IEQ and energy performance of residential smart ventilation strategies in France

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SUMMARY

Smart-ventilation with airflows adapting to the need of buildings reduces energy consumptions and can improve IAQ. In some countries, smart ventilation strategies have been widely used for a long term (like Belgium, France,…). We still need to quantify IAQ and energy benefits of smart ventilation through a common internationally validated performance assessment scheme, still under development, notably in the framework of the IEA-EBC Annex 86. The SmartAIR French project focuses on the adaptation of the tools developed in the framework of the Annex 86 project and test their relevance in the context of the generalization of humidify-based ventilation and the innovation towards new ventilation systems.

KEYWORDS

Smart ventilation; Pollutant; Ventilation strategies; Dwellings.

1 INTRODUCTION

Several pollutant emissions have been identified in dwellings due to building materials and household furniture, human activities and occupancy. In addition to metabolic activities, which produce CO_2 and humidity, human emit pollutants due to their activities, such as cooking ($PM_{2.5}$ and humidity), laundry, laundry dry and shower (humidity). Therefore, the level of indoor pollutant concentrations combined with the amount of time humans spends indoors are the cause of respiratory and cardiovascular diseases, that can evolve and lead to death due to chronic or acute exposures (Clark et al., 2019).
In this context, the implementation of a ventilation system in dwellings is crucial for human health, since it improves the indoor air quality by diluting the pollutants concentrations. However, it can increase energy consumption depending on the specifications of the fans and the control system applied (De Jonge et al., 2023). The smart ventilation is as an alternative solution, as it provides continuous adjustment of the ventilation system in real-time and by location, thereby achieving the desired indoor air quality (IAQ) while minimizing energy consumption (Durier et al., 2018; Guyot et al., 2018b).
Various ventilation systems and strategies can be employed within the scope of smart ventilation, directly impacting system performance and indoor air quality (IAQ). These systems have been used for a long time in European countries such as France and Belgium, focused on a humidity or CO_2 controls (Poirier et al., 2021a; Guyot et al., 2018a), but their widespread implementation and further innovation remain challenging. One challenge is that we still need to quantify IAQ and energy benefits of smart ventilation through a common internationally validated performance assessment scheme, still under development, notably in the framework of the IEA-EBC Annex 86. This is a pre-condition to make possible to identify energy and IAQ benefits of such systems, at an international level and to open the markets to this innovation. Therefore, the present work aims to evaluate several smart ventilation systems and the influence

of the country, dwelling geometry, occupancy scenario, pollutant emissions on dwelling ventilation.

2 METHODOLOGY

The development of the present work was based on the results of the 1st common exercise of the IEA-EBC Annex 86, that evaluated different ventilation systems, each one adapted to a participating country. Most cases selected the same input values, such as CO_2 and humidity emissions, while the occupancy schedules, cooking and showering times and duration varied to better represent the country's habits.

The ventilation systems developed by the research groups of Cerema (France), DTU (Denmark), KU Leuven (Belgium), PUCPR (Brazil) and UIBK (Austria) were selected for further studying in the 2nd common exercise and the SmartAIR French project, that aims to improve the energy efficiency of the IAQ management strategies in operation and focuses on the adaptation of the tools developed on the Annex 86. Since each research group worked with different modelling softwares, geometries and other input conditions, it is difficult to compare the performances of the different ventilation systems tested. Therefore, it was created a modelling plan, validated by the participating research groups, to better compare these cases.

First, all simulations are going to be performed in the software CONTAM, for the same geometry, a single-family house with 5 occupants (2 parents and 3 children), the same occupancy scenarios, emissions rates, meteorological data and simulated period, from 1st October to 1st April (heating period in France), to each ventilation system selected. Then, the next step is to evaluate the influence of the country, performing the simulations with different meteorological and external pollution data, occupancy scenarios, cooking and emissions times and duration. After that, it will be evaluated the ventilation in an apartment geometry, for the conditions that presented the better results in the previous steps. Finally, a sensibility analysis will be performed to determine the influence of these parameters on the ventilation strategies performances.

Detailed information about the parameters studied is given in the following subtopics.

2.1 Geometry and occupancy scenarios

The floor plant of the single-family house simulated in the first part of the project is represented in Figure 1 (Poirier et al., 2021a) and has two floors and eleven rooms, each one represented by a zone in CONTAM. On the first floor there is a hall, a living room with an integrated kitchen, a children's bedroom, a bathroom and a toilet, while on the second floor there is a mezzanine, a parent's bedroom, 2 other children's bedroom, a second bathroom and toilet. Besides that, the occupancy schedule used was the same as Poirier (2019), showed in Table 1.

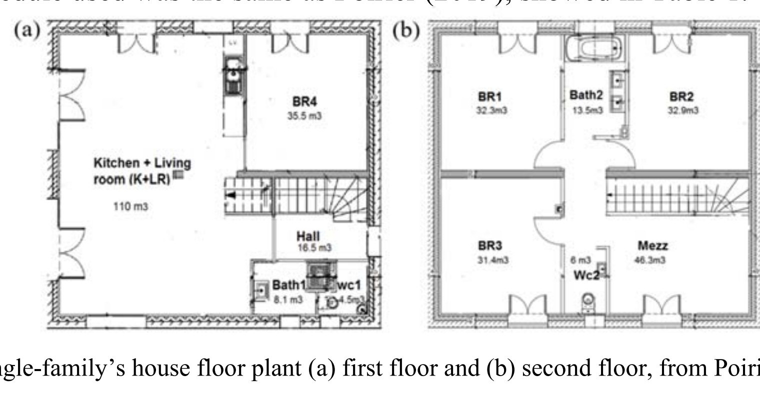

Figure 1: Single-family's house floor plant (a) first floor and (b) second floor, from Poirier et al. (2021)

Table 1: Single-family house occupancy scenario

Room | Occupant	Mother/Father	Child 1	Child 2	Child 3
Living room + Kitchen	07h00-08h30 12h00-14h00 19h00-21h00	06h20-08h30 12h00-14h00 19h00-20h20	06h20-08h30 12h00-14h00 19h00-19h40 20h20-21h00	06h20-08h30 12h00-14h00 19h00-20h20
Bathroom	06h20-07h00 (BATH2)	20h20-21h00 (BATH2)	19h40-20h20 (BATH1)	20h20-21h00 (BATH1)
Bedroom	21h00-06h20 (BR1)	21h00-06h20 (BR2)	21h00-06h20 (BR3)	21h00-06h20 (BR4)

2.2 Pollutant emissions

Poirier et al. (2021b) did an extensive research about the inputs used in ventilation systems and most were selected to be used in this work. However, the values of formaldehyde emissions were obtained using the Pandora Database developed by the laboratory LaSIE at University of La Rochelle (Abadie and Blondeau, 2011). This database gathers the emission rates of different pollutants and allows the user to select the room dimensions and sources.

Table 2: Pollutant emissions

Pollutant	Source	Emission
CO_2	Breathing	Awake/Asleep: 18/15 $L.h^{-1}$
Humidity	Breathing	Awake/Asleep: 55/40 $g.h^{-1}$
	Cooking	Breakfast/Lunch /Dinner: 1512/2268/2844 $g.h^{-1}$ (15/30/40 min)
	Shower	1440 $g.h^{-1}$ (10 min/day/person)
	Laundry	252 $g.h^{-1}$ (2h/week/person)
	Laundry dry	136.8 $g.h^{-1}$ (11h/week/person)
Formaldehyde (HCHO)	Furniture	Low/Medium/High: 5.6/14.8/29.1 $\mu g.h^{-1}.m^{-2}$
$PM_{2.5}$	Cooking	Low/Medium/High: 1.26/1.91/2.55 $mg.min^{-1}$
Fictive	-	10 $\mu g.h^{-1}.m^{-2}$

2.3 Ventilation systems

Five main ventilation systems were selected to the simulations, 2 are exhaust-only ventilation and 3 are balanced ventilation. These systems are briefly described below and further details regarding the constant air volume and the humidity control systems can be found in Poirier et al. (2022b), and the room-based systems are detailed in Poirier et al. (2022a).

- Mechanical exhaust-only ventilation (MEV):
  - Constant air volume (MEV-cav): presents air exhausts in the kitchen, the toilets and bathroom[1] and 1-hour boost of 135 $m^3.h^{-1}$ in the kitchen during cooking activities. As a result, the total extract airflow in the whole house is 135 $m^3.h^{-1}$ during basic mode and 225 $m^3.h^{-1}$ during peak mode. Air enters the building through trickle vents located on windows of bedrooms and living room.
  - Humidity control (MEV-rh): the inlets (trickle vents on windows) and outlets airflows are located at the same place than in the MEV-cav system, but are regulated by adjusting the cross-section through its hygroscopic fabric, also with 1-hour boost.

- Mechanical balanced ventilation (MVHR):
  - Heat recovery and constant air volume (MVHR-cav): The exhausted airflows are the same than with MEV-cav but the trickle vents are replaced by suppliers in the living room and bedroom.

[1] Exhausts are 30 $m^3.h^{-1}$ in each bathroom, 15 $m^3.h^{-1}$ in each toilet, and 45 $m^3.h^{-1}$ in the kitchen

- Heat recovery and humidity control at the apartment level (MVHR-rh): this system has a relative humidity sensor in the exhaust duct that regulates the airflows to operate in a low, nominal or high level, this last one is activated during the 1-hour boost in the kitchen.
- Heat recovery, CO_2 and humidity control at the room level (MVHR-room): in this system, a sensor can be placed into each room to provide an individual airflow control, based on CO_2 for the living room and bedrooms, while in the kitchen is based on CO_2 and humidity (with 1-hour boost).

2.4 Output data and performance indicators

To each ventilation system simulated, CO_2 and relative humidity concentrations profiles will be collected in all rooms, as well as the exposure concentrations profiles to all contaminants. Moreover, these systems will be evaluated by the performance indicators described in Table 3.

Table 3: Description of the performance indicators selected

Performance Indicator	Unit	Description
DALY	[years.10^5]	The total health impact is the sum of all DALYs (Dynamic Disability-Adjusted Life Years).
E_{CO2}	[ppm.h]	Normalized cumulative exposure when concentrations are higher than 1000 ppm in a room.
P_{CO2}	[ppm]	95^{th} percentile of the CO_2 exposure concentrations.
T_{RH}	[%]	Percentage of time spent out of the humidity range of 25-60%.
E_{HCHO}	[µg m^{-3}. h]	Cumulative formaldehyde occupant exposure.
$E_{fictive}$	[µg m^{-3}. h]	Cumulative fictive occupant exposure.
$E_{PM2.5}$	[µg m^{-3}. h]	Cumulative $PM_{2.5}$ occupant exposure.
E_{HCHO_acute}	[µg m^{-3}. h]	Maximum of the formaldehyde cumulative occupant exposure over 1h.
$E_{fictive\_acute}$	[µg m^{-3}. h]	Maximum of the fictive cumulative occupant exposure over 1h.
$E_{PM2.5\_acute}$	[µg m^{-3}. h]	Maximum of the $PM_{2.5}$ cumulative occupant exposure over 1h.
ACH	h^{-1}	Average building air changes per hour due to ventilation.
E_{losses}	[kJ]	Energy losses due to ACH ventilation
E_{elec}	[kJ]	Energy due to the fan(s) electric consumption

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