Balanced ventilation - energy efficient and healthy

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ABSTRACT

When making homes more sustainable, the emphasis is on scaling up to achieve the climate and energy objectives. Little attention is paid to air quality in homes, despite the fact that an estimated 98% of the Dutch homes do not meet the WHO's 2021 annual guideline value for $PM_{2.5}$. Tackling sustainability and the indoor environment hand in hand is therefore important. Airtight homes with balanced ventilation and effective range hoods offer the opportunity to significantly improve the air quality for residents in the homes, by reducing both particulate matter from indoor and outdoor sources. This possibility is currently not fully utilized. Most systems use coarse filters, while better indoor air quality can be achieved with a better filter class. The research question in this article is: What influence do ventilation systems, airtightness and effective range hoods and users have on the particulate matter concentration in the indoor air and, in particular, what is the effect of improved filtering? To answer this question, simulations were carried out with a ventilation model that included the effect of the type of ventilation system, cooking extraction, air tightness and window use. The effect of open windows was modelled with wind pressure coefficients and turbulent exchange.

The simulations show that good cooking extraction in combination with better filtering of the ventilation air in the mechanical supply can significantly reduce exposure to particulate matter in homes, even when windows are open in the bedrooms for a large part of the year. This is mainly due to the much lower exposure in the living room.

The simulated $PM_{2.5}$ exposure in for both homes with supply via grilles and for homes with balanced ventilation with standard filters did not meet the WHO annual guideline value. Balanced ventilation with F7 particulate matter filters (ePM1 55%) resulted in a exposure below the WHO annual guideline value. Because the simulations assume that windows are open for cooling during part of the year, the use of even better filters only has a limited effect. In homes with active cooling, there is clear added value to using better filters than F7 quality, because then windows can remain closed.

KEYWORDS

$PM_{2.5}$, simulation, window use, ventilation system, cooking exhaust

1 INTRODUCTION

When renovating homes, the emphasis is on energy savings in order to achieve the climate and energy objectives. Energy savings, necessary to meet the obliged energy efficiency requirements, are usually also the reason for using balanced ventilation in new-build homes. In other sectors such as offices and schools near busy roads, balanced ventilation in combination with good filters is also used to protect users against particulate matter from the outside air (PvE Healthy offices 2021; PvE fresh schools, 2021). The fact that balanced ventilation, in addition to meeting energetic requirements, can also be used to improve air quality and thus the health of residents, receives little attention in homes.

In any case, little attention is paid to air quality in homes, despite the fact that an estimated 98% of homes do not meet the WHO's 2021 recommended value for $PM_{2.5}$. A large-scale and long-term monitoring study (TKI Be Aware, 2020) established that 15 of the 100 homes examined did not meet the 'old' WHO $PM_{2.5}$ recommended value of 10 μ g/m^3 annual average. The annual average concentration in the kitchen/living room was on average 8.2 μ g/m^3. In September 2021, this recommended value was adjusted by the WHO to 5 μg/m^3 annual average. Using this new recommended value, 98% of the homes examined no longer met (TVVL 2021).

Based on the Be Aware monitoring study, simulations were carried out in 2020 with the TRNSYS building model linked to the ventilation calculation model TRNFlow (COMIS). Two important simplifications were made when carrying out these simulations. Firstly, a ventilation model was used in which only the living room/kitchen was considered. In addition, the windows were assumed to be closed. This is certainly not a good assumption outside the heating season. The research question in this article is therefore: What influence do ventilation systems and users have on the particulate matter concentration in homes and, in particular, what is the effect of improved filtering? To answer this question, simulations were carried out with a ventilation model that included the effect of the type of ventilation system, cooking extraction, air tightness and window use.

2 SIMULATION SETUP

2.1 Multizone ventilation model

With a multi-zone ventilation model the annual average particulate matter concentration in a single-family home has been determined. The model consists of 4 zones, see figure 1. The zones are all connected to the stairwell via a gap of 120 cm^2 under the interior doors. To prevent drafts from occurring straight through the house from facade to facade at higher wind speeds when windows are open, it is assumed that the interior doors are closed.

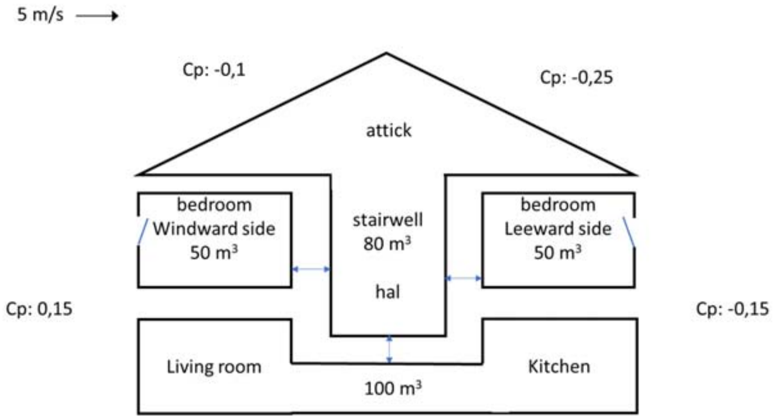

Figure 1: schematic representation of ventilation model with connections between the zones

The ventilation model calculates the air flows between the zones based on wind effects, thermal effects and the type of ventilation system. A constant air speed of 5 m/s perpendicular to the facade has been assumed for the wind. This speed is the average wind speed in the Netherlands. Two air leakages have been assumed, 20 and 80 dm^3/s at 10 Pa. The air leaks through seams and cracks are distributed over the home envelope in accordance with the BKN equivalence methodology (2018) and are mainly present in the attic. The wind pressure coefficients for the facade and roof surface have also been adopted in accordance with this methodology. Thermal effects are modelled depending on the season. The daily average indoor and outdoor temperatures used for this are shown in table 1.

Table 1: Simulated indoor and outdoor temperatures per season

	Outside temperature	**Living room temperature**	**Bedroom temperature**
Winter	6	20	18
Spring and autumn	14	20	20
Summer	20	20	20

2.2 Turbulent exchange through open windows

Many residents of new-build homes, even in the heating season, experience the temperature of the bedrooms as too high and open the windows to cool (Jacobs, 2012). This can cause so-called turbulent exchange, in which warm air simultaneously flows out at the top and cold air flows in at the bottom. This turbulent exchange can be calculated from the temperature difference between inside and outside, the open surface and the height over which the exchange occurs (AIVC, 1988). Here a tilting window has been simulated for each bedroom, which is opened 10 cm at the top in the tilt position. The height of the window is 1.3 m and the width is 0.57 m.

Window use over the seasons has been simplified as follows: in winter all windows are assumed to be closed, in spring and autumn the bedroom windows are in the tilt position while sleeping and in the summer these windows are in the tilt position throughout the day.

2.3 Particulate matter sources and deposition

The annual average $PM_{2.5}$ particulate matter concentration in the outdoor air in urban areas has decreased in recent years due to cleaner techniques and COVID-19 lockdown measures to approximately 9 $\mu g/m^3$ (range 7-11 $\mu g/m^3$). In this simulation study, an average outdoor concentration of 11 $\mu g/m^3$ was used to compare the results with the outdoor conditions during the TKI Be Aware measurement study that was carried out from September 2017 to September 2018.

In the home, the $PM_{2.5}$ particulate matter emissions due to cooking have been simulated according to the 50 percentile emission pattern from TKI Be Aware. This emission pattern includes emissions resulting from the preparation of breakfast, lunch and dinner. Some of the particulate matter in the indoor environment settles on surfaces, this is called deposition. For the simulation study, it was assumed that the effect of this deposition is equivalent to an additional ventilation flow with clean air of 40 m^3 /hour in a room of 100 m^3 (TKI Be Aware, 2020).

2.4 Cooking extractor

Simulations with and without cooking extraction were carried out. A capture efficiency of 95% has been assumed for the capture of $PM_{2.5}$ present in the cooking fumes when the extractor hood is switched on (100% extraction capacity). This is a typical value for a chimney extractor hood at 300 m^3 /hour. The size of this extraction flow is comparable to the maximum extraction flow of a ventilation unit for a single-family home.

2.5 Ventilation system and filtering

Two ventilation systems have been simulated in the house. A system C ventilation system, which consists of supply grilles in the facade in every living room and a mechanical exhaust in the kitchen, bathroom and toilet. And a balanced ventilation system (system D) with mechanical supply in every living room and mechanical exhaust in the kitchen, bathroom and toilet. The nominal ventilation capacities are in accordance with the Dutch Building Decree. Situations with low setting (30% of the nominal ventilation capacity) and medium setting (70% of the nominal ventilation capacity) when there is presence are simulated. In the absence, it is assumed that the system is always in low mode. It is assumed that the ventilation grilles in the living room are closed and that they are continuously open in the bedroom. This is a common practical situation that arises after experiencing drafts in the winter and forgetting to open the grilles in the spring. In system C it is assumed that only very coarse parts such as insects are captured from the grilles and that no capture of $PM_{2.5}$ takes place. The balanced ventilation system is equipped with G3 filters as standard. For a balanced ventilation unit equipped with such a coarse filter, a $PM_{2.5}$ capture efficiency of 15% is expected based on ongoing practical measurements. Equipped with an F7 filter (ePM_1 55%), see figure 2, the capture efficiency of the balance ventilation unit increases to approximately 75%. These two values were used in the simulations. In addition, simulations have also been carried out with a $PM_{2.5}$ capture percentage of 99%. This performance can be achieved when using an electrostatic filter that is placed downstream of the balanced ventilation unit (Khoury et al. 2017).

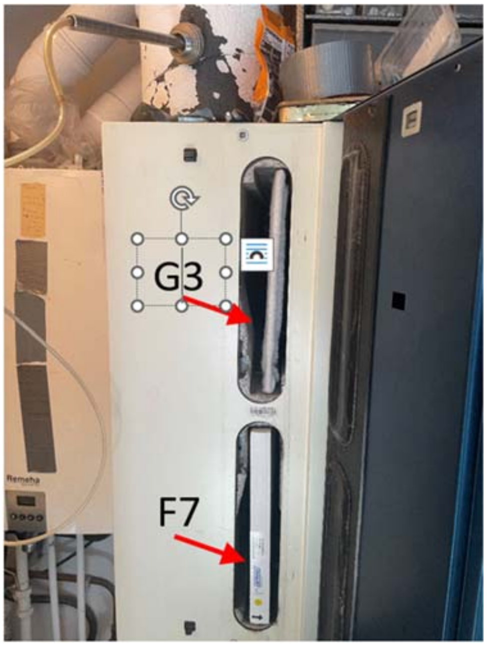

Figure 2: energy-efficient and healthy, in the balanced ventilation unit an F7 (ePM_1 55%) fine dust filter has been placed in the air intake instead of the standard G3 coarse filter, such a filter is still in the exhaust.

2.6 Particulate matter concentration and exposure

The COMIS ventilation model was used to calculate the concentrations in the various rooms in the house over time. The concentration when present in the various living areas was then determined. For this purpose, the following stay has been adopted: 9 hours per day in the bedroom, 5 hours in the living room/kitchen during the week and 10 hours per day in the living room/kitchen at the weekend. The average exposure to particulate matter in the home has been determined based on these times.

3 SIMULATION RESULTS

3.1 Effect of filtering and cooking extraction on concentrations with closed windows

Without using a cooking extractor, see figure 3, the highest particulate matter concentrations occur in the living room/kitchen. The simulated concentrations correspond well with the measured concentrations in the Be Aware study during presence. Figure 4 shows that better filtering of the ventilation air only results in a limited reduction in concentration in the living room/kitchen. In the bedroom on the windward side, relatively high concentrations occur, especially in system C, because a lot of unfiltered outside air flows in through the grille and the seams and cracks. In the leeward room, system C scores better in terms of particulate matter than system D with a standard filter (15% capture efficiency), because exfiltration occurs via the grilles and therefore supply via the inner door from the relatively clean stairwell (as a result of deposition in the home).

With a cooking extractor , see figure 4, the particulate matter concentrations in the bedroom remain unchanged. However, the concentrations in the living room/kitchen decrease sharply. It is striking to see that there is almost no concentration difference between the F7 filter with 75% capture efficiency and a filter with 99% capture efficiency. This is caused by the fact that ventilation is set to low during the rest of the day, except during cooking, and the contribution of infiltration is then relatively large. With ventilation in the middle position (figure not shown), the concentration in the living room with the standard G4 filter (15% capture efficiency) remains virtually the same, but with a filter with 99% capture efficiency it decreases to 2 µg/m^3.

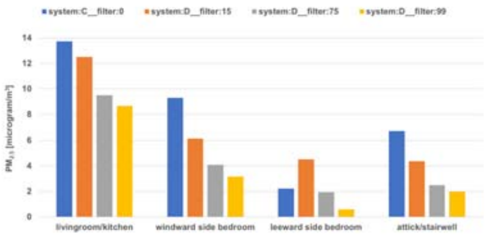

Figure 3 Effect of filter efficiency on the PM$_{2.5}$ concentration per living space during presence, q_{v10}=80 dm^3/s, windows closed, ventilation in low setting, without cooking extraction.

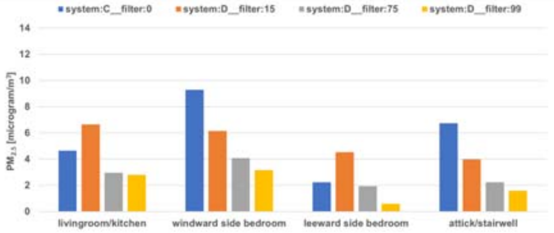

Figure 4 Effect of filter efficiency on the PM$_{2.5}$ concentration per living space during presence, q_{v10}=80 dm^3/s, windows closed, ventilation in low setting, with cooking extraction.

3.2 Effect of airtightness and window use with two filter classes

Figures 5 and 6 show the particulate matter concentration for the different rooms with different assumptions for air tightness and outside temperature for 15% and 75% filter efficiency respectively. A limited influence of the airtightness (q_{v10} value) is visible in winter (Toutside [C]:6) when the windows are closed. In spring and autumn (Toutside [C]:14) and summer (Toutside [C]:20), opening windows in particular determines the exposure to particulate matter in the bedrooms. The filter class has the greatest effect in the living room. In the bedroom, an effect is visible in winter and the effect is limited during the rest of the year due to the assumed window use.

It is striking to see that in the leeward bedroom the particulate matter concentration decreases in summer compared to spring and autumn. This is because the simulations in summer assume that the indoor temperature is the same as the outdoor temperature and therefore no turbulent exchange occurs across the open windows. Turbulent exchange is the phenomenon in which warm indoor air flows out at the top of the window and the same amount of cold outside air flows in at the bottom. Due to the higher particulate matter concentration outside compared to inside, turbulent exchange results in an additional particulate matter load for the bedrooms. It is noted that in reality temperature differences can also be expected in summer and therefore turbulent exchange will also take place (albeit to a lesser extent than in spring and autumn). To study this effect further, simulations with, for example, hourly values will be carried out at a later stage.

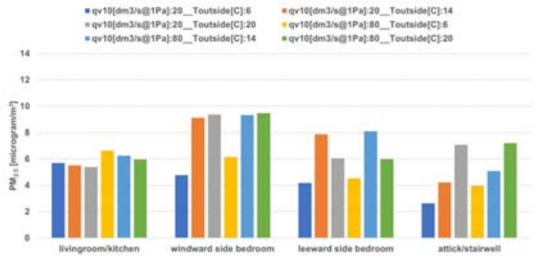

Figure 5 System D with 15% filter efficiency, effect of air tightness (q_{v10}) and outside temperature on the $PM_{2.5}$ concentration in the presence of each living room, ventilation in low mode, with cooking extraction, windows open or closed depending on the temperature.

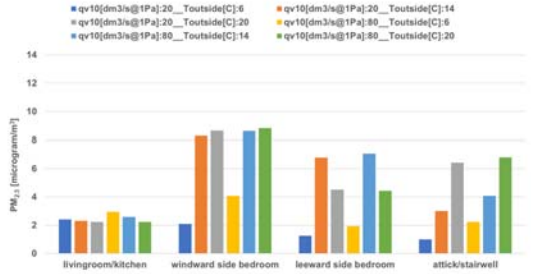

Figure 6 System D with 75% filter efficiency, effect of air tightness (q_{v10}) and outside temperature on the $PM_{2.5}$ concentration when present per living room, ventilation in low setting, with cooking extraction, windows open or closed depending on the temperature.

3.3 Effect on exposure

The average annual particulate matter exposure in the home has been determined by averaging the particulate matter concentrations present in the various rooms during the four seasons. It follows from Figure 7 that in both a home equipped with system C and system D with a standard filter (15% capture efficiency), the exposure is higher than the WHO annual average $PM_{2.5}$ recommended value of 5 $\mu g/m^3$. Increasing the ventilation flow rate when present to the medium setting even results in an increase in exposure in this situation. This is because when the amount of ventilation is increased, the effect of deposition decreases relatively speaking. Replacing the G3 supply filter in system D with an F7 particulate filter leads to exposure below the WHO recommended value. Installing an electrostatic filter with a 99% capture efficiency only results in a limited reduction in exposure, because the bedroom windows are open during part of the year. Figure 8 shows the potential of filtering in combination with mechanical cooling (bedroom windows are no longer opened). This reduces exposure by more than half compared to a F7 filter. And with an electrostatic filter, exposure in the home can even be reduced to below 1 $\mu g/m^3$.

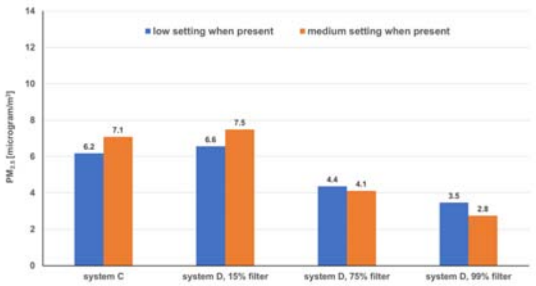

Figure 7 Exposure to $PM_{2.5}$ particulate matter for different ventilation systems and filter efficiencies . Bedroom windows tilted in spring, autumn and summer, airtightness q_{v10}=20 dm^3/s and with cooking extractor.

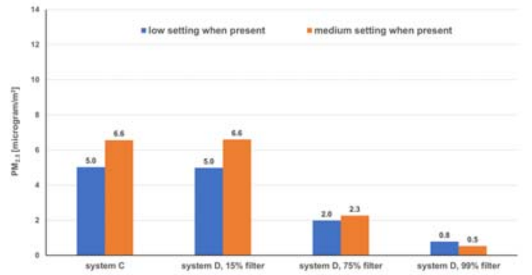

Figure 8 Exposure to $PM_{2.5}$ particulate matter for different ventilation systems and filter efficiencies . Bedroom windows closed (mechanical cooling), air tightness q_{v10}=20 dm^3/ s and with cooking extractor.

4 CONCLUSIONS

This simulation study shows that good cooking extraction in combination with better filtering of the ventilation air in the mechanical supply can significantly reduce exposure to particulate matter in homes, even when windows are open in the bedrooms for a large part of the year. With balanced ventilation with F7 particulate matter filters (ePM$_1$ 55%), the new WHO recommended value is met. Because the simulations assume that windows are open for cooling during part of the year, the use of even better filters only has a limited effect. In homes with active cooling, there is clear added value to using better filters than F7 quality, because then windows can remain closed.

This study is a simulation study with a large number of other assumptions in addition to the previous simplification. Practical measurements are required to validate the results. For this purpose, detailed measurements are planned in homes in 2024, in which particulate matter is measured in multiple zones and information is collected about, among other things, open windows, ventilation flow rates and meteorological data. In addition, the effect of better filtering will be measured in homes with balanced ventilation to validate the model described here.

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