Evaluation of Ventilation and IAQ Parameters Measured in Social Housing in Madrid

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ABSTRACT

Within this paper, an evaluation of Indoor Air Quality in residential buildings, and the experience after a building retrofit is shown. One residential building in a Madrid social housing neighbourhood serves as case study and base for the monitoring.
During the last decades, increasingly in the last years, energy conservation in buildings has become a major concern, as it represents an important share of the global energy use and contributes a great deal the GHG global emissions. This concern leads to promote retrofitting actions in buildings to improve their envelope thermal behaviour and reduce energy demand for HVAC. These retrofits affect the indoor air quality conditions as they change the original configuration of the building, including the ventilation systems. Occupant behaviour and material emissions are main sources of indoor environment pollutants. Atmospheric environment represents also a major challenge in big cities, as the pollutant levels overcome frequently the threshold levels set up in international regulations. Indoor environment quality is affected clearly by all the aforementioned factors, and residential buildings are especially sensitive to all of them as regulations have been less strict for this important building stock. Within this paper, an evaluation of the actual transient indoor air quality conditions depending on all factors influencing is developed. This characterization of a residential unit which is established in a social housing neighbourhood in Madrid (Ciudad de los Angeles), an area which has been object of a deep retrofit process during the last years. Envelope improvement, which is also the most common intervention in this neighbourhood, was executed during the last year. The intervention consisted in wall cavity insulation via injecting glass wool. Indoor environment variations are analyzed and discussed. Monitoring of the indoor comfort and air quality conditions was done before and after the retrofit process. Indoor contaminant sources coming from material and human activity are considered. Actual monitoring is also considered in unoccupied and occupied units. As conclusions, the results from monitoring some aspects of IAQ will be compared to the existing regulations on residential buildings.

KEYWORDS

IAQ, ventilation, residential building retrofit, indoor pollutants

1 INTRODUCTION

Uses and habits in developed societies show that around 90 % of the time is spent indoors [ECA, 2000i] and the main share of this time, from 60 % to 70 % is spent in residential indoor spaces [Thatcher and Layton 1995]ii. In the case study shown in this paper, the share of time spent in houses is even higher, around 80 %, as the most of occupants are around 80 years old. Physical and chemical properties of air in these environments have been thoroughly studied and different regulations have set the parameters to guarantee a healthy and satisfactory indoor environmental quality from subjective comfort and wellness aspects, as the

Percentage of Dissatisfied (PD) [ISO 7730:2005]iii to health and illness correlation pattern issues [WHO,2000]iv. These aspects, and the progressive worsening of the urban environment due to traffic and heating been mostly based on fossil energy sources in cities as Madrid, make it necessary to re-adjust the way to achieve the objectives of lowering the energy demand, evaluating and including in a more precise way the effect on indoor quality due to ventilation systems. Regulations and standards for keeping indoor environment in housing are less strict than those existing in other building types and in European regulations, as the case of Spain, the impact of ventilation for energy calculations is usually underestimated [Sotorrio et al,2013]v.

The SIREIN project [vi] (Integral Systems for Energy Retrofitting) 2011-2015, aimed at bearing down barriers to reach the objective of a deep and wide spread retrofitting process in the residential stock. The solutions selected and investigated, are aimed at reaching the maximum cost-benefit ratio via making use of the Pareto Principle (20% of the causes account for 80% of consequences). By using this principle, the focus is set on the most common building type, user type climate boundary conditions, and combining the most cost-effective technical solutions, we will obtain the most suitable combined solutions to apply to a large stock of buildings, minimizing the need of public and private investment and maximizing the effectiveness of the actions, both in energy and sustainable savings. Leaded by Saint Gobain Isover and the Technical University of Madrid, the project was funded by the National Ministry of Science and Innovation with grant number IPT-2011-1980-920000.

1.1 Environmental pollution in Madrid metropolitan area

Atmospheric environment is currently a major concern for developed countries, especially in cities. Since the 1990’s, urban pollution is monitored in many of european cities (Airqualitynow Project 2010)[vii], and the measured values, though in global have diminished from 2005, still are in many occasions above the reference maximum values established by different Organizations. The European Union has developed an extensive body of legislation which establishes health based standards and objectives for a number of pollutants in air. The so-called CAFE (Clean Air for Europe programme) Directive (2008/50/EC) was published on 21st May 2008 and merges earlier directives into a single directive on air quality. The standards and maximum values are taken from this Directive.

As it can be seen in figure 3, target limits would be overcome in daily basis quite frequently, though they are not on yearly basis. The annual report for 2014 “Air Quality in the Madrid city area” [Madrid region government, 2014] [viii] shows that the general concentrations are below the target limits, and still the perception of the air quality within the population is not satisfactory. In general all the values have decreased, excepting those from Troposphere Ozone (during summer) since 2005 but the traffic and the use of fossil energy sources produce high levels outdoors and indoors that have to be reduced. Most of the pollutants, but specifically NO_2, NO_x, CO and benzene concentrations indoors are highly related with the concentration outdoors.

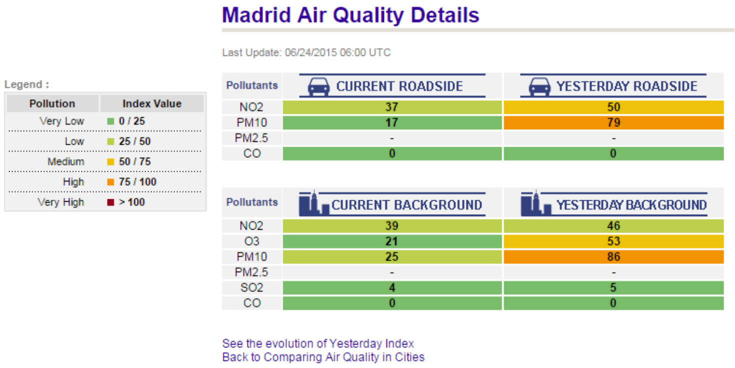

Figure 3: Daily pollutant monitoring extracted from Madrid City Council sources in web
http://www.airqualitynow.eu/

For the purposes of this study it can be assumed that the indoor concentration of these atmospheric pollutants will not be higher than outdoors. The usual solution to solve this high concentration of pollutants in these events of high pollution outside requires filtering the intake air.

1.2 Indoor pollution in residential multi-storey buildings

Indoor pollution inside residential multi-storey buildings has been analyzed and measured thoroughly in Europe, Japan, United States (Järnström 2008)[ix] but it is not deeply studied in Spain. This lack of reference values to evaluate the indoor conditions in Spanish residencies and especially social housing and other representative building stock needs to be changed. In this study several measurements are done.

Usual pollutants found indoors are oxides of nitrogen (NOx), sulphur (SOx) and carbon (CO, CO2). These compounds originate from combustion processes as heating and traffic (WHO 1989)x. Formaldehyde, Total Volatile organic compounds(TVOCs), semi volatile organic compounds (SVOCs), Volatile organic compounds(VOCs) are present in indoor environment and are usually related to material and furniture emissions, human activity, and vary with temperature and humidity changes, as well as depend on the air renovation rate (Järnström 2008).

2 METHODOLOGY AND MATERIALS

The objective of this paper is to evaluate aspects related to the Indoor Air Quality (IAQ) of a representative building unit case study, based on the monitoring of different pollutants commonly present indoors, focusing on dynamic variations of concentrations of indoor pollutants and actual ventilation rates and emission rates.

This evaluation considers different aspects:

1. Measurement of the environmental conditions before and after the building retrofit.
2. Consideration of the occupant profile and occupancy schedules
3. Levels of contaminants due to material emissions
4. Ventilation rates and infiltration

The evaluation begins at studying the case study for the retrofit: The building, the occupants, and the retrofit. Analysis will continue with the material emissions, the ventilation and infiltration drivers.

2.1 The case study

Although building retrofits are still not spread as widely as it would be desirable in Spain, there are specific areas as “Ciudad de los Ángeles”, in the metropolitan area of Madrid, Spain, where a specific plan to promote a neighbourhood retrofit was developed, beginning in 2005, and including a wide range of interventions, but mostly focused on envelope improvement [ARI Ciudad de los Angeles, 2005][xi]."Ciudad de los Ángeles", erected at the end of the fifties, accounts for almost 8.000 dwellings, in 485 buildings, and hosts a population of around 24.250 inhabitants. The socio-economic characteristics of this area are the low income of the neighbours and the advanced age of people. Although new inhabitants have been coming to the neighbourhood in the last years, the economic situation is still modest. Most of the buildings lacked correct groundings, elevators and basic thermal insulation and energy efficiency in the utilities. So the retrofit actions were focused mostly on these interventions. The public investment reached a maximum ratio of 21.000 € per dwelling (around 75% of the total costs). The public entity EMVS (Social Housing Enterprise of Madrid) managed the interventions and approved the actions. The actions were only publicly funded when affecting the whole building.

2.2 The building characteristics

Within the SIREIN research project, a demonstration building was insulated by injecting glass wool inside the wall cavities. The demo is an 8 stories building, with a representative typology within the area and the Spanish residential stock. 16 dwellings, elevator, utility rooms below the first floor and stairs are the main spaces in the building. The housing units surface is around 70 m^2 each, and have cross ventilation due to the three orientations of the facades on each apartment. Fig 1 and 2 show the configuration of the demo-building. The building was built during the sixties, on a concrete matrix structure and a double layer façade. These are the main features:

- Opaque envelope formed by a double brick layer with a 6 cm wide void cavity between them. The finishing to the inside is gypsum tiling and concrete layering painted to the outside.
- Windows are aluminum framed with single glass pane and no thermal bridge break.
- Some of the houses have solar shading elements to south, east and west orientation.
- Heating and hot water is provided by gas boilers excepting one of all the 16 which uses an electric boiler, and other which uses no heating.
- Some of the housing units installed Air conditioning with a divided system.
- Housing units have installed water and electricity, although these utilities are old and should be renovated.

Figure 1: south façade of the demo case

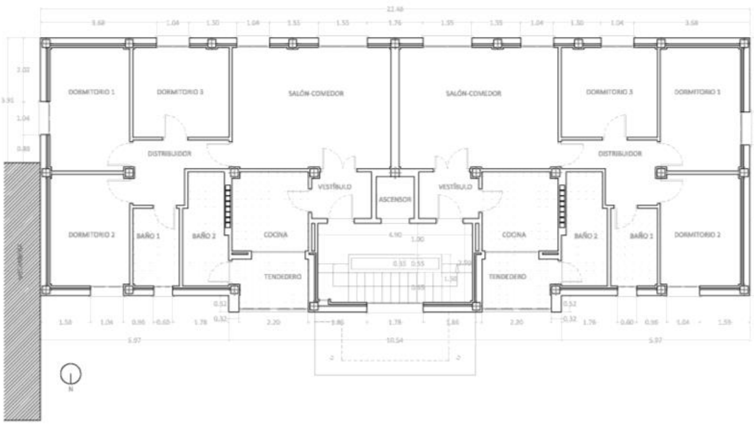

Figure 2: Floor plan of the demo case

2.3 The retrofit

The intervention in the building was intended to improve the façade thermal resistance. Its U value (Thermal transmittance) was measured, helped by flux meter, from 1,50 W/m2K to 0,34 W/m2K in the opaque façade, which is consistent to the theoretical values obtained. Of course, great attention was paid to minimizing the risk of condensation inside the cavity, which was calculated according to the regulation in the building Code. The analysis performed show that internal condensation risk is not relevant, fact that has been confirmed with periodic visits to the building during the last year.

The intervention, not being a deep retrofitting example, has improved the building global performance, showing differences caused in the majority by the difference between users, but accounting for a significant reduction in energy consumption. Previous research show for our case study in the location of Madrid, and a cavity width of 60 mm injection with base of glass wool reduces the annual energy demand in circa 25% (Hernandez et al., 2014)[xii].

2.4 Monitoring and measurement

The measurement of actual concentrations and variations has been done helped by Wireless IAQ (Indoor Air Quality) Profile Monitor unit, from PPM technologies Ltd. The IAQ Profile system has been designed to give a visual representation of indoor air quality in buildings, as part of the buildings management standards in relation to conditions such as Sick Building Syndrome. Since a great number of units can be networked, the system can show precise changes in concentration of selected IAQ parameters in various locations over time. In the experiments, only one unit has been connected to the grid, set up in the living room of the different units.

A continuous monitoring system has been set up to observe the effectiveness on the thermal resistance improvement of the opaque envelope (operative Temperature, superficial temperature inside and outside the cavity) but also other higrothermal and indoor quality indexes were monitored; Relative Humidity (RH), CO_2, Formaldehyde, and TVOCs were measured.

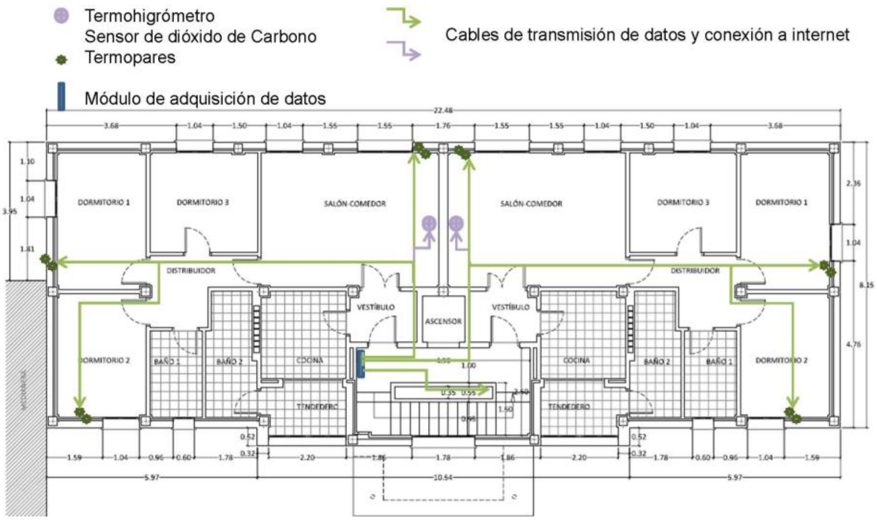

Figure 3: Monitoring set up

2.5 Occupant profiles and behaviour

The residential units are occupied by aged people, around 80 years old. They have a sedentary live style and do not go out often, unless they visit the doctor. There are two persons per apartment. The usual schedule for them is:

Table 2: Occupancy schedule

Room	Monday to friday	% occupancy	Saturdays and sundays	% occupancy
Bed room	0:00 – 7.00	100	0:00 – 9:00	100
Living room	15:00-16:00	50	10:00-12:00	50
	19:00-21:00	100	15:00-17:00	100
	21:00-22:00	50	19:00-21:00	50
	22:00-24:00	100	21:00-22:00	100
			22:00-24:00	100
kitchen	8:00-9:00	100	8:00-9:00	100
	14:00-15:00	50	14:00-15:00	50
	21:00-22:00	50	21:00-22:00	50
Bath room	7:00-8:00	1 person	9:00-10:00	1 person

The trends of this specific type of user allow us to be confident in the behaviour trend to be kept constant along days and to take conclusions from the measurements and the conclusions inferred by them.

3 RESULTS AND DISCUSSION

3.1 Ventilation and infiltration

Regarding ventilation, most of the buildings in the area rely ventilation merely on the windows and openings operated by users, assuming infiltration is a major contribution of the total amount of the air renovated inside of the dwellings. They lack of any intake or exhaust vent. The case study building was built before any regulation regarding thermal insulation or ventilation were applied (in Spain this is in 1979 with the NTE 79), so the ventilation scheme could be assimilated to a multizone indoor space, for which the different orientations and temperatures, wind velocities and wind pressure can be taken to calculate the renovation rate. For the calculations of the air coming inside the building, reference has been taken from the regulation EN 15242.

$$q_{vairing} = 3,6 * 500 * A_{ow} * V^{0,5} \tag{1}$$

$$V = C_t + C_W \cdot Vmet^2 + C_{st} \cdot H_{window} \cdot abs(\theta_i - \theta_e) \tag{2}$$

Aided by the difference of temperatures in the different facades cavities we can estimate the force induced to produce the cross ventilation. Fig. 4 and 5 show the differences in facades and inside the cavities, before the intervention.

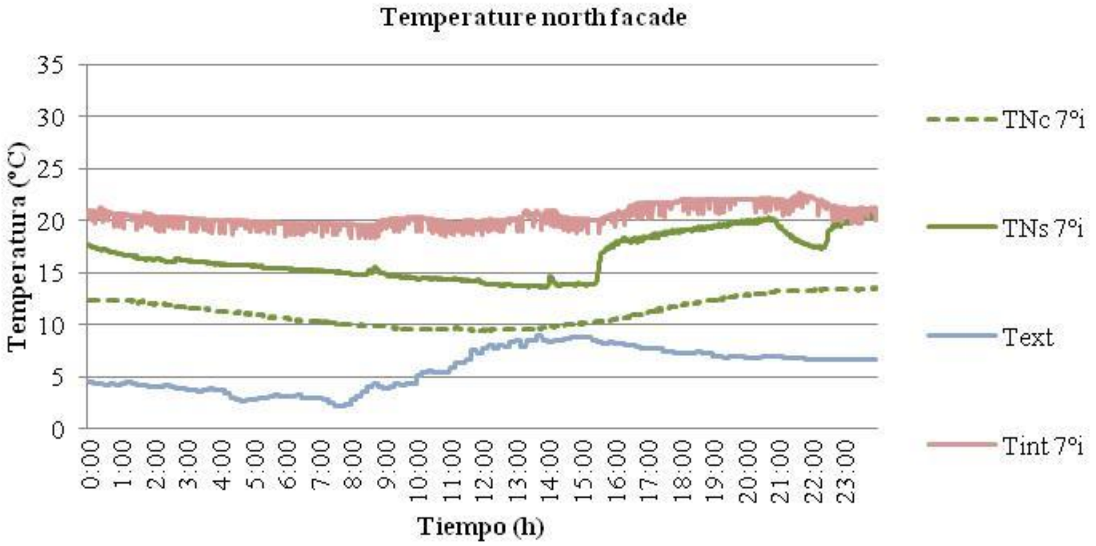

Figure 4: North façade. Temperature

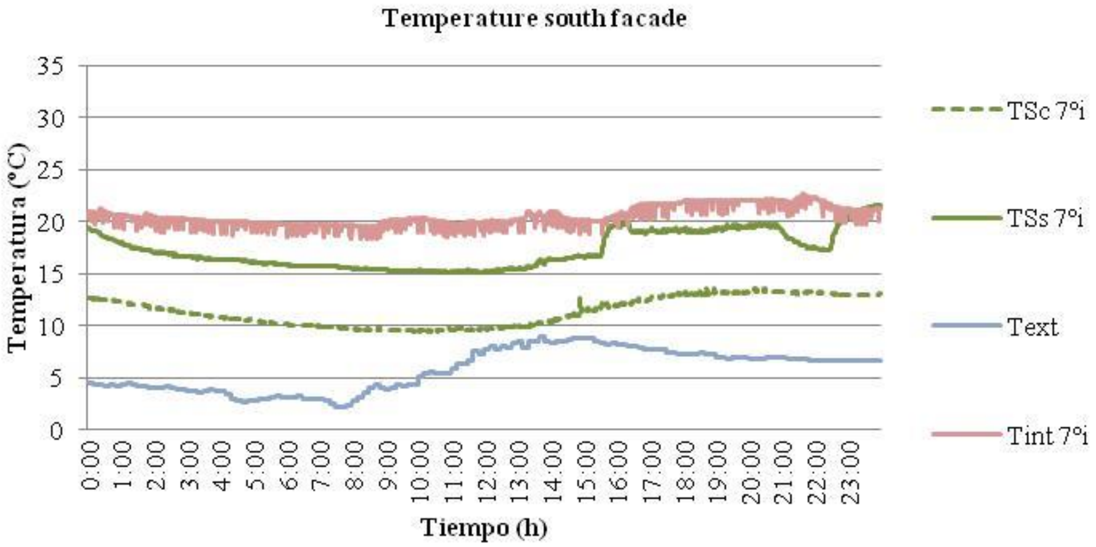

Figure 5: South façade. Temperature

The ventilation produced inside the apartments is not counting on stack effect, as the only duct which could contribute to this aspect is found in the kitchen, with the complementary exhaust duct, reaching the roof. So only infiltration, and operation of windows and pressure and temperature differences between facades and indoor and outdoor temperatures is responsible for providing the adequate renovation air. In many occasions the renovation rate is not enough in this apartments to guarantee a pleasant and healthy atmosphere.

3.2 Indoor pollutants in the case study

Contaminant concentrations and emission sources have been established by reference values taken from literature and actual values taken from measurement During the monitoring one unoccupied apartment has been monitored to extract materials and basal concentration of pollutants. Figures 6 and 7 show basal concentrations in the unoccupied apartment. We have estimated a renovation rate of 0,19 ACH obtained from the CO2 dilution method (Roulet et al., 2008)[xiii].

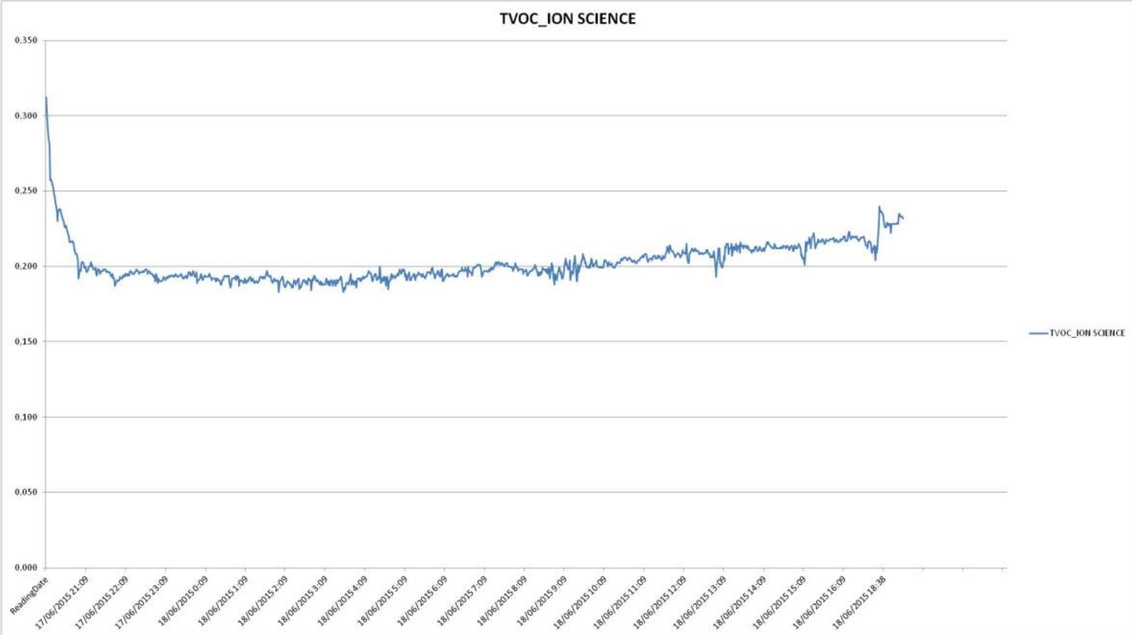

Figure 6: TVOC concentration measurement from the unoccupied apartment

The sum of all individual VOCs, referred to as TVOCs (total volatile organic compounds), measured in mg/m3, are often used as a guide to determine whether chemical levels are elevated in air samples. These levels measured in the unoccupied apartment are nearly constant (fig. 6), and maintains levels similar to LEED's standard levels of 500 μg/m3, established for new houses. In new office buildings, the TVOC concentration at the time of initial occupancy is often 50 to 100 times higher than outdoor air. Occupants almost always complain when TVOC levels are 3000 μg/m3 or higher. IAQ guidelines have been incorporated into the design and construction specifications for new buildings and to a lesser extent homes to reduce VOCs to allowable levels on the basis of current toxicologic information on health, irritation, and odour hazards.

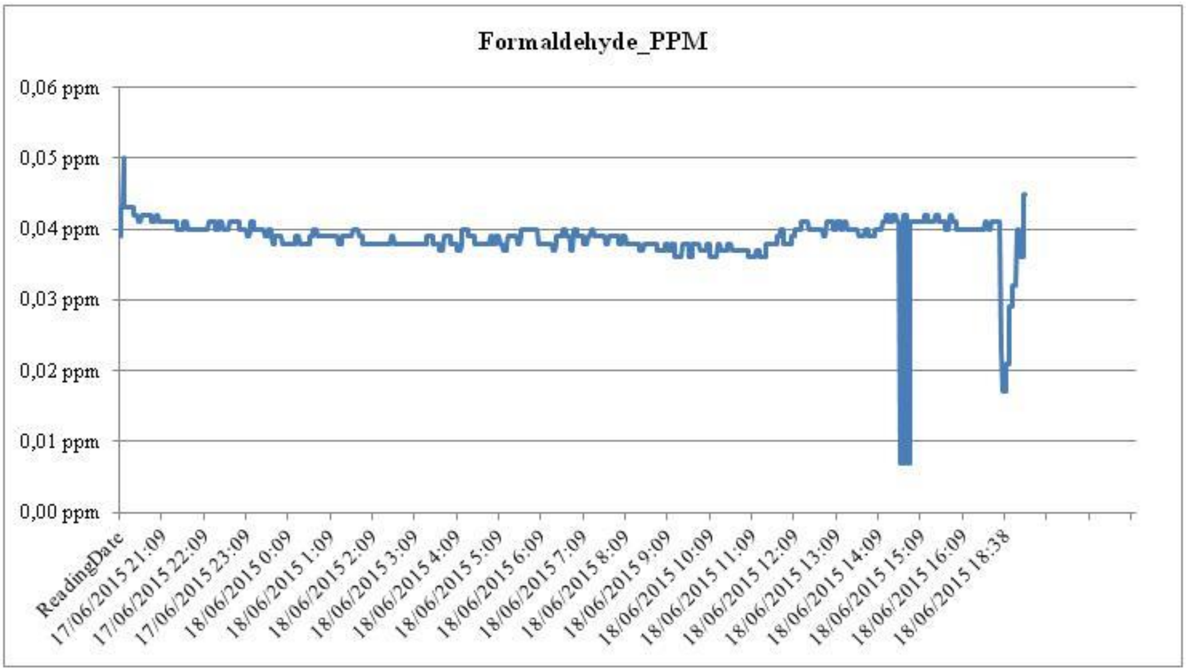

Figure 7: HCHO concentration measurement from the unoccupied apartment

Formaldehyde, among others, is one of the main pollutants in indoor environments, mostly found in offices [Wolkoff, 2013]xiv, but not negligible in residences [WHO 2010]xv. Primary formaldehyde emitters are paints, adhesives, insulations, cabinetry, workstations, ceiling tile, and wallboard. Building occupants and activities are also major sources of these indoor chemicals. The concentration at the unoccupied apartment is kept quite below the standards limits (0,1 mg/m3 is the WHO recommended threshold for 30 min). The major sources of formaldehyde are from indoor construction materials such as particleboard, fiberboard, and plywood. Formaldehyde concentrations are higher in residential buildings compared with office buildings because of the relatively large ratio of pressed wood products to air volume in homes. This concentration is higher in occupied apartments reaching and overpass established levels frequently due to emissions from furniture, materials and occupants as seen in fig. 7.

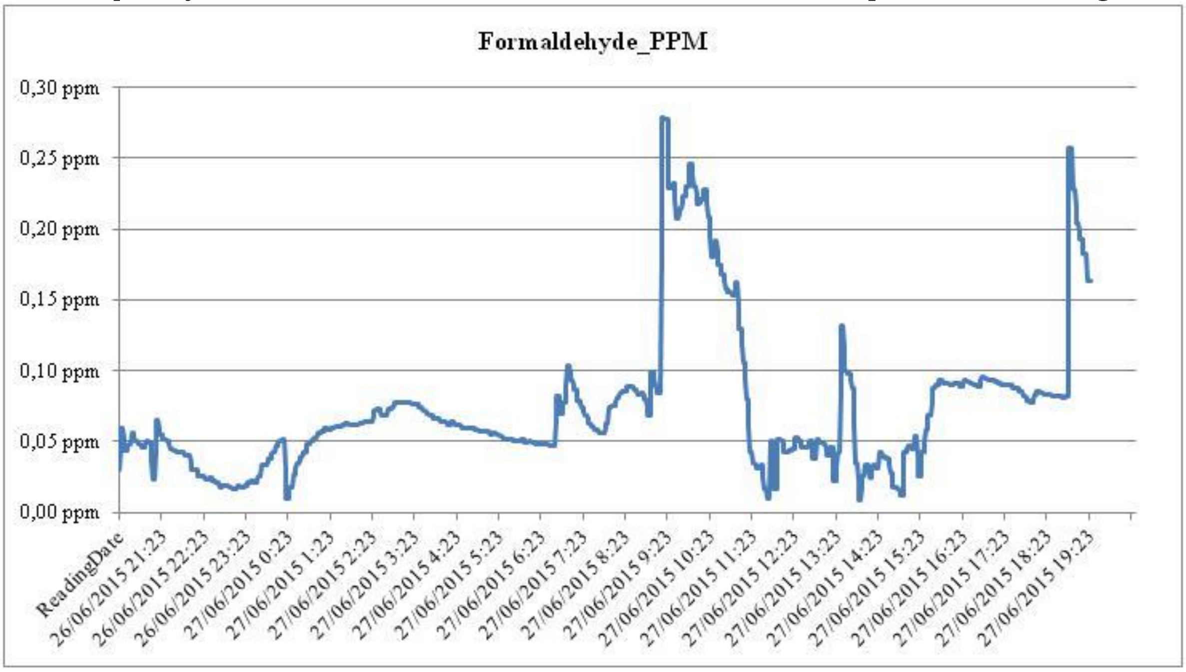

Figure 7: HCHO concentration measurement from the occupied apartment

3.3 Results after the renovation

In the apartments, the retrofit was made during winter. The results in terms of energy demand have been studied for annual consumption, taking as reference the year before and the year after the intervention. The results of the renovation, were significant both in thermal performance of the building and the pollutant levels. There has been a reduction of the energy consumption for heating in around 20%. Other observed phenomenon has been the reduction of the difference between the air temperature in the cavity and the temperature in the surface, as consequence of the reduction in the infiltration through the cavity. Infiltration in the cavity has been stabilized and the consequences of it can be observed in the temperature graphics as can be seen in fig .8 and 9

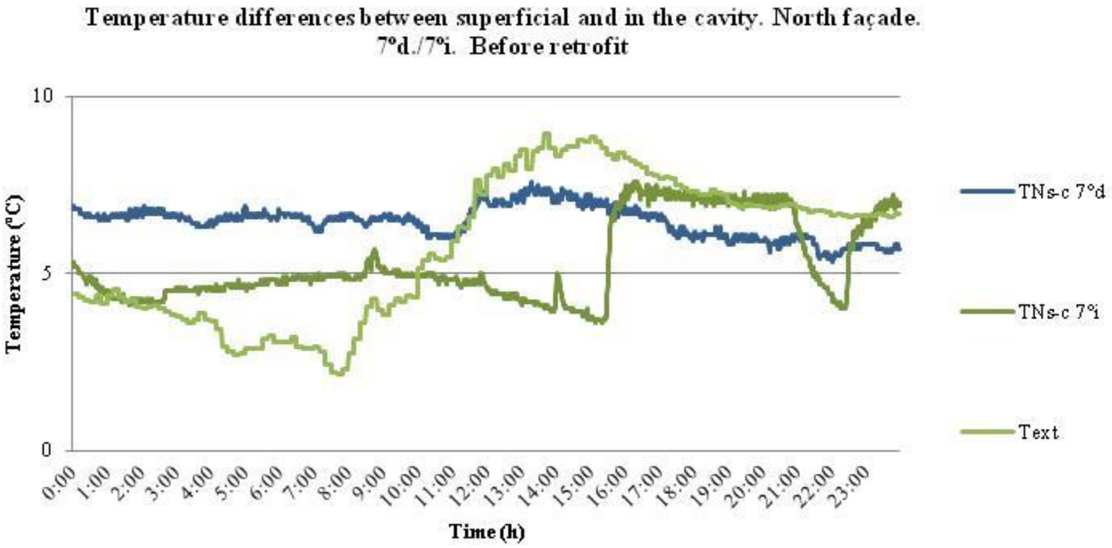

Figure 8: Temperature difference between wall surface and inside the cavity taken from the occupied apartments before the retrofit

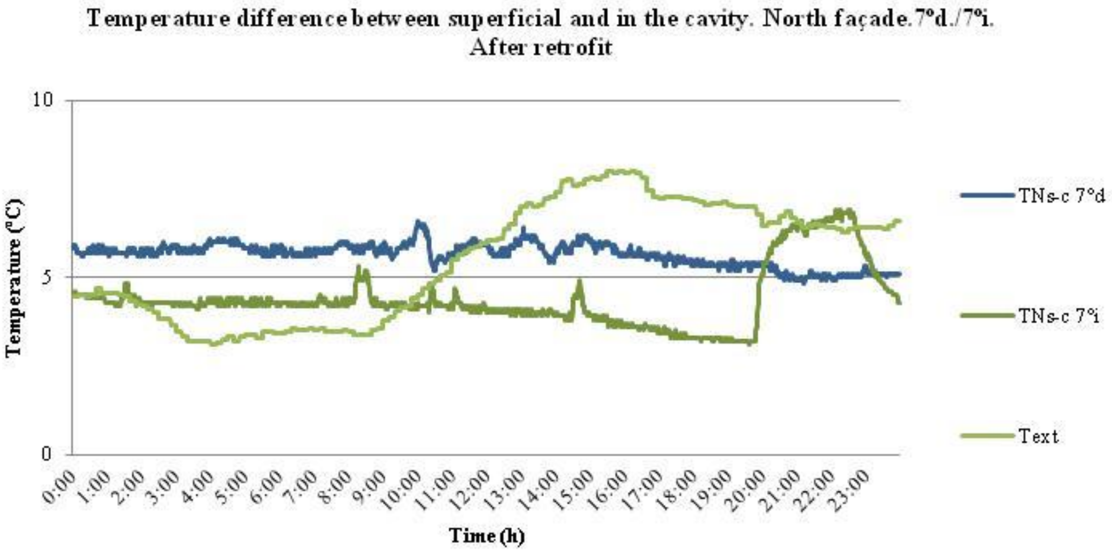

Figure 9: Temperature difference between wall surface and inside the cavity taken from the occupied apartments after the retrofit

We have compared two monitoring days, with similar outdoor and indoor conditions. Before the retrofit process, the concentration of CO2 found inside of the apartments was unusually high in some of the apartments, as only two inhabitants were present in the residence. This can be seen in figure 10. CO2 concentration in apartment 7ºi reached values above 2000 ppm. After retrofitting, we can observe in figure 11 values not only are still above 2000 ppm at some point but the time above this limit is longer. This increased value of CO2 levels after the renovation was a not expected side effect. Searching for an explanation, for these high levels, we consider the existence of fewer ACH (air changes per hour) due to the improved envelope properties and less associated leakiness. The improvement of the wall cavity has some benefit in the infiltration, reducing it, so that the renovation of air through the leaks is less important, showing up in the CO2 levels. We could expect that the users, being able to control the thermal environment, due to the façade improvement, would tend to open the windows more often but they don't seem to notice the higher concentration of CO2, as the windows don't seem to be open to let fresh air inside.

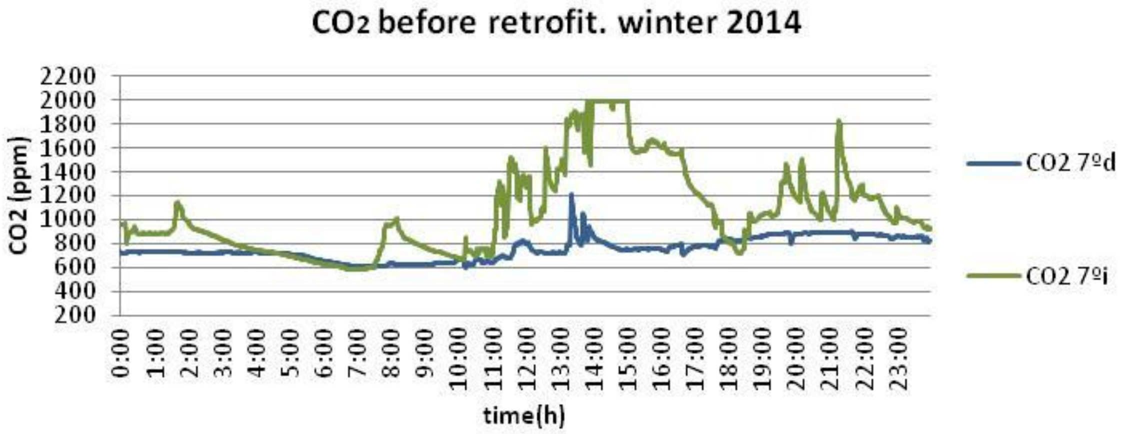

Figure 10: CO_2 concentration measurement from the occupied apartments before the retrofit

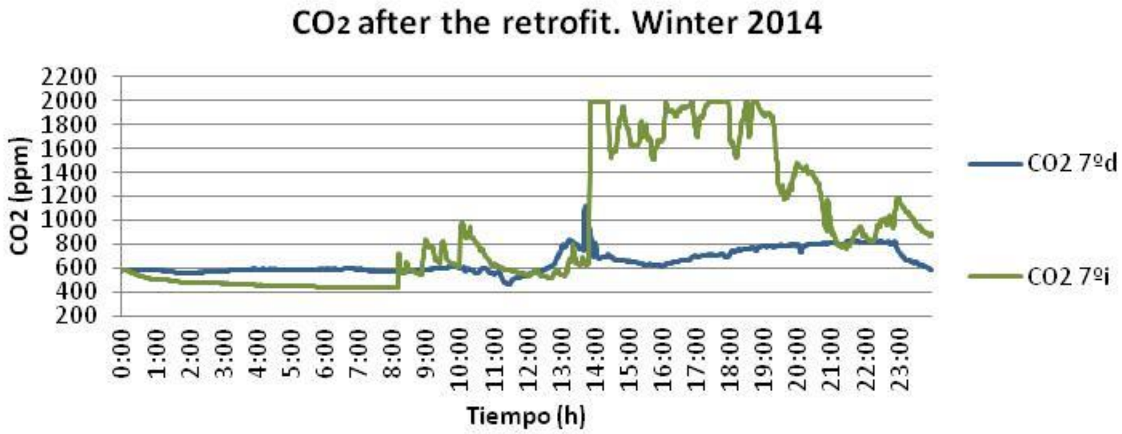

Figure 11: CO_2 concentration measurement from the occupied apartments after the retrofit

There seem to be minor inconsistencies in the schedules extracted from the concentration of pollutants and Humidity shown in the monitoring. These corrections to be made, can better establish the user profile to be able to calculate the actual thermal and IEQ behavior of the apartments in which this retrofit was done.

4 CONCLUSIONS

In this paper, an evaluation of different aspects related to IAQ in a residential representative social housing unit is done; before and after the envelope retrofit works. The main conclusions of the paper are referred to the concentration of different pollutants.

As the main conclusion of the paper, we can affirm that building retrofit, even if not directly affecting the envelope as other solutions, as ETHICS (External Thermal Insulation Composite Systems) produce direct variations in indoor environment quality and indexes due to complex interactions that generate a comfortable environment. This could be measured in reduction of both, infiltration, and concentration of contaminants.

In the case of TVOCs, the emission from materials is found to be low for the unoccupied apartments. It shows to be near to LEED standard levels of 500 $\mu g/m^3$. These levels are not

found in occupied apartments, where other factors, as occupants, cleaning products, furniture and equipment contribute to an elevation of these levels.
Similar case occurs referring to Formaldehyde (HCHO). The concentration in the unoccupied apartment was considerably lower than in occupied ones (0,04 ppm to 0,12 ppm). The mean value was stable in the unoccupied piece but suffered significant variations in occupied environments even thought temperature and humidity was kept stable.
The other gas concentration measured was CO_2. The concentrations varied from before to after the retrofit. Peak values of 2000 ppm were found before and after the retrofit but the frequency of this high values was increased after the retrofit was performed.
Another point to remark is that this variation was observed also with a reduction of the variations in the cavity. The theory suggests that leakage in the envelope can reduce effective ventilation and air change, and this is possibly the case. The improvement in the façade hermeticity reduces the infiltration. Changing the windows would have to be studied in detail to guarantee the air change and not to induce moisture and mould growth.
The case study suggests that retrofit has changed the energy behaviour of the building, as well as the environmental conditions, and pollutant concentration levels. Further studies are being conducted on same demo.

5 ACKNOWLEDGEMENTS

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