Ductwork design flaws and poor airtightness: a case study about a ventilation system reconditioning in a sealed building

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ABSTRACT

In a sealed building with tight facades, conditions for a good indoor air quality and comfortable conditions must be guaranteed all the time especially for employees. This paper deals with the case of a specific retrofitted building without any openings that immediately shows many difficulties to maintain good indoor air quality in some parts of the occupied volume. An assessment of ductwork and HVAC system performance was first realized, conducted by the SNIA (National Airport Engineering Service). This analysis enabled to explain both the poor performance of the ventilation system observed by facility managers at the building scale, and the local Indoor Air Quality (IAQ) discomfort mentioned by occupants.
This paper presents the method and results based on an experimental approach with measurements (pressure and airflow rate in the ductwork, airtightness testing of the ductwork), calculation of pressure drops, and observations (duct and internal envelope leakages search, airflow pattern) in order to identify the causes of the current ventilation dysfunction.
The diagnosis showed that the major problem was due to the poor performance of two supply ventilation ducts (leakages and pressure drops) called A & B, with impact on the fan blowing pressure and on pressure along ducts. Reconditioning measures were proposed by SNIA, including the near-full replacement of ventilation ductwork A and its Air Handling Unit (AHU - 2200 m^3/h), the use of a duct sealing solution for ventilation ductwork B and the installation of a fan speed controller on its AHU (1900 m^3/h).
This paper also illustrates the results based on commissioning period after the 2017 upgrading to check all the installation with duct pressure test, airtightness testing, airflow measurements, electric power input for fans and sound pressure level.

KEYWORDS

airtightness, ventilation system, ductwork design, duct sealing, commissioning

1 INTRODUCTION

Ventilation is essential for securing acceptable air quality in each building by diluting and extracting indoor pollutants and by supplying new air. At the same time, it accounts for 30% or more of space conditioning energy demand (Liddament, 1996). Ventilation standards and regulations about working condition set the requirements for the minimum ventilation rates (French labour code (1984)). The ventilation needs in a sealed building are achieved by mechanical means in order to respect proper airflow in each room, pollutants transfer between room (Richieri, 2016), overpressure of the whole volume, compliance with fire regulations such as for high-rise buildings (CCH 2011), air-inlet treatment with filtering, heating/cooling and dehumidification process.

Ventilation system must be able to ensure a minimum supplied airflow rates greater than a limit depending on number of occupants in each room. At the same time, constant supplied airflow rates are recommended for specific activities in order to induce globally a constant over-pressure of the building.

The studied building is located in France and has no openings due to its specific activities. Thus, indoor air quality conditions, as lightening or thermal ones, are crucial as the task of working without any access to natural light or openings requires a high level of attention and vigilance. As a result, comfortable conditions must be guaranteed all the time. In this paper, we present a building that had many difficulties to maintain good indoor air quality conditions after a complete retrofit of the ductworks in 2012. An assessment of ductwork and Air Handling Unites (AHU) performance was realized by the SNIA which is the main contractor for the project.

2 METHODOLOGY

A poor performance of the air handling system is observed by facility managers at the building scale since the occupation of the site after a long period of retrofit in 2012. The most troublesome phenomena were a bad indoor air quality located in the most distant zones from AHU room.

From 2016, after several months of uncertainty for the site manager about the reasons for these malfunctions, the site manager asked the building department of the SNIA to look for the origin of the ventilation system defects and to propose improvements. The actions carried out by SNIA consisted in the next key steps:

1. a complete ventilation system inspection;
2. a full ventilation system dimensioning, taking into account revised occupancy;
3. the specifications for upgrading all, or part of the air treatment and distribution system;
4. the following-up of the 2017 upgrading carried out by a company according to the SNIA specifications;
5. Commissioning and adjustment of the ventilation system with verification of the flow rates in each room.

This paper presents the results of the ventilation audit based on an experimental approach with both measurements (pressure and airflow rate in the ductwork, building pressure, IAQ), and observations (duct leakages inspection, airflow pattern) in order to understand the current building functioning and to identify the problem causes.

3 BUILDING DESCRIPTION

3.1 Zoning

The one level building has no openings. It was commissioned in 2012 after a long period of renovation, including the retrofit of the ventilation and smoke extraction system, as well as the repair of the heating and air conditioning of occupied and technical rooms. Due to its specificities, the building has a fire safety system. The site is divided into two subdivision zones, called zones A and B, with five local subdivisions (A1, A2, A3) and (B1, B2) for smoke extraction. The boundaries of these zones are composed of fire compartments and fire dampers at each compartment crossing by the ventilation ductwork.

3.2 HVAC system description

Heating and cooling systems
The occupied rooms (kitchen, offices, bedrooms ...) are equipped with 4 tubes - fan coil with local control of the indoor temperature. The technical rooms are cooled by precision air conditioning units.

Ventilation system
Air renewal is based on a supply-only mechanical ventilation done by two Air Handling Units (AHU) located in the HVAC room via two blowing ductworks (Zones A and B) as shown in the figure 1. The ductworks used to deliver air from HVAC room to each rooms are galvanized steel formed into rectangular for high flows, then circular from the diameter 250 mm in the middle and end of the ductwork.

Cooling capacity of each equipment enables refresh external air and dehumidification. The Schneider Electric Programmable Logic Controler (PLC) operates two units to control the supplied temperature. A remote supply air Temperature sensor, located in each supply air path, senses the actual air supply such as temperature and humidity and compares it to its fixed set point (cooling capacity of each unit is modulated on the opening control 3-way valves, with a fixed fan speed).
The volume includes air-outlet openings located in corridors.

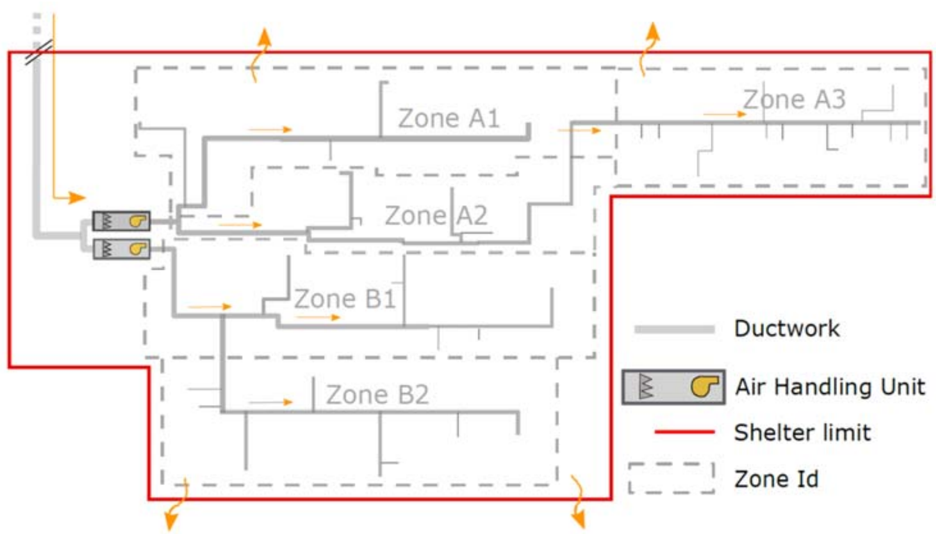


Figure 1: Ventilation principle in the building

The two AHU are identical, equipped with cooling coil running with chilled water, and an electric coil for heating and air-dehumidifying process. A programmable logic controller (PLC) activates a chilled water 3-way valve and a triac power to control the fresh air supply temperature measured by a temperature and hygrometry probe in each duct. Supply air is then blown into each room by diffusers whose flow is self-regulating by registers. The return air from each room exfiltrates towards the corridors through ceiling openings. Table 1 gives the main characteristics of the two AHU.

Table 1: Air handling equipment used for ventilation

Mode	AHU	Heating/Cooling capacity	Airflow
AHU n°1 (Zone A)	Air Handling Unit (2-pipe)	Max Heating capacity: 27 kW elec Total cooling Capacity: 11 kW	Design : 1800 m^3/h
AHU n°2 (Zone B)	Air Handling Unit (2-pipe)	Max Heating capacity: 27 kW elec Total cooling Capacity: 11 kW	Design : 1800 m^3/h

3.3 Indoor air quality before the 2017 upgrading

The site manager regularly conducts indoor air quality measurement campaigns at various points in the building, based on targeted measurements of pollutants related to the occupancy or combustion pollutants (CO_2), and pollutants related to construction products (total VOCs). The results of the measurement campaigns are illustrated by the next two figures.

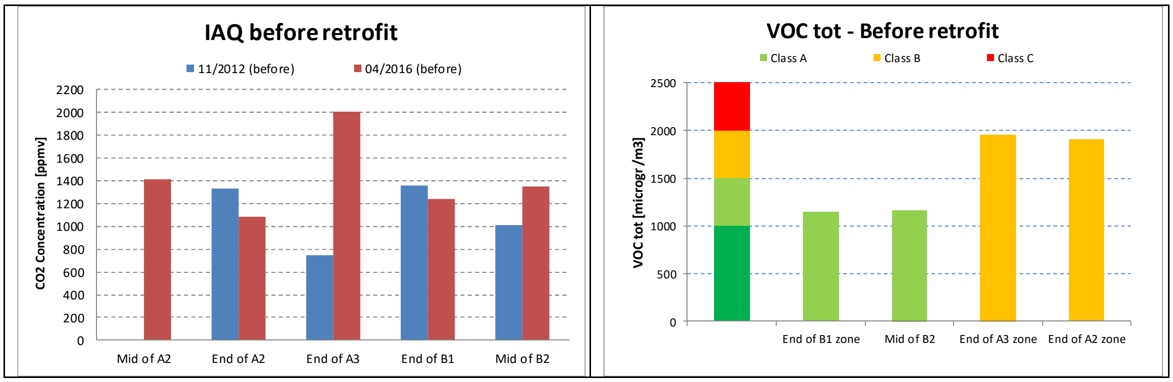


Figure 2: CO_2 (left) and VOC (right) measurements done before upgrading the ductwork and the equipment

CO_2 measurements between 2012 and 2016 showed thresholds greater than 1000 ppmv and sometimes more reaching nearly 2000 ppmv in 2016 in the end of the A3 zone located far away from the AHU room. It should be noted that zone A3 was not occupied in 2012 during the measurement campaign, which results in a low threshold in the absence of human presence.

The total VOC measurements were carried out after the 2012 refurbishment. The levels are compared with the thresholds defined in Legifrance (2011). Again, the measurements showed that the ductwork branch in the end of zone A3 and the whole zone A3 had problems of air renewal and high concentration of pollutant (class B). A search for specific sources of pollution was also carried out to detail the majority VOCs. However, the presence of a large total VOC concentration with high CO_2 levels was a sign of under-ventilation, justifying the SNIA's request for intervention.

4 VENTILATION SYSTEM INSPECTION

4.1 Duct pressure and air flow measurement

The manager initially commissioned by his services, and then by the initial designer of the installation, measured room by room and checked compliances with specifications of the 2012 refurbishment. The results of this measurement campaign are synthesized by zone in the next figure.

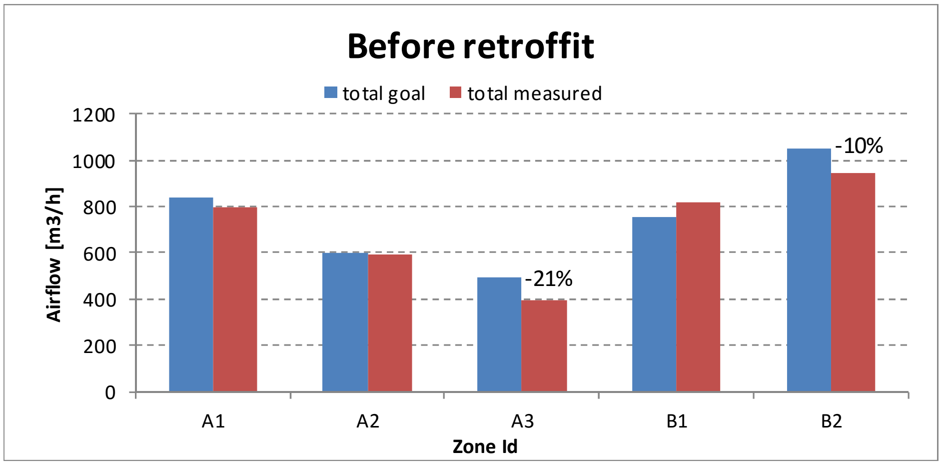


Figure 3: Comparison between measured ventilation rates and regulatory flows for 5 major zones after the 2012 refurbishment, before 2017 upgrading

As we can see, the zone A3, furthest from the AHU room, is globally under-ventilated with total measured airflow rate lower than the specifications of the 2012 refurbishment by -21% , and locally from -30 to -70% (on the basis of a sizing airflow of 15 m^3/h/person).
The ventilation in zone B is better, with an average air-renewall 10% lower than the target in zone B2, furthest from AHU room, with locally -13 to -53%.
Flow measurements were also performed at the outlet of each AHU, and this measurement was compared to the sum of airflow rates of each outlets (Table 2). The results are initially surprising because in both cases, the supply air-flow rate of each AHU is much higher than the ventilation objective of the site. However, the difference with the sum of each air outlets flowrate was + 31% higher in zone A and + 16% higher in zone B, suggesting a very important leak rate confirmed by airtightness measurements of each ductworks. Measurement accuracy however is estimated to be +/- 20% for Coanda air-outlets measured with cone and hot wire (Promevent - 2017).
In addition, there is a duct pressure drop (nearly 95 Pa) between AHU and the duct portion after the first fire damper. The AHU supply airflow rate of zone A (of 2600 m^3/h instead of 1935 m^3/h) causes a drop in the blowing pressure, as well as high and noisy velocities with more than 6.5 to 7 m/s, auguring singular high pressure losses at each fire damper and elbow.

Table 2: Measurement before retrofitting

Measurement before retrofitting	Zone A	Zone B
AHU supply pressure	280 Pa	313 Pa
Duct pressure after the first fire damper	185 Pa	245 Pa
AHU supply rate	2600 m^3/h	2101 m^3/h
Sum of each air-outlets rates	1783 m^3/h	1765 m^3/h
Difference (leak rate and % of leaks)	817 m^3/h (+31%)	336 m^3/h (+16%)

4.2 Duct pressure test and leakage results

Beyond the under-ventilation finding in distant rooms, these initial investigations were completed by a duct-airtightness campaign on zone A and B. The evaluation of the duct leakage class was carried out by a specialized company according to standard NF EN 12237 (AFNOR – 2003) and FD E51-767 (AFNOR – 2017). The results shown in the figure 4 indicate that ducts were "out of class".

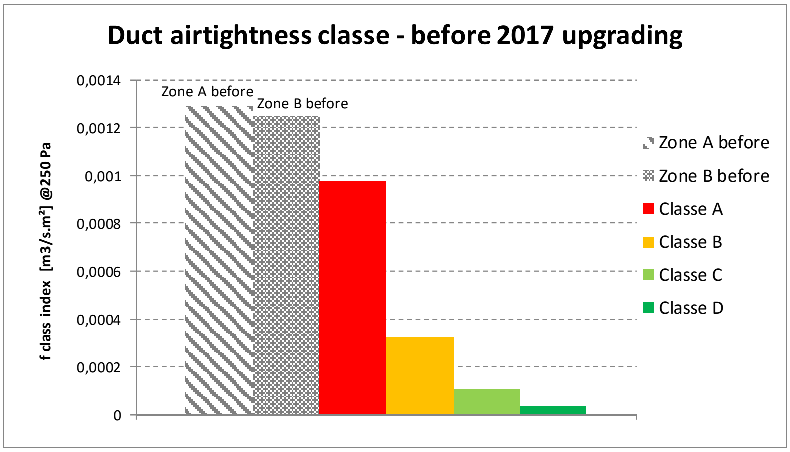
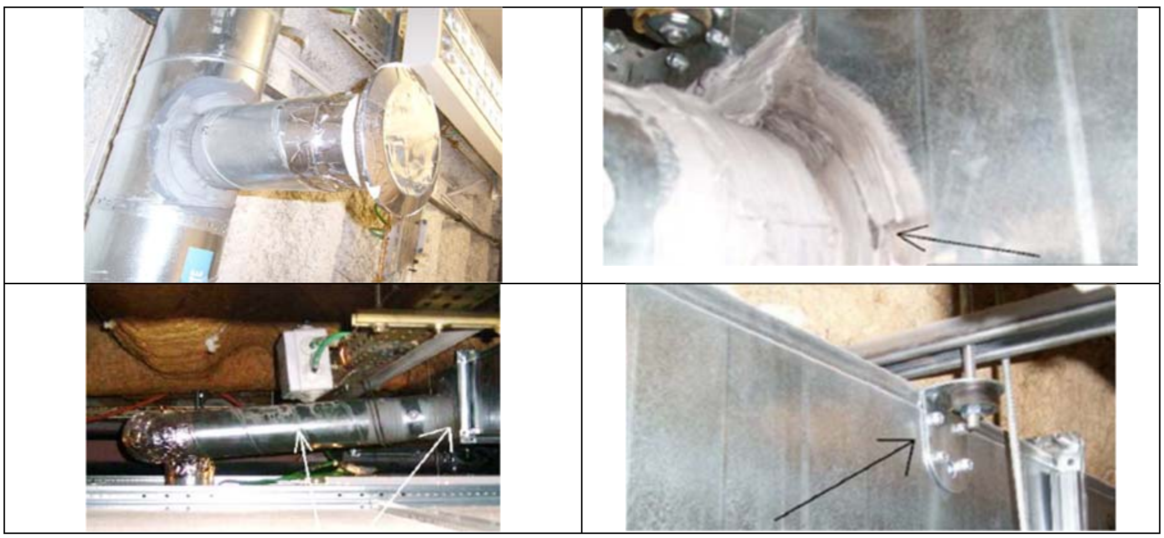


Figure 4: Zones A and B Class performance of duct-airtightness tests before the 2017 upgrading

The leaks search was carried out during the pressure tests and identifies important defects in each duct spigot despite the sealant application. Different examples are seen on newt figures. Many portions of the ductwork have been found to be poorly treated, with also execution difficulties to connect duct with fire dampers.



Figures 5: Examples of ductwork leakages found during test

Cross-investigations with flow measurement, duct pressure measurement, and duct pressure test have shown both poor performances with almost 30% leakage flow, and under-sizing sections resulting in pressure losses along the ductwork.

5 RETROFIT ACTIONS OF VENTILATION SYSTEM

First of all, the retrofitting project of the whole ventilation system has to be in accordance with French regulations, from 15 m^3/h to 25 m^3/h per person, and the expected occupancy in each room. As a result, airflow rates mentioned in the specifications were changed from 1935 m^3/h to 2130 m^3/h (+10%) for zone A, and from 1755 m^3/h to 1905 m^3/h (+ 8.5%) for zone B. In a second step, the SNIA proceeded to a duct sizing check linked to the new ventilation need, and a limiting pressure losses less than 0.8 Pa/m. The next schematic diagram (figure 6) shows:

- replaced ductwork portions because of a problem of under-sizing related to the installation of self-regulated damper (MR Modulo Aldes®) with an operating range of 50 to 250 Pa (in blue);
- conserved ductwork portions fully checked and sealed by the Aeroseal® sealing process (in green);

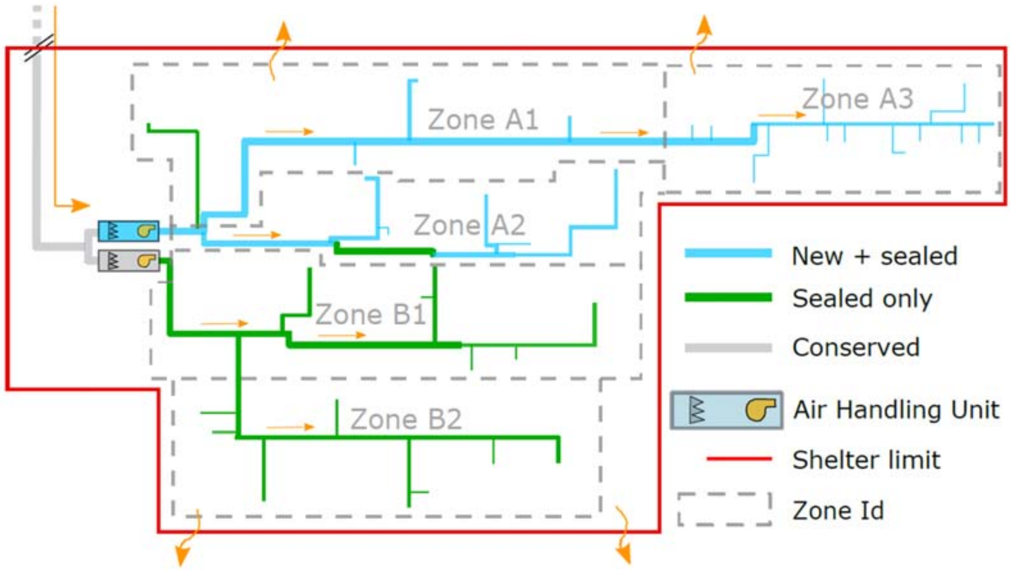


Figure 6: Conserved and replaced ventilation duct and equipment

The path is generally preserved except for the ductwork of the zone A1 which is prolonged towards A3, and a conserved portion of the ductwork in zone A2. The SNIA specifications also mentioned a class B objective for every ductwork, both for new ones and for sealed portions after cleaning / disinfection. All fire dampers of the ductwork A have also been replaced, with the main feature being a significant reduction in singular head losses (<10 Pa per valve).

The AHU used for zone A has been replaced with the consideration of:

- a fan speed variation by maintaining a constant supply pressure with the EC type fan;
- taking into account a suitable available pressure for supply flow and air-inlet, as well as for over-pressurizing the building;
- an improvement of the remote supervision of the equipment;
- the installation of a sound trap in the AHU supply duct;

At the end of the 2017 upgrading on ductwork of zone B, the duct pressure became excessive (+480 Pa). Thus, a frequency converter was installed in order to adjust supply pressure by reducing fan speed.

6 RESULTS AFTER RETROFITTING

6.1 Airflow and pressure measurement

The 2017 upgrading lasted 4 months. Airflow measurements were conducted upon reception in July 2017 on the entire ductwork by a company independent of the HVAC business. As illustrated by figure 7, results by zone are now in accordance with the objective of the specifications at each point of the building.

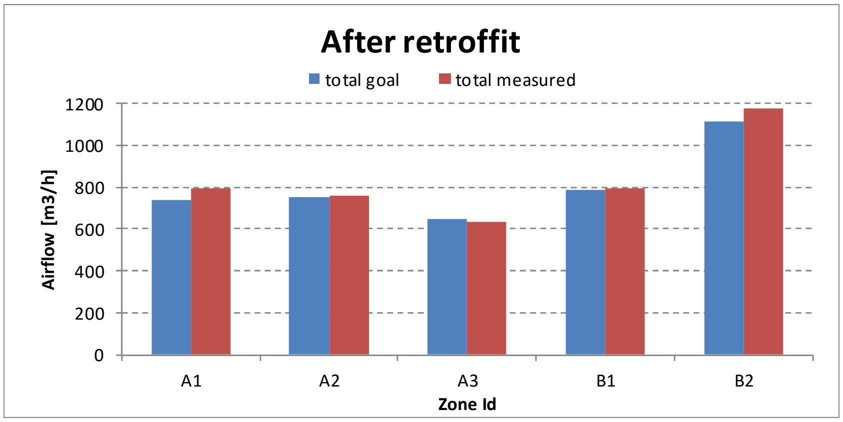


Figure 7: Comparison between measured ventilation rates and regulatory flows for 5 major zones after 2017 upgrading

As detailed on table 3, the duct pressure is now higher with an AHU supply pressure of +350 Pa, which corresponds to the duct pressure needed to maintain a minimum of +80 Pa duct pressure for the last and far self-regulating damper at the end of zone A3. This duct pressure is in accordance with the theoretical calculation of pressure losses for a class B performance. Finally, the difference with the sum of the air-outlets flows is only + 4% in the zone A, and + 6% in the zone B, suggesting a clear improvement in the leakage rate.

Table 3: Measurement after retrofitting

Measurement after retrofitting	Zone A	Zone B
AHU supply pressure	350 Pa	275 Pa
Duct pressure after the first fire damper	280 Pa	200 Pa
AHU supply rate	2293 m^3/h	2095 m^3/h
Sum of each air-outlets rates	2190 m^3/h	1968 m^3/h
Difference (leak rate and % of leaks)	103 m^3/h (+4%)	127 m^3/h (+6%)

6.2 Sealing and Duct pressure test

Results illustrated in the next graph show that the ductworks are very air-tight with an objective class respected in the two zones, with a class C for the sealed ductwork (zone B), and a class D for the new ductwork (zone A). Note that the new ductwork (zone A) was also sealed by Aeroseal®, according to insufficient performance due to existing ducts in zone A2. The performance was class A before sealing procedure. Each measurement was carried out in a single pass due to the good airtightness.

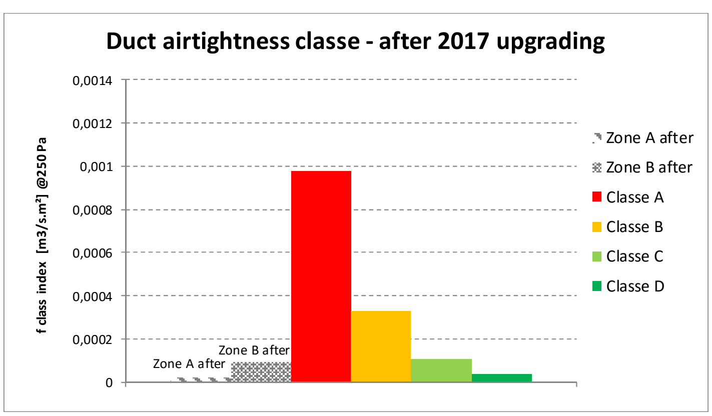


Figure 8: Class performance of Duct-airtightness tests after 2017 upgrading on zones A and B

6.3 Indoor air quality

Only CO_2 measurements were carried out after 2017 upgrading. Figure 9 shows homogeneous values lower than 700 ppmv, as a sign of homogeneous ventilation in each zone (figure 9).

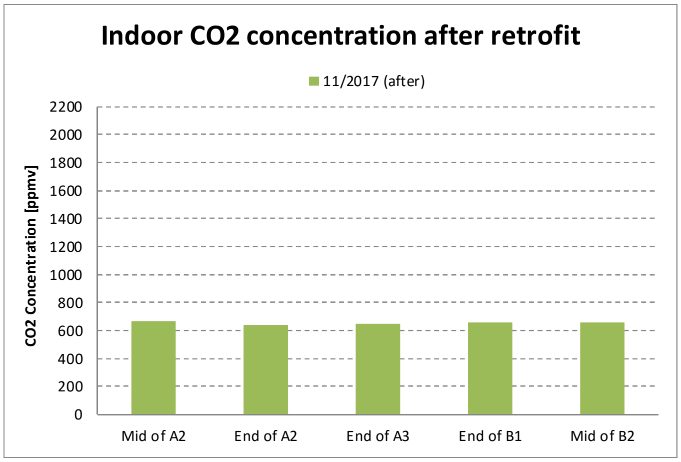


Figure 9: Indoor CO_2 concentration after 2017 upgrading

6.4 Electrical consumption

The installation of frequency variations on each AHU allowed a significant reduction in the power absorbed by each fan by -71% for the AHU of zone A and -78% for the AHU of zone B (figure 10).

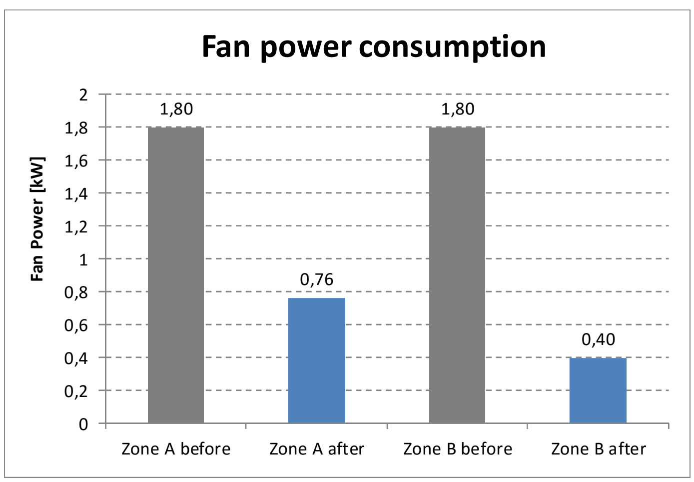


Figure 10: Comparison of the fan powers of each AHU before and after 2017 upgrading

7 CONCLUSION

The method identifies the causes of malfunctions in the ventilation system and made possible to precisely identify the causes after several months of uncertainty for the manager of the site. The diagnosis showed that the major problem was due to the poor performance of ducts airtightness, where no verifications at the execution of the 2012 refurbishment had been required previously. Reconditioning measures proposed by the SNIA allowed delivering a well-functioning installation, with a checked control of all air-outlet airflow rates, as well as a net reduction of the electrical powers absorbed by the fans, like the reduction of the noise nuisances nearby AHU.

8 ACKNOWLEDGEMENTS

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