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Assessment Of The Performance Of Hybrid Ventilation System: Case Study Of A Multi-family Building In France

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ABSTRACT HEADING

By using natural driving forces, hybrid ventilation systems reduce fan energy consumption in buildings. They are of increasing interest as they help to improve buildings energy efficiency while ensuring good indoor environmental quality. However, the performance of these systems is variable and dependent on climatic conditions. Besides, the plurality of openings, variable airflows, and unstable flow patterns make the measurement of the performance of natural or hybrid ventilation systems a challenging task. Therefore, their implementation in new residential buildings, in France, is restricted by regulatory constraints that impose global and permanent air exchange throughout the dwelling using minimum airflow rates. The development of a reliable method to assess the real performance of natural (stack effect) or hybrid ventilation systems can help to promote the use of these systems. This is the objective of the research project VNAT (2017-2021). During this project, we carried out an in situ assessment of the indoor environmental quality of a multi-family apartment building equipped with a hybrid ventilation system. The building was monitored between December 2018 and April 2019. It is located in Lyon. It was constructed in the 1950s, and was retrofitted in 2014 by adding a fan-assisted hybrid ventilation system. The paper presents first the building and the ventilation system followed by the measurement method. It presents second the results regarding the operation of the ventilation system and the indoor environmental quality in the apartments. Results from this paper will help to build a protocol dedicated to the assessment of the performance of hybrid or natural (stack effect) ventilation systems under real conditions.

INTRODUCTION

By using natural driving forces, hybrid ventilation systems reduce fan energy consumption in buildings. They are of increasing interest as they help to improve buildings energy efficiency while ensuring good indoor environmental quality (Op't Veld 2008). However, the performance of these systems is variable and dependent on climatic conditions.

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Besides, the plurality of openings, variable airflows, and unstable flow patterns make the assessment of the performance of natural or hybrid ventilation systems a challenging task. Therefore, their implementation in new residential buildings, in France, is restricted by regulatory constraints that impose global and permanent air exchange throughout the dwelling by means of minimum airflow rates. However, hybrid ventilation systems are commonly used in renovated existing multi-family buildings, formerly ventilated with passive stack systems. Low-pressures induced by hybrid systems make them suitable for existing masonry ventilation ducts, whereas a mechanical ventilation system would require to retrofit the whole duct. The development of a reliable method to assess the real performance of hybrid ventilation systems can help to promote the use of these systems in new and existing buildings. As hybrid ventilation systems may have variations in flow over time, a performance-based approach with indoor air quality (IAQ) criteria is more appropriate for such systems (CEN 2007).

The research project "VNAT" is ongoing since 2017 for a 45-month period, in order to develop an assessment method of the performance of hybrid and natural ventilation systems regarding the indoor environmental quality (IEQ). As part of this project, (Remion et al. 2018) realised a comprehensive literature review about existing methods. This review showed the need for a coupled measurement-modelling approach to assess the IAQ performance of hybrid or natural ventilation systems.

This paper deals with the in situ assessment of the indoor environmental quality of a multi-family apartment building equipped with a hybrid ventilation system. This paper presents the measurement results carried out during four months of the heating season.

METHODOLOGY

Monitored building

A five-level multi-family apartment building was monitored between December 2018 and April 2019. The building is located in Lyon (South-East France). It was constructed in the 1950s. It consists of a five level-rise building with three apartments by levels (except the first level with four apartments). It leads to three stacks of apartments (north, south, and west-oriented), as shown in Figure 1-a. All apartments of the north-oriented stack, as well as four apartments of the south-oriented stack, were monitored.

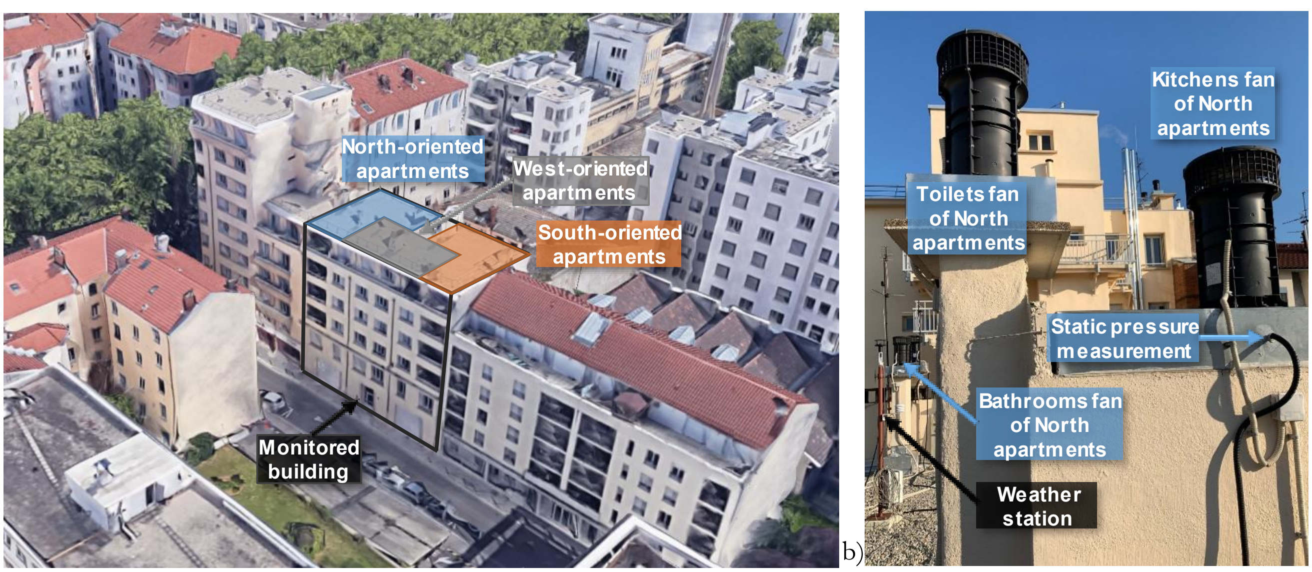
a)  b)

Figure 1 (a) View of the west façade of the monitored five-level multi-family apartment building and (b) view of the assistance fans of the north-oriented apartments located on the roof.

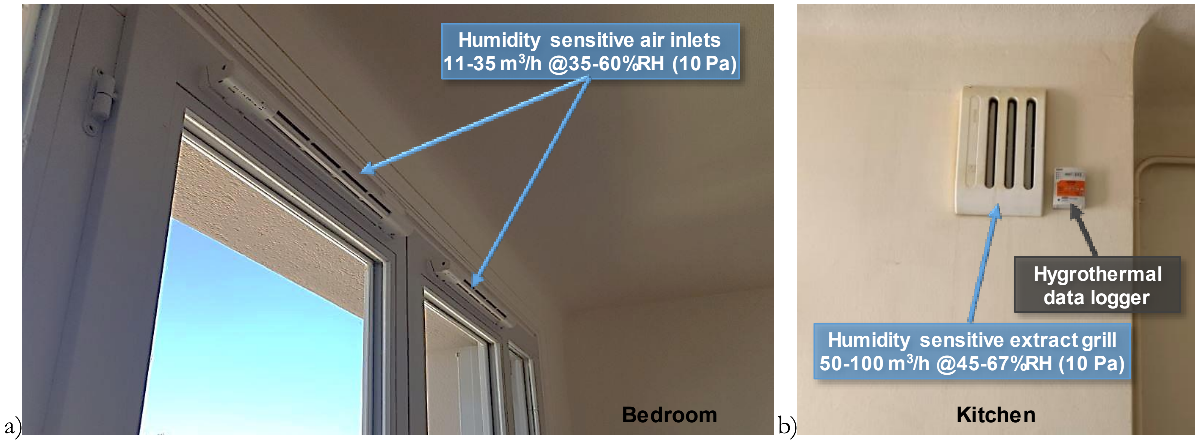


Figure 2 (a) Humidity sensitive air inlets in the main rooms and (b) humidity sensitive extract grill in the service rooms.

The building was initially ventilated using a passive stack system with shunt ducts in the toilets, bathrooms, and kitchens. It was retrofitted in 2014 by adding a fan-assisted hybrid ventilation system that is composed of humidity sensitive air inlets, humidity sensitive extract grills, shunt ducts, and assistance fans for combined natural and mechanical exhaust (Figure 1-b).

In each apartment, air enters in main rooms (living and bedrooms) through humidity-sensitive air inlets integrated into the windows (Figure 2-a), and is extracted from the wet rooms (kitchen, toilet, and bathroom) through humidity-sensitive extract grills fixed on the shunt ducts (Figure 2-b).

Both stacks of the north-oriented apartments (levels 2 to 5) and south-oriented apartments (levels 2 to 5) are composed of three shunt ducts. Dimensions of shunt ducts are 20x20cm. Each shunt duct is fitted with an assistance fan on the roof outlet. The mechanical assistance fan is activated when the outdoor temperature is higher than 2 °C. The maximal energy consumption of the fan is 16 W for an extract flow rate of 400 $m^{-3}.h$ and a static pressure of 17 Pa.

First levels apartments of the building of interest are specific. The first level-apartment of the north-oriented stack has its own passive stack ventilation with two individual ducts in the bathroom and the kitchen. The first floor-apartment of the south-oriented stack is equipped with the same hybrid system as the one of higher floors, with the distinction that the kitchen has a separate individual duct.

Table 1 presents the main characteristics of the monitored apartments. All apartments, except apartment N1, have three main rooms (one living and two bedrooms) and three wet rooms (kitchen, bathroom, and toilet). Apartment N1 has two main rooms (living and bedroom) and two wet rooms (kitchen and bathroom). Apartments N1, S2, and S5 are occupied by elderly persons who are present in the apartments almost all the time. Apartments S1 and S4 are occupied by students; their presence in the apartment is very variable. For other apartments, occupants are absent during the day on weekdays.

Table 1. Main characteristics of the monitored apartments

Apartment Nb.	Location	Area	Nb. of occupants	Air permeability q_{E4} / n_{50}
N1	North – level 1	47 m²	1 adult	1.19 $m^3.h^{-1}.m^{-2}$ / 1.80 h^{-1}
N2	North – level 2	67 m²	2 adults	0.51 $m^3.h^{-1}.m^{-2}$ / 1.03 h^{-1}
N3	North – level 3	67 m²	2 adults + 1 child	0.60 $m^3.h^{-1}.m^{-2}$ / 1.23 h^{-1}
N4	North – level 4	67 m²	2 adults	-
N5	North – level 5	63 m²	1 adults + 3 children	-
S1	South – level 1	76 m²	4 adults	1.64 $m^3.h^{-1}.m^{-2}$ / 1.98 h^{-1}
S2	South – level 2	65 m²	1 adult	0.72 $m^3.h^{-1}.m^{-2}$ / 1.29 h^{-1}
S4	South – level 4	65 m²	4 adults	-
S5	South – level 5	61 m²	1 adult	0.39 $m^3.h^{-1}.m^{-2}$ / 2.04 h^{-1}

Measurement method

In order to assess the indoor environmental quality, we monitored in each apartment: the indoor air temperature, relative humidity (RH) and CO_2 concentration in the main rooms (living and bedrooms), and the indoor air temperature and RH in the wet rooms (kitchen and bathroom). Measurements were recorded every ten minutes. In addition, data loggers were used to monitor the opening and closing of each window. Questionnaires were used to collect information about the occupant pattern.

A weather station was installed on the roof of the building to monitor the outdoor air temperature, RH, wind speed and direction, and CO_2 concentration. Measurements were recorded every ten minutes.

The static pressure of each fan was also monitored with a time step of one minute during March to April 2019. The total energy consumption was monitored in two electrical boxes supplying five fans each.

In addition, the air permeability of six apartments has been measured according to the ISO 9972 (AFNOR 2015).

Performance criteria

The indoor environmental quality is assessed regarding the thermal comfort and the indoor air quality based on the requirements of the European standard NF EN 15251 (CEN 2007) and the French regulation for demand-controlled ventilation (CCFAT 2015) respectively.

Thermal comfort. During the heating season, the standard NF EN 15251 requires indoor temperature in the range of 20-25 °C and RH in the range of 25-60% for new and renovated buildings. The parameters should not exceed the comfort range during more than 5% of occupied hours as recommended by the standard.

Indoor air quality. The French regulation for demand-controlled ventilation (DCV) uses two performance indicators related to humidity and CO_2:

- Regarding humidity, the number of hours when RH is higher than 75% should not exceed 100 hours in the toilet and main rooms, 600 hours in the kitchen, and 1000 hours in the bathroom over the heating period.
- Regarding CO_2, the cumulative exposure indicator over 2000 ppm in each room should not exceed 400,000 ppm.h.

In addition, the numbers of hours when the CO_2 concentration is higher than 1000 ppm and 2000 ppm are calculated.

RESULTS

Air permeability of the building envelope

Table 1 shows the results of the measured air permeability in terms of the French indicator q_{E4} (leakage rate per the envelope area at 4 Pa) and n_{50} (air change rate at 50 Pa). The values of q_{E4} ranges from 0.39 to 1.64 $m^3.h^{-1}.m^{-2}$ with an average value of 0.73 $m^3.h^{-1}.m^{-2}$ (weighted average by envelope area). The apartments have a good airtightness since the French regulatory requirement for new multi-family apartments is 1.00 $m^3.h^{-1}.m^{-2}$.

Operation of the ventilation system

Figure 3 shows the results of the measured static pressure of the fans of each shunt duct of north and south apartments from mid-March until the end of April 2019. The violin plot is used to illustrate the boxplot showing the main descriptive statistics (1st and 3rd quartiles, median, and mean) with the addition of a rotated kernel density plot on each side. During this period, the outdoor air temperature was mild ranging from 3.0 to 27.9 °C with an average of 13.1 °C. The outdoor RH ranged from 19 to 95% with an average of 58%, and the wind speed from 0.2 to 13.7 $m.s^{-1}$ with an average of 1.7 $m.s^{-1}$. As the outdoor temperature never dropped below 2 °C, the mechanical assistance was running permanently. The measured power consumptions of the two electrical boxes were stable around 60 W each.

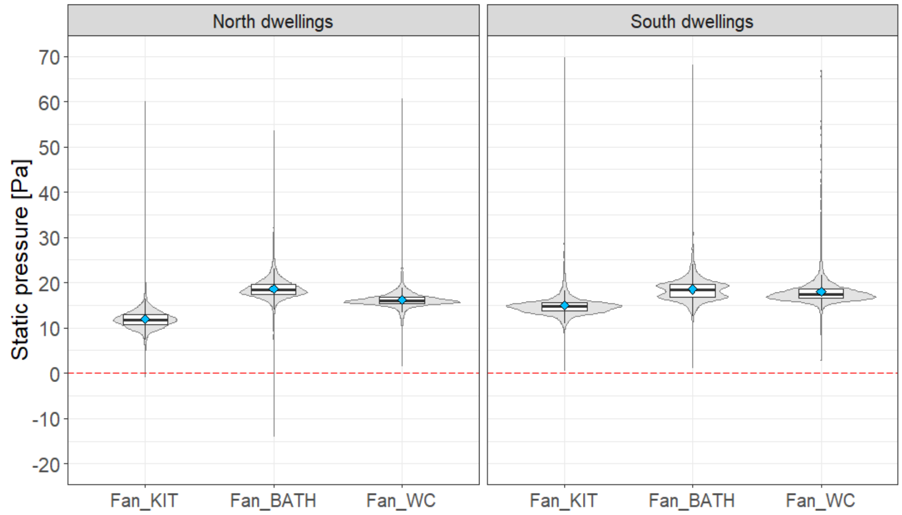


Figure 3 Boxplot of the static pressure measurements of the assistance fans of the north and south apartments (KIT: kitchen, BATH: bathroom, WC: toilet).

The static pressure of the fans varied in a narrow range from 10 to 25 Pa, with slightly lower values for the kitchen fans. For the north apartments, the average static pressures of the kitchen, bathroom, and toilet fans were 11.9, 18.7, and 16.2 Pa with standard deviations of 2.3, 2.6, and 2.1 Pa respectively. For the south apartments, the average static pressures of the kitchen, bathroom, and toilet fans were 14.9, 18.6, and 17.9 Pa with standard deviations of 2.7, 3.1, and 2.9 Pa respectively. As the stack effect was weak during the period of measurement, the mechanical assistance fan helped to maintain an average static pressure between 11.9 and 17.9 Pa with small variations probably due to the wind effect.

Indoor environmental quality

The indoor environmental parameters were monitored from 12th December 2018 until 16th April 2019, during 4 months of the heating season. The measurement period did not cover the entire heating season (6 to 7 months in Lyon), but almost 60% of the heating season including the coldest months.

Indoor air temperature. The outdoor temperature during the measurement period varied from -4 to 22 °C with an average of 6.6 °C and a standard deviation of 4.7 °C. The measured indoor air temperatures were overall in the comfort range with average values ranging from 20.4 to 23.3 °C in the livings and from 19 to 23 °C in the bedrooms. Small temperature variations occurred around average values with standard deviations less than 1 °C in the livings, and less than 1.5 °C in the bedrooms (Figure 4). The apartments were properly heated thanks to the heating system. The temperature occasionally dropped below 19 °C in some apartments, probably due to the opening of windows.

Indoor relative humidity. The outdoor RH varied from 10 to 96% with an average of 68% and a standard deviation of 18.4%. The indoor RH were overall in the comfort range with (Figure 5):

- averages from 29 to 44% in the main rooms and standard deviations less than 10% (4 to 9%),
- averages from 34% to 43% in the kitchens and standard deviations less than 10% (4 to 7%),
- averages from 31 to 46% in the bathrooms and standard deviations less than 10% (4 to 9%).

The indoor RH occasionally exceeded 75% during:

- less than one hour in the main rooms,
- less than three hours in the kitchens,
- less than ten hours in the bathrooms (except S1 with 26.8 hours).

Though the measurements do not cover the entire heating season, the results are far below the thresholds required by the French regulation for DCV. Even by multiplying by 1.75, the number of hours over the threshold of 75% of RH remains below the regulatory requirement.

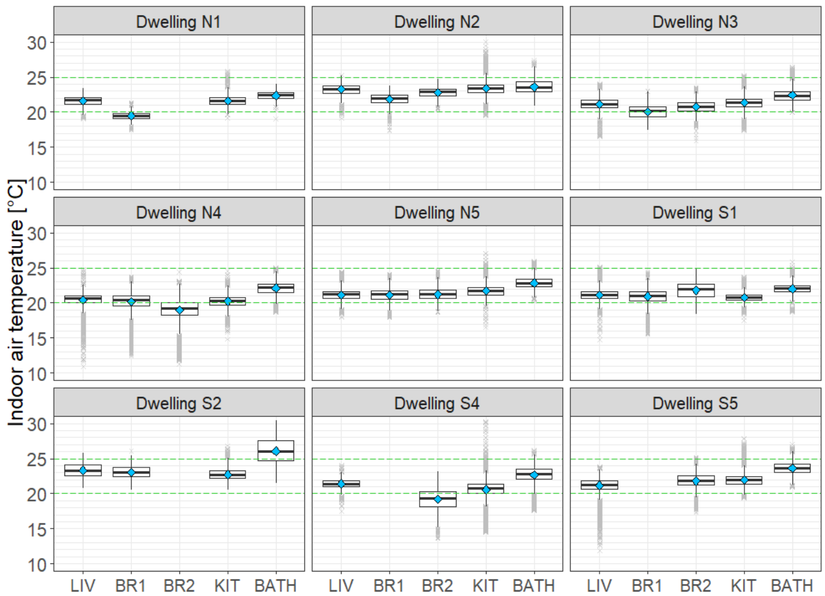


Figure 4 Boxplots of indoor air temperature measurements in each apartment (KIT: kitchen, BR1: bedroom 1, BR2: bedroom 2, BATH: bathroom, WC: toilet).

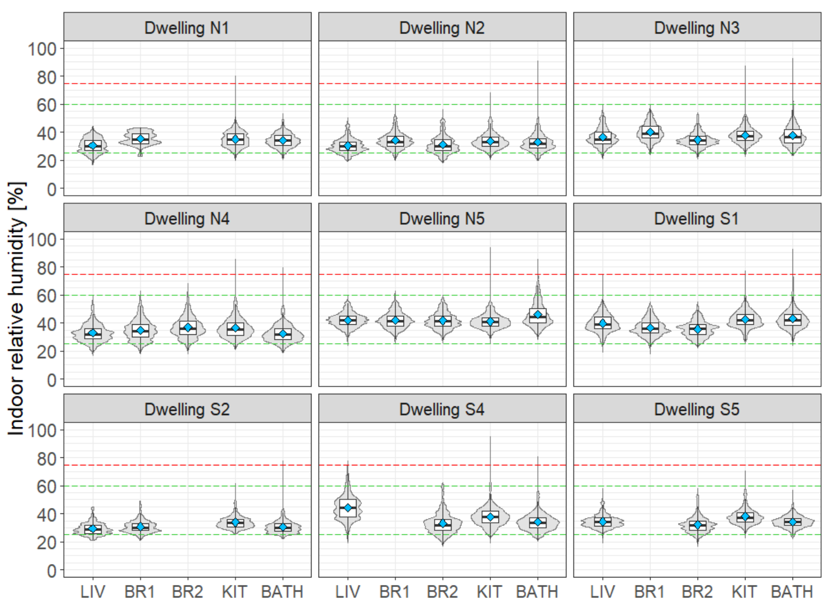


Figure 5 Violin plots of indoor relative humidity measurements in each apartment (KIT: kitchen, BR1: bedroom 1, BR2: bedroom 2, BATH: bathroom, WC: toilet).

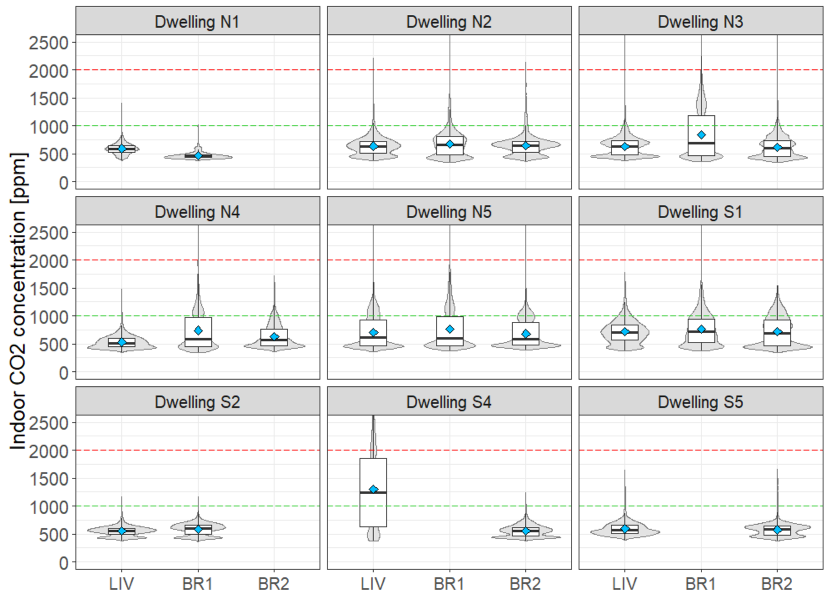


Figure 6 Violin plots of indoor CO_2 concentration measurements in each apartment (KIT: kitchen, BR1: bedroom 1, BR2: bedroom 2, BATH: bathroom, WC: toilet).

Table 1. Results of CO2-based performance indicators

Apartment	Location	Count *hours*	Hours above 1000 ppm *hours (%)*	Hours above 2000 ppm *hours (%)*	ppm hours above 2000 *ppm.h*
N1	Living	967	3 (0.3%)	0 (0%)	0
	BedRoom1	294	0.3 (0.1%)	0 (0%)	0
N2	Living	2951	69 (2.3%)	0.8 (0%)	1,784
	BedRoom1	2950	**222 (7.5%)**	7.5 (0.3%)	17,762
	BedRoom2	1418	53.7 (3.8%)	0.5 (0%)	1,033
N3	Living	2273	60 (2.6%)	0 (0%)	0
	BedRoom1	2951	**985 (33.4%)**	45.7 (1.5%)	108,463
	BedRoom2	2951	94 (3.2%)	0 (0%)	0
N4	Living	2950	11 (0.4%)	0 (0%)	0
	BedRoom1	2951	**688 (23.3%)**	42.2 (1.4%)	113,148
	BedRoom2	2437	**157 (6.4%)**	0 (0%)	0
N5	Living	2951	597 (20.2%)	0 (0%)	0
	BedRoom1	2951	**740 (25.1%)**	28.7 (1%)	66 003
	BedRoom2	2951	**444 (15.1%)**	0 (0%)	0
S1	Living	2099	**176 (8.4%)**	0 (0%)	0
	BedRoom1	2950	**554 (18.8%)**	6 (0.2%)	15,195
	BedRoom2	2950	**513 (17.4%)**	0 (0%)	0
S2	Living	2950	1 (0%)	0 (0%)	0
	BedRoom1	2951	1 (0%)	0 (0%)	0
S4	Living	2951	**1,741 (59%)**	**570.3 (19.3%)**	**1,352,686**
	BedRoom2	2950	4 (0.1%)	0 (0%)	0
S5	Living	2950	34 (1.2%)	0 (0%)	0
	BedRoom2	2950	19 (0.6%)	0 (0%)	0

Indoor CO_2 concentration. Figure 6 and Table 1 present the results of the CO_2 measurements and the CO_2-based performance indicators. All measurements in the livings never exceeded 2000 ppm, and met the requirement of the French regulation DCV, except in the living of the apartment S4, which led to a cumulative exposure far above 400,000 ppm.h. Actually, the apartment S4 is occupied by four students, with two students living in the living room.

Measurements in bedrooms slightly exceeded 2000 ppm in some apartments (especially in bedrooms occupied by two adults), during less than 5% of the measurement period. Cumulative exposures were all below the threshold of 400,000 ppm.h. However, measurements exceeded more frequently 1000 ppm, especially in bedrooms occupied by two adults.

CONCLUSION

A hybrid ventilation system in renovated multi-family apartment building was assessed during four months of the heating season regarding thermal comfort and IAQ criteria. The hybrid system was running in the mechanical mode almost permanently over the 4 months of measurements, with a static pressure between 10 and 25 Pa.

Regarding thermal comfort criteria, measured indoor temperature and RH were within the comfort range almost all the time. The apartments were properly heated thanks to the heating system. It is interesting to notice spatial variations of indoor temperatures between rooms within the same apartment with bedrooms being slightly cooler than other rooms.

Regarding the IAQ criteria, measured RH and CO_2 concentration met the requirements of the French regulation for DCV. However, CO_2 concentration exceeded more frequently 1000 ppm in the bedrooms occupied by two adults.

The results of this case study show a good performance of the studied hybrid ventilation system over the measurement period regarding the selected performance criteria. However, as the ventilation system was running in the mechanical mode almost permanently, measurements have only permitted to characterize then the mechanical mode of the ventilation system. It is difficult to conclude about the ventilation system during the natural mode. Moreover, it is also difficult to conclude on its performance during the entire heating season or the complete year. One way to achieve this is to use the modelling approach coupled to measurements over a short period enabling thus the performance assessment of such systems at all the heating season and covering both natural and mechanical modes. This needs to address the issue of defining the boundary conditions and the assumptions needed for the modelling. In addition, other IAQ performance criteria need to be investigated to better characterize the IAQ. Work is ongoing as part of the project to test the coupled modelling-measurement approach.

ACKNOWLEDGMENTS

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