RENOVAIR : a study of the evolution of airtightness, ventilation, comfort and indoor air quality in energy efficient refurbishment social housing operations in France

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ABSTRACT

Many European programs offer eco-conditioned financial aid to support public policies for the decarbonization of buildings. This is the case, for example, of the 2017-2022 ERDF Operational Program, which financially assists social project management for energy efficient refurbishment operations of its building stock. The eligibility conditions for financial aids concern the energy consumption, the thermal insulation performance of the building envelope and the energy efficiency of heating, cooling and ventilation systems. The current specifications for this program do not condition financial aid on performance criteria on indoor air quality (IAQ), ventilation and the airtightness of the building envelope.
The objective of the RENOVAIR project is to study the impact on occupants' comfort and health of the energy renovation work of low-consumption social housing, when no obligation is made on the performance of IAQ, ventilation and building envelope airtightness.
This three-year project is based on 7 ERDF program candidate operations for the energy efficient refurbishment of multi-family social housing in the Nouvelle-Aquitaine region (south-west of France). In this work, we seek to characterize the IAQ, comfort, airtightness and ventilation performance, before and after the refurbishment works, as part of on-site measurement campaigns over 21 dwellings, in order to investigate on the importance of such requirements for building decarbonization public policies.
In this paper, we present the constructive typologies of the pilot operations, the operating protocol of the measurement campaigns and the preliminary results of the first campaign.
On each of the 7 pilot sites, 3 dwellings have been selected to be subject to metrological monitoring and occupants surveys. The overall protocol is composed of 4 parts:

1) A ventilation audit on each dwelling, based on the PROMEVENT protocol, applicable to new dwellings subject to the new French regulations RE2020 ; it consists in airflow measurements, visual diagnosis, functional checks and occupants survey.
2) airtightness measurements of each dwellings with a Blowerdoor, according to the ISO 9972 standard test protocol. A qualitative classification of the leaks is carried out according to the methodology of regulatory controls for new constructions, for the French thermal regulation RE2020.
3) IAQ measurements for a week during the winter period, through dynamic measurements of temperature, relative humidity and carbon dioxide and passive measurements of volatile organic compounds in each dwelling,
4) surveys and measurements of occupants' comfort by GreenMe® commercially available multi-sensor measuring stations to characterize the indoor environment quality (temperature, humidity, CO2, noise, lighting) in each dwelling for one week, during winter period.

Finally, we present the first results of this work, that characterize the initial state of the dwellings and we discuss the expected impact on the energy performance of the energy refurbishment works.

KEYWORDS

Energy efficient refurbishment, airtightness, IAQ, comfort, field measurements

1 INTRODUCTION

For many decades now, it has been accepted that for efficient energy renovation of buildings, achieving low energy-consumption building-type performance levels is only possible if the issues of air renewal, ventilation or airtightness are very thoroughly taken into account.
In addition, the COVID-19 pandemic crisis has led to public awareness of the importance of indoor air quality (IAQ). Failing to become the priority criterion in decision-making for energy renovation works, IAQ has nevertheless become a major concern for project owners, both in terms of health issues and comfort issues for occupants. Actually, the economic impact of energy renovation work on the scale of countries or regional territories has been demonstrated to be significant in global cost approach studies, if we integrate the loss of productivity and the public health costs associated with poor IAQ (Copenhagen Economics, 2012).
Thus, it becomes essential, when public policies address issues for the massification of buildings' energy rehabilitation, to account for high performance levels of ventilation, airtightness and IAQ of buildings requirements.

2 CONTEXT

Many European programs offer eco-conditioned financial aid to support public policies for the decarbonization of buildings. This is the case, for example, of the European Regional Development Fund (ERDF) Operational Program (OP) 2017-2022, which financially assists social project management for energy efficient refurbishment operations of its building stock.

In its aid program specifications for energy renovation operations in social housing, the 2017-2022 ERDF OP does not take into account any eco-conditionality criterion on the airtightness, nor the IAQ or the occupants' comfort of energy renovation projects. However, it is now accepted that controlling the airtightness and air renewal of buildings has become a necessary condition for achieving very low energy consumption. Thus, it seems very important to be able to link the conditions for implementing airtightness and air renewal in energy renovation operations accompanied by public policies.

This observation has also been highlighted by the results of the TREMI study on the "Energy Renovation Works of Individual Houses" (ADEME, 2017), where improving comfort is identified as the main reason for carrying out work, households having the reflex to start with insulation, but too often forget ventilation. In fact, recent studies in France demonstrate the importance of issues such as airtightness, ventilation, ambient comfort and IAQ if one is targeting low energy efficiency buildings' refurbishment (DGALN, 2019), (ADEME, 2019), (ADEME, 2016).

Cerema has been supporting the Nouvelle-Aquitaine Regional Council since 2016 as part of a technical assistance for the implementation of energy efficiency refurbishment operations in social housing. A total of 70 renovated operations benefit from financial aid from ERDF OP since 2014 (accounting for a total of 7 400 dwellings). Since 2016, on behalf of Regional Council of Nouvelle Aquitaine, Cerema examined approximately 70 of these energy renovation operations. The operations were monitored before, during and after the renovation works, according to specific energy indicators meeting the eco-conditioned requirements of the ERDF OP, that exclude issues related to airtightness, ventilation, IAQ and comfort of occupants.

The main objectives of the assistance consist of:

- Ensuring the good quality of thermal studies and their consistency with their effective implementation
- Ensuring that the planned works really allow a sufficient energy gain corresponding to the planned financial aid
- Check the quality of the works and their consistency with the forecasts
- Support the Nouvelle-Aquitaine region in the analysis of the environmental and social impacts of the ERDF OP.

For this on-going work, the analysis of an operation is broken down into three phases :

- Phase 1 : Study of renovation projects, before works (BW). This phase consists of verifying that the theoretical energy gain presented in the project corresponds to reality. A verification of the consistency between the actual initial state of the building and that of the thermal study is carried out first. Secondly, we verify that the planned work will actually generate the expected energy savings.
- Phase 2 : Verification of the execution and compliance of the renovation work during construction. This stage focuses on monitoring the quality of the work and the effective implementation of the systems provided for in the project.
- Phase 3 : Final verification of the work, after works (AW). The conformity of the works carried out with those planned and their good quality is ensured during this stage. A certificate of compliance or non-compliance will be issued, conditioning the phase of payment of the aid by the instructing service.

3 OBJECTIVES OF THE RENOVAIR STUDY

Since airtightness, ventilation, comfort and IAQ performance indicators are not explicitly required for eco-conditioned aids in the ERDF OP specifications, we aim at studying the impact of air renewal (through ventilation and infiltration) in energy renovation operations, and better understand the underlying energy, comfort and health issues

We present in this paper the first results of the RENOVAIR study (2021-2024), research project backed by the operational support carried out under the ERDF OP. Through the RENOVAIR research project, Cerema aims to assess airtightness, ventilation, comfort and IAQ performance levels on 7 aided operations (namely, 10% of the total inspected refurbishment operations), by in situ measurements carried out before and after the renovation works, then one year after the renovation works receipt. Indeed, our recent research Durabilit'air on the durability of airtightness (ADEME, 2019), has shown us that the main evolution of airtightness after reception is during the first year of use of the building.

The overall RENOVAIR project has three main objectives :

- to note the effectiveness of accounting - or not accounting - for airtightness, ventilation and IAQ in the energy renovation of the 7 housing aided operations monitored.
- to identify the conditions for improving the energy efficiency of renovations, in relation to the implementation of corrective solutions on airtightness, ventilation and IAQ, depending on the expected level of energy performance.
- to support public policies to define eco-conditionality criteria on the airtightness of renovations, ventilation and IAQ, based on this feedback from the field.

In this paper, we report the methodology and the first results related to the first two phases of our work (i.e., comparing the evolution of airtightness, ventilation, comfort and IAQ before and after works). Future works should lead us to deliver an overall analysis of the interest of integrating formalised requirements on airtightness, ventilation, comfort and IAQ indicators into the future ERDF OP specifications.

4 METHODOLOGY

4.1 Sampling

The sample selected for our study consists of 7 social housing operations, applying for ERDF OP funding, located in the Aquitaine region, in the south-west of France.
This sample represents approximately 10% of the total number of refurbishment operations that Cerema inspected for the ERDF PO until now.

The constructive typologies of these operations are as follow:

- ■ Constructive type :
  - - (3/7) Building concrete structure on concrete slab with lost attic
  - - (4/7) Building concrete structure on concrete slab with flat roof
- ■ Construction date :
  - - (3/7) Before 1974 (date of the first thermal regulation in France)
  - - (4/7) After 1974
- ■ Joinery :
  - - (3/7) PVC with double glazing
  - - (4/7) wood with single glazing
- ■ Heating system :
  - - (3/7) gas boiler and radiators
  - - (4/7) electric convectors and electric domestic hot water tank
- ■ Ventilation :
  - - (6/7) single-flow mechanical ventilation
  - - (1/7) natural ventilation on shunt exhausts
- ■ Expected energy gains after energy efficiency refurbishments:
  - - in average, 2-letter gain on the energy label
  - - an average gain in primary energy consumption of 136 kWh/m² or 56%

The detailed presentation of the energy renovation work for each operation is presented in a confidential report. All the refurbishment works included heavy work on the thermal insulation of the envelope, changing the joinery and the heating and ventilation systems.

For the 7 operations, the total costs of the eligible energy efficiency refurbishment works ranged between 0.7 M€ and 6.5 M€ (average value of 0.7 M€). The works total costs per dwelling for each of the 7 operations range between 8.2 k€/dwelling and 32.4 k€/dwelling (average value of 19.5 k€/dwelling).

Table 1: Construction typologies of the sample

number designation	location	constructive type	construction date	joinery	heating system	ventilation	(number of buildings) and intial energy consumption	average energy gain	energy label gain
#01	Pessac, 33	Building concrete structure on concrete slab with lost attic	1958	pvc double glazing	gas boiler and radiators	single-flow mechanical ventilation	(3) 168 kWh/m²	56%	D → B
#02	SMJ, 33	Building concrete structure on concrete slab with lost attic	1989	pvc double glazing	electric convectors and electric domestic hot water tank	single-flow mechanical ventilation	(11) between 231 and 309 kWh/m²	51%	E → C
#03	Talence, 33	Building concrete structure on concrete slab with lost attic	1984	wood single glazing	electric convectors and electric domestic hot water tank	single-flow mechanical ventilation	(5) between 284 and 334 kWh/m²	between 55% and 60%	E, F → C
#04	Mérignac, 33	Building concrete structure on concrete slab with flat roof	1984	wood single glazing	electric convectors and electric domestic hot water tank	single-flow mechanical ventilation	(3) between 280 and 298 kWh/m²	60%	E → C
#05	Villenave d'Ornon, 33	Building concrete structure on concrete slab with flat roof	1967	pvc double glazing	gas boiler and radiators	natural ventilation on shunt exhausts	(3) between 217 and 242 kWh/m²	59% to 64%	E → C D → B
#06	Le Bouscat, 33	Building concrete structure on concrete slab with flat roof	1984	wood single glazing	electric convectors and electric domestic hot water tank	single-flow mechanical ventilation	(4) between 215 and 232 kWh/m²	44% to 48%	D, E → C
#07	Marmande, 47	Building concrete structure on concrete slab with flat roof	1969	pvc double glazing	gas boiler and radiators	single-flow mechanical ventilation	(13) between 199 and 246 kWh/m²	63% to 68%	D, E → B

4.2 IAQ, comfort, ventilation and airtightness indicators

The study consists of carrying out a series of measurements on airtightness, ventilation, comfort and IAQ during the three phases "before works" (BW campaign), "after works" (AW campaign) and "one year after the works" (1yAW campaign), established as follows, for three dwellings on each operation :

- Carrying out on-site measurements of the airtightness of the envelope of the dwellings studied to determine the airtightness level and identifying the location of the infiltration leakage locations in three dwelling.
- Diagnosis of the ventilation system on three dwellings
- Installation of measurement sensors to characterize comfort and IAQ in three dwellings of the operation.

- The airtightness test of the envelope of each dwelling is carried out, according to standard NF EN ISO 9972 (AFNOR, 2015) and its application guide FD P50-784 (AFNOR, 2016), using a "blower door" measuring device. The measurement indicator used for airtightness will be the regulatory value $Q_{4PA-SURF}$ ($m^3/h/m^2$), air leakage rate related to the surface of envelope surfaces of the building under 4Pa expressed, as defined by the french Thermal Regulation RT2012 (MEEDDM, 2012).

  As a reminder and as an order of magnitude, the regulatory value to comply with the RT2012 mandatory requirement for new buildings :
    - 0.60 $m^3/h/m^2$ of heat loss walls, excluding the low floor, in a single-family or attached house.
    - 1.00 $m^3/h/m^2$of heat loss walls, excluding the low floor, in a multi-family residential building.

  A comparison of the measurement results is carried out as well as an analysis of the evolution of the identified infiltration leakage locations, through a normalized inspection.

- Diagnosis of the ventilation system is based on the PROMEVENT protocol (ADEME, 2016) that is applicable as an inspection for the new environmental french new buildings for new residential buildings. The measurements take place in three phases on 3 dwellings per renovated operation :
    1. Carrying out a visual diagnosis of the ventilation system in place, before and after renovation. The functional checks, resulting from the PROMEVENT protocol, are carried out and the anomalies observed are listed in a report relating to the diagnosis of the ventilation systems.
    2. User survey on the use of the ventilation system.
    3. Measurements of the ventilation system before and after renovation, according to the PROMEVENT control protocol for new residential buildings, RE2020 (MTE, 2021).

- The characterization of the comfort is established on the one hand, on a questionnaire given to the occupants of the dwellings aiming to collect their feelings concerning the use and the perceived comfort of their dwelling, and on the other hand on measurements through the GreenMe® commercial IoT multisensor sensor.
  The GreenMe® sensor is a initially developped for office environements, and is intended to be placed in the immediate vicinity of the user. It continuously measures the following eight parameters :
    - Ait temperature (°C)
    - Ait relative humidity (% RH)
    - Air quality (VOC and CO2)
    - Lighting level (Lux)
    - Flicker (%)
    - Color temperature (K)
    - Average noise level (dBA)
    - Maximum noise level (dBA)

  The use of the GreenMe® connected object makes it possible to characterize the indoor environment by the physical measurement of ambient parameters and by the vote of the occupants, expressing their own feelings of comfortable or uncomfortable conditions. The GreenMe® sensors integrate by default a sensor sensitive to VOC and CO_2. It does not give an absolute measurement of an air pollutant but it can be a good indicator of the need for air renewal. For our work, three GreenMe® sensors are installed per dwelling (living room, kitchen, bathroom) for a period of 15 days in each dwelling.

A comfort vote functionality is available on the GreenMe® sensors, in order to let each occupant indicating the comfort level he/she feels. Although the "comfort vote functionality" was explained to each occupants, very few votes were expressed during the measurement periods. This lead us to disregards these results.

Our comfort analysis will focus only on the thermal comfort by analysing the measured air temperature and relative humidity values using psychrometric diagrams for each dwelling, per room (see Figure 1).
The green polygon on the psychrometric diagram shows the comfort zone. It is established based on the comfort ranges as defined in the standard EN 16798-1 (NF EN 16798-1 (AFNOR, 2019)) for category III (existing buildings) during heating season : an air temperature between 20 and 25°C and relative humidity between 20 and 70%. Thus, we assessed the ratio (%) of time in the comfort zone over the whole duration of our instrumentation.

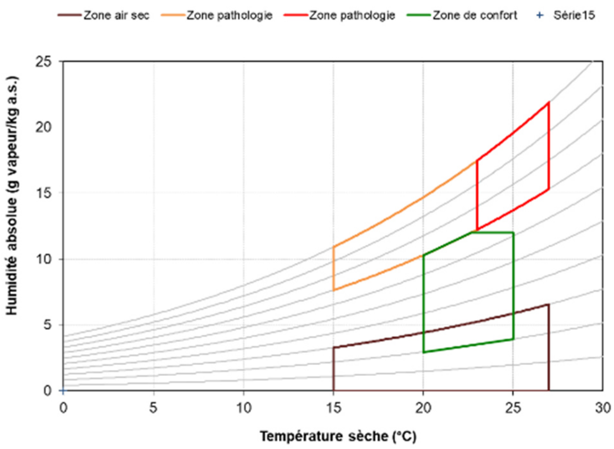


Figure 1: comfort chart from the standard NF EN 16798-1. The comfort zone is represented in green

- The assessment of Indoor Air Quality is carried out using passive tubes to measure Benzene / Formaldehyde / Toluene / Ethylbenzene / Xylenes, and CO_2 and Temperature sensors & Humidity.

Three rooms are instrumented per dwelling (preferably living room) for passive tubes and 2 rooms per dwelling are instrumented with temperature, relative humidity and CO_2 sensors (living room + bedroom). This instrumentation is carried out for a period of one week.

BTEX (benzene, toluene, ethylbenzene, xylenes) are measured by passive samplers set up for 7 days and then analyzed in the laboratory, according to the standard NF EN ISO 16017-2 (AFNOR, 2003).

Formaldehyde is measured by passive samplers set up for 7 days and then analyzed in the laboratory, according to the standard NF ISO 16000-4 (AFNOR, 2012)

Containment is measured continuously using an infrared radiation-based carbon dioxide (CO2) probe (NDIR).
The data is continuously recorded and then extracted after the measurements are completed for processing and analysis.

5 FIRST RESULTS

The first BW field measurement campaign was carried out between January and June 2021. The second AW field measurement campaign measures is still in progress : 6 operations were diagnosed between April and July 2022 and the last operation will be carried out at the end of 2022.

5.1 Airtightness results

Regarding airtightness, if one compares the BW field measurement campaign results to the regulation requirements for new residential buildings in France (MTE, 2021), one can note high levels of airtightness results for 6 operations out of 7 (see figure 2). For these 6 buildings equipped with self-adjusting single-flow mechanical ventilation systems, the $Q_{4Pa\text{-}Surf}$ measurements are less than 1.0 $m^3/h/m^2$ (airtightness requirement for new multifamily buildings). Only one operation (#05) showed results with a mediocre performance: this natural ventilation operation coupled to shunt ducts shows $Q_{4Pa\text{-}Surf}$ values greater than 1.60 $m^3/h/m^2$.

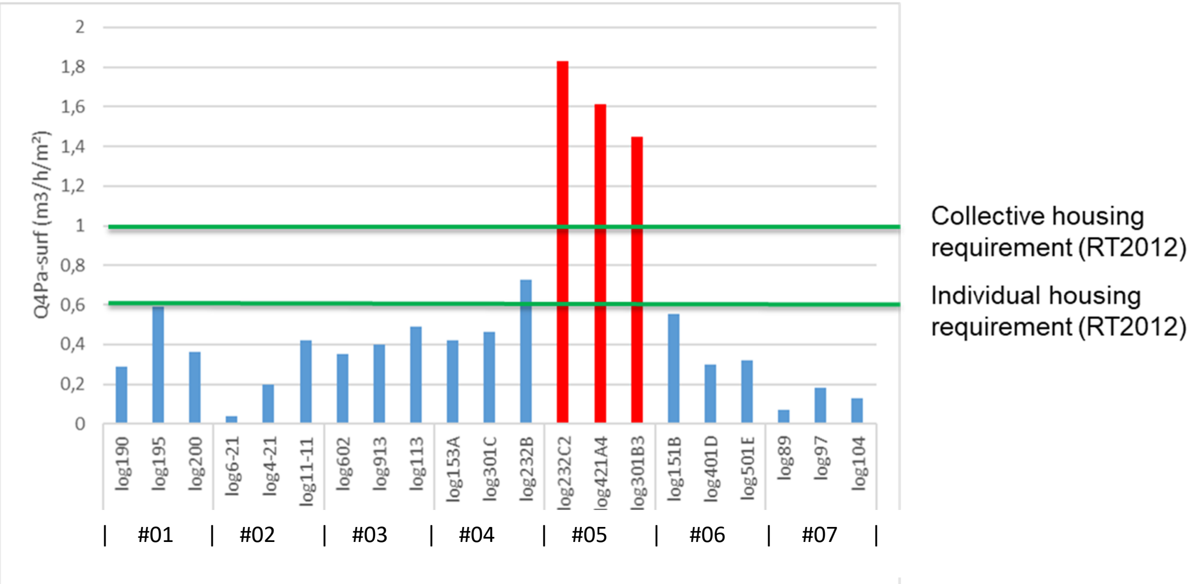


Figure 2: Air permeability measurement BW field measurements

We could compare the airtightness measurements during the two phases BW and AW, on 6 operations (see Figure 3). The results during the AW phase show a marked improvement in airtightness over 3 operations (#03, #05 and #06), in particular for the residence with natural ventilation, which benefited from the installation of a single-flow mechanical ventilation. Inversely, one operation (#01) is experiencing a clear deterioration in its level of sealing due to the installation of glass doors whose frames appeared to be warped after implementation and have to be replaced. For the last 2 operations (#02 and #04), we found comparable levels of airtightness between the BW and AW phases.

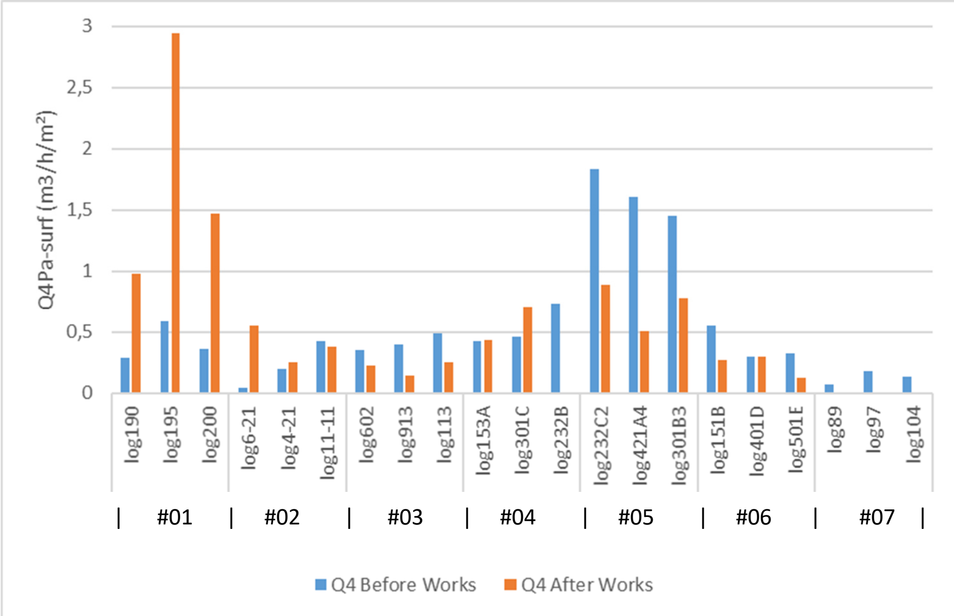


Figure 3: Airtightness air leakage rate (m³/h/m²) comparison BW (blue) and AW (orange) (measurements at the AW phase for operation #07 are still in progress).

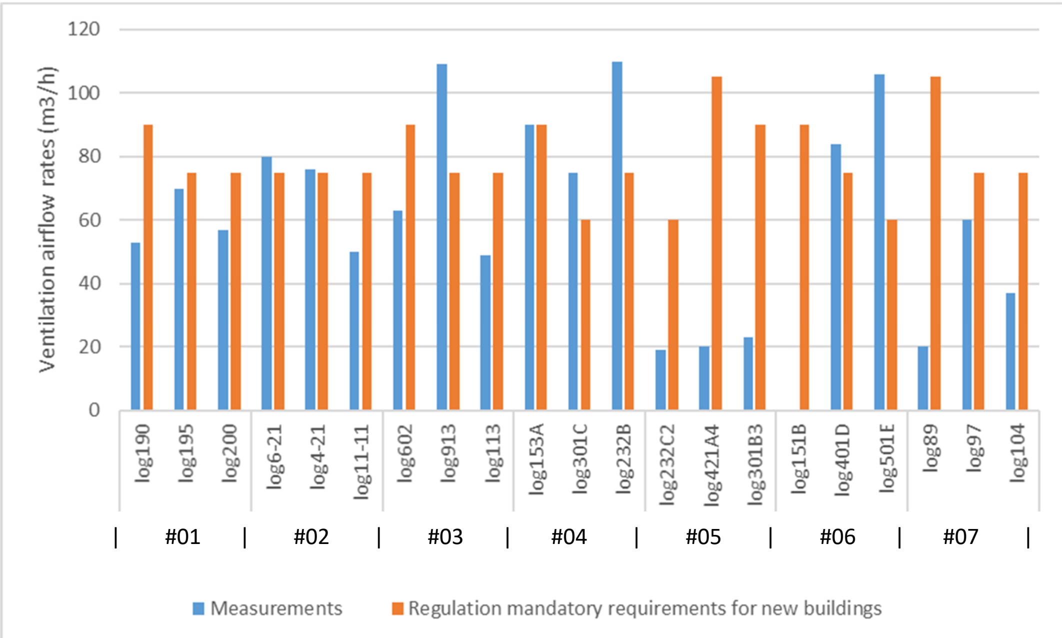


Figure 4 : Ventilation airflow rates (m3/h) measurements BW .
Comparison between measurements and regulation mandatory requirements for new buildings

5.2 Ventilation results

Concerning the ventilation flows assessed during the BW campaign, the majority of the dwellings present systems with significant imbalances that do not allow to reach extracted air flows in accordance with the regulations for new construction (French Government, 1982), see Figure 4. We found a compliance rate of 38% on the total airflows per dwelling for the 21 dwellings studied. This ratio is comparable to the statistics published on ventilation regulation compliance in new residential buildings in France (ADEME, 2016).

The negative differential pressure measurements of the extractions after works are compliant with the regulation requirement for 4 operations. The 2 non-compliant operations show results below 50 Pa on each of the extractions from each of the dwellings (the regulation requirements are in the range between 80 and 160 Pa).

5.3 Comfort results

We assessed the comfort through two different ways :

- qualitative results : from a questionnaire submitted to the occupants,
- quantitative results : from an assessment of the percentage of time of comfort, derived from the temperature and relative humidity measurements.

Concerning the qualification of comfort in the BW phase, it appears from the questionnaires given to the occupants a lack of thermal comfort in winter.

The comfort ratios derived from temperature and relative humidity measurements were assessed for every dwelling, in three different locations, of each three dwellings : the living-room, the kitchen and the bathroom. A total of 63 comfort ratios were then assessed.

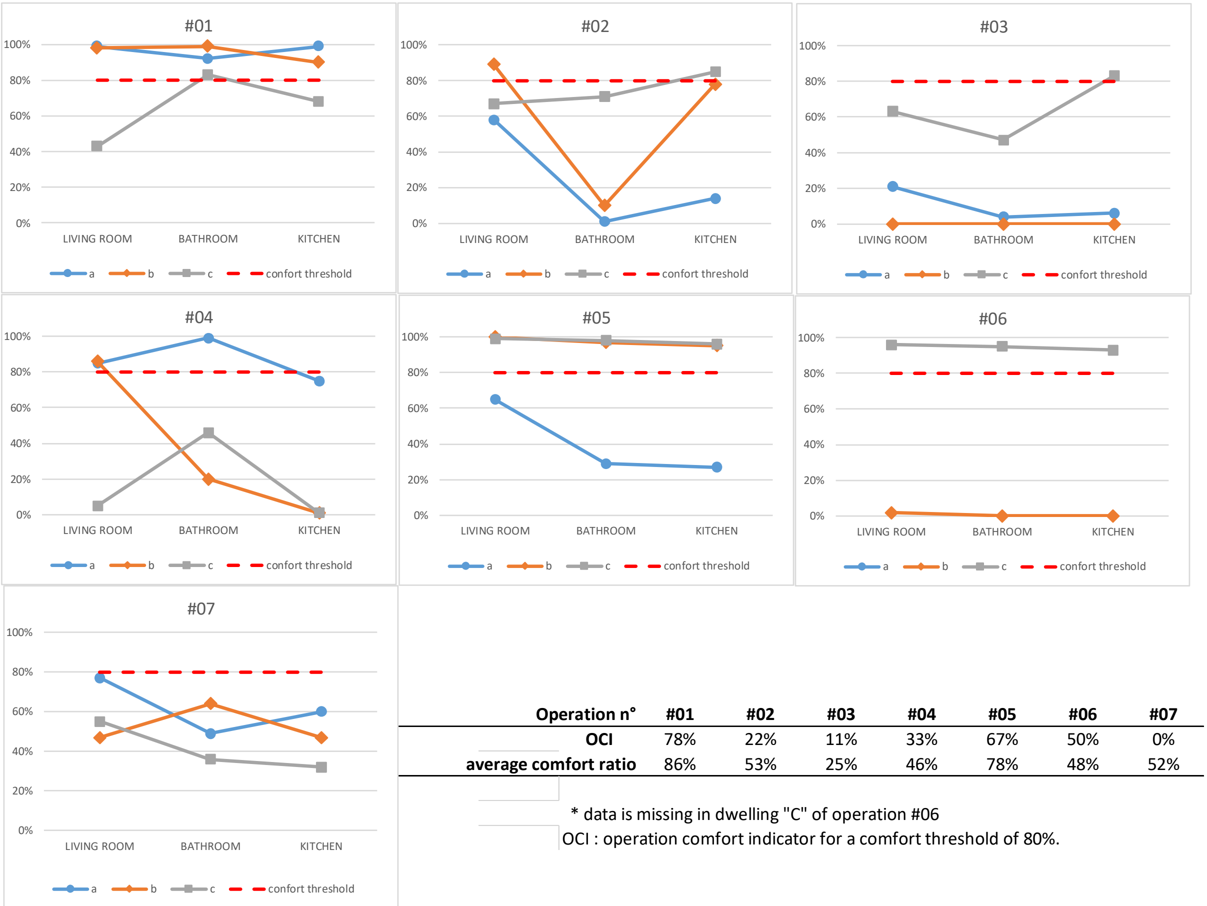
We characterised each of the 7 monitored operations with the OCI_{80} indicator : Operation Comfort Indicator (OCI), that was assessed for a comfort threshold of 80%. The OCI_{80} indicator assesses for each operation, the percentage of locations with a comfort ratio greater than a threshold value of 80% (see figure 5). Namely, for each operation, the OCI_{80} was derived from the results of the comfort ratio of 9 locations (3 rooms per dwelling, 3 dwellings per operation).

The average comfort ratio per operation were calculated in the range between 25% and 86%. For operations with the lowest comfort rates, our measurements essentially reveal discomfort due to temperatures below 20°C (see Figure 6), which corroborates the results of the comfort questionnaires (qualitative results).

Measurement during the AW phase were analysed for 3 operations handled. For that results, we found a marked improvement in comfort with average rates per operation ranging from 71% to 91% compared to 25% to 53% for the same dwellings BW. When the AW phase will be achieved, we expect to compare the evolution of the comfort ratios after and before the renovation works (see Figures 6 and 7), and to assess the evolution of the OCI_{80} indicators.

1.1 IAQ Results

Concerning the indoor air quality before works (BW phase), the instrumentation carried out by ATMO Nouvelle-Aquitaine highlights a higher concentration of formaldehyde and CO_2 for the accommodations of the residence with natural ventilation than for the accommodations of the other residences equipped with mechanical ventilation. High concentrations of benzene could be recorded on certain dwellings. All measurements for VOCs and CO_2 were compared to the first field measurement campaign on French housing of the IAQ observatory results (OQAI, 2005), see Figure 8.



Operation n°	#01	#02	#03	#04	#05	#06	#07
OCI	78%	22%	11%	33%	67%	50%	0%
average comfort ratio	86%	53%	25%	46%	78%	48%	52%

* data is missing in dwelling "C" of operation #06
OCI : operation comfort indicator for a comfort threshold of 80%.

Figure 5 : overall results of the comfort ratio in every dwelling during the BW phase (in red dashed lines, the threshold ratio)

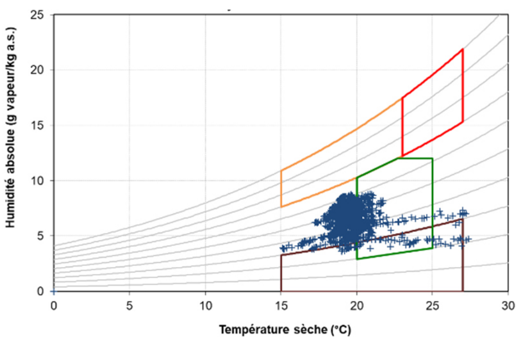


Figure 6 : Site #03 – Living room in dwelling a – BW
Comfort ratio = 21%
Average external temperature : 8,9°C

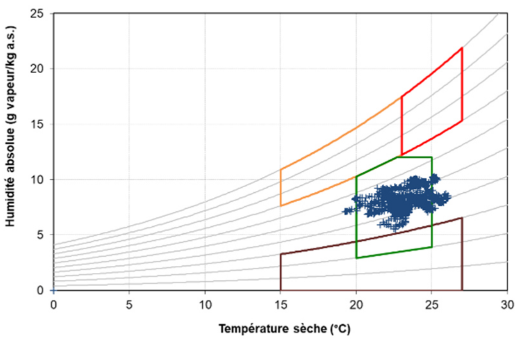


Figure 7 : Site #03 – Living room in dwelling a – AW
Comfort ratio = 80%
Average external temperature : 18,8°C

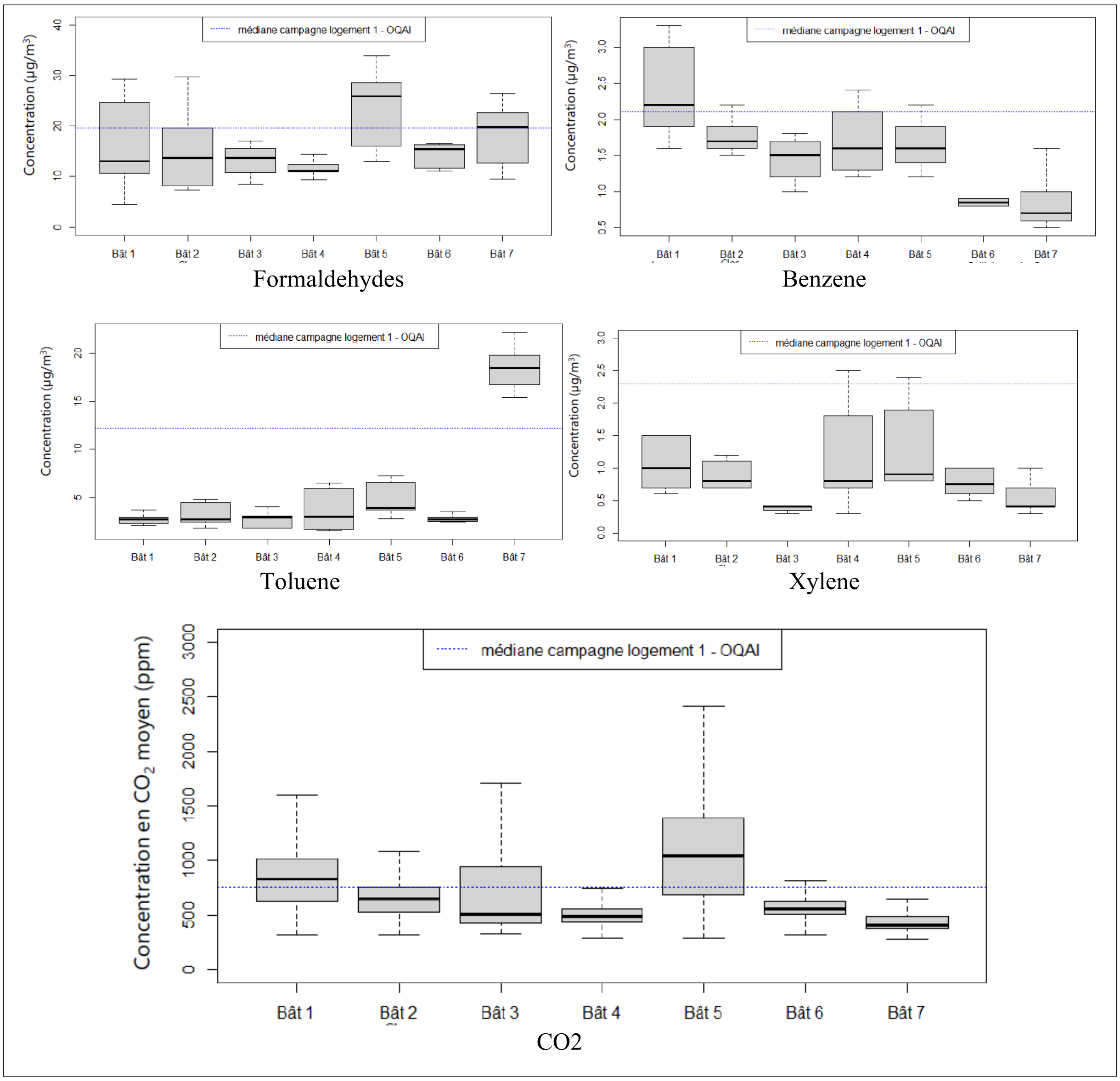


Figure 8 : IAQ measurements during the BW phase.
Comparison with the median results from the national OQAI field measurement results.

2 DISCUSSION

With the exception of one operation, airtightness appears to be effective. The main leaks assessed during the BW phase are leaks on joinery which have been corrected thanks to the replacement of joinery provided for in the package of energy renovation works. This effort during the work phase, may have led to significant improvements in the airtightness measurements in the AW phase. Nevertheless, this result was not systematic in all operation, with even a decrease in airtightness after the works.

On the ventilation component, the lessors of the 2 non-compliant residences were asked for the measurements taken by the companies when the systems were started up in order to compare them with our measurements.

The comfort results showed very heterogeneous results in the dwellings, during the first BW phase. Besides, we planned to time our comparative BW and AW measurements at the same times of the year, so as to reflect the same level of seasonal comfort. Unfortunately, it was difficult to compare our results before and after the works since the seasonality could not be entirely respected for all of our measurements due to the delay in the works. Thus our measurements before work were carried out during the heating period (in winter), while our instrumentation after work took place with the heating systems shut down (in spring).
It was therefore decided to adapt the dates of our measurements "1 year after receipt" (1yAW) in order to carry them out over the same period of the year as the measurements before the works.

The analysis of thermal comfort in the kitchen and the bathroom may not be relevant because the occupation of these two rooms is specific. First the hours of occupation are low, then the activities and the clothing of the occupants are very heterogeneous. In future works, we may apply the analysis of thermal comfort only to measurements in living rooms. For the kitchen and the bathroom, on the other hand, you can check whether the relative humidity exceeds 70% and for how long.

The choice for the 80% threshold for assessing the OCI indicator is complex, because the ISO 7730 and EN 16798-1 standards do not specify the acceptable threshold for the percentage of time in the comfort zone. We can find in the literature related to high environmental quality buildings (HQE) and for the new environmental regulation (RE2020), a maximum number of hours outside the comfort zone. But in the former versions of the EN 16798-1 (EN 15251) standard, an appendix suggested a threshold of 95% of the OCCUPANCY time in the comfort zone (i.e., limiting the overflow of the comfort zone less than 5% of occupancy time). Specifically, it proposed that rooms representing 95% of occupied space in the building should not exceed the comfort zone by more than 5% of occupancy hours. As a matter of fact, an overrun of 20% seems then to be a high value, it represents approximately 34 hours over a week.

On the IAQ component, the measurements taken before the works highlight the lack of efficiency of natural ventilation compared to the controlled mechanical ventilation systems that equip the other operations in our sample.

Thanks to the exploitation of the questionnaires given to the occupants concerning their feelings and the use of their accommodation, the abnormally high measurements in benzene can be explained by the behaviour of the occupants (smoking, use of candles, incense, etc.).

3 CONCLUSIONS AND FUTURE WORKS

This article presents the methodology and the first results of the RENOVAIR study (2021-2024), which is currently in the middle of its development. The objective of RENOVAIR is to quantify the consideration of four parameters directly influencing the energy and health performance of buildings and the comfort of the occupants of renovated social housing (i.e., airtightness, ventilation, IAQ and ambient comfort), when no requirement explaining these four parameters has been given in the specifications of eco-conditioned financial aid programs.

We have developed a metrological protocol to instrument 63 apartments of energy renovation operations of financially assisted social housing, to carry out measurements before and after the works. This protocol was developed with a view to controlling metrology costs, in order to consolidate this type of inspection, to support social contracting authorities wishing to better monitor the actual performance of their renovations.

The first results obtained are presented in this article. They mainly concern the characterization of buildings before the works and show rather efficient results for the airtightness of the constructions before the works. Conversely, we did not observe a significant systematic improvement in all operations after the works (for operations that were subject to before/after measurements). In fact, some operations even led to a significant deterioration of the airtightness after the works. Regarding air renewal, the observation on the efficiency of the ventilation systems in place before the works shows a compliance rate of 62%, which is comparable to that of new housing in France. Finally, with regard to comfort and IAQ, the initial results are very heterogeneous, with significant potential sources of gain between before and after the works.

Finally, we have defined indicators, which we will follow throughout the work of the RENOVAIR project, up to one year after the delivery of the work for each operation. Our work should lead us to study the evolution of these indicators in order to see how these four parameters are taken into account in the context of major renovation operations subsidised by public aid programs. The final objective of the RENOVAIR project remains to help public policymakers to define requirements to effectively improve the energy and health performance of renovated buildings, as well as the ambient comfort for their occupants.

4 ACKNOWLEDGEMENTS

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