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IMPROVING BUILDINGS REFURBISHMENT THROUGH OPERATIVE CONDITIONS EVALUATION

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Abstract

As EU existing buildings stock account for 40% of the total energy consumption, it is important to take measures to reduce these needs and, consequently, reduce the EU external energy dependency as well as reducing the greenhouse gas emissions, in accordance with what is prescribed in the EU Directive 2002/91/EU on Energy Efficiency in Buildings (EPBD) and reinforced with the "EPBD-recast". The implementation of energy efficiency measures in the existing building stock is necessary to meet the 2020 targets. Thus, energy refurbishment of existing buildings is essential to achieve these goals. However, during the buildings refurbishment, energy issues should not be the only concerns since the indoor air quality is also as important. When planning a building refurbishment it is then necessary to take into account the energy efficiency exigencies and also the indoor air quality. To do so, the main problems of the existing buildings should be identified, in order to do the right choices regarding the refurbishment project. This work presents a study carried out in a large office building to identify the main pathologies, related to the energy efficiency and also to the indoor air quality. The study encompasses an "in-situ" evaluation of the operating conditions, indoor air quality and air change rate. The main objective of this study was to support the development of a refurbishment project of the building that can optimize the energy efficiency, but also the relevant parameters to the Indoor Air Quality. The results showed that the building has a poor envelope thermal resistance, inadequate shading systems and also several problems regarding high concentration of some pollutants like CO_2 or VOC.

Keywords: buildings' refurbishment, indoor air quality, operating conditions

1. Introduction

Nowadays the improvement of the energy performance of the building stock is, without question, one of the biggest challenges that the construction sector has to face, as the European building stock is responsible for 33% of raw materials consumption, 33% of final energy consumption and 50% of electricity use [1, 2, 3]. From the energy performance perspective, the main building requirements are to increase the insulation thickness, reduce thermal bridges and reduce the air changes. The latter parameter has to be thought carefully, since the reduction of air changes can decrease the intake of fresh outside air and consequently increase the build-up of internally generated pollutants. However, only in the last decade indoor air quality (IAQ) has become an important occupational health and safety concern with public and governmental awareness.

The harmonization of the buildings energy performance requirements with the indoor air quality (IAQ) should be done in every building project, both for new and existing buildings.

Portugal implemented in 2006, the National Building Energy and Indoor Air Quality Certification System, corresponding to the transposition of the Energy Performance of Building

Directive, EPBD [4], which imposes minimum energy efficiency for all buildings and periodic IAQ audits for office buildings.
As 90% of the population spends about 90% of their time in enclosed spaces exposed to consistently higher concentrations of air pollutants than outdoors, which led to the increase of the allergies and asthma incidence rate, thus a good indoor air quality has a vital impact in human health.
Asthma affects of about 150 million people worldwide and approximately 1 million in Portugal (10% of the population) and its incidence continues increasing, both in young as in elderly people [5].
Suspended particles are seen by many as one of the most critical air pollutants and some estimates suggest that particles are responsible for up to 10,000 premature deaths in the United Kingdom each year [6]. The IAQ is then an important factor in men well-being, health and productivity. Thus, when planning a building refurbishment, energy efficiency issues should be merged with the indoor air quality exigencies.
This paper present a study carried out in a large office building to identify the main pathologies, related to the energy efficiency and also to the indoor environmental quality. The study encompasses an "in-situ" evaluation of the operating conditions, indoor air quality, and air change rate. The main objective of this study was to support the development of a refurbishment project for the building that can optimize the energy efficiency but also the relevant parameters to the IAQ.

2. Methodology

This paper presents the assessment of the Indoor Air Quality and the Energy Performance of an office building located in the centre of Oporto, Portugal. The measurement campaign was divided in two major areas:

- IAQ conditions – measurement of the concentration of suspended particles (PM10), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), formaldehyde (HCHO) and total volatile organic compounds (VOC).
- Characterization of the operating conditions of the buildings – Building air tightness (air change rate), occupation patterns, equipment and appliances existing in the rooms and their use pattern.

2.1 Building Characteristics

The building under analysis is located in an urban area, the city centre of Oporto in the North-West of Portugal. The building, represented in Figure 1, has 5 floors. The ground floor is partially underground. The building was built in the 1970's and suffered some changes in the 1990's. This building was chosen as it is representative of most of the Portuguese office buildings and was built before the implementation of the first Portuguese Thermal Regulation.

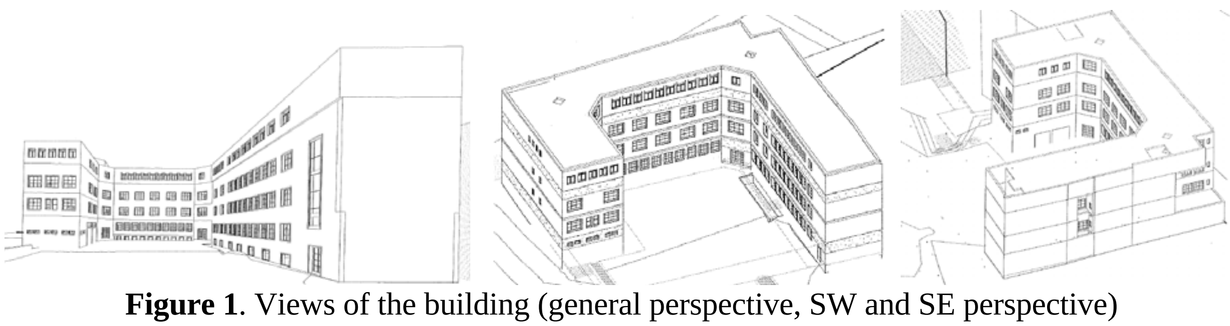

Figure 1. Views of the building (general perspective, SW and SE perspective)

The walls are concrete masonry units (CMU) with 27 cm thickness with plaster finishing and the roof is a concrete slab. All the windows are single glazed with metallic frame. The ground floor windows do not have any shading devices and the first floor windows have inside venetian blinds. The windows in the second and third floor have roller shutters and the windows in the fourth floor have curtains.
The building is naturally ventilated and has a diesel boiler associated with water radiators in the offices. Some rooms have additionally electrical oil radiators. There is no centralized cooling system and most part of the offices did not have any active cooling system, some had fans and others had split systems for cooling that were only turned on when the occupants were in the room.

2.2 Measurement procedures

The measurement campaign was performed during the summer months of June and July.
To measure "in situ" parameters associated to the IAQ and energy efficiency, procedures defined in national standards were followed [7, 8].

2.2.1 Indoor Air Quality (IAQ)

According to the thermal regulations in Portugal it is mandatory to carry out IAQ audits in office buildings [7, 8]. In this study a complete IAQ audit was not performed, only a set of physical and chemical pollutants were measured in several offices with portable measuring equipments: Testo 435 (CO_2 and CO); TSI DustTrack II (PM10); ZDL-300 (HCHO); ZDL-1200 (O_3); Photovac 2020ppb (VOC).

2.2.2 Air tightness

The air tightness of the building is also an important indicator of the IAQ and of the energy performance of a building and it can be obtained by the building Air Changes Rate (ACH). If the building is naturally ventilated this parameter can be estimated using the methodology presented on the Portuguese building thermal code [9]. However, in existing buildings, a more accurate ACH value can be obtained using measuring equipment such as the blower-door, which will pressurize/depressurize the building, measuring the air flow that enters/exits the building.

3. Results

The results obtained through the measurement campaigns performed on several offices are presented below according to the type of analysis done. In Figure 2 are shown the offices where the measurement campaign was performed, i.e., all the offices with permanent occupation. Some additional measurements were also performed outdoors (temperature, relative humidity, pollutants, L_{Aeq}).

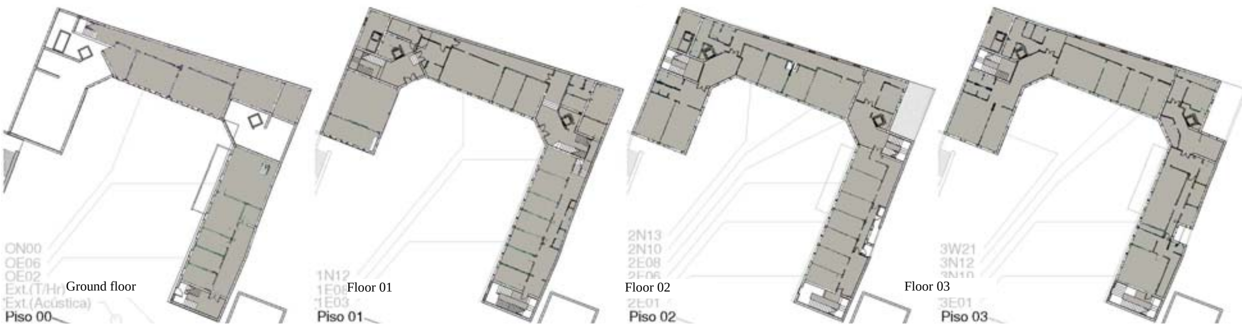

Figure 2. Measured rooms (first number represents the floor, the letter represents the orientation of the room, the last two numbers represent the room number)

3.1 Indoor Air Quality (IAQ)

The Indoor Air Quality (IAQ) was assessed through the measurement of the concentration of physical pollutants (CO, CO_2, CHOH, VOC, O_3, PM_{10}). The presence of radon and microbiological contaminants was not assessed since they require significantly higher measurement times, and thus were scheduled for a 2nd measurement campaign.

Figure 3 shows the results of the carbon dioxide and monoxide (CO_2 and CO) measurements for the different office rooms of the building that were studied. The measurements shown considerably lower concentrations than the maximum limits since the occupants open the windows and the outdoor concentration is also low.

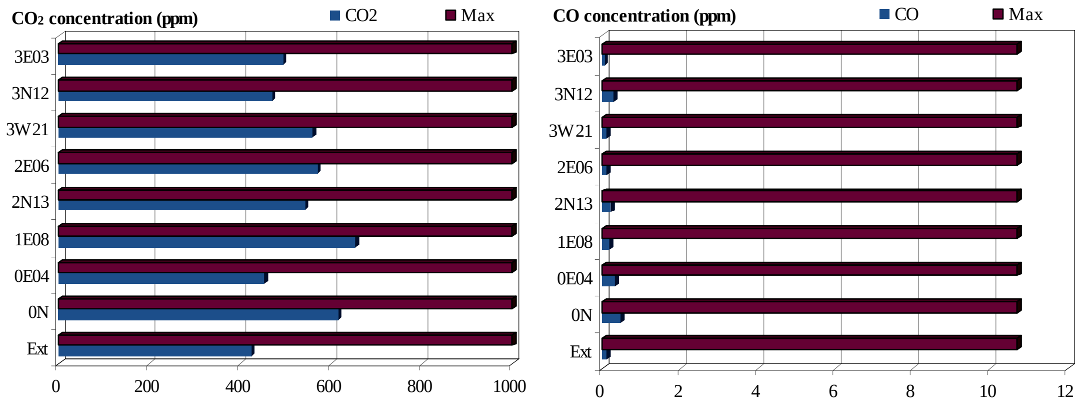

Figure 3. CO_2 and CO concentration and maximum reference values

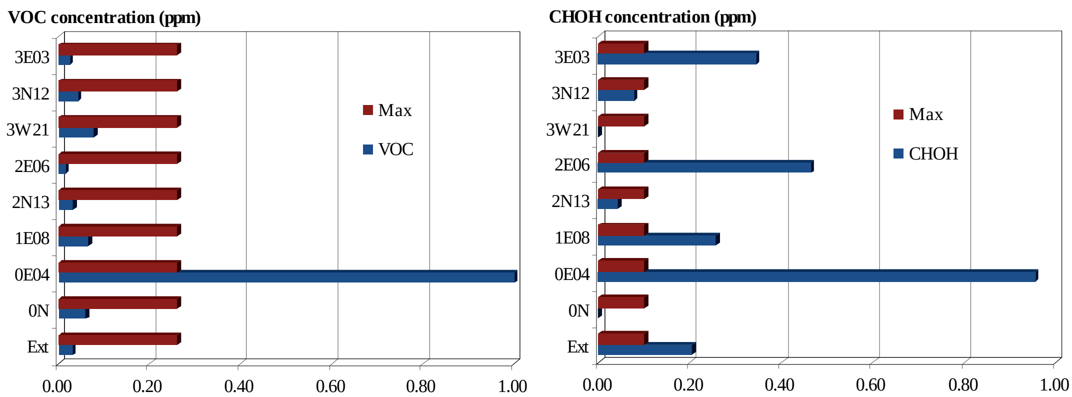

Figure 4. VOC and CHOH concentration and maximum reference values

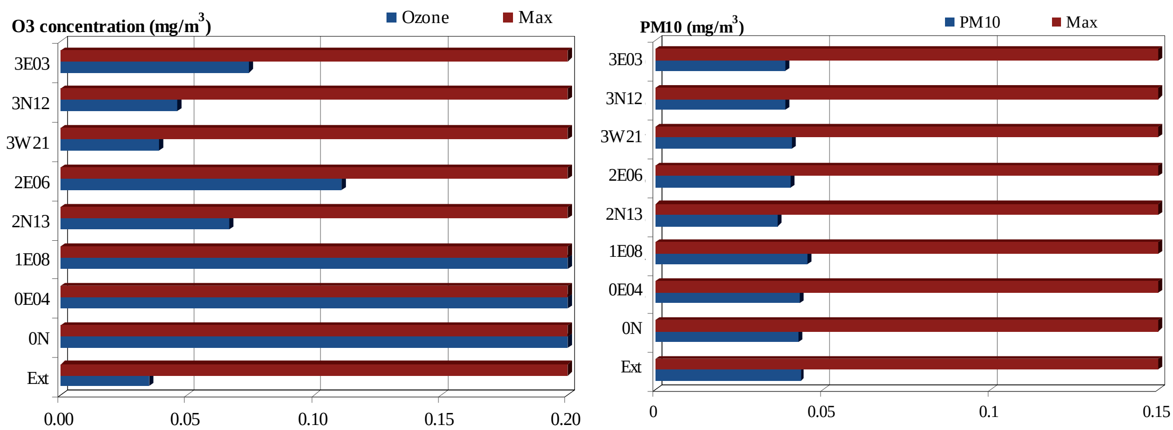

Figure 5. O_3 and PM_{10} concentration and maximum reference values

Figure 4 shows the results of the volatile organic compounds (VOC) and formaldehyde (CHOH) measurements for the different office rooms of the building that were studied. The measurements showed a high concentration of volatile organic compounds in the room 0E04 – a laboratory – where several reagents are used. A high concentration of formaldehyde was also measured in the exterior and in rooms 0E04, 1E08, 2E06 and 3E03.
Figure 5 shows the results of the ozone (O_3) and suspended particles (PM_{10}) measurements for the different office rooms of the building that were studied.
The high ozone concentrations are probably due to the outdoor concentration (intense traffic) and the presence of laser photocopiers in some of the rooms. Also, the air movement between spaces transfer the contaminant between rooms. The suspended particles concentration does not present a problem and are mainly due to the outdoor concentration, as the building is located near heavy traffic circulation road.

3.1.5 Air tightness

A blower-door was applied to measure the number of air changes per hour (ACH) of the room 1E08. The minimum air change rate according to the Portuguese thermal code is of $0.6h^{-1}$.
The air change rate of the room, obtained from Equation (1) [10], was of $1.03\ h^{-1}$.

$$Q = C \times P^n \quad (1)$$

with:

Q – Air flow rate (m^3/s);

C – Flow coefficient ($m^3/s/Pa^n$);

P – Pressure difference from indoors and outdoors (Pa);

n – Flow exponent (-).

The air change rate is quite high and will result in substantial heat losses in winter and heat gains in summer. Thus, interventions at this level are also essential to increase the energy performance. Mainly through the replacement of the windows and use of mechanical ventilation systems with heat recovery, which will be the most efficient way to achieve the optimum values for the air change rates, with minimum waste of energy especially in winter.

3.2 Energy Analysis

Taking into consideration the results of the IAQ and air tightness assessment, an estimation of the building thermal behavior was performed using Energy Plus 5.0 simulation code [11]. The building characteristics, envelope construction solutions, shading systems (venetian blinds on the first floor and roller shades on the second and third floors on the outside, these systems are sometimes complemented by sliding shutters and venetian blinds in the interior), lighting systems (tubular fluorescent lamps and sometimes compact fluorescent lamps), appliances, air-conditioning systems were also assessed and occupation and systems use schedules were defined in accordance with the Portuguese thermal code [7]. Most of the rooms have a water radiator associated to a 20 years old centralized diesel boiler, several rooms have also a electric radiator (1500 W) and a fan (45 W). Some of the spaces have portable split system for cooling.
Besides the actual situation, two refurbishment options were studied: thermal insulation placed inside (6cm of cork and 1.3cm plasterboard) and thermal insulation placed outside (6cm of expanded polystyrene). In both options a suspended ceiling with a 10cm thick layer of cork and 1.3cm plasterboard was added to the roof. The existing windows will be replaced by aluminium with thermal break with double clear glazing with venetian blinds placed on the outside. Table 1 presents the main building envelope characteristics considering the original state and the two refurbishment options.

Table 1. Main building envelope characteristics

	Walls	Roof	Windows	
	U-Value [W/m^2.ºC]	U-Value [W/m^2.ºC]	U-Value [W/m^2.ºC]	Shading Factor (inc. glazing and shading device)
Original	1.90	1.40	6.20	0.45
Refurbishment - outside insulation	0.49	0.30	3.30	0.11
Refurbishment - inside insulation	0.48	0.30	3.30	0.11
Maximum Value allowed	1.60	1.00	-	0.56

Only with the refurbishment of the envelope, considering an ideal HVAC system with efficiency of 100%, the heating needs will be reduced in 45% and the cooling needs in more than 25% (Figure 6, left). The annual reduction is more than 40%. With the installation of a pellets boiler (efficiency of 60%) and the chiller (COP of 3) in addition to the improvement of the envelope the installed power needed is reduced in more than 20% (Figure 6, right).

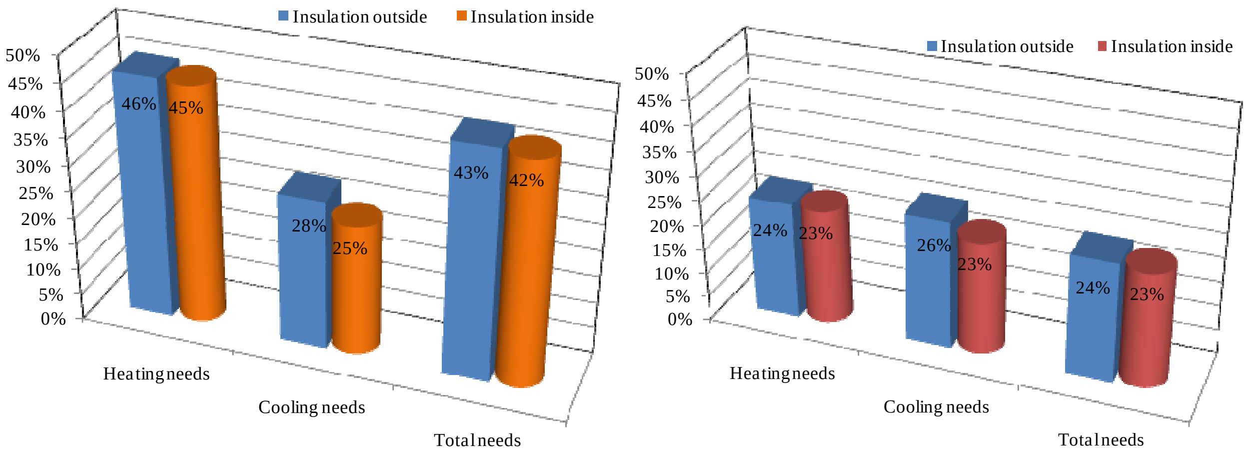

Figure 6. Percentage of reduction in the heating and cooling needs (left) and percentage of reduction in the heating and cooling power (right) due to building retrofit

4. Conclusions

This paper presents the operating conditions assessment as well as the Indoor Air Quality of a Portuguese office building. The measurement campaign was divided in two major areas: characterization of the operating conditions of the buildings and Indoor Air Quality.

With the operating conditions assessment carried out, it was possible to identify some of the most critical problems of the building, the ones that need particular attention during the rehabilitation interventions.

The measurement campaign confirmed the necessity of reducing the envelope U-values, using higher insulation levels, since the original building values are always higher than the recommended values by the Portuguese legislation (0.6 and 0.45 W/m^2.ºC for walls and roofs, respectively), and in some cases even higher than the maximum allowed values (1.6 and 1.0 W/m^2.ºC for walls and roofs, respectively). Since the results obtained applying exterior or interior insulation are similar, it is recommended that, when possible, use a continuous external thermal insulation layer since it also correct the many thermal bridges in the buildings envelope. If the exterior insulation is not an option, like in this case, as due to the location of the building - Porto historical center - the façade must remain with the same aesthetic, thus the only solution to improve the envelope thermal performance is to apply insulation by the interior.

It is also important to reduce the uncontrolled infiltrations through the envelope, using more airtight window frames and doors, with adjustable air inlets to ensure an adequate air change rate and using mechanical ventilation systems with heat recovery units. However, the control of the air change rate must be done very carefully in order to ensure the indoor air quality, since, even with high air change rates, there were detected high concentrations of some pollutants like volatile organic compounds and formaldehyde, and also small concentrations of ozone.
It is important to enhance that the occupants' behaviour has a significant effect on the indoor environmental quality and energy efficiency of the buildings and must be taken into consideration during design phase of the rehabilitation processes. They should be informed of the correct way of using the buildings to ensure the comfort conditions, indoor air quality and energy efficiency. The existence of a "building manual" is a way of achieving this purpose.

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