Minimising the influence of the stack effect and wind on the operation of mechanical exhaust ventilation systems

Romy Van Gaever*[1], Samuel Caillou[1] and Sébastien Pecceu[1]

1 Belgian Building Research Institute (BBRI)
Avenue P. Holoffe 21
1342 Limelette, Belgium
**Corresponding author: romy.van.gaever@bbri.be*

ABSTRACT

Ventilation systems play an important role in providing a good indoor air quality in dwellings. Mechanical exhaust ventilation systems implement natural vents, also called trickle vents, to supply outdoor air to the dwelling. The airflow through these natural supply vents depends on the natural driving forces, i.e. wind and the stack effect, which vary in time.

This study examines several interventions to minimise the influence of the stack effect and wind on the operation of a classical mechanical exhaust ventilation system as defined by the current Belgian standard NBN D50-001 (1991). These interventions contain the overall use of smaller natural supply vents, additional mechanical extraction in the bedrooms, the use of natural supply vents only in the hallway, the use of mechanical transfer openings, balanced airflow rates per building level, increased air flow rates and the use of larger transfer openings. This paper covers a simulation study using CONTAM to investigate the effectiveness of the different interventions on the operation of a mechanical exhaust ventilation system in two types of single-family dwellings, i.e. a detached 3-bedroom dwelling and a terraced 2-bedroom dwelling. The operation of the mechanical exhaust ventilation system is evaluated in terms of the exposure of the occupants to CO_2 in the living spaces.

All of the above described interventions have a positive effect, to a greater or lesser extent, on minimising the influence of wind and the stack effect on the operation of the mechanical exhaust ventilation systems in both types of dwellings. However, some of the interventions are not as efficient to be considered as a valid solution to minimise the influence of the stack effect and wind.

KEYWORDS

Natural ventilation, Mechanical exhaust systems, IAQ

1 INTRODUCTION

Mechanical exhaust ventilation systems supply outdoor air to the dwelling by using natural supply vents and extract the indoor air from the dwelling mechanically using (a) fan(s) (AIVC, 1996). Currently, the Belgian standard NBN D50-001 (1991) permits the use of mechanical exhaust systems to supply air in the living spaces (ex. living room or bedrooms) by natural vents and to mechanically extract air from the service spaces (ex. kitchen, bathroom). The standard refers to these systems as C-systems.

The Belgian standard also defines that the airflow rate (capacity) of a fully opened naturally supply vent must be designed at a pressure difference of 2 Pa. However, the actual pressure differences over the supply vents fluctuate in time due to natural driving forces, i.e. wind and the stack effect. Therefore, the actual supply flow rates through the vents vary in time depending on the weather conditions.

The conference paper 'The effectiveness of mechanical exhaust ventilation systems in dwellings', presented at the AIVC conference in 2017, discussed the influence of the wind and the stack effect on the airflow rate through the natural vents by taking the sizing of the natural vents and the airtightness of the dwelling envelope into account. This paper concludes that due to wind and the stack effect the flow rates vary in time and are not as designed. Wind is responsible for higher flow rates in the rooms at the windward side and lower or even negative flow rates at the leeward side. The stack effect is responsible for higher supply flow rates downstairs (living room) and lower supply flow rates upstairs (bedrooms). In a leaky dwelling, these negative effects are even bigger than in an airtight building: air will enter the dwelling through the leakages in both the living and service spaces, leading to more variable flow rate through the natural supply vents and the total supply flow rate in the living room and bedrooms will decrease and an additional supply flow rate in the service spaces will occur. Smaller natural supply openings, designed at e.g. 10 Pa, lead to less variable and more controlled flow rates, closer to the desired design flow rate in airtight dwellings. However, in leaky dwellings these smaller vents are not as favourable: lower flow rates through the natural vents occur compared to the airtight dwelling.

This paper discusses several interventions to minimise the influence of the stack effect and wind on the operation of mechanical exhaust ventilation systems in airtight as well as more leaky buildings. This influence is investigated based on multi-zone flow rate simulations in CONTAM and is evaluated by the exposure of the occupants to CO_2.

2 METHOD

The simulation study uses the multi-zone airflow and contaminant transport calculation software CONTAM to determine the occupants exposure levels to CO_2 during the whole heating season in two reference dwellings.

The first reference dwelling used in this study represents a two-storey detached, three-bedroom house with a total living area of 117 m². The day zone (living room, kitchen, utility room, toilet, entranceway) is located downstairs and the night zone (bedrooms, bathroom, hallway) upstairs (Figure 1).

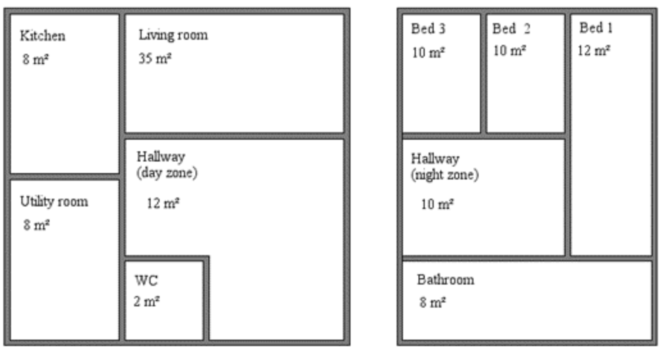


Figure 1: The first reference dwelling is a two-storey dwelling with the day zone downstairs and the night zone upstairs

The second reference dwelling is a two-storey, terraced house with a limited total living area of 63 m². The downstairs contains a small living room and open kitchen, a toilet and the entrance; the first floor two small bedrooms, a bathroom and the hallway.(Figure 2).

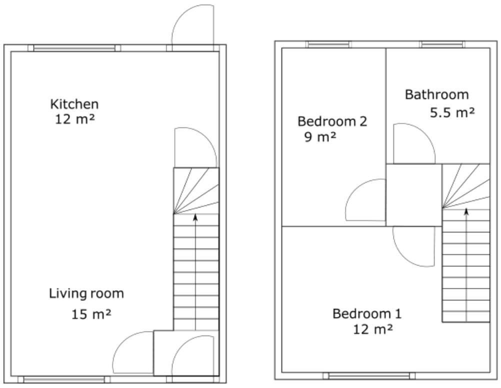


Figure 2: The second reference dwelling is a two-storey dwelling with a limited total living area

Dwelling 1 and 2 are occupied by respectively four (2 adults and 2 children) and three (2 adults and 1 child) persons. The occupants are always at home (fixed occupation schedule), representing the 'worst case' scenario regarding the production of and the exposure to contaminants.

The CO_2-production rate in the house depends on the emission rates of humans and their activities. The occupant's CO_2-emission rates are based on CEN/TR 14788:2006 (European Committee for Standardization, 2006):

- CO_2 awake: 16 l/h
- CO_2 asleep: 10 l/h

The design airflow rate for each room in these dwellings are listed below. The supply and extraction airflow rates are balanced.

	Dwelling 1	**Dwelling 2**
Supply (natural)	Flow rate [m³/h]	Flow rate [m³/h]
Living room	100	75
Bedroom 1	50	42
Bedroom 2/3	25	32
Extraction (mechanical)	Flow rate [m³/h]	Flow rate [m³/h]
Kitchen	50	75
Bathroom	50	50
Utility room	50	n.a.
Toilet	25	25
Hallway day zone	-	-
Hallway night zone	25	-

Both dwellings are equipped with a C-system, i.e. mechanical exhaust ventilation with natural supply vents in the living room and bedrooms and mechanical extraction in the service spaces. Two sizes of natural vents are studied: class P3 designed at 2 Pa and class P0 designed at 10 Pa.

The natural supply vents of class P3 designed at 2 Pa are self-regulating, while the class P0 vents designed at 10 Pa are non-self-regulating. The design flow rates of the self-regulating vents of class P3 occur at 2 Pa, while by closing the valve the flow rate at 4.5 Pa is maximum 1.5 times the flow rate at 2 Pa. The non-self-regulating vents of class P0 don't include a closing valve.

The airtightness, defined as the airflow through the dwelling envelope per m² at a pressure difference of 50 Pa (v_{50}) for reference dwelling 1 and as the air change rate at a pressure difference of 50 Pa (n_{50}), also varies throughout the study.

The airtightness is simulated by 2 cracks in the outer wall of each room. The first crack is located at ¼ of the height of the wall and the second at ¾. The in-/exfiltration rate through each crack is determined according to the surface area that each crack represents (uniform airtightness/air permeability). The in/exfiltration rate through the roof is evenly divided over the cracks in the walls.

The hourly Test Reference Year Uccle (Brussels) is used to determine the outdoor conditions. This file contains, among other parameters, the wind speed, the wind direction and the outdoor temperature of an entire 'reference' year in Uccle. The indoor temperature is 20°C. The simulation reporting time is set to each minute, corresponding to the simulation time step.

3 RESULTS AND DISCUSSION

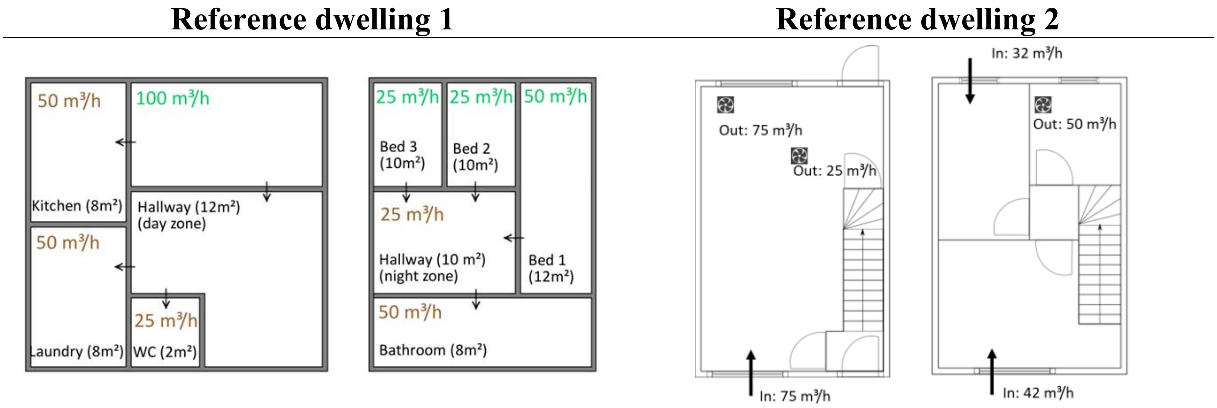
The simulation study investigates four interventions which minimize the influence of the stack effect and wind on the operation of mechanical exhaust ventilation systems in comparison with the classical system C. This results in the following five schemes (including the reference one):

1. Classical C-system with P3@2Pa supply vents (reference)
2. C-system with smaller P0@10Pa natural vents
3. C-system with additional mechanical extraction in the bedrooms
4. Natural supply with P3@2Pa vents in the entrance way and mechanical extraction in the living room, bedrooms and service spaces.
5. C-system with mechanical transfer openings in the living room and bedrooms

The simulation results show the cumulative occupant exposure to CO_2 for the whole heating season for the four intervention (scheme 2-5) in relation to the classical C-system (scheme 1).

3.1 Classical C-system with P3@2Pa supply vents (reference)

The simulations investigate the influence of a classical C-system with class P3 natural vents designed at 2 Pa on the occupant exposure levels in both reference dwellings with varying airtightness (Figure 3).



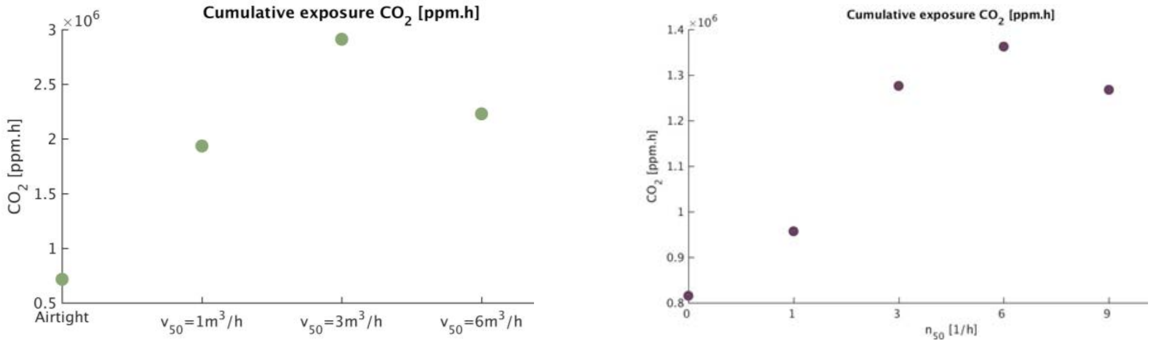


Figure 3: Both reference dwellings are equipped with a classical C-system (above). The graphs (below) show the occupant exposure levels to CO_2 of this ventilation system for different airtightness levels.

In both reference dwellings and with decreasing airtightness, the occupant exposure to CO_2 increases as a result of less airflow supplying the living spaces as a consequence of more airflow through leakages in the service spaces due to the mechanical driving force of the extraction. However, at very low airtightness the occupant exposure decreases again as a result of high airflow through all leakages in all spaces. Notice that the leakages are uniformly distributed over the surface area of the building envelope.

3.2 C-system with smaller P0@10Pa natural vents

The simulations investigate the influence of a C-system with smaller class P0 natural vents designed at 10 Pa on the occupant exposure levels in both reference dwellings with varying airtightness in relation to the classical C-system (Figure 4).

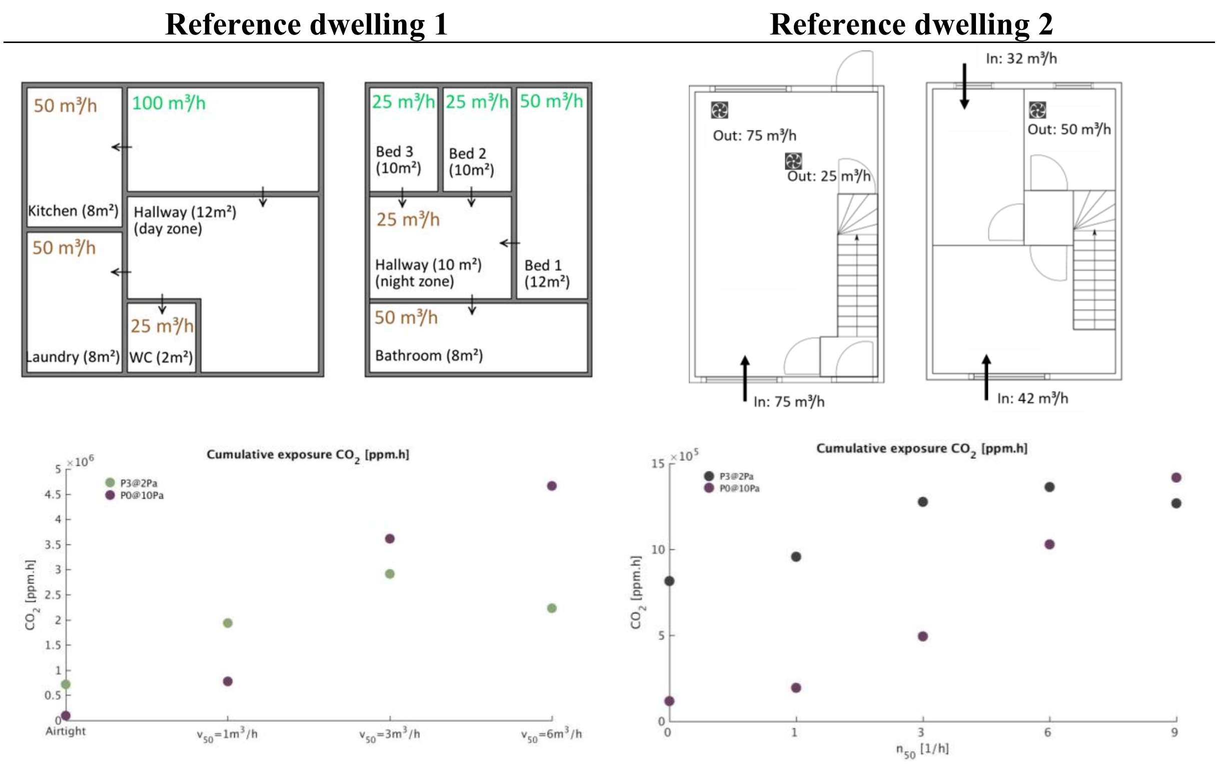


Figure 4: Both reference dwellings are equipped with a C-system with smaller class P0 vents designed at 10 Pa (above). The graphs (below) show the occupant exposure levels to CO2 of this ventilation system for different airtightness levels. The results for classical supply vents designed at 2 Pa are shown for reference dwelling 1 and 2 in respectively green and grey; for the smaller vents designed at 10 pa in purple.

For high levels of airtightness, the smaller natural vents designed at 10 Pa lead to lower levels of occupant exposure to CO_2. The smaller vents are less sensible to the wind and the stack effect resulting in less variable airflow rates. However, at lower airtightness levels the smaller vents lose their advantage, resulting in higher exposure levels in comparison with the larger vents designed at 2 Pa.

Furthermore, Figure 5 shows that the smaller vents designed at 10 Pa are less sensible to the wind direction compared to the vents designed at 2 Pa (similar results for dwelling 1).

Reference dwelling 2 (n_{50} = 3/h)

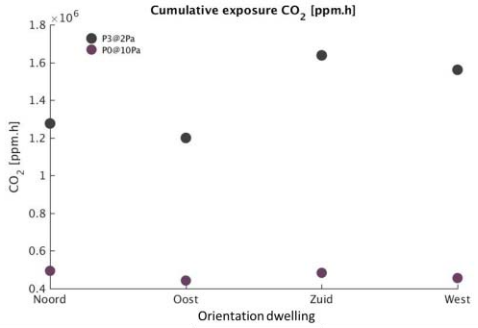


Figure 5: The graph shows the occupant exposure levels to CO_2 for different orientations of the reference dwelling 1 for an airtightness of n_{50} = 3/h. The results for the classical vents designed at 2 Pa are shown in grey and results for the smaller vents designed 10 Pa in purple.

3.3 C-system with additional mechanical extraction in the bedrooms

The simulations investigate the influence of a C-system with class P3 natural vents designed at 2 Pa with additional mechanical extraction in the bedrooms on the occupant exposure levels in both reference dwellings with varying airtightness (Figure 6).

Reference dwelling 1 **Reference dwelling 2**

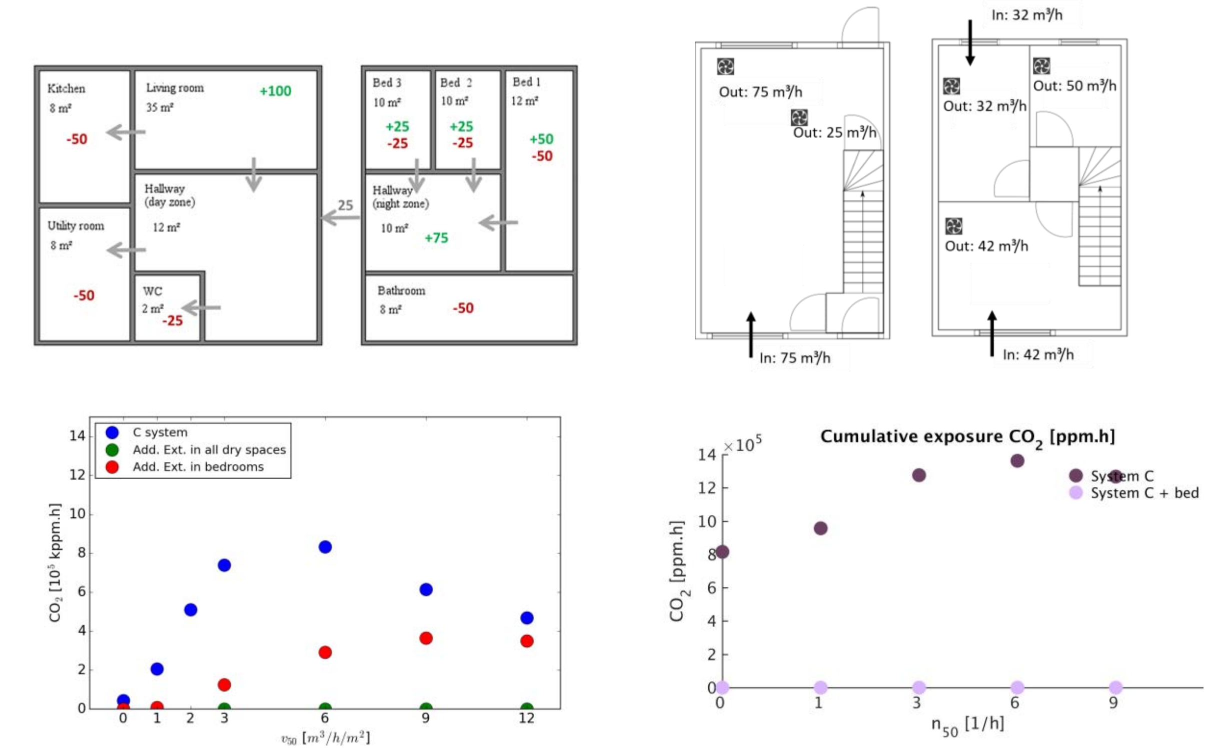


Figure 6: Both reference dwellings are equipped with a C-system with class P3 natural vents designed at 2 Pa with additional mechanical extraction in the bedrooms (above). The graphs (below) show the occupant exposure levels to CO_2 for different airtightness levels. The results for the classical C-system are shown for reference dwelling 1 and 2 in respectively blue and dark purple; for the ventilation system with additional mechanical extraction in the bedrooms respectively in red and light purple; for additional mechanical extraction in the living room and bedrooms in green (reference dwelling 1).

For both reference dwelling, adding mechanical extraction to the bedrooms, greatly decreases the occupant exposure to CO_2, leading to (very) low exposure levels due to the more controlled airflow rates in the bedrooms. However, in the reference dwelling 1 is adding an mechanical extraction only in the bedrooms not as efficient as in the reference dwelling 2 because of the closed kitchen. An additional mechanical extraction in the bedrooms and living room does leads to very low occupant exposure levels in dwelling 1.

Please note that the total airflow rate of the C-system with additional extraction is higher than the classical system. Therefore, a demand control system could be recommended in this case.

3.4 Natural supply with P3@2Pa vents in the entrance way and mechanical extraction in the living room, bedrooms and service spaces

The simulations investigate the influence of a ventilation system with class P3 natural vents designed at 2 Pa in the entrance way and with mechanical extraction in the living room, the bedrooms and the service spaces on the occupant exposure levels in both reference dwellings with varying airtightness (Figure 7).

Reference dwelling 1 **Reference dwelling 2**

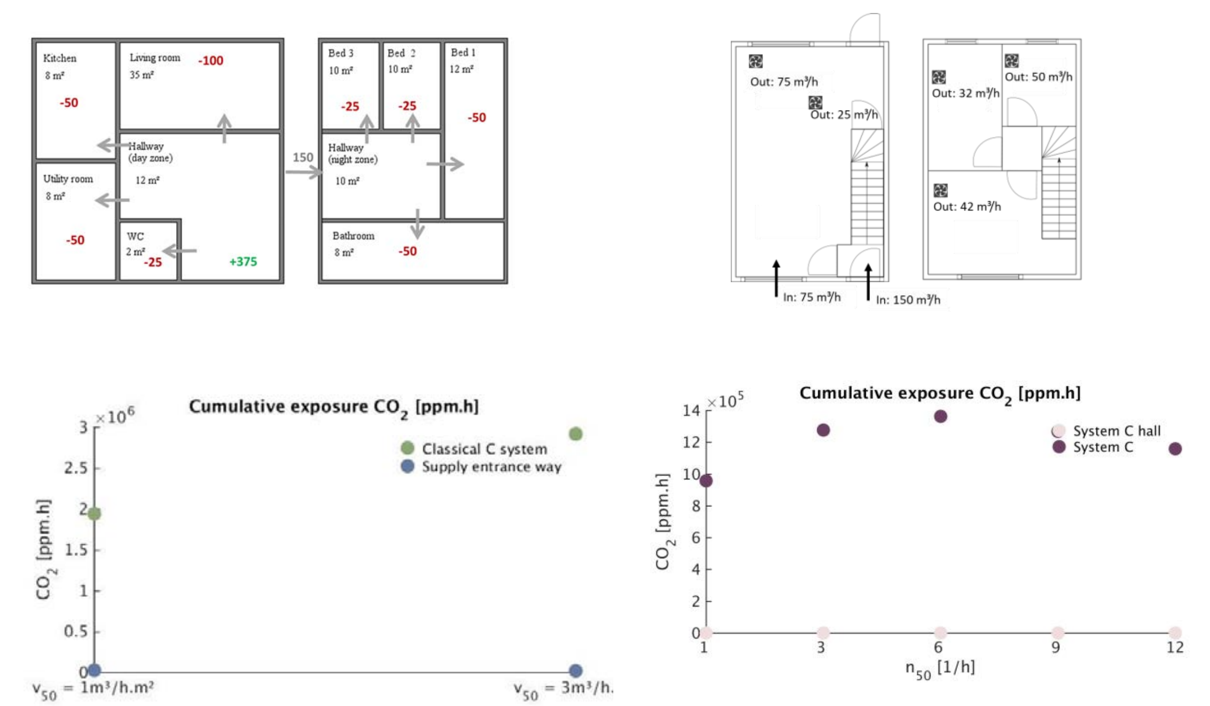


Figure 7: Both reference dwellings are equipped with a ventilation system with class P3 natural vents designed at 2 Pa in the entrance way and with additional mechanical extraction in all other spaces (above). The graphs (below) show the occupant exposure levels to CO_2 for different airtightness levels. The results for the classical C-system are shown for reference dwelling 1 and 2 in respectively green and dark purple; for the ventilation system with natural supply vents in the entrance way respectively in blue and light pink.

For both reference dwelling, implementing only natural supply vents in the hallway (for reference dwelling 2 in hallway and living room) greatly decreases the occupant exposure to CO_2, leading to very low exposure levels. The supply flow rate is less dependent to both the wind (direction) and the stack effect, as the natural vents are situated on only one side of the building and only on the ground level. However, the total airflow rate of the C-system with additional extraction is higher than the classical system. Therefore, a demand control system could be recommended.

3.5 C-system with mechanical transfer openings in the living room and bedrooms.

The simulations investigate the influence of a classical C-system with natural supply vents designed at 2 Pa and mechanical transfer openings between the living room/bedrooms and respectively the entrance and the hallway of the night zone on the occupant exposure levels in reference dwelling 1 with varying airtightness in relation to the classical C-system (Figure 8).

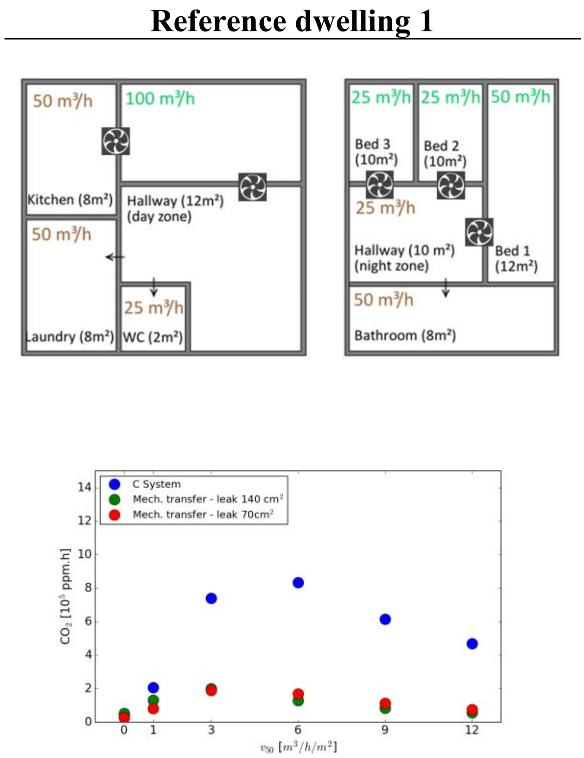


Figure 8: Reference dwelling 1 is equipped with a classical C-system with mechanical transfer opening in the living room and bedrooms (above). The graphs (below) show the occupant exposure levels to CO_2 for different airtightness levels. The results for the classical C-system are shown in blue; for the ventilation system with mechanical transfer openings in green and red for respectively large and smaller leakages between the rooms .

Applying mechanical transfer openings between the living room and entrance hall and kitchen and between the bedrooms and the hallway of the night zone leads to lower occupant exposure levels to CO_2, even if there are leakages between the spaces in the dwelling. Although this intervention is not as efficient as the previous ones because of the recycling of air that can occur, this intervention remains a valid solution to decrease the occupant exposure to a sufficient level.

3.6 Inefficient intervention to minimize the influence of the stack effect, wind and the airtightness on the operation of mechanical exhaust ventilation systems

This study also investigated other interventions to minimize the influence of the stack effect and wind on the operation of mechanical exhaust ventilation systems in comparison with the classical system C, such as:

1. Increasing the mechanical extraction airflow rates
2. Balancing the airflow rates per floor level
3. Decreasing the internal resistance by using larger transfer openings between the spaces in the dwelling

Without presenting the actual results, following conclusion can be drawn: all of the above interventions don't lead to an efficient decrease of the occupant exposure levels to CO_2. Increasing the mechanical extraction airflow rates and balancing the airflow rates per floor level only lead to a small decrease; decreasing the internal resistance even leads to slightly higher exposure levels in dwellings with a good airtightness.

4 CONCLUSIONS

The first four presented interventions lead to considerably lower exposure levels of the occupants to CO_2 for both types of dwellings. However, implementing smaller natural supply vents is only effective in dwellings with high airtightness levels.

Adding mechanical extraction to the bedrooms, implementing the natural supply vents only in the entrance hallway or adding mechanical transfer openings lead to very low levels of exposure and are therefore very effective solutions to minimise the influence of the stack effect and wind on the operation of mechanical exhaust ventilation systems.

These solutions are even very effective in less airtight dwellings, where a negative impact of the leakages in the building envelope occurs in addition to the effects of wind and the stack effect, by enhancing the effective air renewal in the living and bedrooms

However, these solutions require higher total ventilation design flow rates whereby demand control ventilation is advised.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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