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Performance Analysis of the Maximal Used Extract Ventilation Capacity of Dwellings During the Heating Season

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ABSTRACT

The design heat load of buildings is composed of maximal heat losses via ventilation, infiltration and transmission. Ventilation control possibilities can have an impact on these maximal simultaneous ventilation losses. An automated zonally and locally controlled residential mechanical extract ventilation system (rVST) was investigated with respect to the maximal occurring total extract rate during the heating period. The analysis was performed based on big field and simulated data of a smart connected ventilation system. In that way, a reduction factor F(capacity) could be deduced that represents the maximal used fraction of the nominal installed ventilation capacity during the heating period. This reduction factor was elaborated as a function of a moving average value and percentiles, which corresponds with a negligeable chance that the maximal total extract rate is passed during the coldest winter day. Two statistical approaches when analysing the field data were compared. The reduction factor derived from simulated data corresponded very well with the field data in case of the zonal rVST. Values down to 50% were found, depending on the moving average and the percentile considered. For the local rVST, differences in reduction factor were significant between simulations and practice, due to a more complex and variable system to model. The reduction factor of the local compared to the zonal rVST is on average and relatively 14% and 28% lower, based on respectively field data (analysis 2) and simulation data. The installed ventilation capacity, however, in case of the local rVST is about 40% higher.

INTRODUCTION

This paper deals with the possible impact of demand control (DC) of residential ventilation systems (rVST's) on the required heating capacity (kW) of the building. Building heating systems are designed according to the standard NBN EN 12831-1:2017 "Energy performance of buildings – Method for calculation of the design heat load" and the corresponding national annex, for instance the NBN EN 12831-1 ANB:2020 in case of Belgium. The European standard describes the calculation methodology. The national annex describes the national and local variables that may be applied within the European

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methodology.

When the ventilation flow rate is controlled locally or zonally according to the demand, the maximal simultaneous flow rate may be lower than the total design flow rate (m³/h) generally used in the national annexes. However, an airflow control according to the needs and its impact on the maximal ventilation losses, is not recognized in the European standard or the Belgian annex. In the Netherlands, automated DC on a rVST allows to reduce the installed total airflow rate to 70% of its nominal capacity (Bouwbesluit 2012). As a consequence, this reduction factor of 70% can also be applied to the design heat load calculation in case of a DC rVST.

A large scale analysis of different characteristics of the climate and the properties of a DC residential MEV system was reported already in literature (De Maré et al. 2019). In this study, the maximal flow rate is investigated for the zonally and locally controlled configuration of the same DC MEV system, through analysis of field and simulated big data of the system. From this maximal flow rate, a reduction factor on the installed nominal capacity can be deduced, which can be used to calculate the maximal heat losses in case of DC ventilation. The reduction factor is applicable to design the total power of the heat production unit, but not of the local heating elements in the room. On room level, the total installed ventilation capacity is used from time to time and as a consequence, a reduction on this ventilation capacity to reduce the power of the heat exchange elements is not allowed. The objective of this study is to determine to which extent DC has an impact on the maximal ventilation losses and in that way on the required heating capacity of dwellings.

METHODOLOGY

Ventilation systems

From 2018 onwards, commercially available demand controlled MEV (so-called Healthbox 3.0) systems with cloud connection possibility were installed in Belgian houses and residential buildings (see Fig. 1). The cloud connection allowed to monitor and analyse the characteristics of these smart central exhaust units on a large scale. The mechanical extraction took either (1) only place in the wet rooms, so-called zonal, or (2) in the habitable and the wet rooms, so-called local, as illustrated in Figure 1.

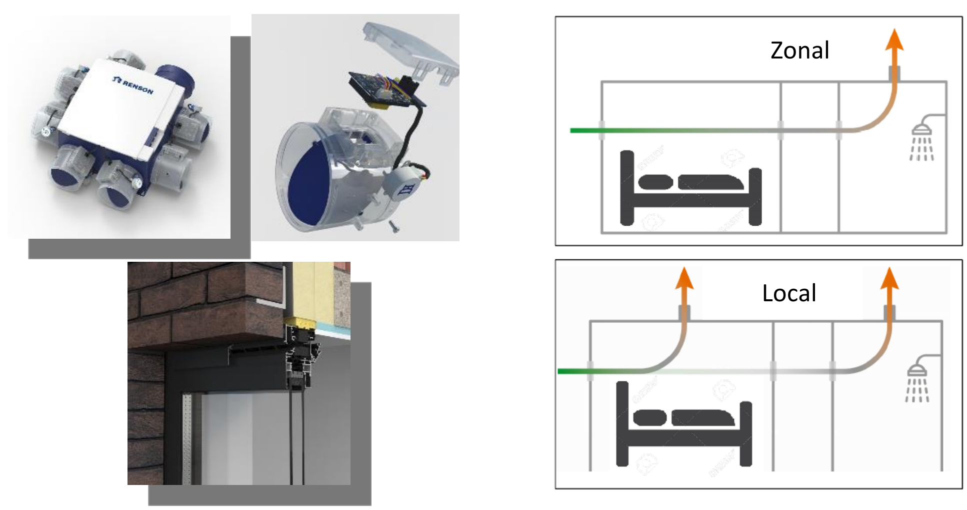


Figure 1 DC MEV system (above-left), passive vents (below-left) and the difference between zonally and locally controlled extraction (right).

The outdoor air was supplied through passive vents placed on top of the windows in the habitable rooms (Fig. 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.

The following standard control algorithms were implemented in the system to regulate the extract airflow rate between a minimum and the required ventilation capacity of the room according to the Belgian regulations (these nominal flow rates are for open kitchen: 75 m³/h; bathroom, closed kitchen and laundry: 50 m³/h; toilet: 25 m³/h; bedroom: 30 m³/h):

- CO_2: in kitchen and habitable rooms with extraction, proportional between 800 – 950 ppm CO_2
- Humidity: in bathroom and laundry, step function as function of a gradient $\Delta AH/\Delta t$ and a RH setpoint
- VOC: in toilets, step function as function of a gradient $\Delta VOC/\Delta t$ setpoint

By means of an app on his/her mobile phone the user could to some extent adjust the control settings if needed or temporarily overrule the automated extraction. Changing of the standard settings (airflow or controle setpoint) thresh by the user or installer was rarely done, since only allowed in existing buildings, while most units were installed in newly built dwellings. Data during overruling of the automated control were ignored in the analysis.

In Flanders (northern half of Belgium) where most of the ventilation units were installed, the newly built housing stock is quite evenly distributed over single-family SF and multi-family MF dwellings (VEA, 2019), with an increasing shift towards multi-family dwellings. Presently, the cloud data from the Healthbox 3.0 could not be sorted on SF and MF dwellings. The kitchen is usually open to the living room, since the share of closed kitchens is at most 5% and 2% in respectively SF and MF newly built houses. In case of an open kitchen, the IAQ in the living room can be controlled by the extraction in the open kitchen, reducing in that way the number of extract valves in the habitable rooms when applying locally extraction. Based on data of VEA (2019), the average air tightness n_{50} of the studied houses peaked between 1.5 and 2.0 volumes/h.

Indoor air quality

The assessment of the indoor air quality IAQ is not required for a design heat load calculation. As long as the rVST complies to the national ventilation regulation, the occurring IAQ is supposed to be acceptable. In this study, however, the IAQ of both zonal and local rVST's was modelled and compared with a constant MEV as reference. Big field data of IAQ was also analysed on the local rVST by De Maré et al. (2019). The IAQ was analysed in the simulation study with respect to the overall cumulative exposure to CO_2 (in kppm.h) of the inhabitants over the heating period, with a threshold of 950 ppm. The cumulative exposure to CO_2 is a commonly used metric in IAQ research.

Determination of the reduction factor

According to the NBN EN 12831-1 ANB:2020, the external design temperature θ_e is the minimum daily average outdoor temperature with a return period of 1 year. Under Belgian climate conditions, this external design temperature varies between -6 and -11°C depending on the location. The mechanical extract rate was considered instead of the natural supply rate, since this latter is unknown in the field monitoring. As a consequence, non fan driven extraction via vents (= cross ventilation) was not taken into account in this analysis. In/exfiltration via leakages was also not considered.

The reduction factor, called F(capacity), on the maximal ventilation losses (in kW) in case of DC ventilation is derived from the maximal occurring airflow rate relative to the total installed extract rate (= nominal ventilation capacity). Several elements are of importance when determining this reduction factor: (1) the moving average of the total mechanical extract rate (2), the percentile value of the reduction factor derived from this moving average and (3) the chance of concurrency of the external design temperature and the maximal airflow rate.

Since a heating system doesn't react on the instantaneous airflow rate, a moving average of the time series extract flow rates was calculated to smooth out short-term fluctuations on a 2 hrs, 8 hrs and daily basis. A daily basis was also chosen analogously with the external design temperature, however, a 2 or 8 hrs moving average on the ventilation rate is a more realistic value to take into account in the calculation of the power of the heating system, keeping in mind the heat capacity of the building structure itself.

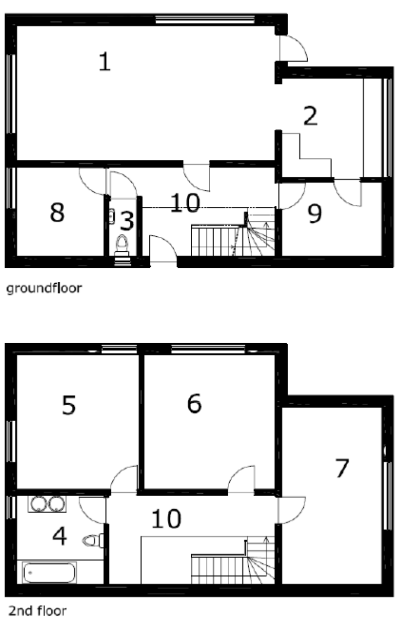
Subsequently, several percentiles of these 3 moving averages per ventilation unit were derived, i.e. 0.90; 0.95; 0.99 and 1,0. The maximal value of the box plot distribution of these percentiles, per percentile, is considered as a possible maximal airflow rate, i.e. without the outliers.

Finally, the chance of concurrency of the external design temperature and the maximal extract airflow rate is considered. The daily chance that the external design temperature occurs over a heating period of about 5 months, is nearly 0.67% (1/150). The daily chance that during the heating period the total extraction rate is higher than the derived percentiles of 0.90; 0.95; 0.99 and 1,0, is respectively 10%, 5%, 1% and 0%. When combining both chances, the overall yearly chance on concurrency of both situations is respectively 0.067%, 0.034%, 0.0067% and 0%. The designer of the heating capacity can choose between these small responsible chances, taking in mind that the end user has always the possibility to manually reduce the extract rate and in that way the required heating capacity.

Big field data. The analysed monitoring period extended from the beginning of October 2020 up to the end of March 2021, corresponding with the main Belgian heating period (temperate maritime climate). Python code was used to retrieve the desired data from the connected ventilation units and further processing. The airflow rates were theoretically derived from sensor values and control algorithms. The instantaneous data, with a sampling and storage interval of 5 min, were filtered on several parameters in order to only keep the units that were correctly installed in the dwellings. Also periods with manual overrule of the airflow rate were excluded to focus only on the effect of DC on the maximal airflow rate over the heating season. A total number of 134 devices with zonal extract control and 694 with local extract control was investigated.

Furthermore, 2 different analysis methods were applied on the moving averages of the total extract flow rate: on the one hand, determining the percentiles 0.90; 0.95; 0.99 and 1,0 of the total number of moving averages over all units as one data set (= method 1, overall), and on the other hand, determining the maximum per percentile (0.90; 0.95; 0.99 and 1,0) of the moving averages derived per unit (= method 2, per unit).

Big simulation data. Dynamic multi-zone simulations were carried out (in Contam) on a detached dwelling with occupancy and activity schedules as also modelled by Laverge (2013). The 2-storey house consists of a ground and first floor, with 3 bedrooms (BRs) and a playroom (PR), as illustrated in Figure 2. The zonally and locally DC ventilation system as analyzed in the field study were also modelled.



1: living room
2: open kitchen
3: toilet
4: bathroom
5-6-7: bedrooms
8: playing room
9: laundry
10: hall-staircase

Figure 2 Floor plans of the detached house.

Direct mechanical extraction was present in bedrooms in case of the local rVST. The playing/study room of the model contained no mechanical extraction and was not occupied, in order to simulate a more representative smaller dwelling. Air supply vents upon the windows of the habitable rooms were designed at 2 Pa and 10 Pa respectively, when no or mechanical extract was present. The kitchen was open, as is mostly the case in new homes in Flanders. On this model house, 3 variants were created by varying the airtightness v_{50} between 0.6; 3.0 and 6.0 $m^3/h/m^2$ enveloppe area. The simulation period extended from Octobre 1th up to April 15th.

A Monte-Carlo (MC) approach was then applied to several variants, performing 100 simulations in that way to reach convergence (Laverge et al. 2013). Over these 100 simulations there was a random variation in occupancy (1 to 6 inhabitants), orientation (0-359°), start day type (Monday to Sunday) and terrain roughness (0.15-0.374), to increase the representativeness of the modelling results. Modelling 3 airtightness levels, a total of 300 different configurations were simulated, of which the moving averages were calculated. Similar to the second analysis method on the big field data, the maximum per percentile (0.90; 0.95; 0.99 and 1,0) of these unit moving averages was determined.

RESULTS AND DISCUSSION

IAQ related performance

Since airflow rates are strongly related to perceived IAQ and guaranteeing IAQ at an acceptable level is the primary goal of a VST, field and simulated IAQ data were also briefly analysed. The total exposure of inbabitants to CO_2 concentrations above 950 ppm for the zonal (red) and local (green) MEV system, based on simulations, is illustrated in Figure 3. The median total exposure to CO_2 of the zonal and local MEV system was respectively 426 and 24 kppm.h per house. For an MEV system operating at 100% extract rate, the total exposure to CO_2 is also shown in Figure 3 (blue) with a median value of 334 kppm.h.

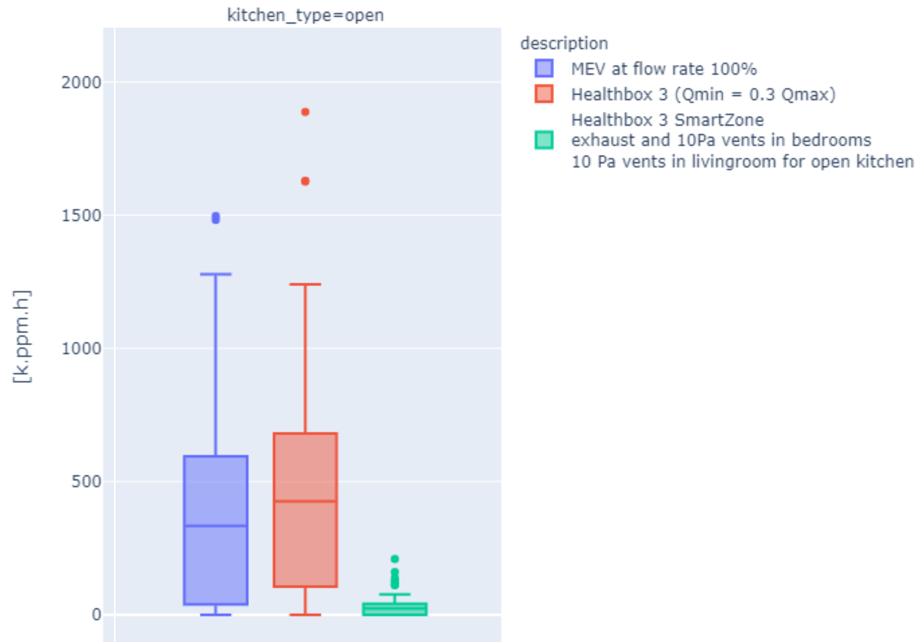


Figure 3 Simulated total exposure of inhabitants to CO_2 in the dwelling (with open kitchen) for the constant (blue), zonal (red) and local (green) MEV system.

The simulations pointed out that the local rVST provides on average good IAQ, since the average exposure to CO_2 above 950 ppm is negligeable. The exposure to CO_2 in case of zonal extraction without direct CO_2 controlled extraction from habitable spaces as bedrooms is remarkably higher (factor 18). A clear spread on the exposure was observed, mainly depending on the number of inhabitants varying between 1 and 6. In general, omitting direct extraction from the bedroom gave rise to maximal CO_2 level in the parent bedroom belonging to category 4 (> 1350 ppm) according to the standard EN16798-1 (2019). This explains the significant higher exposure to CO_2. The order of magnitude of the IAQ of the zonal rVST was similar to that of an MEV system operating at constant nominal airflow rate, as can be deduced from Figure 3.

Determination of the reduction factor

Figure 4 shows the reduction factors F(capacity) for the zonal and the local MEV system derived from field data and simulation data. The field data were analysed according to the 2 different methods: overall or per unit. The simulation data were presented as analysed in method 2.

The percentile values according to analysis method 1 on the total data set are obviously lower than those derived in method 2 per unit, with the exception of the 100th percentile. Both findings are related to the fact that the maximal value of the separate ventilation systems is taken in method 2. The 100th percentile according to method 2 can be lower, since outliers are omitted. Moreover, analysis method 2 uses a similar weighting factor per ventilation unit. Analysis method 2 was assessed as statistically more correct and therefore also proposed to derive a reduction factor F(capacity) to apply in design calculation. The higher the reduction factor, the higher the installed heating capacity will be.

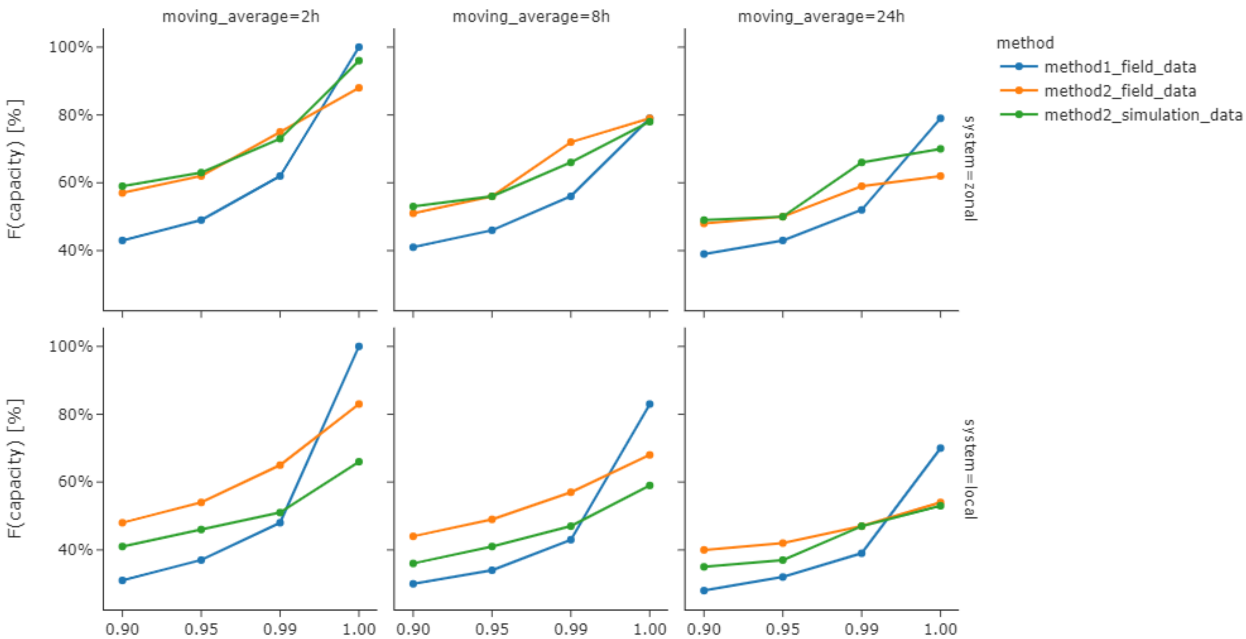


Figure 4 Reduction factor F(capacity) of the zonal (upper) and the local (lower) MEV system, based on field data (method 1 and 2) and simulation data (method 2), as a function of the moving average and the percentile.

Logically, the higher the time period of averaging, the lower the maximal airflow rates and the lower the reduction factor. When comparing the field data and the simulated data from Figure 4, according to method 2, the trend as a function of the percentile is very similar. Moreover, the absolute differences between the reduction factors are remarkably low and usually limited to some percentages. Higher differences between field and simulated data occur rather at high percentiles of 0.99 or 1.00, where outliers can have a more significant impact on the percentile. Based on a 8 hrs moving average, the yearly chance that the maximal air flow rate is higher than nearly 50%, 55%, 70% or 80% of the nominal extract rate, during the coldest day of the year, is respectively 0.067%, 0.034%, 0.0067% and 0%. These negligeable chances allow to apply a reduction factor on the installed ventilation capacity to dimension the power of the heating system. This possibility is enforced by the fact that the inhabitant can manually and temporarily reduce this maximal ventilation rate or the setpoint temperature, if desired.

The reduction factor of 70% as used in the Netherlands for DC rVST's, belongs also to the ranges as found in this study. When referring to the moving average values over 8 hrs, a reduction factor of 70% means that less than 1 unit per year per 10.000 installed units would have a maximal air flow rate higher than 70% of its nominal capacity, during the coldest winter day.

The reduction factor values of the local MEV system, is similarly to the zonal MEV system presented in the lower part of Figure 4. Similar to the zonal rVST, the overall analysis method 1 of the local rVST data set resulted in clearly smaller reduction factors than the method 2 per ventilation unit, with the exception of 100th percentile. While differences between field and simulation results were limited for the zonal rVST, according to method 2, simulation results are clearly lower than field data, with the except for the 24 hrs average. In case of the 8 hrs average, the reduction factors derived from the simulations are 8 to 10% lower than those measured. The higher the number of rooms controlled by the MEV, the more complex the model becomes. The higher reduction factor in the field can be related to a room extract capacity that is longer in operation, compared to the modelling assumption. This situation can be caused by higher CO_2 emission rates per room/person and/or lower supply capacities in practice. During the heating period, for instance, natural air supply vents are rather used on half of their ventilation capacity.

The spread in reduction factor values between the different moving averages (2 hrs, 8 hrs, 24 hrs) is remarkably smaller when based on simulations than on field data. This may indicate that in reality the occupancy pattern varies more in time and between dwellings than assumed in the MC simulations.

Based on a 8 hrs moving average, the yearly chance that the maximal airflow rate of the local rVST is higher than nearly 45%, 50%, 55% or 70% of the nominal extract rate, during the coldest day of the year, is respectively 0.067%, 0.034%, 0.0067% and 0%. When comparing the field data (method 2) of the zonal and local rVST, the reduction factors of this latter are clearly lower, 10 to 20% relatively. The main reasons are the day (open kitchen) and night (bedrooms) extraction zones, that are not simultaneously in operation, combined with a significant higher installed ventilation capacity. On average, the nominal capacity of a local rVST is about 40% higher than that of the zonal rVST. The IAQ and as a consequence the total extract rate of a local rVST is also higher compared to zonal control. This explains the smaller relative difference between the reduction factors of both rVST's, compared to the difference in nominal capacity.

The reduction factor of the local compared to the zonal rVST is on average and relatively 14% and 28% lower, based on respectively field data (method 2) and simulation data. The lower difference in practice could indicate that the IAQ related to the zonal rVST is better in reality compared to the modelling results. However, big field data of the exposure to CO_2 in case of the zonal rVST are not available.

CONCLUSION

Data analysis on big field and simulation data of a zonally and locally demand controlled residential MEV system, allows to determine a reduction factor F(capacity) which represents the fraction of the installed nominal capacity (m^3/h) really used during the heating season. This reduction factor for automatically controlled MEV systems can be applied on the nominal flow rate to calculate the maximal heat losses when dimensioning the heating capacity need (kW) of the house. Two data analysis methods were compared on the field data, with a significant difference between both.

In case of the zonal rVST, the reduction factors derived from field and simulation results were remarkably similar, with reduction factors down to 50%, depending on the moving average and the percentile considered. In case of the local rVST, reduction factors derived from field measurements were obviously higher compared to simulations. The local rVST is extended over all the habitable and wet rooms of the dwelling, and in that way more parameters can differ between reality and prediction. The reduction factor of the local compared to the zonal rVST is on average and relatively 14% and 28% lower, based on respectively field data and simulation data (method 2). The installed ventilation capacity, however, in case of the local rVST is about 40% higher. The chance that the real total extract airflow is higher during the coldest winter day, than the one related to the reduction factor, is almost negligeable. This negligeable chance allows to take the reduction factor into account in the design heat load calculation of the heat production units.

Further research will focus on the maximal level of cross ventilation and in/exfiltration compared to the extration flowrate. A flat model will also be used to perform the simulations.

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