Sensitivity analysis of inhabitant behaviour on the performance of ventilation systems

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ABSTRACT

In this study, a sensitivity analysis on the effects of inhabitant behaviour on the performance of ventilation systems is carried out. Inhabitants behave differently in terms of presence at home, window opening, door opening, etc. Relating to the ventilation system, this is reflected in the ventilation demand and consequently the energy consumption, but also in the indoor air quality. Therefore, care should be taken to compare ventilation systems to each other as the inhabitants can be the most determining factor for the performance. In this study, the effect of inhabitant behaviour, and more specifically the window opening behaviour, on the ventilation system is evaluated with a focus on the ventilation demand and indoor air quality. A model-based approach is used which includes stochastic inhabitant behaviour together with models of the dwellings, heating systems and ventilation systems in order to obtain simulations close to reality. Furthermore, real measurements in occupied residential dwellings are analysed to validate the simulation results. By exposing the dominance of the window opening behaviour on the performance of ventilation systems, this study aims to show that the way ventilation systems are compared at the moment are arguable.

KEYWORDS

Ventilation, Indoor air quality, Inhabitant behaviour, Model-based, Telemetry

1 INTRODUCTION

As ventilation has taken a prominent role in buildings, a lot of research has been done to map the effect of ventilation on energy consumption and indoor air quality (IAQ). For example, McEvoy and Southall (McEvoy, Southall, 2005) compared the performance of different ventilation systems in terms of energy consumption and thermal comfort for contrasting European climatic regions. Organisations as ANSI even make standards about the minimum ventilation rates to provide an optimal IAQ (American National Standards Institute, 2019). The main goal of ventilation is achieving a good IAQ while keeping the energy losses and consumption to a minimum. Durier, Carrié and Sherman (Durier, Carrié, Sherman, 2018) defined that smart ventilation tries to reach this goal, together with optimizing the utility bills, thermal comfort and noise. This is done by regulating the ventilation system constantly in terms of time and optionally by location due to occupancy, outdoor temperature, electricity grid needs, etc. Smart ventilation strategies include, among other things, demand controlled ventilation, heat recovery and zoning.

Although these ventilation strategies are trying to achieve optimal performance, several disturbances can have a big impact on the actual performance. One of these disturbances are the inhabitants. Several studies on inhabitant behaviour have been carried out, such as the study by Silke Verbruggen (Verbruggen, 2021) where a model generating stochastic residential occupancy behaviour was made based on data from a Nearly Zero-Energy Building social housing neighbourhood. This model includes window opening, CO_2, humidity and heat production, etc. These characteristics together form a certain inhabitant profile and can have an important effect on the performance of ventilation systems. A retired couple behaves differently compared to a family with two working parents and two school going children. While the first household could be more at home throughout the day, the second could only be at home in the morning and evening. Their window opening behaviour is consequently linked to their presence. Variations in ventilation demand and IAQ can be linked specifically to these behaviours.

This study exposes the dominance of inhabitant behaviour on ventilation performance with a focus on window opening. In a situation where the outside air quality is good, it is obvious that the more windows are opened, the less relevant the ventilation system becomes. As a result, deviations between ventilation systems are less clear or even tend to disappear. Claiming that one system performs better than the other is then more difficult. In current regulation calculations, there is a lack of these types of inhabitant behaviour. The question can be raised whether this assumption is realistic.

2 METHOD

It's impossible to have real measurements of ventilation system performances for all possible inhabitant profiles. For a better understanding of these effects, a model-based approach is useful. A wide spectrum of inhabitant profiles can be obtained using stochastic models of residential inhabitant behaviour. In this study, the EROB (Event-based Residential Occupant Behaviour) - model from Silke Verbruggen (Verbruggen, 2021) is used for generating the inhabitant profile. Together with models of dwellings, ventilation systems, heating systems, etc., the aim is to obtain a simulation setup close to reality enabling to simulate specific scenarios. These simulations highlight specific shortcomings and points of attention of the ventilation system in the simulated scenarios.

The simulation setup is built upon five main components, namely the dwelling, weather conditions, heating system, ventilation system and inhabitants. A typical terraced dwelling with three floors and three bedrooms is used with a lightweight construction type. The bedroom doors are always open. The dwelling is varied in terms of orientation, namely the north, east, south and west. Weather data from Twenthe, The Netherlands, are used from 2011 and 2019. For the ventilation systems, VST3 and VST5 systems are included. For both of them, a 2-zone configuration is simulated and for the VST5 system, a 1-zone configuration is also considered. For the inhabitants, a family consisting of one fulltime working parent with a long workday of 07:00 to 20:00, a parttime working parent and two children going to school is considered. Two inhabitant profiles with identical CO_2, humidity and heat production and window opening in the day zone, but with different window opening behaviour in the night zone are generated. One profile has no window opening in the bedrooms and one profile includes window opening in the bedrooms. It is this variation that will expose the dominance on the performance of the ventilation system. In this study, we also focus on the IAQ in the bedrooms. A time-based assumption is made for the situation with window opening. Table 1 shows the duration of the window opening during occupancy for the main bedroom where the couple sleeps and for the two bedrooms where the children sleep.

Table 1: Window opening hours per month and room type

Months	Main bedroom	Bedroom kids
December to March	2 hours	2 hours
April to May and October to November	4 hours	4 hours
June to September	7 hours	11 hours

With this simulation setup and the mentioned variations, a total of 48 year simulations are performed in order to compare ventilation performance with enough variation in the scenarios. A one-to-one comparison can be interesting, but is less suitable to make conclusions on general tendencies. The goal is to check whether separate clusters can be identified with the window opening behaviour from the inhabitants in the night zone as a determining factor.
To support the simulation results, real measurements are analysed to check the assumptions and the findings from the simulation study. Four almost identical dwellings with different inhabitants are monitored. The inhabitants are two person families and differ in age and working habits. The measurements include window positions, door positions, ventilation demand and IAQ parameters such as CO_2 and relative humidity. The dwellings under research are topologically almost identical with three terraced dwellings and one half open dwelling. They include the same ventilation system and the sensors are located at the same location. This study focuses on the ventilation demand, CO_2 level and window opening behaviour in the bedrooms.

3 RESULTS

The effect of the inhabitant behaviour on the ventilation systems is evaluated based on the ventilation demand and IAQ specifically for the night zone. First, some characteristics of the inhabitant profile are discussed. Thereafter, the effect of the variation in window opening behaviour on the ventilation system performance is examined. Finally, real measurements from sensor data in occupied dwellings are analysed to check the findings from the simulations.

3.1 Inhabitant profiles

The simulated inhabitants consist of four occupants. The CO_2 and humidity production and window opening behaviour are important for the performance of the ventilation system. The two inhabitant profiles included in the simulations differ only in the window opening behaviour in the night zone, as this is the main focus in this research. The effect of door opening behaviour is also not negligible, especially for VST3 ventilation systems where there is less control on the supply flow via trickle vents in case of closed doors. As the effect of the door opening is not the focus of this study, the doors in the bedrooms are always kept open for both profiles.

Figure 1 shows the total CO_2 production in the three bedrooms together with the average occupancy per person in these rooms. The CO_2 production is represented as the total amount of CO_2 that is injected into these rooms on an annual basis. There is a clear difference in the CO_2 production between the three rooms. The main bedroom has the biggest amount of CO_2 injection, as it accommodates two adults. On average, these two adults are each 8 hours present in the bedroom. The other two rooms accommodate only one child each, but there is also a difference visible there. As the child sleeping in bedroom 2 is more present, this is reflected in a bigger amount of CO_2. This figure shows that the CO_2 production increases with the number of occupants, but also with the presence in the room.

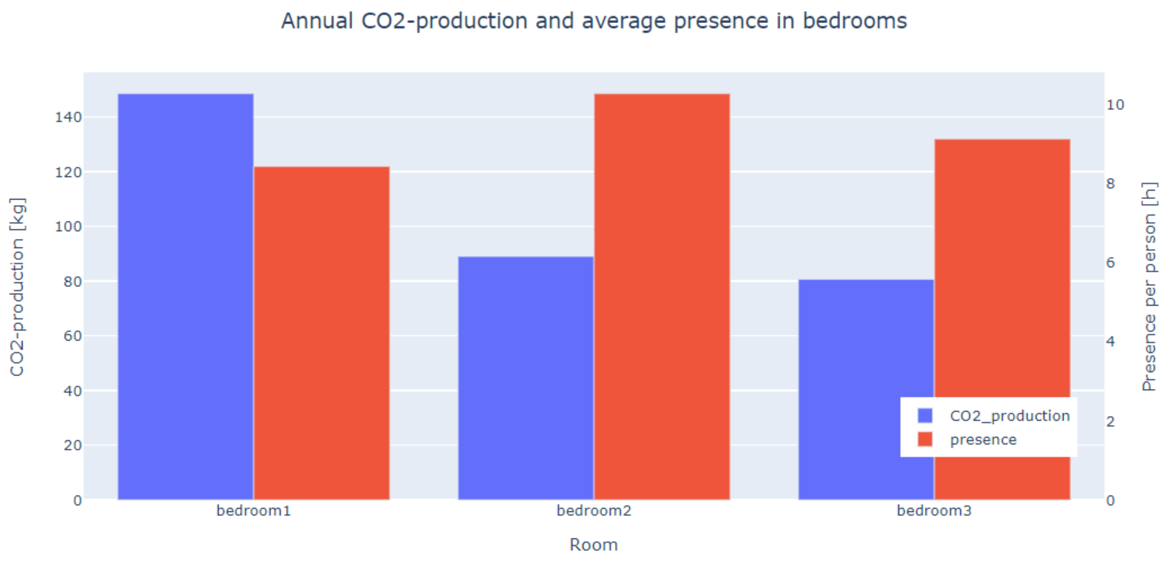

Figure 1: Inhabitant behaviour in bedrooms

3.2 Simulation results

The behaviour of the ventilation system is mainly determined by the CO_2 and humidity level. As discussed above, the source for CO_2 production is the inhabitants, while the humidity production is also influenced by other actions such as taking a shower or a bath, cooking, etc. This study focuses on the IAQ in terms of CO_2 level and the ventilation demand in the bedrooms.

Figure 2 shows the monthly average ventilation demand for the inhabitant profile without the window opening in the night zone, as well as the indoor CO_2 level. The ventilation demand and CO_2 level are evaluated in a time-window between 20:00 and 08:00 and are averaged over the 24 simulations with this specific inhabitant profile. During the summer months, inhabitants tend to open the windows in the day zone more, which has a beneficial effect on the CO_2 in the bedrooms and lowers the average ventilation demand.

Figure 3 show the monthly average ventilation demand for the inhabitant profile with the window opening in the night zone, as well as the indoor CO_2 level. The results are similarly processed as above. It can be seen that due to the window opening, especially during summer time, the ventilation demand is much lower and close to the minimum required demand of 10%. Consequently, the CO_2 level is hardly above the outside CO_2 level of 400 ppm. On average throughout the year, the ventilation demand is close to 20% lower for the profile with the window opening in the night zone.

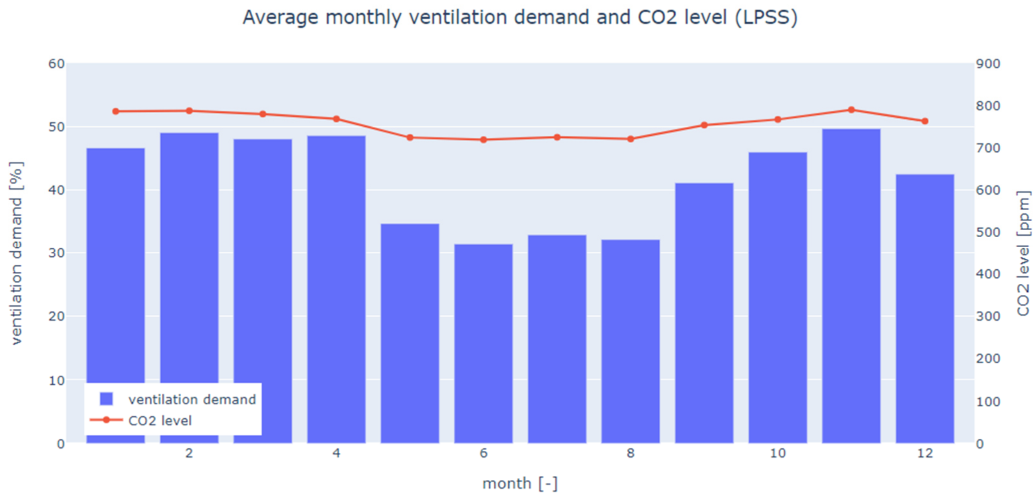

Figure 2: Average ventilation demand and CO_2 level without window opening in the night zone

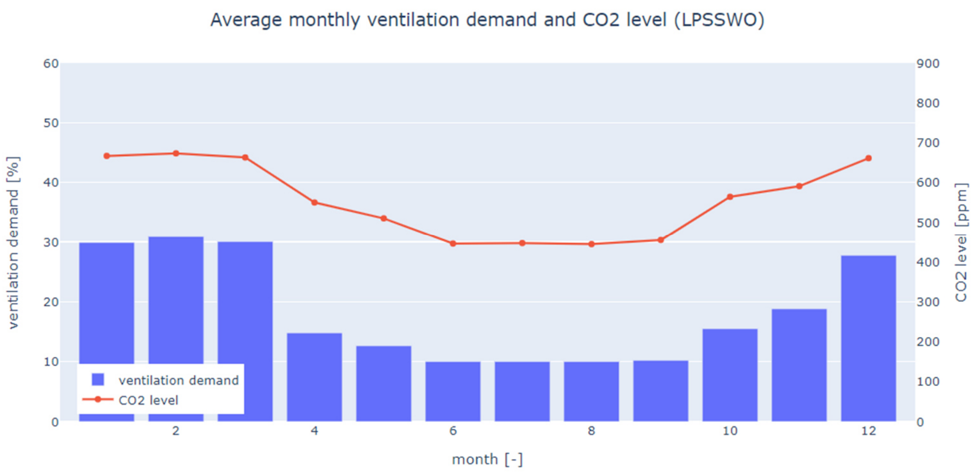

Figure 3: Average monthly ventilation demand and CO_2 level with window opening in the night zone

Figure 4 shows the annual average ventilation demand and the CO_2 level, evaluated in a time-window between 20:00 and 08:00, for the 48 different simulations. For the inhabitant profile without the window opening (LPSS, circular markers), there is a clear difference between the ventilation systems: the 2-zone VST3 system has the lowest ventilation demand and CO_2 levels. This can be explained by the fact that a certain amount of natural ventilation through the grids can take place depending on the weather conditions, such that the mechanical ventilation system has to work less during these times. The 2-zone VST5 system on the other hand has slightly higher CO_2 levels and ventilation demand than the 1-zone VST5 system. The reason is that the 2-zone system will supply clean air to the night zone only based on the demand in the night zone, whereas the 1-zone system will be supplying clean air both to the day and the night zone. This results in an over-ventilation of the night zone even when there is no demand in the night zone, thus resulting on average in lower CO_2 levels.

For the inhabitant profile with the window opening in the night zone (LPSSWO, diamond shaped markers), the difference between the ventilation systems is much less. The spread between the ventilation systems for the inhabitant profile with window opening is less than the mutual spread for a specific ventilation system for the inhabitant profile without window opening.

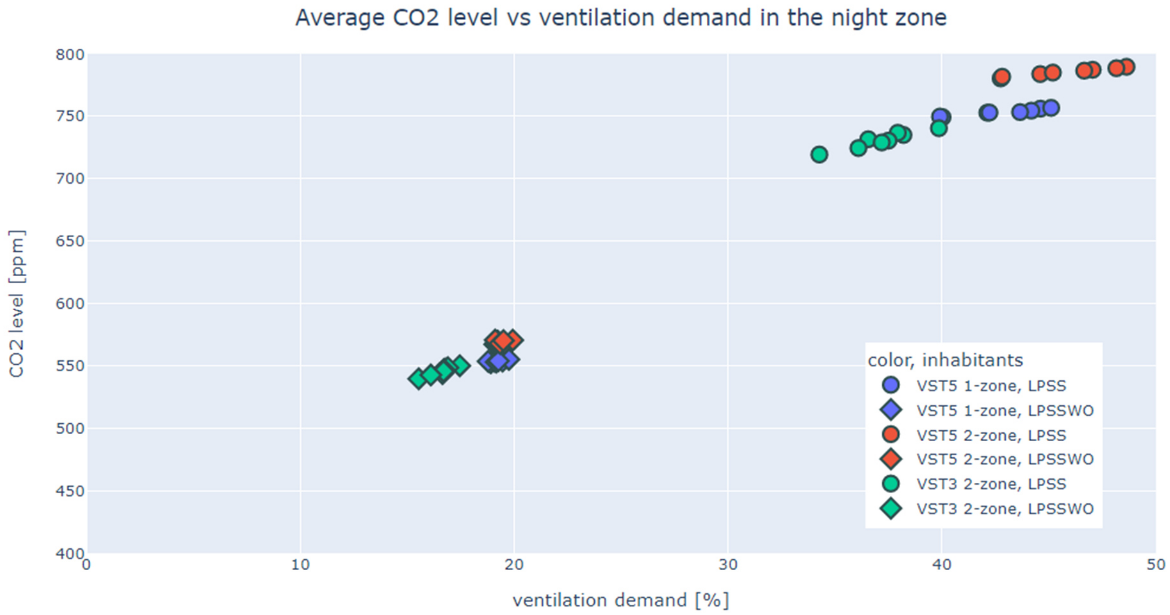

Figure 4: Annual average CO_2 level vs ventilation demand in the night zone

3.3 Measurements

When comparing the performance of ventilation systems, it is important to consider a realistic window opening behaviour. Therefore real measurements are also investigated in this study. Data from four occupied dwellings are available which is used to complement the simulations. Each family of the monitored dwellings exists of two inhabitants. However, they differ in terms of working habits and occupancy. This consequently leads to different window opening behaviour and CO_2 production.

Figure 5 shows the average CO_2 level and ventilation demand for the four different dwellings in the summer months June to August and evaluated as above in a time-window between 20:00 and 08:00. Similar as for the simulations, the average ventilation demand is mostly lower when the average CO_2 level is lower. In general, the average CO_2 levels are somewhat lower than expected, especially for dwelling D.

In addition to the ventilation demand and CO_2 level, Table 2 shows the average time that the windows are open in the night zone, also evaluated between 20:00 and 08:00. Although it is difficult to only evaluate the effect of window opening in real dwellings, as the inhabitants have completely other occupancy and activities, a general tendency is visible whereby the average CO_2 level is lower when windows are opened more.

In dwelling A and B, the windows are opened most of the time and the average CO_2 level and ventilation demand are also the lowest. In dwelling C, the windows are opened the least amount of time and the average CO_2 level is the highest. For dwelling D, the opening time is in between and the CO_2 level is in between that of dwellings A and B on the one hand and dwelling C on the other hand. The measured window opening times of around 7 to 9 hours are also well in line with the assumptions for the simulations in Table 1.

As the measured dataset is now limited to the summer months, the capturing and analysis of the window opening and ventilation data should be continued in the coming fall and winter months to complete the comparison with the simulation results.

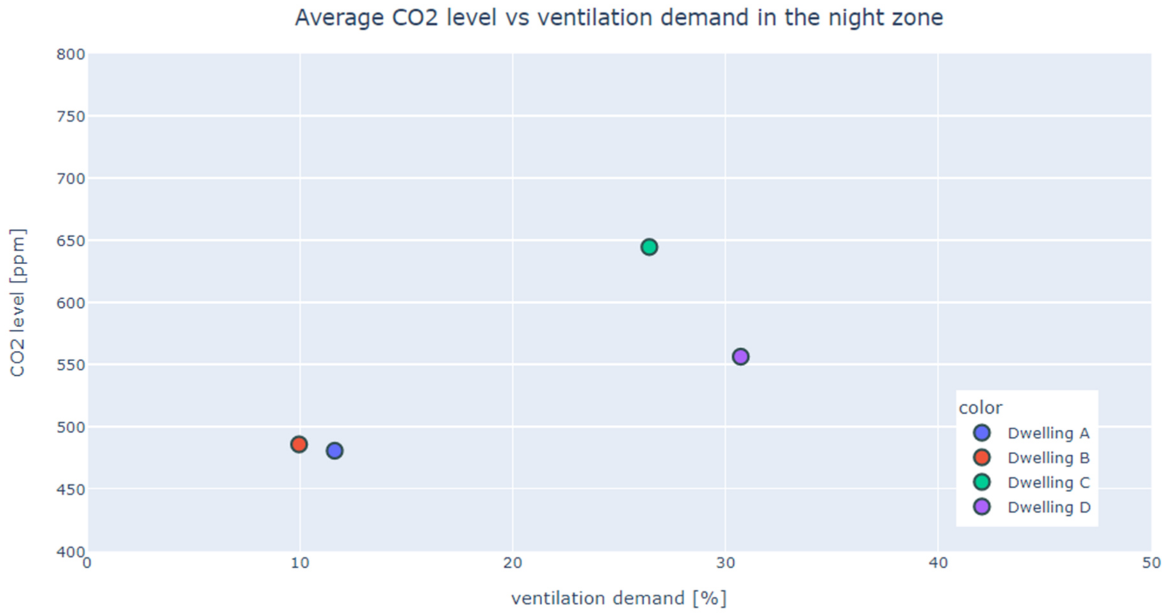

Figure 5: average CO2 level vs ventilation demand in the night zone

Table 2: Average window open hours, ventilation demand and CO2 per month for the night zone, evaluated between 20:00 and 08:00

Dwelling	Months	Windows open hours	Average ventilation demand	Average CO2 level [ppm]
A	June to August	7.6 hours	12%	481 ppm
B	June to August	8.8 hours	10%	486 ppm
C	June to July	6.9 hours	26%	645 ppm
D	June to August	7.4 hours	31%	556 ppm

4 CONCLUSIONS

The goal of this study was to expose the dominance of inhabitant behaviour on the performance of ventilation systems. This study focused on the effect of window opening in the night zone to the ventilation demand and the IAQ in terms of CO_2 level. Using a model-based approach, a total of 48 simulations were executed. The variation in window opening behaviour from the inhabitants was shown to be a very determining factor in the results. In case of no window opening, a clear distinction between ventilation systems in terms of ventilation demand and CO_2 level is observed. The results of the simulations with window opening showed a less clear distinction and were more similar. As windows are opened more often, the ventilation system becomes less relevant. High flow rates with the outside environment already clean the inside air. Therefore, comparing ventilation systems among each other is not always substantiated when inhabitant behaviour is not taken into account. Real data from almost identical occupied dwellings with the same ventilation system also illustrate the dominance of inhabitant behaviour on the differences in ventilation demand and average CO_2 levels.

5 REFERENCES

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