The influence of different ventilation strategies and airflow control on the indoor air quality in dwellings.

Romy Van Gaever *1, Jelle Laverge 2, Samuel Caillou 1

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

2 Ghent University (UGent)
Gent, Belgium

ABSTRACT

The context of ventilation in Belgian dwellings has changed since the publication of the prescriptive Belgian standard NBN D 50-001:1991. The current more energy efficient context calls for new rules for improved ventilation strategies to establish a good indoor air quality with high energy-efficient ventilation. A first step is to compare the achieved IAQ for different ventilation strategies, including strategies not compliant with the current standard. This comparison takes both manual airflow control and demand control ventilation into consideration. This paper outlines the results of a simulation study for which multi-zone airflow and contaminant transport calculation software (CONTAM) is used. The results compare the effectiveness of four ventilation strategies and different types of airflow control in terms of average airflow rates, occupant exposure to CO2 and VOCs and the relative humidity in the dwelling. All four ventilation strategies can achieve a good IAQ, depending on the type of airflow control. However, some strategies require up to twice the airflow rate.

KEYWORDS

Residential ventilation; Airflow rate; IAQ; Demand controlled ventilation

1 INTRODUCTION

The Belgian standard NBN D50-001 1991 “Ventilation systems for housing” currently regulates the ventilation in dwellings (Belgisch Instituut voor Normalisatie (BIN), 1991). This standard follows a prescriptive approach based on minimal design airflow rates in each room of the dwelling and prescriptive design rules. However, the context has changed significantly since the publication of the standard 25 years ago. Dwellings have become more energy efficient, in particular at the level of the airtightness and insulation of the building envelope. Therefore, the ventilation system plays nowadays an essential role in assuring a sufficient air exchange and a good indoor air quality. As a result, the energy impact of the ventilation system increases relative to the impact of other energy performance parameters of a building. The new more energy efficient context calls for new rules for improved ventilation strategies to establish a good indoor air quality with high energy-efficient ventilation.

Currently, the Belgian standard defines four basic systems, i.e. natural ventilation (A), supply ventilation (B), extract ventilation (C) and balance ventilation (D), with required minimal design airflow rates for each room proportional to the floor area. The standard also dictates, regardless the chosen basic system, the airflow path through the dwelling: air supply in the living spaces (living room, bedrooms, office), transfer towards the service spaces (kitchen, bathroom, toilet, laundry room) and extraction in these service spaces (Belgisch Instituut voor Normalisatie (BIN), 1991).

However, today this standard presents some shortcomings to be tackled. Firstly, the four basic systems designed according to the standard don't provide an equivalent IAQ. Secondly, the standard doesn't include any performance-based criteria regarding manual airflow rate control or demand control ventilation (DCV). Therefore, the compromise between lowering the airflow rate and the corresponding energy consumption and the indoor air quality is neglected. Finally, alternative ventilation strategies (e.g. supply in the hallways with extraction in each living and service space) are not treated in the standard.

This paper first compares the average airflow rates and indoor contaminants (CO_2, VOC, and relative humidity RH) of three different ventilation strategies (airflow paths) to the current strategy, described in the Belgian standard. Secondly, this paper considers both manual airflow rate control and DCV, including CO_2-detection, H_2O-detection and CO_2H_2O-detection, each with local, zonal and central airflow control. The comparison is based on multi-zone indoor air quality and ventilation simulations.

2 METHOD

The simulation study uses multi-zone airflow and contaminant transport calculation software CONTAM to determine the airflow and contaminant transport (CO_2, VOC, RH) in a reference dwelling. This dwelling, which is based on previous studies performed by BBRI and UGent (Caillou, Heijmans, Laverge, & Janssens, 2014), represents a detached, three-bedroom house with a total living area of 117 m² as shown in Figure 1.

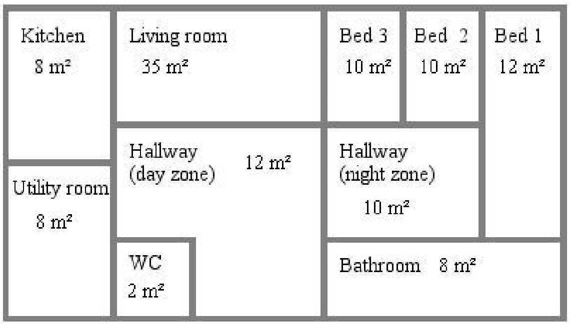

Figure 1: This detached, 3-bedroom house of 117 m² is used in the simulations.

Four occupants, 2 adults and 2 children, occupy the dwelling during the entire day. The fulltime occupancy represents the 'worst case' scenario regarding the production of and exposure to contaminants. The current study uses a fixed occupancy schedule as summarized in Table 1.

Table 1: The 4 occupants are home during the entire day according to this summarized occupancy schedule. This summary shows the total hours spend by an occupant in each room.

	Occupancy [h/day]			
	Adult 1	Adult 2	Child 1	Child 2
Kitchen	0.75	1.08	0.25	0.5
Living room	14.83	8.33	9.58	8.0
Laundry room	0	0.25	0	0
Hallways	0	0.25	0	0
WC	0.25	0.25	0.25	0.25

Bedroom 1	7.58	12.5	0	0
Bedroom 2	0	0.25	13.42	0
Bedroom 3	0	0.25	0	14.5
Bathroom	0.58	0.83	0.5	0.75

The contaminant production in the dwelling depends on the emission rates of the occupants, of the building itself and the activities in the dwelling. Both the occupant's carbon dioxide (CO_2) and water vapour (H_2O) 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
- H_2O awake: 55 g/h
- H_2O asleep: 40 g/h

The source of VOC is proportional to the floor area of each room (fixed emission rate) to represent the material emission in a simplified manner. The VOC sources are only used to compare the different ventilation strategies relatively (no absolute quantification). Both the CO_2 and the VOC sources are modelled using constant coefficients.

The humidity production in the kitchen, bathroom and laundry room depend on the human activities. Following production rates are used accordingly to CEN/TR 14788:2006:

- H_2O kitchen: morning and noon 0.5 l/s (10min); evening 0.6 l/s (10min) + 1 l/s (10 min) + 1.5 l/s (10min).
- H_2O Bathroom: 0.5 l/s per shower (10min)
- Laundry room: 0.06 l/s (12h)

The humidity buffering potential of the walls is taken into account by a "Boundary Layer Diffusion controlled" model (Heijmans, Bossche, & Janssens, 2007), (Caillou, Heijmans, Laverge, & Janssens, 2014).

The supply airflow rate for each room is calculated based on 7 l/s.person (Class II NBN EN 15251) (Bureau voor Normalisatie, 2007) which differs from the approach of airflow rate per m² in the current Belgian standard. The supply and extraction airflow rates are balanced. The building envelope and the internal walls are considered airtight.

The simulation period is reduced to one day in winter using climate data of a mean Belgian winter day, i.e. $T_{outdoor} = 3.6°C$, RH = 86% and $CO_2 = 400$ ppm. The indoor temperature is 20°C. The simulation reporting time is set to each minute, corresponding to the simulation time step.

Four different ventilation strategies are compared in this study (Figure 2):

- Strategy 1: air supply in the living spaces and transfer toward the service spaces (Belgian standard)
- Strategy 2: air supply and extraction in each room.
- Strategy 3: air supply in the hallways and extraction in each room.
- Strategy 4: supply in the night zone (bedrooms), recirculation in the day zone (living room with additional supply of outdoor air) and extraction in the service spaces.

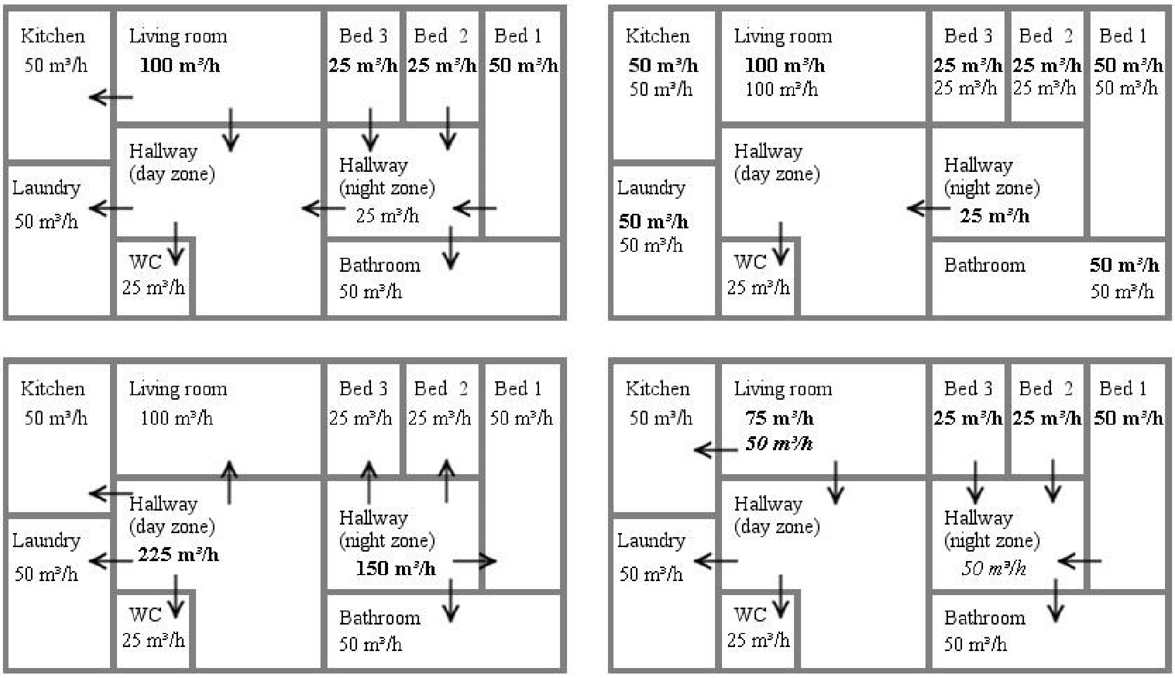

Figure 2: Four different ventilation strategies are compared: strategy 1 (top left), strategy 2 (top right), strategy 3 (bottom left) and strategy 4 (bottom right). Supply rates are indicated in bold, extraction rates in normal, recirculation rates in italic and air tranfers with arrows.

For all four strategies both manual airflow rate control and DCV are simulated. The manual control varies the total flow rate between 100 % and 30 %. The demand control relies on CO_2-detection, H_2O-detection and on both CO_2- and H_2O-detection, each with local, zonal and central airflow control.

3 RESULTS

The simulation results for various parameters are evaluated in MATLAB for a period of an entire day. The evaluated parameters are the occupant exposure to CO_2 and to VOC and the RH in the service spaces (kitchen, bathroom and laundry room).

The occupant exposure to CO_2 [ppm.h] is the cumulative exposure during the entire day to CO_2 concentrations above 1000 ppm (400 ppm outdoor concentration + 600 ppm indoor). The exposure is averaged over the four occupants, representing the total exposure of an average occupant during 1 day. This exposure as a function of the airflow rate for all four ventilation strategies is shown for the manual airflow rate control and for the different DCV methods in Figure 3 (left) and Figure 4.

The occupant exposure to VOC [kg/kg.h] is calculated similarly to the exposure to CO_2 and represents the cumulative exposure to VOC of an average occupant during one day. In this case, no threshold is used. The results in function of the airflow rate are not shown in this paper.

The RH [%h] is determined as the cumulative RH in the kitchen, bathroom and laundry room above 70% during the entire day. The RH as a function of the airflow rate for all four ventilation strategies is presented for both the manual airflow rate control and for the different DCV methods in Figure 3 (right) and Figure 5.

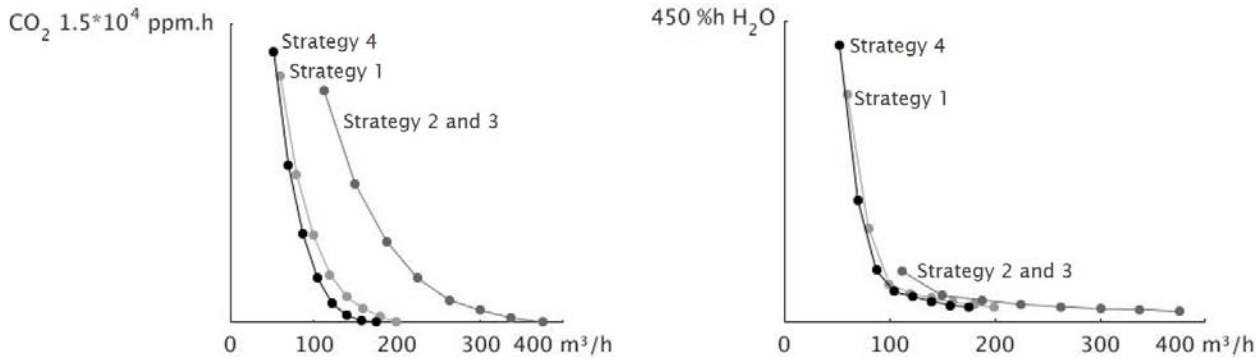

Figure 3: The cumulative occupant exposure to CO2 concentration above 1000 ppm [ppm.h] (left) and the cumulative RH in the service spaces [%h] (right) during an entire day are plotted for the 4 different ventilation strategies using manual airflow control (100 % - 30%) in function of the averaged airflow rates [m^3/h].

4 DISCUSSION

The occupant exposure to CO_2 presented in Figure 3 (left) shows that all four strategies achieve negligible CO_2 exposures above 1000 ppm at the 100 % design flow rate.

Figure 3 (left) also clearly indicates two main groups of manual controlled ventilation strategies, i.e. strategy 1 and 4 versus strategy 2 and 3. The results for strategy 2 and 3 are identical as the flow rate of fresh air supplied to each room is equal. For almost each manual control position, strategy 1 and 4 show similar exposure concentrations to strategy 2 and 3 but with significantly lower airflow rates. Therefore, strategies 1 and 4 are more efficient as they transfer and recirculate the air without significantly influencing the CO_2 concentrations in each room. The potential of significantly reducing flow rates by recycling air (i.e. strategy 4) compared to the classical strategy 1 is largely lost by balancing the design supply and extraction air flow rates.

The DCV results in Figure 4 also show two main groups for each strategy: the H_2O-controlled systems versus the CO_2 and CO_2/H_2O-controlled systems. The latter systems evidently control the CO2-exposure much better. For all strategies the systems with local detection reduce the airflow rate in comparison to the systems with zonal and central detection. The spread of airflow rates in the local, central and zonal controlled systems is more narrow for strategies 1 and 4 in comparison to strategies 2 and 3. For similar exposures, the airflow rates of strategies 1 and 4 are much lower as their design flow rates are approximately twice as low in the first place.

The humidity levels presented in Figure 3 (right) show comparable results for all four strategies at the 100 % design flow rate.

The RH results show no distinct difference between the four strategies in terms of RH for manually controlled airflow rates from 50% up to 100% (Figure 3 (right)). However, the flow rates of strategies 2 and 3 are much higher compared to strategies 1 and 4.

The DCV results show no significant difference between H_2O-, CO_2- and CO_2/H_2O-detection systems in terms of RH levels (Figure 5). Meaning that the CO_2 is the most critical contaminant in the current simulations. However, the H_2O-controlled systems are more efficient using less airflow rate. Similar to the CO_2-exposure results, the locally controlled systems need less flow rate and a wider spread exists in airflow rates for the strategies 2 and 3.

The VOC occupant exposure is not presented in this paper. In a nutshell, the VOC exposure levels increase with decreasing flow rate for all strategies and both the manually controlled as the DCV systems.

In general, the most efficient strategies are 1 and 4, showing comparable results. Even the least efficient DCV methods of these two strategies show similar results to the most efficient DCV methods of strategies 3 and 4. Strategy 1 has important advantages over strategy 4 as the demand control is easier to implement, no recirculation ventilator is needed and no contaminated recirculated air is used. An advantage of strategy 3 is the simplicity of the local demand control in practice. However, central demand control with strategy 1 is as simple.

It is important to note that these findings apply to the current simulation model. More simulations are needed in terms of different occupant schedules and different configuration of dwellings, e.g. small apartment, large family house…

5 CONCLUSIONS

All four strategies achieve negligible CO_2 exposures above 1000 ppm and comparable humidity levels at the 100 % design flow rate. However, the identical design flow rates of strategies 2 and 3 are approximately twice as high compared to strategies 1 and 4. Therefore, strategies 1 and 4 are more efficient as they transfer and recirculate the air without significantly influencing the CO_2 concentrations and humidity levels in each room.

Manuel airflow rate control doesn't always guarantee a good IAQ. Lower airflow rates lead to higher CO_2 exposures and higher humidity levels. The IAQ with manually controlled flow depends largely on the flow rate in normal use and the minimal defined flow rate.

For DCV systems, the CO_2H_2O-detection and CO_2 detection achieve a comparable CO_2 exposures than the 100 % design flow rate but with considerable lower flow rates. The flow rates decrease in respect to central, zonal and local control. However, the H2O-detection leads to a largely higher exposure to CO_2. In terms of humidity levels in the service spaces, all types of detection and control are equally or more effective than the manual control.
A higher potential in flow rate reduction lies with strategies 2 and 3.

In general, from all the ventilation strategies, strategy 1 is the most efficient in terms of contaminant control combined with a relative simple practical implementation.

These results serve as a first step in defining new rules for improved ventilation strategies to accomplish high-energy efficient ventilation accompanied by a good indoor air quality. However, future work is needed on different dwelling configurations and occupancy schedules to generalise these findings.

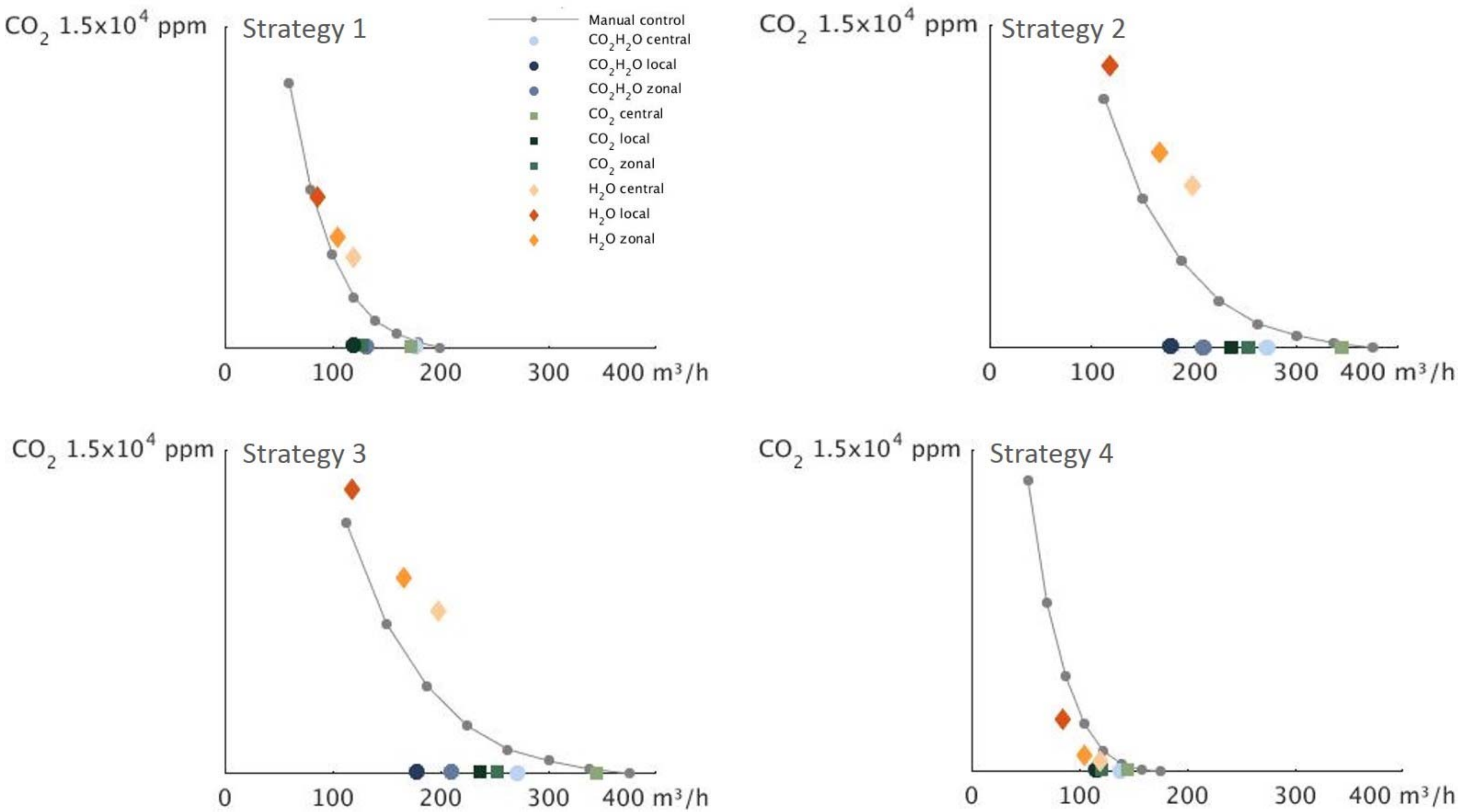

Figure 4: The cumulative occupant exposure to CO_2 values above 1000 ppm for one day [ppm.h] in function of the average airflow rate [m³/h] is shown for the 4 different ventilation strategies. For each strategy, different DCV methods are implemented: CO_2-based, H_2O-based and CO_2/H_2O-based DCV each with local, zonal and central control.

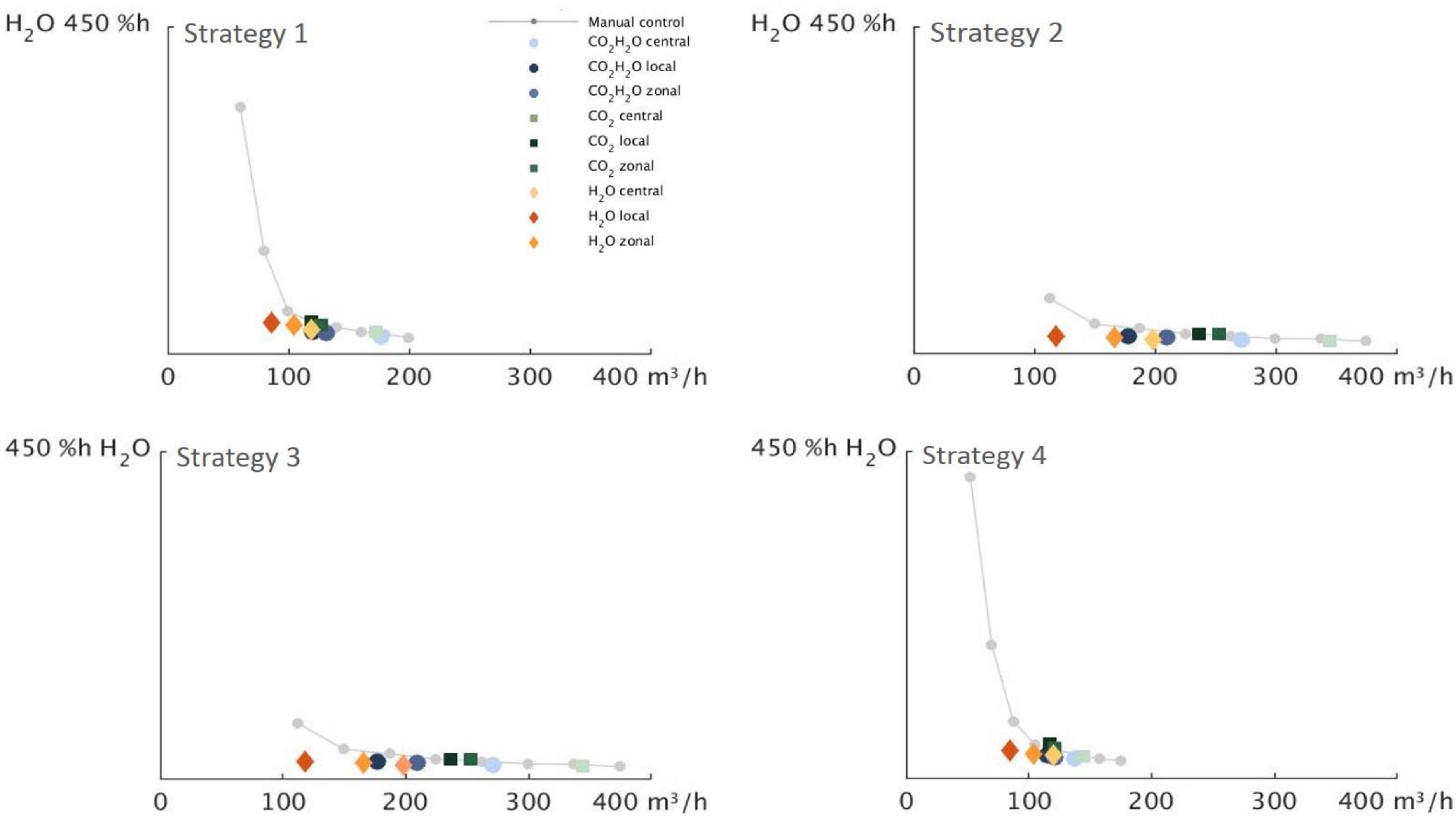

Figure 5: The cumulative RH values above 70% for one day [%h] in function of the average airflow rate [m³/h] are shown for the 4 different ventilation strategies. For each strategy, different DCV methods are implemented: CO_2-based, H_2O-based and CO_2/H_2O-based DCV each with local, zonal and central control.

6 ACKNOWLEDGEMENTS

This paper is based upon work supported by the Federal Public Service Economy (FPS Economy) in Belgium.

7 REFERENCES

Belgisch Instituut voor Normalisatie (BIN). (1991). *NBN D 50-001: Ventilatievoorzieningen in woongebouwen.* Brussel.

Bureau voor Normalisatie. (2007). *NBN EN 15251: Binnenmilieu-gerelateerde inputparameters voor ontwerp en beoordeling van energieprestaties van gebouwen voor de kwaliteit van binnenlucht, het thermisch comfort, de verlichting en akoestiek.*

Caillou, S., Heijmans, N., Laverge, J., & Janssens, A. (2014). *Méthode de calcul PER: Facteurs de réduction pour la ventilation à la demande.*

European Committee for Standardization. (2006). *CEN/TR 14788: Ventilation for buildings, Design and dimensioning of residential ventilation systems.*

Heijmans, N., Bossche, N. V., & Janssens, A. (2007). *Vraaggestuurde draadloze ventilatiesystemen met natuurlijke toevoer voor woongebouwen: berekeningsmethode gelijkwaardigheid.*