Experimental study of the combination of a positive input ventilation and active air vents on the air change rates of a house

Antoine Leconte*[1], Clément Lafféter[2], Thomas Fritsch[3], Nicolas Giordano[3], Julien Escaich[2] and Ophélie Ouvrier Bonnaz[1]

1 Univ Grenoble Alpes
CEA, LITEN, DTS, INES
F-38000 Grenoble, France
**Corresponding author: antoine.leconte@cea.fr*

2 Ventilairsec
16 rue des Imprimeurs
F-44220, Couëron, France

3 Bubendorff
24 rue de Paris
F-68220, Attenschwiller, France

ABSTRACT

This study aims to experimentally evaluate the influence of the combination of a supply only ventilation, called here positive input ventilation, and innovative active air vents on the Indoor Air Quality of a house. The positive input ventilation draws fresh air from the outside, filters and pre-heats it before blowing it in living areas. Active air vents are small motorised damper set up in upper parts of windows that can move according to local pollutants measurements or according to the measurements of the other active air vents in the house. This combination is expected to improve the Indoor Air Quality by increasing efficiently the air change rate of a room when it is too polluted. The goal of the tests presented in this paper is to evaluate quantitatively the air change rate in a real scale for different configurations of this combination. To do so, a positive input ventilation and active air vents are set up in an experimental house. The tests were carried out in 3 different rooms. For each room, the air change rate is evaluated for different configurations of the combination. CO2 is used as a trace gas to evaluate the air change rate. The results of 52 tests are used for those characterizations in order to take into account the possible variability of the results due to the real operation conditions. Results are promising and show that the studied combination enables to modulate significantly the air change rate of each room. An appropriate Demand Control Ventilation strategy based on the sensors of each active air vents and the communication between all the devices would thus lead to an efficient while simple improvement in the use of a positive input ventilation system.

KEYWORDS

Positive Input Ventilation, Active Air Vents, Real Scale Experimentation, Air Change Rate Estimation

1 INTRODUCTION

Indoor air pollution is one of the biggest environmental risks to public health. Most policies, at European scale (European Commission, 2013) and national scales ((Direction générale de la Santé, 2013) for the French case), agree on the importance of improving the indoor air quality and the related benefits. On the other hand, new buildings are more and more airtight in order to reduce their energy consumption. Thus it is important to develop and use optimal Demand Control Ventilation (DCV) systems in order to ensure healthy and comfortable internal environment while keeping an appropriate level of energy consumption. Numerous DCV systems has been studied for decades, as reviewed by (Fisk & De Almeida, 1998) and (Guyot, Walker, & Sherman, 2018) for instance. Some DCV systems for dwellings are based on Indoor Air Quality (IAQ) sensors to modulate the air removal from wet rooms, like those introduced by (Faure, Losfeld, Pollet, Wurtz, & Ouvrier Bonnaz, 2018). However, most of them are only based on exhaust mechanical ventilation and can be complicated to set up if the control and the process of the supply air is also required.

This study aims to experimentally evaluate the influence of a new simple combination of a supply mechanical ventilation system with innovative active air vents on the IAQ of a house that would lead to an effective DCV system.

2 DESCRIPTION OF THE TESTED SYSTEM

2.1 Positive Input Ventilation (PIV)

The Positive Input Ventilation (PIV), also known as Supply-Only Ventilation, is a mechanical ventilation that draws fresh air from the outside, filters and pre-heats it before blowing it in one or several supply points in the building. Thus, the whole building is slightly pressurize which makes internal air leaks out through intentional vents. The U.S. Department of Energy (U.S. Department of Energy, 2002) introduces supply ventilation systems as relatively simple and inexpensive systems that allow a good control of the incoming air (including pollens and dust filtering) while discouraging the entry of pollutants from outside the living space and avoiding back drafting of combustion gases from fireplaces and appliances. The performance of such a system has been studied and optimized by (Rahmeh, 2014) in its PhD and by (Ouvrier-Bonnaz, Rahmeh, Stephan, & Potard, 2015) for instance. To the knowledge of the authors, the PIV has only been studied with passive air vents as evacuation points, which do not allow to significantly control and modulate the air removal between the rooms – as with the Active Air Vents introduced hereunder.

Figure 1: Pictures of the Positive Input Ventilation in the experimental house – Left: Central ventilation device in the attic, Right: Air diffusing unit in the first floor hall

2.2 Active Air Vents (AAVs)

Active Air Vents (AAVs) are small motorised damper, patented by BUBENDORFF (Europe Brevet n° EP3396267 A1, 2018). They are made up of:

- One main opened still plastic frame;

- One smaller opened metallic frame on the opening of the main frame, moved by an electric motor;
- One slat between the still frame and the mobile frame, independent so that it can close the opening when the mobile frame is opened to prevent the outside air from entering the house this way (like a double check valve);
- One electronic card that controls the motor, measures IAQ variables close to the opening, sends and receives information from the other AAVs.

As introduce in section 1, nowadays, some devices already use pollutants measurements in several rooms to adjust their air removal. However, most of them are implemented on exhaust mechanical ventilations which makes impossible to benefits from the advantages of the supply mechanical ventilation (see section 2.1). AAVs are easy-to-install and easy-to-use modules that would further improve the air quality management of a PIV.

For the tests presented in this paper, AAV prototypes were set up in upper parts of every window of the experimental house (see Figure 2).

Figure 2: Pictures of one AAV prototype in the experimental house – Left: From inside, Right: From outside

Thanks to its different parts, an AAV can have three different positions (see Figure 3, where the mobile frame is marked to clearly identify its position):

a) “Minimal position” – the mobile frame is completely closed on the main frame with an adjusting screw that leaves a slight opening;
b) “Maximal position” – the mobile frame is completely opened and the higher pressure inside the building than outside keeps the slat on the metallic frame;
c) “Non-return damper” – the mobile frame is completely opened but the higher pressure outside the building closes the slat on the opening so that the outside air can’t enter the house this way.

(a) (b) (c)

Figure 3: Pictures of the 3 possible positions of a tested AAV – (a) Minimal position (b) Maximal position (c) Non-return damper

The control card measurements and communications enables the closing or opening of a AAV according to its own measurement and also according to the measurements of the other AAVs, creating this way as a possible concerted action.

2.3 Combination of PIV and AAV

The combination of PIV with AAVs is expected to improve the IAQ of the building by increasing efficiently the air change rate of a room when needed. The fresh air blown by the PIV in the building can be smartly directed to the more polluted rooms.

For instance, the operation steps could be as follow (see **Error! Reference source not found.**):

a) *Initial state – standby mode*: the IAQ is satisfactory in all rooms of the building, every AAV is in "Minimal position" so the fresh air from PIV is distributed in the different rooms in an almost balanced way.
b) *Foul air in one room – autonomous action*: the concentration of a pollutant is high in one room, the AAV of this room switches to the "Maximal position" so the fresh air from PIV is preferably directed to this room.
c) *Foul air in several rooms – autonomous actions*: the concentration of a pollutant is high in several rooms but still in a reasonable level, the AAV of those rooms are in "Maximal position" so the air change rate is increased in all those rooms in the same time.
d) *Foul air in several rooms – concerted actions*: the concentration of a pollutant is high in several rooms and especially in one room where the concentration is above a critical level, the AAV of this room holds the "Maximal position" while all others switch to "Minimal position", so the critical room is treated in priority until its pollutant level returns to an appropriate level. The warning signal can also be sent to the PIV in order to temporarily increase the fresh air flow rate.

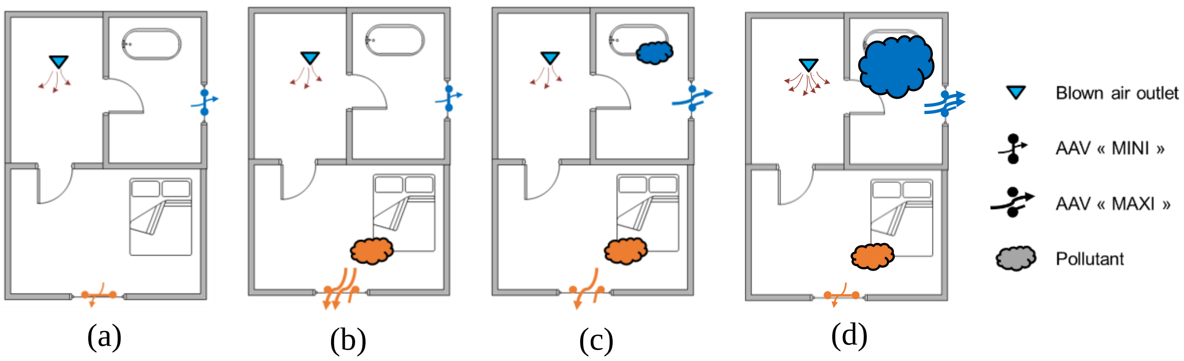

Figure 4: Different possible states of the combination of PIV and AACs to improve efficiently the IAQ of the building – (a) Steady State (b) Pollutants in one room with autonomous action (c) Pollutants in several rooms with autonomous actions (d) Critical level of pollutants in one room and concerted action

3 EXPERIMENTAL PROTOCOL

3.1 Goal of the tests and global approach

The goal of the tests presented in this paper is to quantify the impact of the studied PIV+AAVs combination and the different steps presented in section 2.3 on the air circulation in a building. No specific regulation is considered here (no specific pollutants levels for AACs opening for instance). The main idea is to assess the air change rate of different rooms of the building according to the possible positions of AAVs and fresh air flow rate in a real scale.

To do so, a PIV and AAVs are installed in an experimental house. For each test, the required configuration (mainly fresh air flowrate and AAVs position) is setup. The air change rate is estimated thanks to CO2 used as trace gaz. Each test is repeated several times in order to estimate the variability of the results.

3.2 Experimental setup

The equipped experimental house (see **Error! Reference source not found.**) is located in Le Bourget du Lac (France). It was built in 2011 with a recent constructive principle. The air tightness of the building was characterized thanks to blower door tests: the air change rate was 0.26vol/h at 50 pascal (69m^3/h) at the end of the construction work.

The living area is about 100m², on two levels:

- First floor : one large room (kitchen [KIT], dining [DIN] and living room [LIV]) and a cellar [CEL];
- Second floor: 3 bedrooms ([BED1], [BED2] and [BED3]), one bathroom [BATH], one toilet [WC].

Floors and rooms are represented on Figure 5 below.

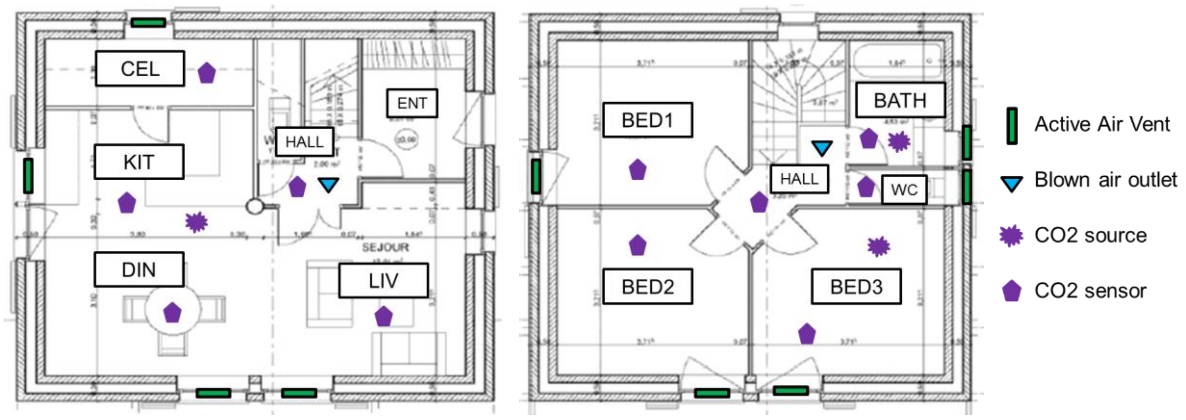

Figure 5: Introduction of the experimental house – Left: Plan of the first floor. Right: Plan of the second floor.

The PIV is set up in the attic. The fresh air is blown through two air outlets: one in the hall of each level (see Figure 5 and Figure 1 above). The global blown air flowrate is measured thanks to an ultrasonic air flow meter (*ULTRAFLUX 2000*). AAVs are set up in upper parts of every window of the experimental house (see Figure 5 and Figure 2 above). Sensors (*KIMO COT 212*) measure the CO2 concentration in the main rooms of the building. A set of CO2 bottles, pressure reducer and gas pipes enables to inject pure CO2 in the required room. A fan is used to homogenise the gas for the initialization of the test (see section 3.4). The complete experimental setup is summarized by the Figure 5.

3.3 Tested configurations

The tests are carried out in 3 different rooms:

- [BATH]: the bathroom (second floor – volume around 16m^3);
- [BED3]: One bedroom (second floor – volume around 39m^3);
- [KIT]: Kitchen + Dining + Living room (first floor – volume around 126m^3).

For each room, the air change rate is evaluated for different configurations of the combination:

- [REF]: With a classic static air vent (*ANJOS VM-G* self-regulation units);
- [MIN]: With all the AAVs of the room at the “Minimal position”;
- [MAX]: With all the AAVs of the room at the “Maximal position”.

For the first case, every window is equipped with a classic air vent (no AAV at all in the building). For all other tests, classic air vents are removed and the AAVs of the other rooms remains at the “Minimal position”, except for some of the “concerted operation” tests which both bathroom’s and bedroom’s AAV are opened together to estimate the potential of the concerted action (see section 2.3 and 4.2). All internal doors are properly undercut and kept closed during the tests. All blinds are partially closed except for the tested room. The nominal speed of the PIV fan for this house (speed “2”) is kept the same for all those tests except for some of the “concerted operation” tests: the speed is occasionally raised in order to estimate the impact of a possible communication (see section 2.3 and 4.2).

3.4 Air Change Rate estimation

The air change rate for each test is estimated thanks to CO2 used as a trace gas. The procedure is as follow:

- The experimental setup is tuned according to the room and the configuration to be tested;
- The studied room is filled with CO2 up to a high concentration, around 5000ppm, with the homogenisation fan turned on;
- The CO2 injection is stopped and so is the fan couple of minutes later;
- The decrease of the CO2 concentration is measured to estimate the air change rate.

As described by (Etheridge & Sandberg, 1996), the CO2 mass balance inside the studied room, taking into account the incoming and the outgoing CO2, links the air change rate and the CO2 concentration variation (see equation (1)).

$$\tau . dt = \frac{dC}{C_e - C} \tag{1}$$

According to equation (1), the air change rate (τ) can be estimated by computing the negative slope of the time evolution of the logarithm of the difference between the concentration in the studied room (C) and in its environment (C_e). In this case, the concentration C_e is considered as the measured concentration in the halls, where the PIV blows the fresh air (first floor hall for the tests in the kitchen, second floor hall for the tests in the bathroom and the bedroom). The inherent hypothesis is that the fresh air always goes from the halls to the studied room and then evacuated outside. The opposite case has never been observed on those tests. An example of the air change rate estimation is presented by Figure 6. For all the results selected for this analysis, the regression coefficient of the air change rate estimation is above 0.98.

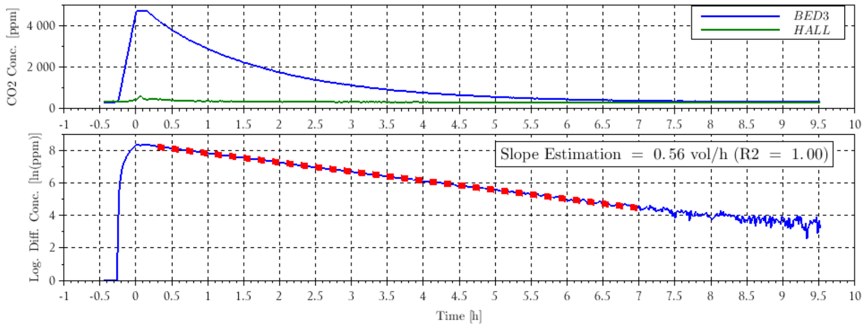

Figure 6: Estimation of the air change rate for one test – Upper: CO2 concentrations in the studied room and its environment. Lower: Logarithm of the differential concentration and slope estimation (red dots)

4 RESULTS

Results from 52 tests are used to characterize the air change rate in the different rooms, for the different configurations. Each configuration is tested several times in order to take into account the possible variability of the results due to the operation conditions, mainly the weather conditions during the tests. For each characteristic presented below (air change rate and global blown air flowrate), the number of tests considered and the standard deviation σ is presented (in brackets).

4.1 Autonomous operation of the AAVs in each room

Results of the tests for characterizing the AAVs' autonomous operation are presented in Table 1 and Figure 7. The autonomous operation in one single room is described by steps a) and b) in section 2.3 and **Error! Reference source not found.**. The tests were carried out between January and June 2018.

Table 1: Results of the tests for characterizing the AAVs' autonomous operation

Room	AAV Configuration	PIV fan speed	Number of tests	Global blown air flowrate [m3/h]	Air change rate [vol/h]
BED	REF	2	3	148 (σ=1)	0.58 (σ=0.02)
BED	MIN	2	7	159 (σ=2)	0.66 (σ=0.05)
BED	MAX	2	4	160 (σ=1)	1.53 (σ=0.04)
BATH	REF	2	3	150 (σ=3)	1.34 (σ=0.13)
BATH	MIN	2	4	157 (σ=6)	1.61 (σ=0.41)
BATH	MAX	2	4	157 (σ=6)	3.74 (σ=0.76)
KIT	REF	2	2	151 (σ<0.5)	0.85 (σ=0.03)
KIT	MIN	2	5	162 (σ=5)	1.03 (σ=0.17)
KIT	MAX	2	3	167 (σ=3)	1.51 (σ=0.13)

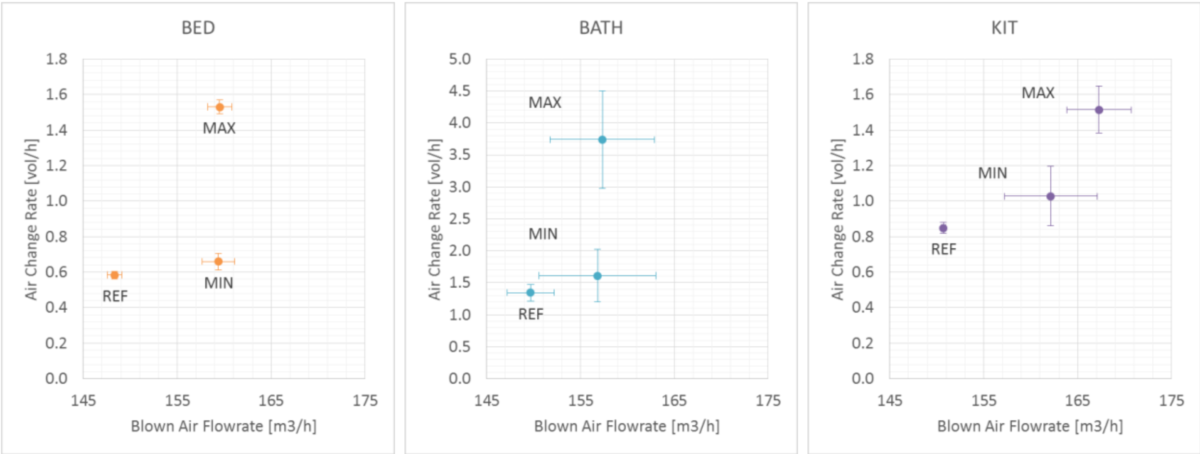

Figure 7: Evolution of the air change rate according to the AAV configuration in each tested room

The global blown air flow rate vary from 148 to 169m^3/h whereas the fan speed is the same for each test. This is due to the changing weather conditions that can naturally introduce variation on the volumetric flow rate of a fan even with the same speed. That is why Figure 7 shows air change rate estimations according to the measured global air flow rate. This representation enables to clearly distinguish the impact of the input air flow from the impact of the AAV configuration on the air change rate of each room.

Firstly, for each room, considering the global blown air flowrate changes and the standard deviations, the air change rate with the minimal position of the AAV is similar to the case with classic air vents. The gap could be even reduced by working further on the setup and the tuning of the AAVs in their "minimal position".

Comparing the results between "minimal position" and "maximal position", still including their standard deviation, it can be stated that the opening of the active air vent raises significantly the air change rate for each room : from 1.5 times more in the kitchen to 2.3 times more in the bathroom when considering the average values.

This means that in this case, an appropriate control of the autonomous action of the AAVs would treat basic IAQ issues very efficiently by changing significantly the air change rate of a room when needed.

4.2 Concerted operations between AAVs and the PIV

Additional tests were carried out in order to evaluate the relevance of a concerted action between the AAVs and with the PIV as well. The concerted operations in one single room is described from step a) to d) in section 2.3 and **Error! Reference source not found.**. For those tests, the trace gas is injected simultaneously in both the bedroom and the bathroom. The CO2 injection is then stopped at the same time and the air change rate estimated over the same period. The tests were carried out between July and August 2018. For this campaign, some AAV prototypes were changed and the bathroom and bedroom blinds were kept both opened. So the following results can't be strictly compared with the previous ones in section 4.1.

Table 2: Results of the tests for characterizing the AAVs' concerted operation

Step	AAV configuration in the bedroom	AAV configuration in the bathroom	PIV fan speed	Nb of tests	Global blown air flowrate [m3/h]	Air change rate in the bedroom [vol/h]	Air change rate in the bathroom [vol/h]
a)	MIN	MIN	2	4	168 (σ=2)	0.52 (σ=0.03)	1.27 (σ=0.14)
b)	MAX	MIN	2	3	171 (σ=1)	1.28 (σ=0.12)	1.31 (σ=0.10)
c)	MAX	MAX	2	3	168 (σ=3)	1.32 (σ=0.07)	3.59 (σ=0.28)
d)	MIN	MAX	2	3	165 (σ=4)	0.56 (σ=0.02)	4.52 (σ=0.37)
d')	MIN	MAX	4	4	236 (σ=18)	0.66 (σ=0.02)	5.71 (σ=0.25)

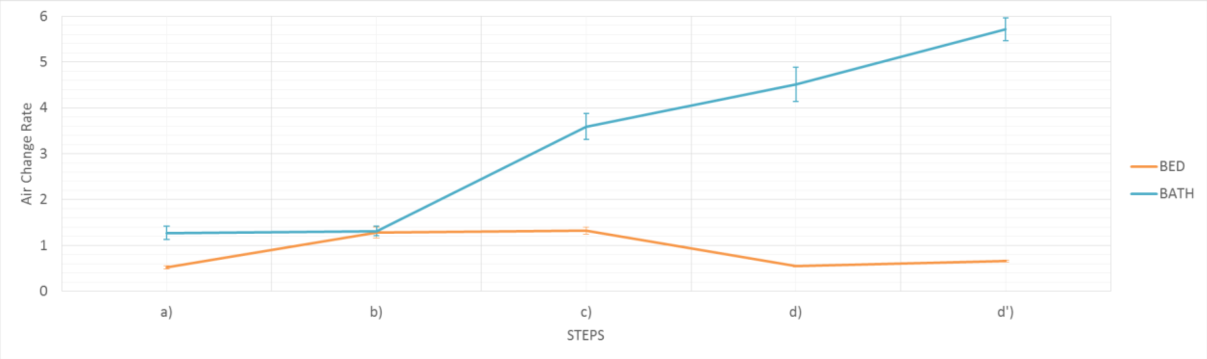

Figure 8: Evolution of the air change rate in the bedroom and the bathroom according to the possible steps of the AAVs and PIV concerted operation

The impact of the AAVs and PIV operations is clearly visible:

- From step a) to b) (pollution in the bedroom for example) :

The opening of the AAV in the bedroom increases the air change rate significantly in the bedroom but hardly impacts the air change rate in the bathroom.

- From step b) to c) (additional pollution in the bathroom for example):

The opening of the AAV in the bathroom highly increases the air change rate in the bathroom but hardly impacts the air change rate in the bedroom. The latter is a little increased in average but not significantly with regards to the standard deviations.

- From step c) to d) (critical pollution level in the bathroom for example):

The closing of the AAV in the bedroom brings a significant extra increase of the air change rate – around 25% in average in this case. The air change rate level in the bedroom is similar as the step a) case.

- From step d) to d') (PIV fan speed increased by 2 levels):

When the PIV fan speed is increased, the air change rate raises by another 25% in the bathroom in this case. And since the other AAVs are closed, the additional air flow rate is preferably led to the bathroom (the air change rate in the bedroom is hardly increased in this case).

Those results show that the communication between AAVs and the PIV could treat very efficiently critical pollution cases – when the bathroom is too humid for instance. In the latter configuration, the bathroom air would be completely removed in a few dozen minutes.

5 CONCLUSIONS

A combination of a central Positive Input Ventilation (PIV) and distributed Active Air Vents (AAVs) in each room were tested in an experimental house. Several tests were carried out to characterize the air change rate of different rooms with different combinations of AAVs and PIV. The results can be summarized as follows:

- The air change rate of minimal position AAVs is similar to classic ones,
- The opening of the AAV in a room raises significantly its air change rate when all others are in “MINI” position (from 1.5 times more in the kitchen to 2.3 times more in the bathroom),
- The closing of the bedroom air vent when the bathroom air vent is opened raises by around 25% the air change rate of the bathroom, which could be very helpful as a concerted action to treat critical situations, when the bathroom is exceedingly humid for instance.

Those results show the relevancy of using AAVs with a PIV to improve the IAQ of a house. The air change rate of each room can be significantly modulated when needed. So with an appropriate sensor based DCV strategy, the PIV + AAVs system could be very effective. The hysteresis opening of the active air vent - as autonomous operation - would have a significant impact on the pollution venting of a room. The concerted action could even enhance the pollution venting with appropriate critical thresholds. The tested system could then offer a lot of possibilities to smartly modulate the air change rate of each room (damp room as well as living room) according to its pollution level.

6 ACKNOWLEDGEMENTS

This work was supported by the French Unique Interministerial Fund (FUI).

7 REFERENCES

Direction générale de la Santé. (2013). *Plan d’actions sur la Qualité de l’Air Intérieur.* Obtido de https://solidarites-sante.gouv.fr: https://solidarites-sante.gouv.fr/IMG/pdf/Plan_Qualite_de_l_air_interieur_octobre_2013.pdf

Etheridge, D., & Sandberg, M. (1996). *Building Ventilation: Theory and Measurment.* John Wiley & Sons.

European Commission. (18 de 12 de 2013). *Environment: New policy package to clean up Europe's air.* Obtido de http://europa.eu/: http://europa.eu/rapid/press-release_IP-13-1274_en.pdf

Faure, X., Losfeld, F., Pollet, I., Wurtz, E., & Ouvrier Bonnaz, O. (2018). Resilient Demand Control Ventilation system for dwellings. *39th AIVC Conference.* Juna Les Pins, FRANCE.

Fisk, W. J., & De Almeida, A. T. (1998). Sensor-based demand-controlled ventilation: a review. *Energy and Buildings*, 35-45.

Fritsch, T. (2018). *Europe Patente Nº EP3396267 A1.*

Guyot, G., Walker, I. S., & Sherman, M. H. (2018). Performance based approaches in standards and regulations for smart ventilation in residential buildings: a summary review. *International Journal of Ventilation*, 1-17.

Ouvrier-Bonnaz, O., Rahmeh, M., Stephan, L., & Potard, M. (2015). Whole-house air distribution with a supply-only ventilation system VMI® for an optimum air change. *CLIMAMED 2015 Congress Sustainable Energy Performance of Buildings.* Juan Les Pins.

Rahmeh, M. (2014). *Etude expérimentale et numérique des performances de la ventilation mécanique par insufflation : qualité de l’air intérieur dans les bâtiments résidentiels.* La Rochelle: Université de la Rochelle.

U.S. Department of Energy. (2002). *Whole House Ventilation Systems - Improved control of air quality - Technology Fact Sheet.* Obtido de https://www.nrel.gov: https://www.nrel.gov/docs/fy03osti/26458.pdf