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Cloud based large-scale performance analysis of a smart residential MEV system

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This study is a first large-scale analysis of the performance of a cloud connected and smart residential mechanical extract ventilation (MEV) system based on field data. About 350 units were analysed over a period of 4 months from December 2018 up to March 2019, corresponding with the main winter period in Belgium. Half of the units were installed as a smartzone system which means additional mechanical extraction from habitable rooms as bedrooms. The air extraction was controlled on different parameters (humidity, CO_2 and VOC) depending on the room type. Indoor climate and IAQ were analysed with respect to design criteria set out in standards as well as fan characteristics and energy consumptions. Since rooms are often unoccupied or occupied at a low level, advanced demand control technology proves to have a high potential to limit total energy consumption, while assuring a good IAQ. These findings should also be reflected within the European ventilation legislation, such as Ecodesign.

Keywords: Smart connected ventilation, demand controlled MEV, large-scale in-situ monitoring, IAQ, energy consumption

Ventilation is a quite complex process whose quality is affected by many parameters related to the manufacturing, design, installation, use and maintenance of the system over its life cycle. Up to now, the design of ventilation is usually descriptive in its approach and the performance is often theoretically analysed under ideal conditions. As a consequence, some of the aforementioned aspects are not taken into account. During recent years, however, several ventilation field studies in the residential sector were carried out due to the availability of affordable and/or plug-and-play monitoring apparatus (see overview by De Maré et al., 2019). Nowadays, IoT devices become also available in the residential ventilation industry, allowing to investigate the real performance of these ventilation units during their lifetime on a large scale. This study is a first global analysis and part of a large research programme to investigate over time the occurring indoor air quality in the main rooms and the overall fan characteristics of a connected demand controlled central mechanical extract ventilation (DC MEV) unit. In the study mainly the performance of units without air extraction in the bedrooms (no-smartzone) and with air extraction in the bedrooms (smartzone) was compared under Belgian winter conditions.

Methodology of the Ventilation system analysis

From 2018 on, commercially available "smart" DC MEV (so-called Healthbox 3.0) systems with cloud connection possibility were installed in Belgian houses and residential buildings (see **Figure 1**). The mechanical extraction took place locally in the wet rooms and in about half of the dwellings also directly from the bedrooms. The system with bedroom extraction is hence forward called "with smartzone", and without extraction from the bedroom "no smartzone", as illustrated in **Figure 1**.

The outdoor air was supplied through passive vents placed on top of the windows in the habitable rooms (**Figure 1**). These passive vents are pressure controlled and can additionally be gradually adjusted by the inhabitants between fully open and closed. By means of valves directly attached to the central unit at the end of the extract duct, the air extraction was locally controlled on different parameters depending on the room type: in bathroom and utility room on absolute and relative humidity (AH and RH); in kitchen and bedroom (if extraction available) on CO_2 and in toilets on volatile organic compounds (VOC). Sensors were located at the valves and not within the rooms, which means that sensor values could -to a certain extent- deviate from the room conditions.

In this study during the typical Belgian heating period from December 2018 up to March 2019 (temperate maritime climate), the performance of a fixed number of about 350 devices divided over no-smartzone and smartzone types was investigated. The ventilation units were installed without extra commissioning afterwards to correct or improve the performance of the system. The large-scale cloud data were not filtered on false values or outliers.

Different characteristics of the climate and the system were analysed: indoor comfort (CO_2, humidity), fan characteristics (average and nominal airflow, time fraction minimal airflow rate, average pressure and power input) and total energy consumption. Design values of RH and CO_2 concentration as especially specified in the standard EN 16798-1 (2019) (replaces the EN 15251 standard) were used as criteria to analyse the indoor comfort. Comfort analysis of bedrooms on a large-scale could only take place when direct mechanical extraction with sensor control was present (with smartzone), since sensors were located at the extract valves. For the data analysis, active ventilation was defined as ventilation at flow rates higher than the minimum control values.

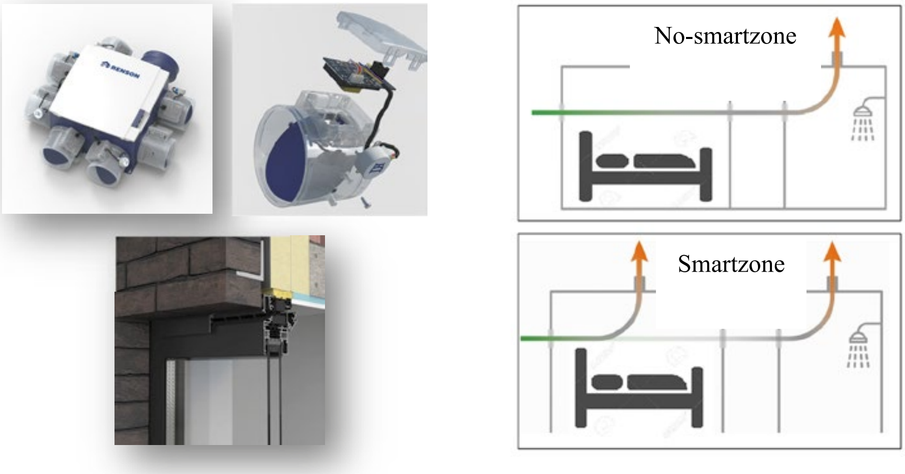

Figure 1. DC MEV system (above-left), passive vents (below-left) and the difference between no-smartzone and smartzone principle (right).

Results

Humidity

Figure 2 illustrates the mean time fraction of RH < 80%, 30% < RH < 70% and 25% < RH < 60% in different rooms (kitchen, bathroom, laundry and bedroom) over the 4 months considered. In the different rooms considered the RH values higher than 80% were very limited. The lowest occurrence was found in the kitchen, the highest in the bathroom where water vapour productions are usually highest. Lower peaks in the kitchen can be due to a quasi-permanent heating, the mostly open connection with the (dry) living room and the standard availability of a separate cooker hood to extract water vapour. For the several rooms considered, the average time fraction with RH values <80% was at least 97.5%, as found in the bathroom.

The mean time fraction of RH between 30 to 70% was close to 90% for the different rooms, with the highest and the lowest time fraction in the kitchen and the bathroom, respectively. This latter logically agrees with the previous findings on RH >80%.

When looking to the average time fraction of RH between 25 and 60% in **Figure 2**, more variation was found between the rooms, with a minimum of 80%. The lowest value was also reported in the bathroom where the highest water vapour productions can be expected. In addition, Lokere (2019) found a negligible risk on mould growth in the different rooms. Newly built houses are well insulated without thermal bridges to prevent condensation.

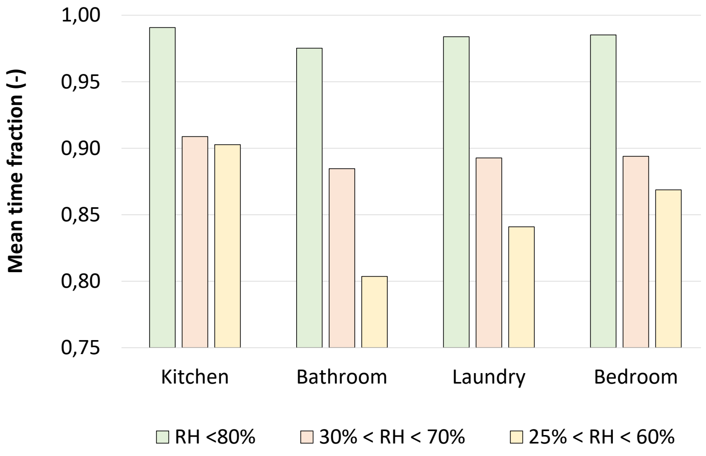

Figure 2. Mean time fraction of RH<80%, 30%<RH<70% and 25%<RH<60% in different rooms.

CO_2 concentration

The IAQ was analysed based on CO_2 categories defined in the EN 16798-1 standard for habitable rooms as (mainly open) kitchen and bedroom, as illustrated in **Figure 3**. Data for the kitchen were derived as an average from systems without and with smartzone, whereas bedroom results concerned only smartzone systems. The data were selected on two different bases: day or night time and during active ventilation (when airflow rate in the room is higher than minimum, corresponding best with the unknown occupancy period). Substantial differences occur between these selections.

In the bedroom, the CO_2 levels belong 80 to 90% of the night-time to category 1 or 2 (< 950 ppm), with a main fraction in category 1 (< 800 ppm). In 90% of the bedrooms with extraction, the CO_2 level was <1,200 ppm during at least 95% of the night-time. When considering only active ventilation (during occupancy) this percentage varied between 70 and 80%, with a dominant group in category 2 and only about 20% in category 1. Comparing the results during night-time and active ventilation points at that approximately half of the night, ventilation is at its minimum flow rate (< 800 ppm) due to no occupancy, low occupancy and deep sleep with CO_2 levels lower than 800 ppm. When considering the total daytime instead of the night-time, the smartzone system also worked on its minimum flow rate during half of the time (see **Figure** 4). For bedrooms, the mean time fraction with CO_2 levels in category 3 (moderate IAQ < 1350 ppm) and 4 (bad IAQ >1350 ppm) were limited to respectively 30% and 5% of the time during active ventilation. This means that the extract capacity of 30 m^3/h in bedrooms can be considered as a minimum design value. Van Holsteijn and Li (2014) reported in the Monicair study similar results with a fraction of at most 1 hr or 10% of the night time that CO_2 concentrations were higher than 1,200 ppm.

The IAQ in the kitchen was analysed during daytime and active ventilation based on the CO_2 categories as illustrated on the right part of **Figure 3**. The IAQ belongs nearly permanently to category 1 and 2 (< 1200 ppm). The difference with the findings in the bedroom can be explained by the shorter occupancy period, the larger room volume of the open kitchen, the presence of a cooker hood and the CO_2 categories according to the EN16798-1 that are less severe in kitchens than in bedrooms. During active ventilation the time percentages with CO_2 levels lower than 800 ppm and between 800-950 ppm were slightly higher than in the bedroom, due to less severe conditions in the kitchen.

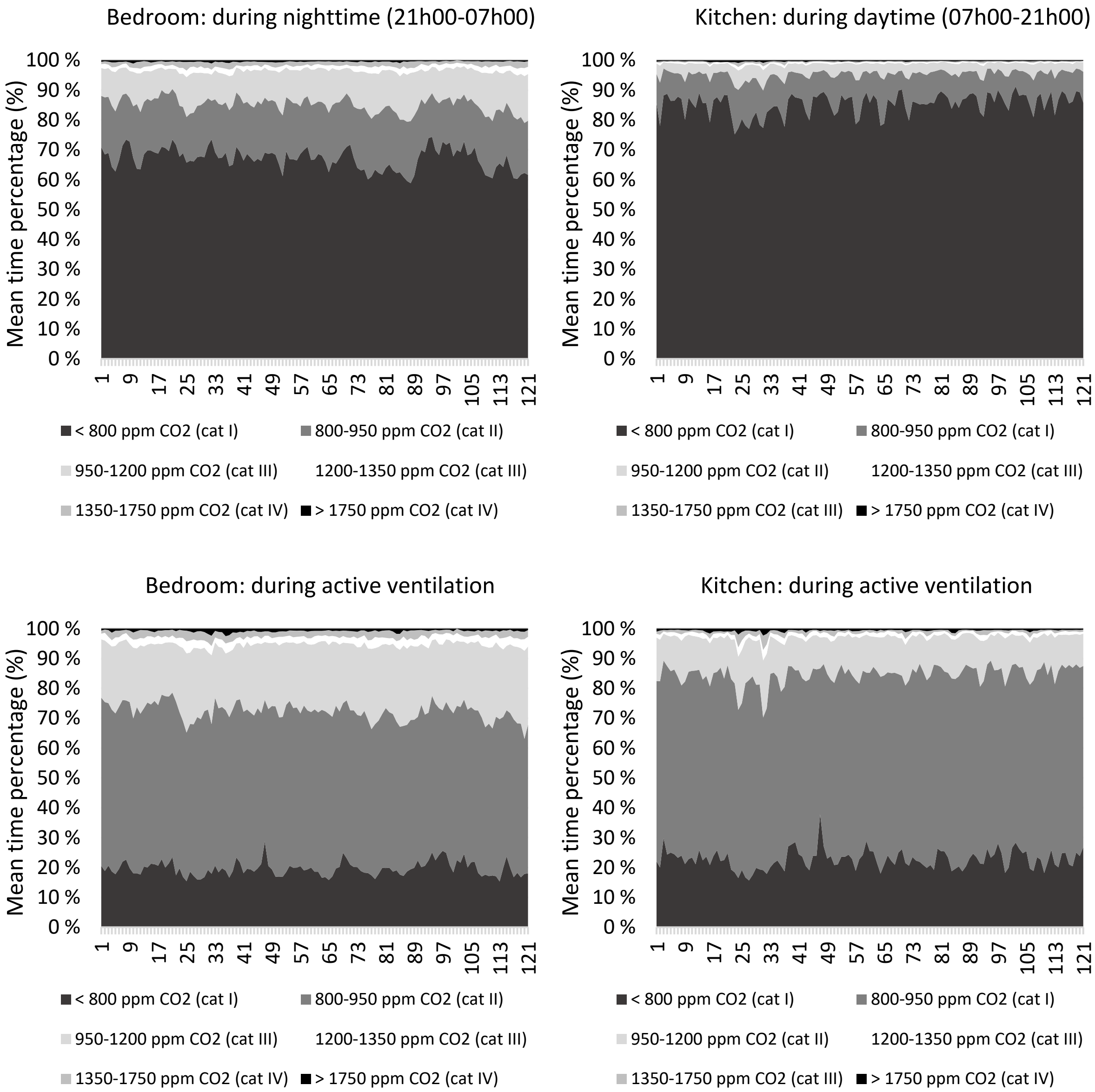

Figure 3. Mean daily time percentage of CO2-categories according to the EN16798-1 standard for bedroom (left) and open kitchen (right) during day or nighttime (above) and during active ventilation (below).

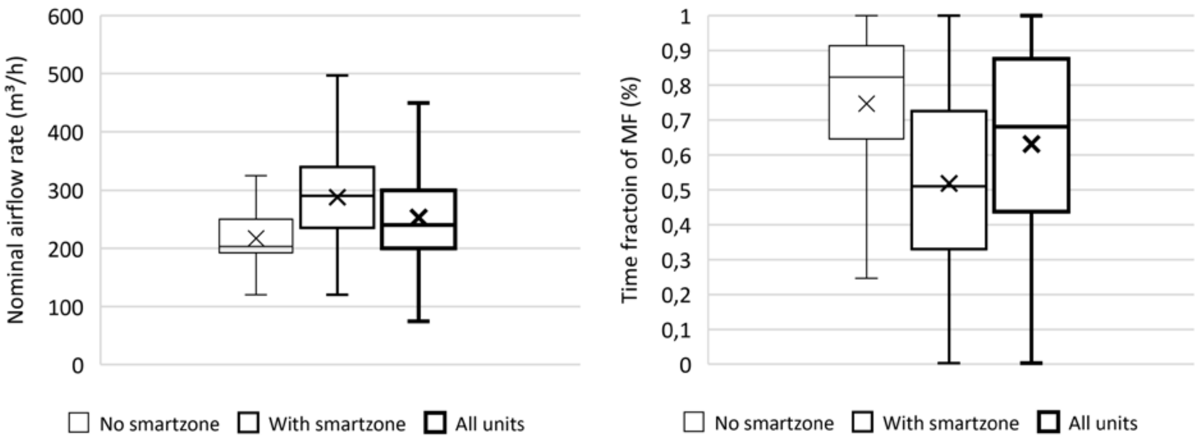

Figure 4. Nominal airflow rate (left) and the average time fraction of minimal ventilation MF (right) of the units.

When looking over the wintertime period a constant trend containing some fluctuations was observed, which can be caused by user behaviour (difference between week and weekend days) and wind conditions.

Furthermore, the exposure to CO_2 expressed as the cumulative CO_2-concentration above 1200 ppm (in ppmh) was calculated, since this is a commonly used parameter in IAQ research. The average daily exposure over the dwellings was 245 ppmh/day which is only 33% of the 733 ppmh/day reported by van Holsteijn and Li (2014). This big difference can be explained by the lower control setpoint of 950 ppm instead of 1200 ppm.

Since large-scale data of the IAQ in bedrooms without direct extraction is not available, some dwellings without smartzone were monitored separately. It was found that many elements have an impact on the IAQ in the bedrooms, such as size of the supply opening, position of the door, occupancy level and wind direction. As a consequence, CO_2 levels can vary between very good (< 1000 ppm) and very bad (>2000 ppm). In general, omitting direct extraction from the bedroom gave rise to maximum CO_2 level in the parent bedroom belonging to category 4 (>1350 ppm).

Fan characteristics and energy consumption

The fan characteristics and the energy consumption were analysed by comparing no-smartzone and smartzone systems. The average values over the 4 months period of several parameters of the connected units were set out as a box plot in **Figure 4 to 6** (daily average in case of time fraction of minimal flow rate MF).

When analysing the time fraction of minimum airflow rate MF over the entire box (= none of the valves is activated), the daily average time fraction is about 75

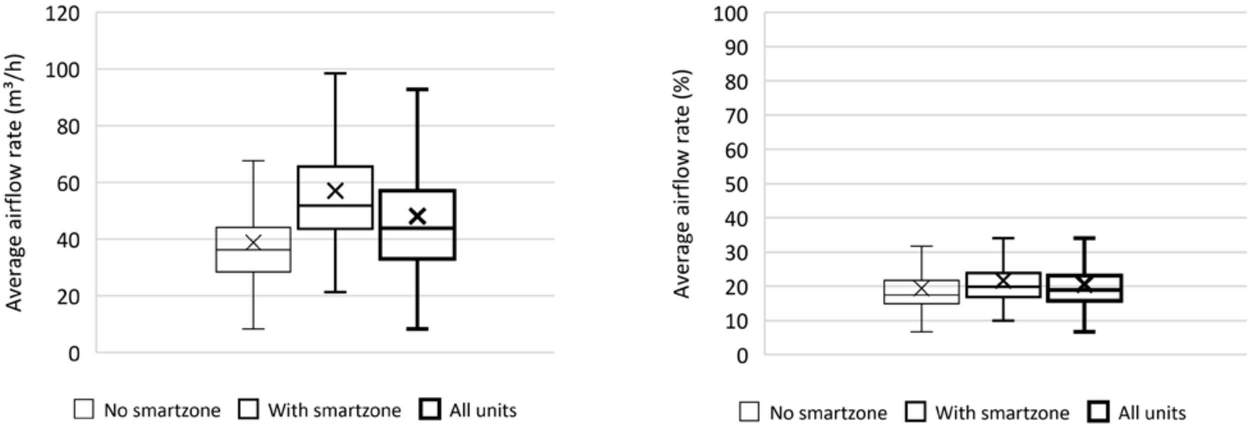

Figure 5. Average airflow rate of the units expressed as "m^3/h" (left) and "%" (right).

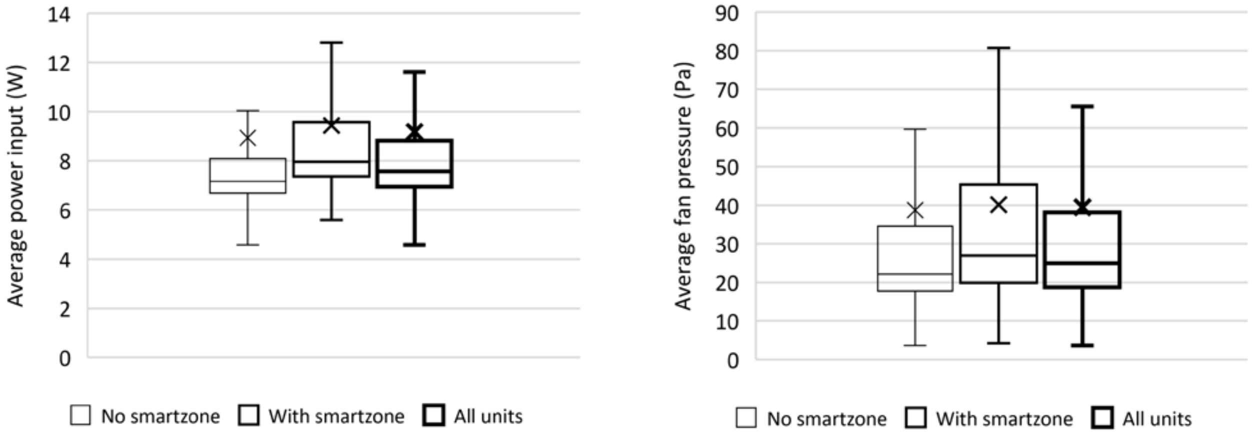

Figure 6. Average power input (left) and average fan pressure of the units (right).

and 50% for the no-smartzone and smartzone system. The high fractions of both systems proved already the huge potential of demand controlled ventilation to save energy. When comparing no-smartzone with smartzone systems, on average 25% of the time or six hours/day, the smartzone system is activated in at least one of the bedrooms to guarantee IAQ. The spread in time fraction is quite large indicating that substantial differences occur over time and between the units. The relation of this MF time fraction with the period of non-occupancy could be further investigated.

The average extract airflow rate of 57.1 m³/h of the smartzone systems was about 50% higher than the value of 38.8 m³/h for no-smartzone systems, however, the IAQ realised with the smartzone system was also better. This was clearly due to the higher installed nominal airflow capacity via the additional extraction points and the higher mean ventilation levels in bedrooms than in wet rooms.

The mean nominal airflow rate (= ventilation capacity) of 288 m³/h of smartzone systems was on average about 32% higher than the value of 218 m³/h of no-smartzone systems.

Compared to the study of van Holsteijn and Li (2014) who found an average extract rate of 76.9 m³/h for a similar ventilation system with smartzone (C4c), the cloud data average extract rate is 26% lower. This is quite remarkable since the MEV system studied controlled the air on a lower setpoint of 950 ppm instead of 1,200 ppm in the habitable rooms. Nominal airflow rates of both ventilation systems were also comparable.

The airflow rate expressed as a fraction of the installed nominal capacity, the so-called reduction or ctrl-factor was about 0.20 in case of smartzone systems. Usually, the ctrl-factor is expressed to the nominal airflow rate of systems with no smartzone. In that case the ctrlfactor of the smartzone systems becomes 0.26, neglecting a small fraction of cross ventilation. In the Belgian (EPB), Dutch (NTA 8800) and European (EN 13142) regulation, the default ctrl-factor for MEV systems with local control and detection in all rooms is substantially higher with values of 0.43, 0.55 and 0.50, respectively. In case of the no-smartzone system, the ctrl-factor cannot be determined since the assumption of equal IAQ is not guaranteed for the bedrooms under the monitored airflow rates.

When looking at all the boxes, the mean operating pressure of the fan was respectively 38.9 and 40.1 Pa for the no-smartzone and smartzone systems (maximum pressure level of the unit is 350 Pa). Median pressure values, however, were substantially lower. Also, the average power input of no-smartzone and smartzone systems was quite similar with values of 9.0 and 9.4 W, respectively, including the power consumption due to electronics and sensors (maximum power input of the unit is 85 W at 400 m³/h and 200 Pa). These average values were about 1.5 W higher than the median values, pointing out that the design or installation of some units was not optimal, giving rise to higher mean electricity consumptions. The small difference between no-smartzone and smartzone systems was realized by means of smart fan and valve control. The required auxiliary energy per unit of airflow rate of the unit, the so-called specific power index SPI as defined in the standard EN 13142, was equal to nearly 0.23 and 0.16 Wh/m³ for the no-smartzone and smartzone respectively.

Extrapolating the average power input to an entire year, resulted in a yearly auxiliary consumption of the extract system of about 79 kWh and 82 kWh for no-smartzone and smartzone systems, corresponding to a total electricity cost of about 20 € in case of an electricity price of 0.25 €/kWh. Van Holsteijn and Li (2014) and Derycke et al. (2018) found an electricity consumption of more than twice that high for similar systems with also extraction from the habitable rooms, i.e. 187 and 186 kWh, respectively. The substantial lower energy consumption in this study is due to a recent optimisation of the MEV system at the hardware- and software-level and probably due to a lower overall occupancy level and a larger dataset.

The C4a system without smartzone and without local control in the wet rooms, as investigated by van Holsteijn and Li (2014) showed a lower yearly auxiliary consumption of 50 kWh and a higher average airflow rate of 95 m³/h compared to the no-smartzone system investigated. The CO_2-exposures in case of C4a, however, were considerably higher.

The average ventilation heat losses could be estimated based on a mean measured indoor air temperature of 21°C, a mean outdoor temperature of 6°C over a six-month heating period from November up to April in Belgium and a 85% efficiency of the heating system, approaching 5350 MJ for a smartzone system. These ventilation heating losses are 32% lower than the value of 7874 MJ reported by van Holsteijn and Li (2014) for a similar heating season. Assuming a gas price of 0.05 €/kWh, the yearly average heating cost for ventilation with the smartzone MEV system is about 75 €. Additional cross ventilation through passive vents can to some extent increase that heating cost. It can be stated that in many cases the total yearly energy cost related to the operation of the smartzone ventilation system (heating and auxiliary energy) will be limited to 100 €.

Within the Ecodesign framework and its requirement to provide consumers with accurate information regarding energy consumption, it is relevant to compare the smartzone MEV-results with a MVHR system. Ecodesign and its labelling scheme must allow consumers to identify how energy efficient a product actually is and to assess a product's potential to reduce energy costs. In order to make this comparison, the following assumptions were made for the balanced MVHR system:

- The real average airflow rate is 125 m³/h which equals half of the mean nominal airflow rate system of 250 m³/h over all the units (cf. **Figure** 4).
- This average airflow rate, which varies between a minimum and a maximum value, is assumed to assure an adequate IAQ in case of no zone controlled systems.
- The overall efficiency of the heat recovery unit in-situ is 60% taking into account real circumstances such as leakages, defrosting, unbalance, pollution, usability of recovered heat, … This lower recovery efficiency in practice compared with laboratory measurements is justified by studies as Merzkirch et al. (2015), Faes et al. (2017) and Knoll et al. (2018).

Under these assumptions the ventilation heat losses are about 4,700 MJ or nearly 12% lower than the MEV system with smartzone. The similar heat losses of both the MVHR and the smartzone system are comprehensible since the mean ctrl-factor of 0.26 of the MEV system corresponds with a virtual heat saving efficiency of 74%. Besides, the real electricity consumption of a MVHR system will be at least four times higher due to the presence of two fans and the much higher pressure losses in the unit caused by filtering and heat recovery (Derycke et al., 2018). As a consequence, since electricity is at least three to four times more expensive than gas, the mean yearly energy cost of a MVHR system will not be lower than that of the MEV with smartzone.

Conclusions

Cloud connected ventilation systems combined with data analysis allows to investigate their performance on a large-scale. Due to technological and digital evolutions MEV systems with smartzone combined with natural supply are able to guarantee IAQ in every room and perform energetically equally or better than MVHR systems in countries with a mean winter temperature not lower than freezing point. These real performance data should also be reflected in the Ecodesign calculation and labelling to limit the gap between what is promised and the final reality. ■

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