A comparison of different ventilation strategies for dwellings in terms of airflow rates and airflow paths.

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SUMMARY

The context of ventilation in Belgian dwellings has changed since the publication of the Belgian standard NBN D 50-001:1991. Due to the higher energy performance of these dwellings, ventilation plays nowadays a more essential role in maintaining a good indoor air quality. Therefore, new rules for improved ventilation strategies are needed to accomplish high energy-efficient ventilation while providing a good indoor air quality. A first step is to compare different ventilation strategies, including strategies that don’t comply with the current standard, in terms of airflow rates and airflow paths. This comparison also includes the influence of demand controlled ventilation. This paper covers a simulation study using multi-zone airflow and contaminant transport calculation software (CONTAM) which compares the performances of the different ventilation strategies in terms of indoor air quality and average airflow rates. The evaluation of the indoor air quality is based on the exposure of the occupants to CO_2 and VOC and on the relative humidity in the rooms. The different ventilation strategies can achieve a comparable indoor air quality, including the strategies not conform to the Belgian standard. However, some strategies require up to twice the airflow rate than others.

PRACTICAL IMPLICATIONS

This work contributes to the development of a new scientific basis for new performance criteria and new design rules for ventilation systems in Belgian dwellings

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 is supplied in the ‘dry’ spaces (living room, bedrooms, office) and transferred towards the ‘wet spaces’ (kitchen, bathroom, toilet, laundry room) where the air is extracted (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 indoor air quality. 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 the ‘dry’ and ‘wet’ spaces), although not explicitly prohibited, are not treated in the standard.

This paper compares, in terms of airflow rates and indoor contaminants, different ventilation strategies (airflow paths), including strategies that don’t comply with the current standard with both manual airflow control and DCV. The comparison is made regarding average airflow rates and indoor contaminants (CO_2, VOC, and relative humidity RH) and based on multi-zone indoor air quality and ventilation simulations.

2 METHODS

The airflow and contaminant transport (CO2, VOC, RH) are simulated in a reference house, implementing four different ventilation strategies. The simulation study uses multi-zone airflow and contaminant transport calculation software CONTAM.

The simulation model consists of a detached, three-bedroom house, based on previous studies performed by BBRI and UGent, with a total living area of 117 m² as shown in Figure 1 (Caillou, Heijmans, Laverge, & Janssens, 2014).

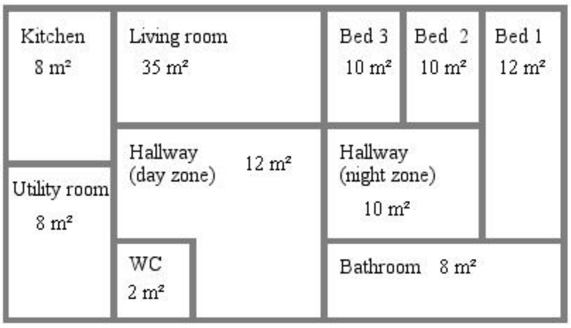

Figure 1: This detached, 3-bedroom house of 117 m² is used in the simulations.

The house is occupied by four persons, 2 adults and 2 children. These four occupants are always at home, representing the ‘worst case’ scenario regarding the production of and exposure to contaminants. This first step in the 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 simulation period is initially 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.

The contaminant production in the house depends on the emission rates of humans, the building itself and the activities in the house. Both the occupant's carbon dioxide (CO_2) and water vapor (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, Van Den Bossche, & Janssens, 2007),
(Caillou et al., 2014).

The airflow rate for each room is calculated based on 7 l/s.person (Class II NBN EN 15251) (Bureau voor Normalisatie, 2007). The building envelope and the internal walls are considered airtight.

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

- Strategy 1: air supply in the 'dry' spaces and transfer toward the 'wet' spaces (200 m³/h).
- Strategy 2: air supply and extraction in each room (375 m³/h)
- Strategy 3: air supply in the hallways and extraction in each room (375 m³/h).
- Strategy 4: supply in the night zone (bedrooms), recirculation in the day zone (living room with additional supply of outdoor air if necessary) and extraction in the 'wet' spaces (175 m³/h).

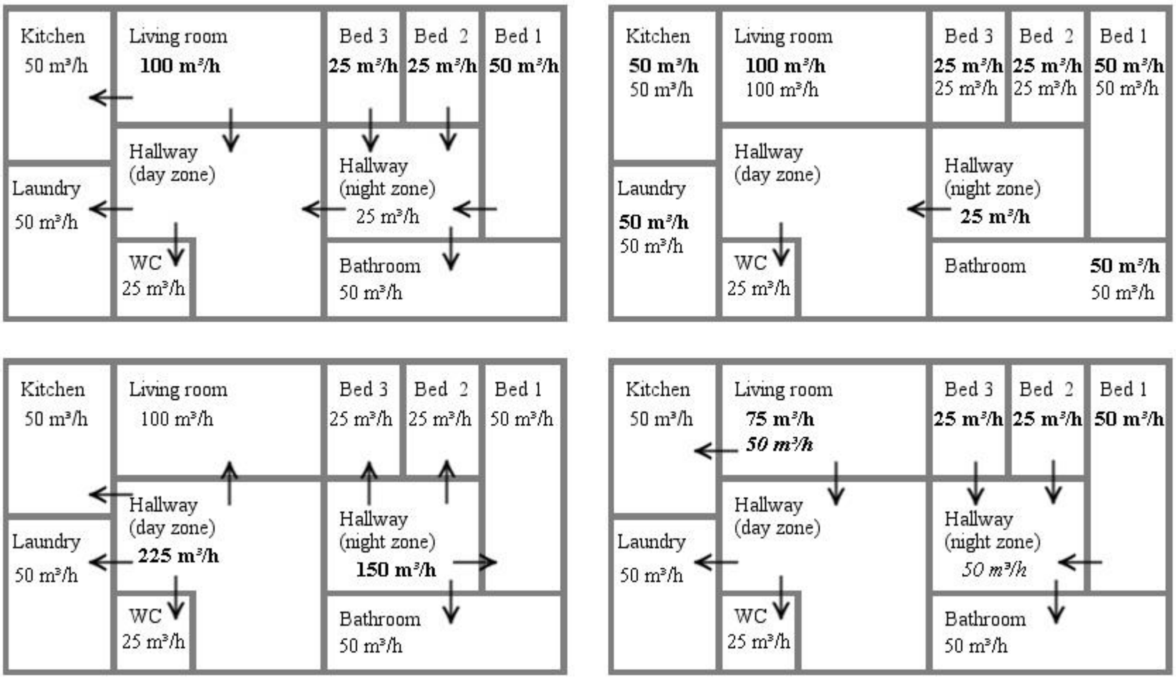

Figure 2: Four different ventilation strategies are compared: strategy 1 (top left), strategy 2 (top right), strategy 3 (bottom left) and strategy 4 (bottom right). Supply rates are indicated in bold, extraction rates in normal, recirculation rates in italic and air transfers with arrows.

For all four strategies both manual flow rate control and DCV are simulated. The manual control varies the total flow rate between 100% and 10%. The demand control relies on CO_2-detection, H_2O-detection and on both CO_2- and H_2O-detection with each 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 exposure of the occupants to CO_2 and VOC and the RH in wet 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. In other words the result is 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 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 control and for the different DCV methods in Figure 3 (right) and Figure 5.

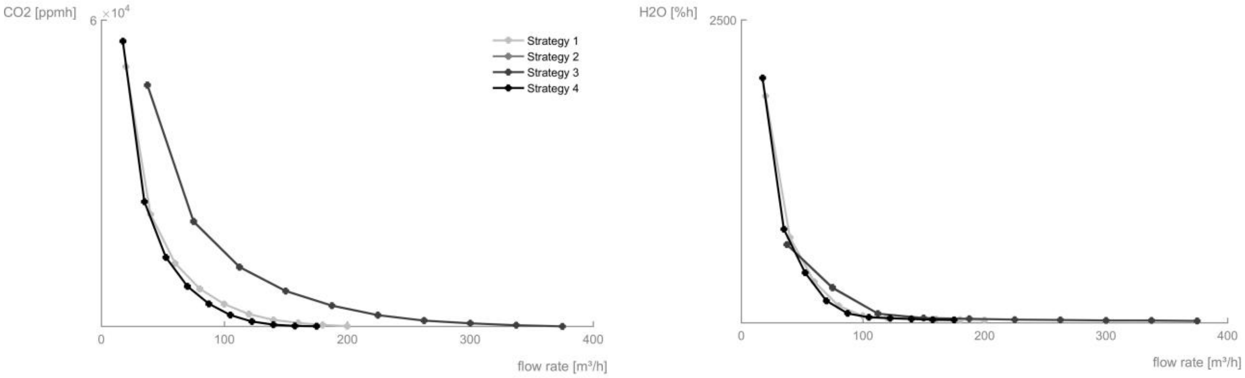

Figure 3: The cumulative occupant exposure to CO2 concentration above 1000 ppm [ppm.h] (left) and the cumulative RH in the wet spaces [%h] (right) during an entire day are plotted for the 4 different ventilation strategies using manual airflow control (10%-100%) in function of the averaged airflow rates [m^3/h].

4 DISCUSSION

The occupant exposure to CO_2 presented in Figure 3 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 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, the airflow rate is reduced 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 first of all about twice as low.

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). 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-controlled 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 with 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

This paper compared different ventilation strategies, including strategies that don't comply with the current Belgian standard. This comparison uses multi-zone airflow and contaminant transport simulations to obtain occupant exposure levels to CO_2 and VOC and the RH levels in the kitchen, bathroom and laundry room.

In general, all DCV systems are significantly more efficient compared to the manual controlled systems in terms of the supplied airflow rate for similar CO_2 exposures and RH levels for all four ventilation strategies.

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.

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6 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 energieprestatie 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., Van Den Bossche, N., & Janssens, A. (2007). *Vraaggestuurde draadloze ventilatiesystemen met natuurlijke toevoer voor woongebouwen: berekeningsmethode gelijkwaardigheid*.

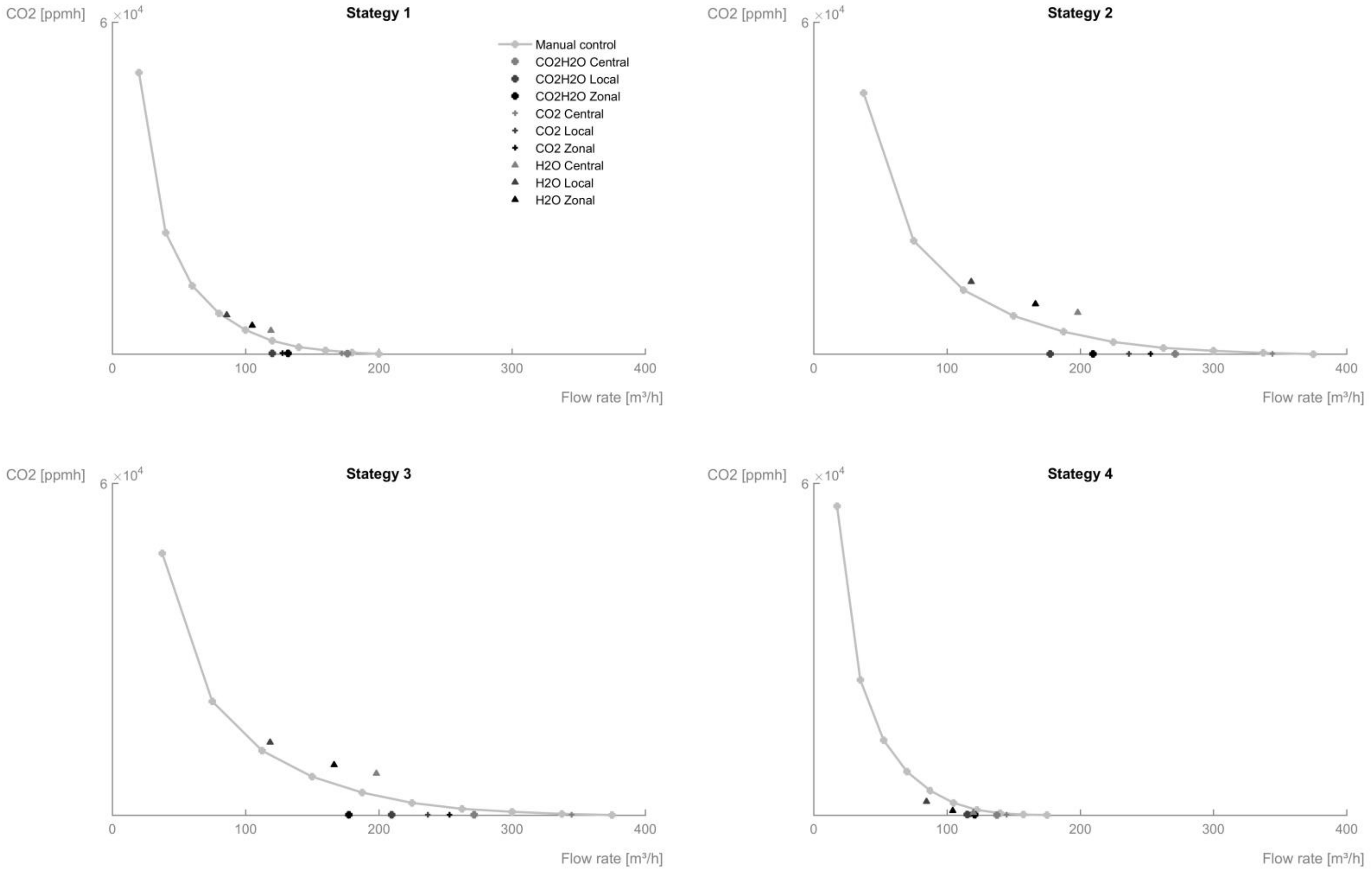

Figure 4: The cumulative occupant exposure to CO_2 values above 1000 ppm for one day [ppm.h] in function of the average airflow rate [m^3/h] is shown for the 4 different ventilation strategies. For each strategy, different DCV methods are implemented: CO_2-based, H_2O-based and CO_2/H_2O-based DCV each with local, central and zonal control.

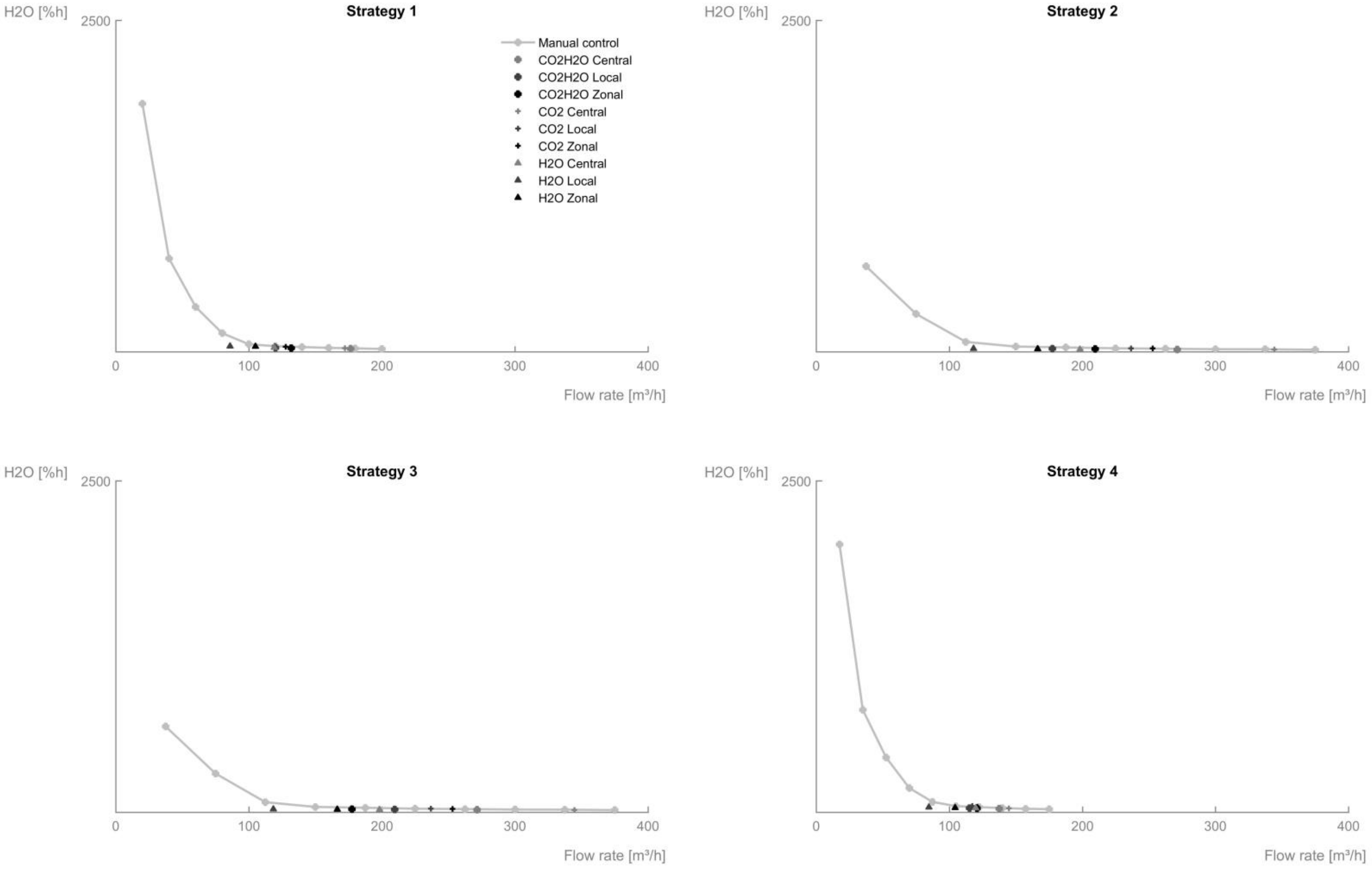

Figure 5: The cumulative RH values above 70% for one day [%h] in function of the average airflow rate [m³/h] are shown for the 4 different ventilation strategies. For each strategy, different DCV methods are implemented: CO_2-based, H_2O-based and CO_2/H_2O-based DCV each with local, central and zonal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