# A case study on residential mixed-mode ventilation using the Ventilation Controls Virtual Test Bed

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## ABSTRACT

Mixed-mode ventilation uses intelligent switching between natural and (partly) mechanical ventilation modes to find the best possible balance between indoor air quality, user comfort and energy consumption. It applies demand-control at the level of the operating mode depending on the constraints imposed by the building, its users and its surroundings. Although mixed-mode ventilation is said to have the potential to achieve a comfortable and healthy indoor environment while achieving significant energy savings, it is rarely used in practice. Both academia and practitioners state that a lack of dedicated simulation tools, capable of modelling the inherent complexity of mixed-mode ventilation and its control algorithms, constitutes an obstacle. Also, case studies demonstrating the potential of mixed-mode ventilation in a residential context are scarce. A newly developed tool, VCVTB, is used to compare the performance of a generic mixed-mode ventilation system to a number of ventilation systems that are commonly used in the Belgian residential ventilation context. As key performance indicators, the unmet hours for operative temperature, relative humidity and $CO_2$ level while people are present are used, as well as the energy demand for heating and the auxiliary energy use for fans. To test the robustness towards users all systems are tested by a semi-probabilistic virtual user panel. A low-energy house for which long-term measurement data is available constitutes a spatial boundary condition. The case study showcases the possibilities of VCVTB to design and compare advanced ventilation strategies. More importantly, it illustrates that mixed-mode ventilation may be a promising concept for residential ventilation within the Belgian context and in other climate areas with mild winters and cool summers. In the investigated building the main advantage of the mixed-mode strategy is not so much the reduction in auxiliary energy use for fans, but rather the outdoor connection during warmer months. Repeated opening of windows effectively reduces unmet hours by adopting adaptive comfort limits. Over an entire year, the windows are opened 30% of the time when using MMV. This can mainly be attributed to the opening of windows during the summer months. Finally, the case study shows that mixed-mode ventilation can provide a solution that is robust towards user behaviour.

## KEYWORDS

mixed-mode ventilation, airflow network, indoor air quality, user behaviour, building simulations

## 1 INTRODUCTION

Ventilation systems must find the best possible balance between indoor air quality (IAQ), user comfort and energy consumption within the constraints imposed by the building and its users. In the current Belgian residential ventilation context, this largely translates into the use of two groups of ventilation strategies: (1) mechanical extract strategies with natural inlets through purpose provided openings, and (2) balanced mechanical ventilation strategies with mechanical supply, mechanical extract, heat recovery and air filters. Both strategies are accompanied by a continuous auxiliary electricity consumption for ventilation fans. Demand-controlled algorithms that adjust airflow rates based on sensor measurements can reduce auxiliary energy use. However, as minimum flow rates must be maintained, the use of auxiliary energy is never completely eliminated. By intelligently switching between various ventilation strategies, single-mode systems can be upgraded to multi-mode solutions. Multi-mode systems that include both natural and mechanical operating modes are referred to as mixed-mode (MMV) ventilation.

Many authors point out the potential of MMV in climate areas with mild winters and cool summers (Köppen classication, $C_{fb}$), such as Belgium. The frequent use of natural ventilation modes during warmer periods creates indoor conditions that fluctuate with the outside. The resulting adaptive context can broaden the comfort limits of the building occupants in relation to the comfort limits in a mechanically controlled indoor climate (Carlucci, Bai, de Dear, & Yang, 2018). Both practitioners and researchers state that a lack of dedicated simulation tools, capable of modelling the inherent complexity of MMV and its associated control algorithms, constitutes an obstacle for the further development and its use in daily practice (Gandhi, Brager, & Dutton, 2014). Also, there are few simulation based studies investigating the potential of mixed-mode ventilation in a residential context. In response, this study seeks to bring MMV awareness to the fore. A comparative case study is added to the list of residential MMV studies and the functioning of a novel research tool for MMV is illustrated.

# 2 CASE STUDY

A new simulation tool, is used to compare the performance of a generic mixed-mode ventilation system to a number of ventilation systems that are commonly used in the Belgian residential ventilation context. A low-energy house for which long-term measurement data is available constitutes a spatial boundary condition. The performance comparison is made based on the number of unmet hours for operative temperature, relative humidity and $CO_2$ concentration in the living room and the master bedroom of the house, the energy use for heating and the auxiliary energy use for fans. To assess the robustness towards users, the investigated ventilation systems are tested by a virtual user panel. Robustness is defined as the ability to be indifferent in terms of performance relative to varying user behaviour. In this study it is assessed on the basis of the standard deviation on unmet hours.

## 2.1 VCTVB

VCVTB, the Ventilation Controls Virtual Test Bed is a modelling and testing environment for advanced ventilation strategies built around the building energy modelling (BEM) software EnergyPlus 8.8.0 (Belmans, Aerts, Verbeke, Audenaert, & Descamps, 2019). For the calculation of airflows, it uses the integrated EnergyPlus airflow network (AFN) model (Gu, 2007). In contrast to quasi-dynamic coupling of AFN and BEM calculations, typical for co-simulation (Dols, Emmerich, & Polidoro, 2016), the integrated coupling approach is fully dynamic. In VCTVB, the capabilities of the integrated EnergyPlus AFN model have been extended by source code changes. E.g. components have been added to model self-regulating trickle vents and it has been made possible to simulate demand-control on the supply and extract side of a balanced mechanical ventilation system. The platform is enriched with additional modules for pre- and post-processing, including modules for automated graphical output. To incorporate the impact of a realistic environment with obstacles and elevations, wind pressure coefficients on the building envelope are determined using CFD simulations in OpenFOAM. To charge for user behaviour, a novel semi-probabilistic user model focused on indoor air quality studies is used. This model builds on the user model of Aerts (Aerts, 2015) for single zone building energy demand simulations which uses data from Belgian time-use surveys (Minnen, Glorieux, & van Tienoven, 2016). It was enhanced for multi-zone IAQ modelling.

### 2.2 Case study house

The case study house, Figure 1, that is used for the comparative analysis is a low energy house in a suburban environment close to the city of Mechelen (Belgium). It is inhabited by a couple in their thirties (full-time employed) with two school-bound children. The annual primary energy consumption for heating, cooling, domestic hot water and auxiliary energy use of systems and fans is rated at 43 kWh/m². The overall heat transfer coefficient of the building envelope is 0.31 W/m²K. The internal air volume of the house is ~700m³. The infiltration rate was determined by means of a blower door test to be 0.6 ACH50. The house is equipped with a balanced mechanical ventilation system with a counter flow heat exchanger with summer bypass. A control valve linked to a time switch is used to alternate between a daytime and night time duct network. The airflow rates are controlled using a weekly time schedule. A long-term measurement campaign was carried out in the house from September 2016 - September 2017. It involved monitoring dry bulb temperatures, relative humidity and $CO_2$ levels inside the living room and the master bedroom of the house and dry bulb temperatures, relative humidity, $CO_2$ levels, wind direction and wind speed outside the house. The opening positions of the most important windows in the living and master bedroom were monitored as well, as was the auxiliary energy use of the ventilation fans. All measurements were taken at a time interval of one minute. Based on the outside measurements, an .epw weather file with a time step of one minute was created. Missing data was completed with data from MERRA-2 (Gelaro, et al., 2017) and CAMS (Schroedter-Homscheidt, 2016).

### 2.3 Modelling assumptions and tuning

A model of the case study house was created in EnergyPlus. A virtual household with similar characteristics as the real household (family composition, age, gender, employment level) was added using the behaviour module of VCVTB . In the comparative study $CO_2$ is used as an IAQ tracer and as a control parameter for demand-control. To include a credible $CO_2$ production of users, the user model of Aerts (Aerts, 2015) was expanded with $CO_2$ generation rates for the human metabolism based on Persily (Persily & de Jonge, 2017). Age and gender were combined with occupant activity to assign every occupant a metabolism. As a result, the synthetic users that are created using VCVTB have a varying metabolic heat, moisture and $CO_2$ production rate throughout the simulation. Electrical heat sources are introduced to model appliance related heat and moisture production. A distinction is made between a sensible, latent and lost fraction of the electrical power level of the source. The $CO_2$ production from people is introduced into the model using EnergyPlus *ZoneContaminantSourceAndSink* objects.

An airflow network model of the building was implemented in EnergyPlus. By using an airflow network approach all airflows are calculated simultaneously using pressure-based calculations. As a result mechanical ventilation flow rates, wind and stack driven ventilation flow rates and in/exfiltration are interconnected and can affect each other. Each room was represented by one AFN node assuming well-mixed conditions at room level. Flow coefficients and flow exponents for purpose provided openings were based on Liddament (Liddament, 1996) and Orme (Orme, Liddament, & Wilson, 1998). For modelling natural ventilation, tilt and turn windows were opened in a slight tilting position with a discharge coefficient of 0,82. They were modelled using *AirflowNetwork:MultiZone:Component:DetailedOpening* objects that allow bidirectional airflow.

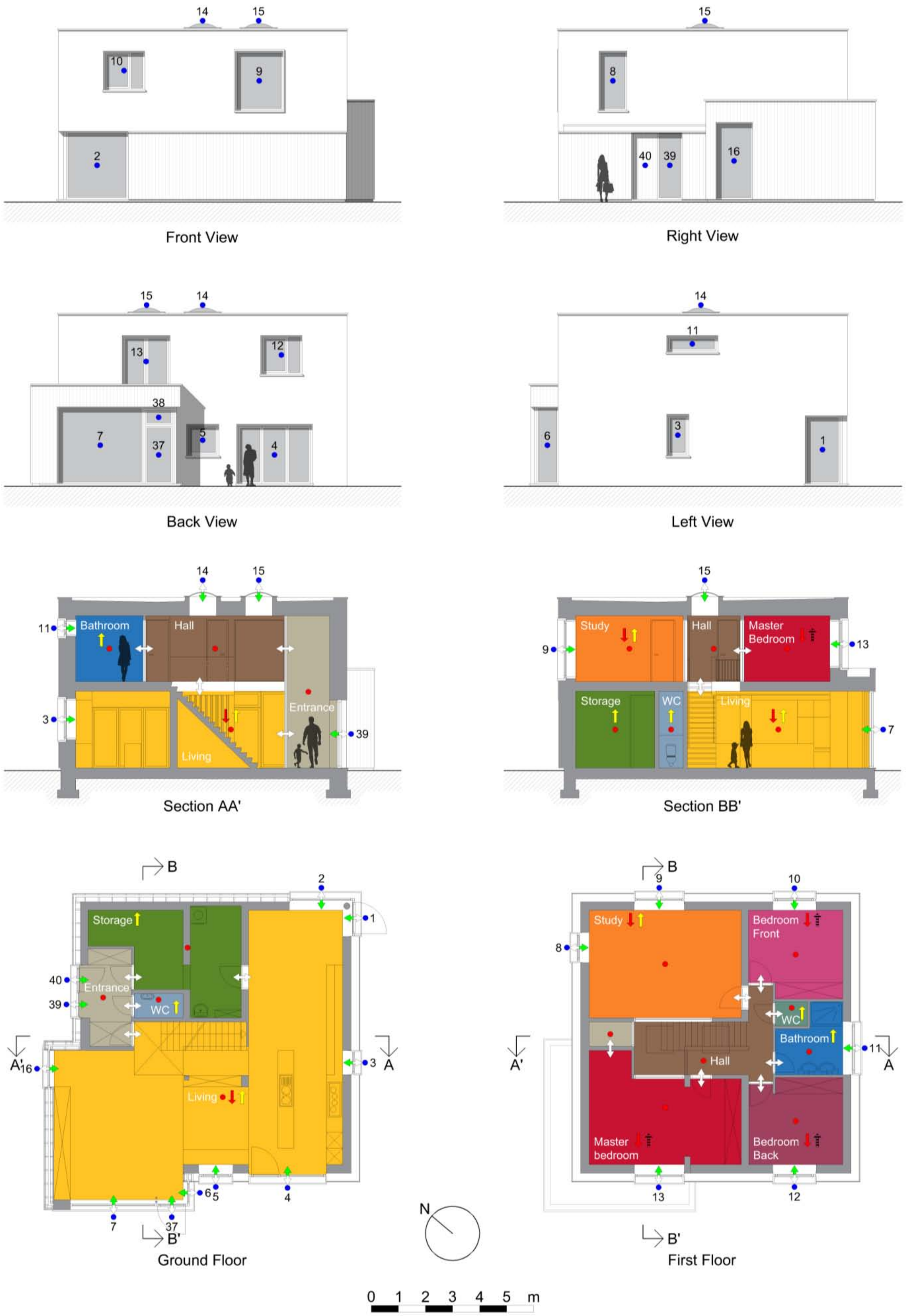


Figure 1: Layout of the case study house

The cracks responsible for infiltration and exfiltration were assumed to be located around the windows. Their flow coefficients and exponents were defined based on the infiltration flow rate obtained from a blower door test. The blower door test was mimicked in the virtual model to verify the infiltration flow rate in the Airflow Network. The moisture buffering capacity of the building was included using the EnergyPlus Effective Moisture Penetration Depth (EMPD) model. The moisture production of activities in the user model was balanced based on the difference in vapour pressure levels between the modelled and the monitored house.

### 2.4 Comparison with in-situ measurements

Instead of looking at point-wise chronological similarities between the monitored and the modelled case study house, a comparison is made based on a cumulative distribution of the occurrence of a condition, Figure 2. Looking at point-wise data makes little sense since the behaviour of the virtual users is similar, but never the same as the behaviour of the real residents. The simulated and monitored dry bulb temperatures in June and the simulated and monitored $CO_2$ levels in the living room and the master bedroom in January are shown in the top graph. For temperature a summer month is shown because an idealised heating system is used in the simulation. To exclude the influence of window opening in summer a winter month is shown to compare $CO_2$ concentrations. In the bottom graph the monthly averaged internal and external vapour pressure levels $p_{vi}$ and $p_{ve}$ are compared for the period January-July. This comparison is used to evaluate the ratio between moisture production and moisture removal. It was also used as a control utility to fine-tune the moisture production of activities in the user model.

The indoor temperature is on average 0.5°C higher in the simulations than in the collected data. Also, the spread in the simulation data is less pronounced. The difference in spread can be explained by the well-mixed AFN assumption. This assumption can also be a reason for the 0.5°C deviation. Not all windows were monitored in the case study. Of the windows that were monitored, it was only recorded whether they were open or closed. It was not recorded how far they were open. It was assumed that when open, they were in a small tilt position. User operated shading control actions were implemented based on the temperature difference between inside and outside and incident solar radiation. The uncertainty in assumed and actual window opening behaviour and shading control may be a second reason for deviating results. Though not perfect, we conclude that there is a good match in terms of predicted and measured temperatures.

Mechanical ventilation flow rates were fixed based on measured values. Because the $CO_2$ concentrations in the simulation results show a good correlation with the monitored data this indicates that the $CO_2$ production of the virtual users bears a good resemblance to that of the real inhabitants. Offsets can be explained logically. Measurements were made in a limited number of discrete locations in space, while simulated values represent an aggregated value. Also, the simulated users are approximations of real users with similar but nevertheless different activities. In the bedroom there is a better correlation because the uncertainty on the activities is small. In the living room this uncertainty is bigger. Finally, the mixed-mode assumption better approximates the bedroom because of its size. The living space is considerably larger and more difficult to approximate by the well-mixed assumption of a single AFN node. Still, we conclude that there is a good match.

The air change rate in the model due to mechanical ventilation is based on the time schedule of the actual flow rates in the case study house. The airtightness of the model corresponds to the actual airtightness of the building. The graph shows that the moisture production and moisture removal balance each other in the same way in the model as in reality. The internal moisture production must therefore be reasonably well estimated by the occupant model. To conclude, the similarity between the modelled and measured values give sufficient confidence in the adopted approach. The virtual model is retained as a basis for the further comparison between ventilation systems.

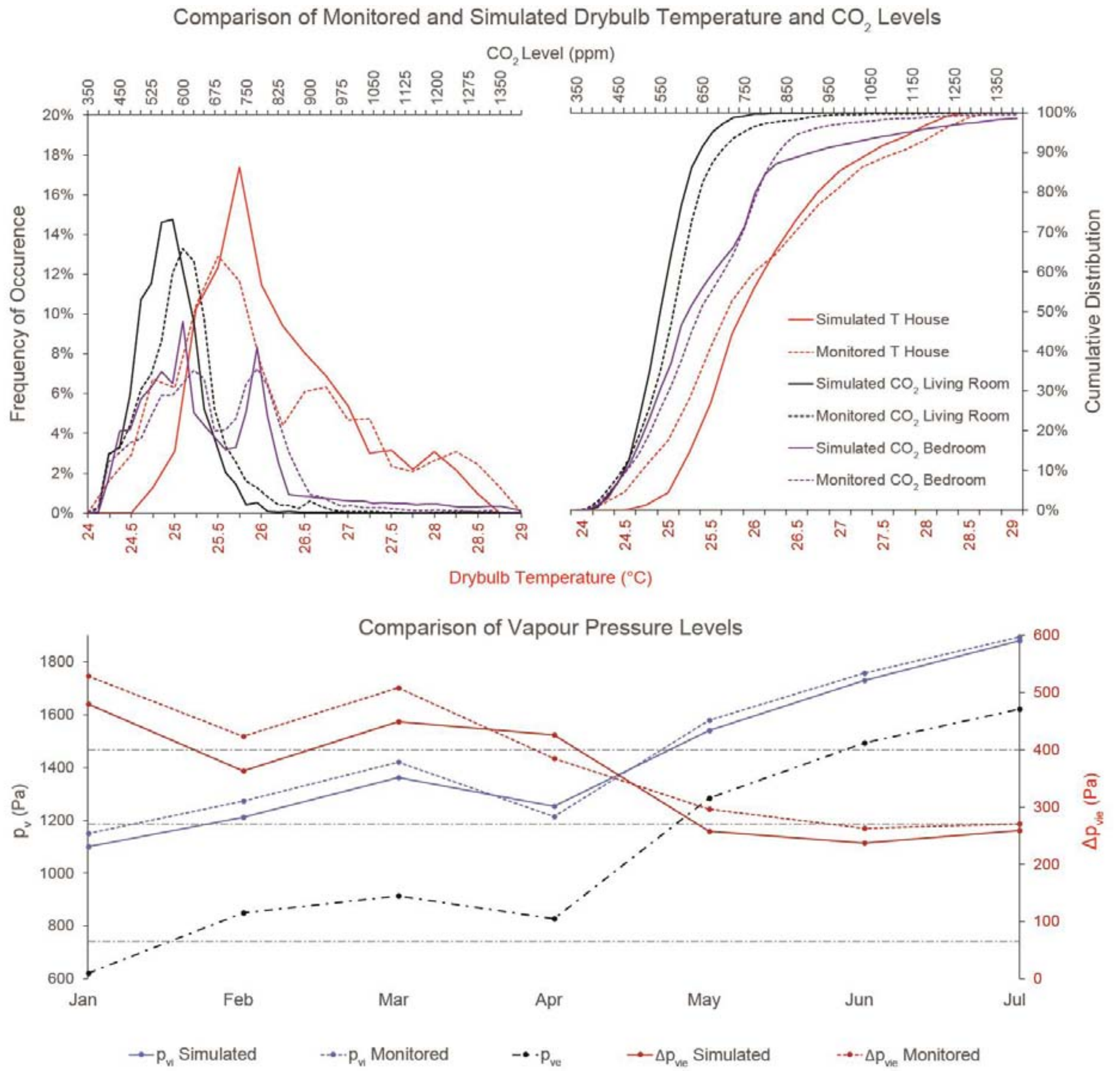


Figure 2: Comparison between measured and simulated drybulb temperatures and $CO_2$ levels in the living room and the master bedroom of the case study house, and between measured and simulated vapour pressure levels.

## 2.5 Generic Mixed-Mode Ventilation System

A generic mixed-mode ventilation strategy is implemented. It has three operating modes: Mode 1 is a fully natural ventilation mode where purpose provided openings are opened and closed to provide hygienic ventilation (small window opening positions and trickle vents). It is considered to be the preferable mode if outside conditions are favourable. There is no auxiliary energy use for fans. In Mode 2, a central mechanical extract fan is activated to assist natural ventilation through purpose provided openings in the event that the natural driving forces (stack, wind) are insufficient to ensure the required flow rates. There is auxiliary energy use of one ventilation fan. Mode 3 is a balanced mechanical ventilation mode with heat recovery. It is used when the outside conditions are unfavourable for natural ventilation (too noisy, too windy, too warm/cold, bad outdoor air quality…). It ensures good IAQ and thermal comfort while avoiding unwanted ventilation losses and heat gains. Mode 3 is well controllable but there is auxiliary energy use of two ventilation fans. In Mode 2 and 3, demand-control is applied on top of the adjustment of the operating mode. In Mode 1, the opening position of the windows is adjusted to the required airflow rates. The ventilation mode that is active at a given time is adjusted by means of a control algorithm, which is implemented in an EnergyManagementSystem (EMS) program, Figure 3. This approach offers increased control as compared to the integrated *EnergyPlus AvailabilityManager:HybridVentilation*. After selecting an operating mode, the air flow rates and window opening positions are adjusted.

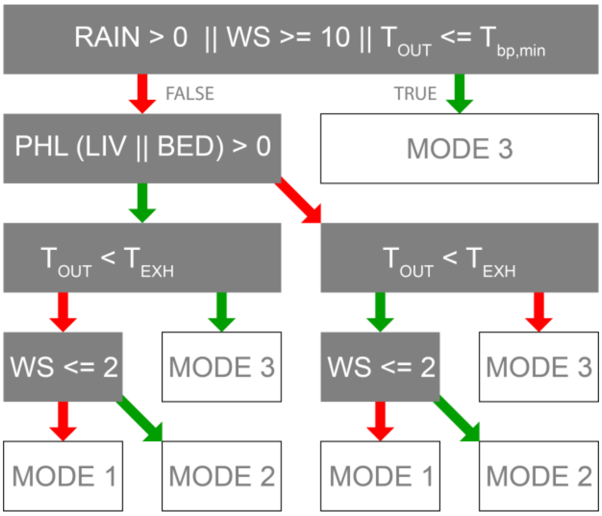


Figure 3: Control logic for the selection of the operating mode of the MMV system. PHL = predicted heat load (W), WS = local undisturbed windspeed at a height of 10m (m/s). $T_{bp,min}$ = The minimum threshold value of the outdoor temperature at which the bypass of the heat exchanger is allowed to operate. It is set at 13°C. $T_{OUT}$ = outdoor drybulb temperature (°C) , $T_{EXH}$ = return air temperature (°C) after the *AirLoopHVAC:ZoneMixer*. Adjustment of window opening positions and airflow rates are a next step in the control algorithm. They are not included in this schematic.

### 2.6 Comparative Study

The behaviour module of VCVTB is used to generate a test panel of households of synthetic users with semi-probabilistic behaviour. These users move through the virtual building model and perform activities depending on the probability of an activity to occur. The panel consists of 7 household types with a particular family composition. It includes 20 families per type. Five ventilation systems are tested by the panel, resulting in 700 simulations. The systems under comparison are:

- A natural supply / mechanical extract ventilation system (n/M NBN) with self-regulating trickle vents and continuous extract flow rate. The extract flow rate is set to 50% of the normative design flow rate resulting from NBN D50-001 (Belgisch Instituut voor Normalisatie, 1991).
- A constant flow balanced mechanical ventilation system (M/M NBN) with a counter flow heat exchanger. The summer bypass of the heat exchanger can operate when the outside temperature is at least 13°C. The supply and extract flow rate is set to 50% of the normative design flow rate, cfr. n/M NBN.
- A balanced mechanical ventilation system with demand-controlled supply and extract flow rates at room level (M/M DCV) and a counter flow heat exchanger. DCV control is based on $CO_2$ concentration, relative humidity and zone air temperature. The maximum $CO_2$ threshold is set at IDA1 (Very Good Quality, NBN EN 13779. The maximum RH threshold

is set at 60% RH (Upper limit of Class B, Good Quality, NBN EN 15251). $CO_2$ control is active in all rooms. RH control is active in the living room and the bathroom.

- A demand controlled mixed-mode ventilation system (MMV) that combines a fully natural mode, by opening windows, with a mechanically assisted extract mode and the balanced mode of M/M DCV. Unlike M/M DCV the balanced mode is only controlled based on $CO_2$ concentration and relative humidity. Temperature control is achieved by selecting an appropriate operating mode. In MMV 'auto' the controller can switch between operating modes at any time. In MMV 'manual' the operating mode can only change if an adult is at home and awake. A mode remains active if no one is present. Perfect users are assumed.

The MMV systems are the only systems in which windows are opened. Because they actively use window opening in summer, the indoor climate fluctuates with the outside. As a result, people are expected to adapt their clothing and metabolism. Therefore adaptive comfort limits are applied according to NBN EN 15251 (Nicol & Humpreys, 2010). The other systems only operate using the designed airflow paths in accordance with the provisions of NBN D50-001. These systems are subject to strict comfort limits. The unmet hours for the key performance indicators operative temperature, relative humidity and CO2 level as well as the auxiliary energy use for fans and the energy demand for heating are compared in Table 1. The standard deviation due to user behaviour is included to reflect the robustness of each system.

The M/M NBN strategy limits unwanted ventilation losses and uses heat recovery. The energy demand for heating is low compared to n/M NBN. The auxiliary energy use for fans is more than twice as big as n/M NBN. M/M DCV is an energy efficient alternative to M/M NBN. It has negligible unmet hours in terms of $CO_2$. Relative humidity levels are good and robustness is high. The heating demand is reduced through demand-control. The summer comfort is worse compared to systems with natural ventilation possibilities because natural ventilation (free cooling) rates can be much higher. The auxiliary energy use is high because DCV is also used for temperature control (bypassing the heat exchanger). The MMV system resembles the M/M DCV system in terms of robustness and IAQ. The Unmet hours for RH and $CO_2$ are similar, as is the energy demand for heating. The auxiliary energy consumption is reduced. The MMV systems combine the summer comfort of systems with natural supply with the energy efficiency of balanced mechanical ventilation with heat recovery. MMV successfully limits the CO2 concentration to IDA 1. Relative humidity is within the limits of moisture class B (25-60%, Good). The temperatures are within the limits of temperature class C (Acceptable). Windows open around 30% of the year in the MMV systems. Window opening is mainly concentrated in the summer period. In brief, the MMV systems have good performance and good robustness. Their main asset is that they can benefit from adaptive comfort limits in summer so that unmet hours remain low. Based on the investigated case study they do not outperform demand-controlled balanced mechanical ventilation with heat recovery in terms of energy consumption, however they do perform equally well. The auxiliary energy use for fans is lower, but the energy demand for heating is slightly higher.

## 3 CONCLUSIONS

Several authors indicated a need for dedicated simulation tools for MMV without the hassle of co-simulation. In response to this, a new test platform for MMV studies, the Ventilation Controls Virtual Test Bed was presented in earlier research. This test bed was used to compare the performance of two generic MMV systems to the performance of several reference systems in a case study house in Belgium. For a well-documented case (building + ventilation system) a good connection was found between in-situ measurements and modelling results. The model of this case was used as starting point for a performance comparison between ventilation systems. This comparison showed that during winter MMV systems behave almost identical as a demand-controlled balanced mechanical ventilation system with heat recovery. However, during summer, natural ventilation modes prevail and the MMV systems benefit from the adaptive comfort limits that apply. This effectively reduces unmet hours for overheating compared to a state-of-the-art demand-controlled mechanical ventilation system. Moreover, the comparison shows that the investigated MMV systems provide a robust solution in relation to user behaviour. The auxiliary energy use for fans is lower when using MMV, but the energy consumption for heating is slightly higher than the M/M DCV system. The energy demand for heating could be further reduced by optimisation. However, based on this study MMV should mainly be seen as a strategy that can contribute to an increase in summer comfort by leveraging adaptation capabilities.

Table 1: Comparative table with aggregated results of key performance indicators for 700 simulations. Note that the MMV* systems employ adaptive comfort criteria according to NBN EN 15251.

| **VENTILATION SYSTEM COMPARISON** | | | **n / M NBN** μ | 2σ | **MMV* manual** μ | 2σ | **MMV* auto** μ | 2σ | **M / M DCV** μ | 2σ | **M / M NBN** μ | 2σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Yearly Unmet Hours** | | | | | | | | | | | | |
| **Yearly Unmet Hours Living Room** | | | | | | | | | | | | |
| Class A* | T < 25.5 °C | $UH_{PP}$ | 525 | 260 | 176 | 222 | 191 | 242 | 685 | 284 | 812 | 372 |
| Class B* | T < 26 °C | $UH_{PP}$ | 422 | 248 | 12 | 36 | 15 | 54 | 485 | 224 | 679 | 334 |
| Class C* | T < 27 °C | $UH_{PP}$ | 211 | 204 | 0 | 1 | 0 | 1 | 167 | 130 | 423 | 280 |
| Class A | 30 % < RH < 50 % | $UH_{PP}$ | 1959 | 426 | 1274 | 320 | 1244 | 300 | 985 | 316 | 1045 | 240 |
| Class B | 25 % < RH < 60 % | $UH_{PP}$ | 397 | 98 | 104 | 48 | 100 | 40 | 49 | 38 | 84 | 30 |
| Class C | 20 % < RH < 70 % | $UH_{PP}$ | 31 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IDA1 | $CO_2 < CO_{2env} + 400$ ppm | $UH_{PP}$ | 0 | 0 | 7 | 16 | 8 | 18 | 0 | 0 | 0 | 1 |
| IDA2 | $CO_2 < CO_{2env} + 600$ ppm | $UH_{PP}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IDA3 | $CO_2 < CO_{2env} + 1000$ ppm | $UH_{PP}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Yearly Unmet Hours Master Bedroom** | | | | | | | | | | | | |
| Class A* | T < 25.5 °C | $UH_{PP}$ | 291 | 66 | 27 | 22 | 29 | 26 | 119 | 40 | 425 | 104 |
| Class B* | T < 26 °C | $UH_{PP}$ | 215 | 72 | 4 | 6 | 5 | 6 | 57 | 26 | 328 | 100 |
| Class C* | T < 27 °C | $UH_{PP}$ | 91 | 46 | 4 | 6 | 5 | 6 | 6 | 6 | 142 | 90 |
| Class A | 30 % < RH < 50 % | $UH_{PP}$ | 1359 | 186 | 976 | 178 | 915 | 154 | 552 | 80 | 544 | 126 |
| Class B | 25 % < RH < 60 % | $UH_{PP}$ | 209 | 38 | 110 | 32 | 102 | 20 | 21 | 6 | 0 | 2 |
| Class C | 20 % < RH < 70 % | $UH_{PP}$ | 14 | 8 | 13 | 14 | 5 | 8 | 0 | 0 | 0 | 0 |
| IDA1 | $CO_2 < CO_{2env} + 400$ ppm | $UH_{PP}$ | 706 | 106 | 31 | 18 | 22 | 18 | 6 | 6 | 1585 | 142 |
| IDA2 | $CO_2 < CO_{2env} + 600$ ppm | $UH_{PP}$ | 254 | 140 | 4 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| IDA3 | $CO_2 < CO_{2env} + 1000$ ppm | $UH_{PP}$ | 4 | 7 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |

| **VENTILATION SYSTEM COMPARISON** | | | **n / M NBN** μ | 2σ | **MMV* manual** μ | 2σ | **MMV* auto** μ | 2σ | **M / M DCV** μ | 2σ | **M / M NBN** μ | 2σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Energy Demand for Heating , Auxiliary Fan Electricity and Average Airflow Rates** | | | | | | | | | | | | |
| **Yearly** | | | | | | | | | | | | |
| Average auxiliary energy use of fans | | kWh/a | 110 | 0 | 133 | 16 | 137 | 18 | 401 | 72 | 352 | 0 |
| Average energy demand for heating | | kWh/a | 9933 | 860 | 4640 | 566 | 4648 | 580 | 4440 | 614 | 5574 | 640 |
| Average | Min | m3/h | | | 0 | 0 | 0 | 0 | 40 | 0 | | |
| Ventilation | Mean | m3/h | 145 | 0 | 56 | 10 | 57 | 10 | 112 | 20 | 210 | 0 |
| Flow Rate | Max | m3/h | | | 425 | 4 | 425 | 4 | 427 | 2 | | |
| **Heating Period** | | | | | | | | | | | | |
| Average auxiliary energy use of fans | | kWh | 54 | 0 | 73 | 4 | 73 | 4 | 74 | 4 | 173 | 0 |
| Average energy demand for heating | | kWh | 9140 | 646 | 4476 | 482 | 4488 | 498 | 4353 | 570 | 5381 | 562 |
| Average | Min | m3/h | | | 0 | 0 | 0 | 0 | 37 | 2 | | |
| Ventilation | Mean | m3/h | 145 | 0 | 58 | 10 | 58 | 10 | 58 | 10 | 210 | 0 |
| Flow Rate | Max | m3/h | | | 210 | 18 | 213 | 16 | 207 | 22 | | |
| **Summer and mid-season** | | | | | | | | | | | | |
| Average auxiliary energy use of fans | | kWh | 56 | 0 | 60 | 14 | 64 | 14 | 327 | 70 | 179 | 0 |
| Average energy demand for heating | | kWh | 793 | 214 | 164 | 86 | 160 | 84 | 87 | 44 | 192 | 78 |
| Average | Min | m3/h | | | 0 | 0 | 0 | 0 | 37 | 4 | | |
| Ventilation | Mean | m3/h | 145 | 0 | 55 | 12 | 56 | 12 | 167 | 32 | 210 | 0 |
| Flow Rate | Max | m3/h | | | 425 | 4 | 425 | 4 | 427 | 2 | | |

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