat load for each hour of the year. The profiles are identical for all ventilation scenarios.

The ventilation flow rate was kept on the same level all over the day, which is plausible from the interviews. We also assumed that an average temperature of 18 °C was maintained all over the day. The heat exchanger recovers heat from the exhaust air as long as the temperature difference between outdoor and indoor air is 2 K. Below this limit there is no heat recovery. Hourly calculations are made, using the Dutch average climate year TRYdeBilt.

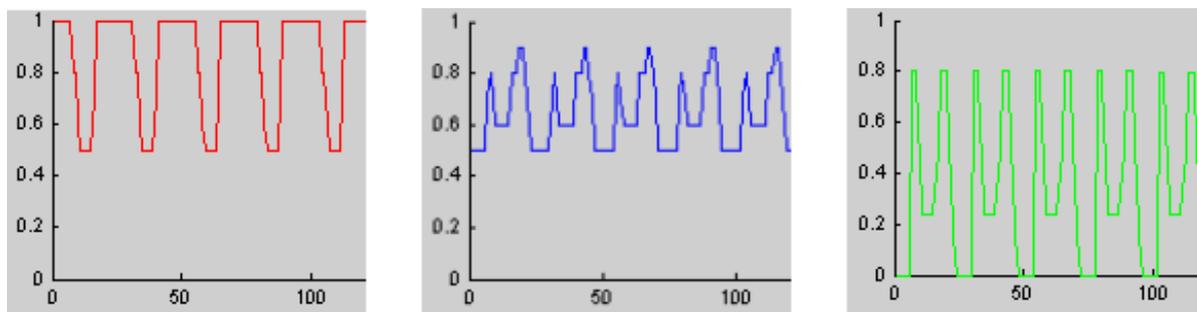


Figure 1: 1) occupancy profile, 2) appliances profile, 3) lighting profile x-as: hours (0 is midnight); y-as: fraction of the maximum occupancy, heat load from appliances and heat load from lighting respectively.

The energy consumption at the meter box, which is the energy delivered to the heating and ventilation system (gas and electricity), is calculated from the energy demand. For room heating a high efficiency boiler is used ($\eta=0.83$ on year basis). The electricity needed for the ventilation systems is calculated assuming a pressure drop of 150 Pa in the supply and

exhaust ducts. The efficiency of the ventilators is 0.85 and the efficiency of the motor is 0.7. The primary energy use is calculated from the energy consumption. It includes the energy needed to generate electricity. We used an average power plant generation with an efficiency of 0.4.

RESULTS AND DISCUSSION

The results of the calculation are shown in table 3. The total primary energy use of all options is plotted in figure 3. The electricity consumption of the ventilators appears to be minimal in comparison with the gas consumption for heating. If the occupants shut down the supply ventilator, there is no heat recovery (variant c). Compared to the case with heat recovery (variant a), an increase of primary energy use from 11 % (variant 1) up to 36 % (variant 3) is observed. In variant 3, the system works optimally and the air flow rate is much higher than in variant 1, where the system is sub-optimal. Heat recovery plays a more important role at larger flow rates. That is why the effects of not using heat recovery are stronger in variant 3 than in variant 1. Comparing variant 1, 2 and 3 it appears that the energy use of the sub-optimal systems is lower than the energy use of the optimal system (variant 3). This is logical because of the decrease in ventilation losses arising from the reduced air flow rates. However, the flow rates in variants 1 and 2 are far below the minimum acceptable ventilation flow rate, resulting in a poor indoor air quality and possibly in health problems. It is plausible (see first section of this paper) that the occupants would compensate these too low air flow rates by opening windows more often, resulting in variant 1b, 2b, 4 or 5 depending on the air tightness of the house and on the way occupants use natural ventilation openings. It is therefore possible that no energy savings are achieved by a balanced ventilation systems when compared to natural ventilation. It appears from figure 3 that air tightness of the house and use of the natural ventilation openings will play a major role in achieving or not the aimed savings. The comparison of a well working balanced ventilation system (option 3a) with natural ventilation option 4, shows that the maximum savings could amount 24 %, but could also be reduced to zero or even be negative.

Table 3: Energy consumption and primary energy use.

	1a	1b	1c	2a	2b	2c	3a	3b	3c	4	5
Gas cons. (heating), kWh	5918	23597	6693	7145	24824	9130	9157	26836	13127	13127	22812
Elect. cons. (ventilators), kWh	63	63	31	160	160	80	321	321	160	0	0
Total primary energy use, MJ	21870	85514	24379	27162	90806	33588	35856	99500	48700	47257	82123

1: sever under-capacity (30x65%); 2: under-capacity (50%); 3: full capacity; 4: natural ventilation, same capacity as in 3); 5: natural ventilation, high infiltration.
a: low infiltration; b: high infiltration; c: no heat recovery

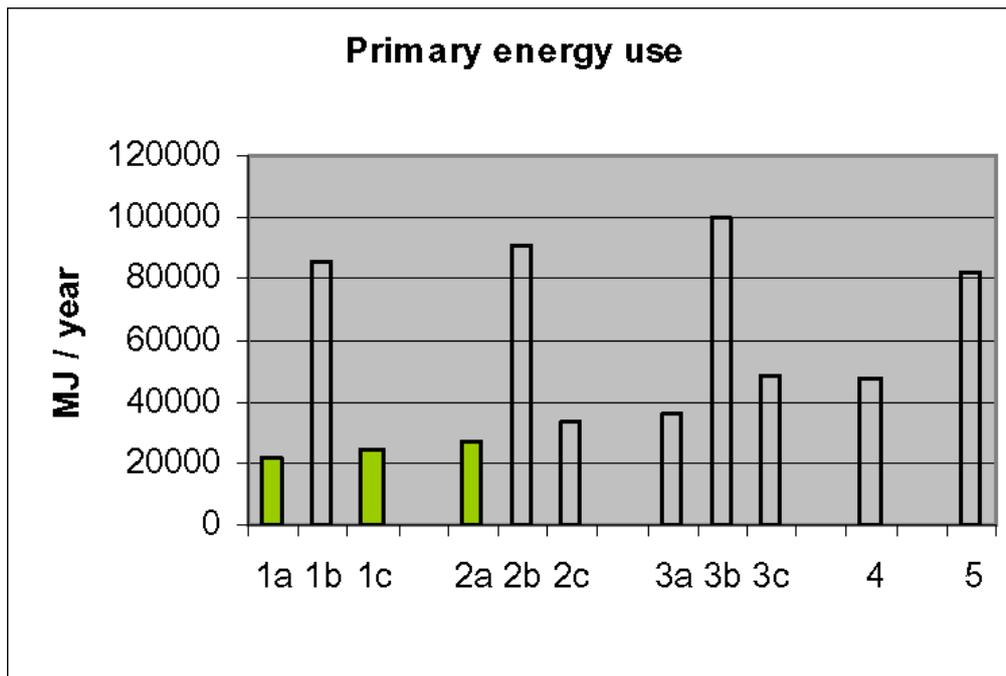


Figure 3: comparison of the primary energy use for several options.

CONCLUSIONS

In this paper we gave an overview of the ways occupants use ventilation systems and made a first attempt to quantify the effects of their behaviour on the final energy use for heating. This energy use was studied for several behaviour scenarios, leading to the conclusion that occupant behaviour may easily reduce the predicted savings to zero, or even may increase the energy use when compared to natural ventilation. From the data we gather it appears that most of occupants use the system in sub-optimal settings, in which energy savings may be high because of the low ventilation flow rates. However this would cause a poor indoor air quality, which may be compensated by a more wide use of natural openings, resulting in an energy performance identical to that of a natural system. More research is needed to obtain statistical data and to validate the calculation model, in order to be able to make more accurate prediction of the possible savings by balanced ventilation systems.

ACKNOWLEDGEMENT

The calculations were made possible by Deerns Consulting Engineers, who put the h.e.n.k software at the disposal of Research Institute OTB for this research. This research was partly financed by Corpovenista, an expert centre of housings associations and universities.

REFERENCES

1. Beerepoot, M., 2007. Public energy performance policy and the effect on diffusion of solar thermal systems in buildings: a Dutch experience. In *Renewable Energy*, Januari 2007.
2. Leidelmeijer, K. and P. Van Grieken, 2005, *Wonen en energie. Stook-en ventilatiegedrag van huishoudens*, Amsterdam (RIGO).
3. Jeeninga, H., M. Uyterlinde, and J. Uitzinger, 2001, *Energieverbruik van energiezuinige woningen. Effecten van gedrag en besparingsmaatregelen op de spreiding in en de hoogte van het reële energieverbruik*, ECN).

4. Macintosh, A. and K. Steemers, 2005, Ventilation strategies for urban housing: lessons from a PoE case study, in: *Building Research and Information*, 1, 33, pp. 17-31.
5. Dubrul, C., 1988, Inhabitant behaviour with respect to ventilation-a Summary Report of IEA Annex VIII, 23, Bracknell (Air Infiltration and Ventilation Centre).
6. Markttracé, 2001, Onderzoek balansventilatie, Groningen (Markttracé)
7. Fleury, B. en C. Nicolas, 1992, Occupants' behaviour with respect to window opening: a technical and sociological study, 13th AIVC Conference, Nice, pp. 197-206
8. Liddament, M.W., 2001, Occupant Impact on Ventilation, 53, Brussels (Air Infiltration and Ventilation Centre)
9. Wouters, P. en D. De Baets, 1986, A detailed statistical analysis of window use and its effect on the ventilation rate in 2400 Belgian social houses, 7th AIC Conference, Stratford-upon-Avon, pp. 33-53.
10. Van Dongen, J.E.F., 2004, Occupant behaviour and attitudes with respect to ventilation of dwellings, (RESHYVENT)
11. Engvall, K., C. Norrby, en E. Sandstedt, 2004, A sociological approach to validate a questionnaire for the assessment of symptoms and perception of indoor environment in dwellings, in: *Indoor air* 14, pp. 24-33
12. Steenbekkers, J.H.M., H.M.E. Miedema, en H. Vos, 2002, Gezondheid en tevredenheid in energiedichte woningen, Leiden (TNO Preventie en Gezondheid).
13. Hainard, F., P. Rossel, en C. Trachsel, 1986, A sociological perspective on tenant behaviour with regard to domestic ventilation- an example at Lausanne, Switzerland, 7th AIC Conference, Stratford-upon-Avon, pp. 12.1-12.20
14. Hasselaar, Evert. 2006. Health performance of housing. Indicators and tools. OTB Research Institute. Delft University of Technology.
15. Dutch building decree, www.bouwbesluitonline.nl
16. SenterNovem http://duurzaambouwen.senternovem.nl/nieuws/ventilatiesystemen_juist_gebruiken_en_goed_onderhouden/
17. NEN 5128, Dutch Norm Energy performance of residential buildings, www.nen.nl
18. Itard L. 2003 H.e.n.k., a software tool for the integrated design of buildings and installations in the early design stage, Proceedings 8th IBPSA International Building Simulation Conference 2003, Eindhoven, The Netherlands.