Indoor Environment and Energy Efficiency in Higher Schools Buildings

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Abstract— **The paper presents the main results obtained in a Higher School Building, which are analyzed in view of the actual Indoor Environmental Quality (IEQ) and Energy Efficiency. Measurements were carried out in one building, ventilated by mechanical system. Direct measurements were made with portable monitoring data loggers and in some long-term measurements. The students assessed through questionnaires the IEQ parameters felt in the classrooms a few moments before the end of the class. The IEQ in higher/university schools buildings has been found to be poor because of the high density of students in class rooms. In particular, the Indoor Air Quality is a significant issue for these buildings in order to be healthy and comfortable for learning performance of students.**

Keywords- Indoor Environmental Quality (IEQ), Indoor Air Quality (IAQ), Building Simulation, Thermal Comfort, School Buildings, Thermal Comfort.

I. INTRODUCTION

The sector of buildings is, on a global scale, one of the largest energy consumers (together with transport and industry sectors), becoming essential to ensure a higher energetic and environmental efficiency, thermal comfort and health conditions. Due to high energy prices people are increasingly isolating the buildings and reducing the ventilation rate.

Therefore, it is essential to ensure that they improve their energy and environmental efficiencies, but while ensuring the health conditions. Today we spend 90% of our time inside buildings [1][2][3]. The quality of environment air (outdoor) in cities of developed countries has improved greatly in recent decades. During this same period, IEQ decreased because of energy conservation, reduced ventilation and the introduction of new materials and new sources of indoor pollution. The growing demand for lower energy consumption of buildings resulted in the reduction of heat loss due to transmission by transforming the buildings into closed buildings where the ventilation rates become lower. This fact and the introduction of new building materials can often lead to unacceptable levels of IAQ [4].

There are some investigations that point to lack of knowledge about the effects of poor environmental conditions in classrooms, considering that this type of researches found inadequate school environmental conditions, far worse than in office buildings [5][6][7][8][9].

A. *Indoor Environmental Quality (IEQ) and Energy Efficiency*

The international standard ISO 7730:2005 [10], developed in parallel with the revised ASHRAE 55 standard [11], considers that a room provides thermal comfort if not more than 10% of its occupants feel discomfort [12]. These studies establish a relationship between the outcome of the energy balance of the body and the trend of dissatisfaction. ISO 7730 standardizes the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfaction) as the method for evaluation of moderate thermal environments. The standard recommendation for an acceptable environment is -0,5 < PMV < 0,5; PPD < 10 %. Besides the general thermal state of the body, a person may find the thermal environment unacceptable or intolerable if local influences on the body from asymmetric radiation, high air velocities, vertical air temperature differences or contact with hot or cold surfaces are experienced. It was found that persons with lower activity levels (sedentary or standing) are sensitive to draughts, a undesired local cooling of the human body caused by air movement. Occupants who are subjected to draughts in winter tend to elevate the room temperature to counteract the cooling sensation thereby increasing the energy consumption. In extreme cases ventilation systems are shut off or air supply outlets are blocked off with a consequent deterioration of the indoor air quality. Fanger [12] developed a mathematical model to quantify the draught risk in terms of the percentage of dissatisfied people. In this model, the percentage of dissatisfied people due to draughts, DR (%), is calculated from:

$$DR = (34 - T)\,(v - 0{,}05)^{0{,}62}\,(3{,}14 + 0{,}37vI) \qquad (1)$$

for v < 0,05 m/s let DR = 0 %
and for DR > 100 % let DR = 100 %.

where T is the local air temperature (ºC), v is the mean velocity (m/s) and I is the turbulence intensity (%), which is defined as the velocity fluctuation over the mean velocity.

The first factor to take into account when carrying out an analysis of air quality is what are the potential contaminants that can be found, their concentrations and the sources of origin [13].

Ventilation is the process of exchanging indoor air (polluted) by outside air (presumably fresh and clean). The main objective is to create better conditions for humans indoors, taking into account the health, comfort and productivity by providing air to breathe (indoor air), which may be through the removal and dilution of pollutants, the removal of pollutants and addition of treated air and heating or cooling.

Several authors have published about the effects of ventilation on health and finds that low ventilation rates can significantly worsen health outcomes, particularly at the Sick Building Syndrome (SBS) [1][2][9][11][15][16][17][18][19][20][21].

Evaluation of IAQ in buildings, according to the Portuguese legal requirements, resulting from the implementation of European directive for building energy efficiency, are defined and specified in Regulation of Energy Systems and Air Conditioning in Buildings (RSECE) [22].

For new buildings, IAQ requirements include minimum values of air exchange (minimum flow of fresh air) per room, depending on the type of activity, and a maximum speed of the indoor air (requirement of thermal comfort) of 0,2 m/s. For existing buildings, IAQ evaluation will verify compliance with same requirements, including maximum concentration of pollutants and maintenance of systems in hygienic conditions to ensure the IAQ (Table 1).

TABLE I. MAXIMUM CONCENTRATIONS REQUIREMENTS OF POLLUTANTS WITHIN EXISTING BUILDINGS (RSECE) [22]

Pollutants	**[mg/m^3]**	**[ppm]**
PM_{10}	0.15	---
Carbon Dioxide	1800	984
Carbon Monoxide	12.5	10.7
Ozone	0.2	0.10
Formaldehydes	0.1	0.08
Volatile Organic Compounds	0.6	0,26 (isobutylene) 0,16 (toluene)
Radon	400 Bq/m^3	
Fungi	500 UFC/ m^3	
Bacteria	500 UFC/ m^3	
Legionella	100 UFC/ L H_2O	

The standard EN 15251:2007 [23] for Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

II. TECHNICAL WORK PREPARATION

This present work consist essentiality in an evaluation of indoor environmental quality and energy sustainability conditions in a college/higher school building of the Polytechnic Institute of Leiria, located in a temperate climate region of Portugal (Figure 1), ventilated by mechanical systems. The study of higher school buildings has a great importance, not only by the large number of buildings in Portugal, but also due to the high energy consumption, often with low efficiency. Moreover, their occupations are usually a young population, in the process of academic training and are therefore more aware to these issues. It is worth noticing the extreme importance of the study to be undertaken in this research area, because significant numbers of evaluations in such buildings are not known, in Portugal. The School of Technology and Management of Polytechnic Institute of Leiria (ESTG) has currently about 6000 students and consists of modern buildings (Building A, B, C, D, E, and Library).

Figure 1. IPLeiria Plan View of Campus II - *Building D.*

Building D (Pedagogic building) - The building is 8851 m^2, is a recent building (2004) and has a L-shaped implantation and have plenty of areas provided with glass. The building has a maximum valence for this type of use, which consists of many classrooms, laboratories, computer rooms, reprography rooms, auditoriums, rooms for storage, toilets, coffee-shop/bar area, offices for teachers, meeting rooms and passage areas. Its ventilation system is mechanical (heating, ventilation and air conditioning-HVAC) and has a capacity of 985 occupants.

Direct measurements with portable monitoring data loggers were carried out in the *Building D* of the Campus II of IPL, belonging to ESTG. The measurements were carried out in the winter and summer season. Measurements were made by long-term continuous and by point sampling, with portable monitor equipment always following best practice recommendations for audits of IEQ and Energy Efficiency as much Portuguese as ISO 7726 [17].

The study of indoor environmental quality and energy efficiency of buildings higher education becomes increasingly important, not only because of its complexity due to various factors, which emphasizes the large number of variables that influence performance, as due to its subjective nature and the fact that the buildings were made of areas with different purposes often enough and the high number of users. Due to the complexity of this research, analysis was done into two points of analysis:

1. Energy analysis
2. Analysis of indoor environment quality

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III. RESULTS

These results reflect the reality found in *Building D* through direct measurements and questionnaires made during one year.

A. *Energy analysis*

The electric energy consumption on *Building D* was compared to one measurement in the power station. Figure 2 represents the diagram of charges in the building.

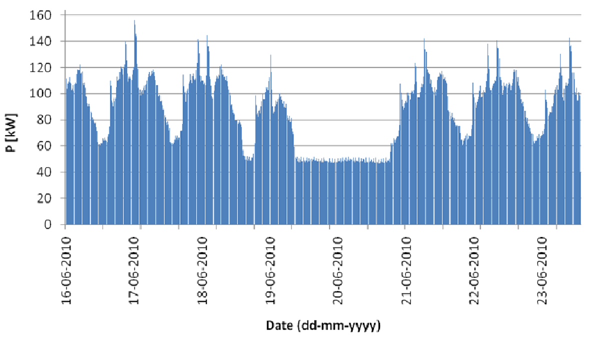

Figure 2. Diagram of charges in the Building D

The measurement of energy consumption on a daily basis is a reasonable range of recording, it can be used to distinguish between weekdays and weekends and disaggregating energy end uses is essential to validate the model.

The electric energy consumption verified on *Building D* was dissociated between the computer center, the HVAC, cooling and the rest of the building, as presented in Figure 3.

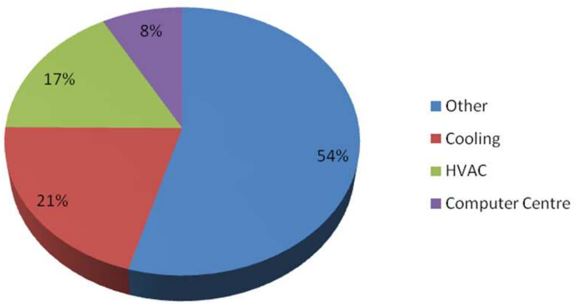

Figure 3. Dissociation of *Building D* consumption

The computer model of *Building D* (Figure 4) is properly calibrated and validated with the field measurements as a way to improve Indoor Environment Quality (IEQ) and the energy efficiency of the Building.

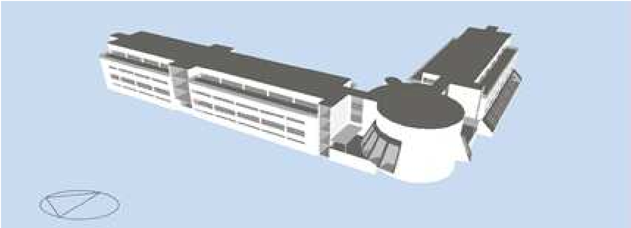

Figure 4. View of Building D (DesignBuilder)

The dynamic simulation has four distinct cases:

Case 1. The closest possible to the actual case study (real consumption of *Building D* – Calibration Model);

Case 2. The reference values and schedules of the Portuguese legislation for Higher Education Buildings (Spain does not provide recommended values for these cases);

Case 3. Conditions optimization (schedules, temperature set points, computers, office equipment and lighting improvements, lighting and shadow control).

Case 4. Same conditions as Case 3 but with the reference schedules of the Portuguese legislation for Higher Education Buildings.

The different case simulations are performed on *DesignBuilder / EnergyPlus*. The Table II presents some of the simulation results.

TABLE II. SIMULATION RESULTS

Simulation results	Case 1	Case 2	Case 3	Case 4
CO_2 (kg)x10^3	715,71	722,82	437,93	314,16
Relative Humidity (%)	46	45,94	47,38	48,38
Fanger (PMV)	0,5	0,45	0,41	0,34
Mech Vent + Nat Vent + Infiltration (ac/h)	0,63	0,61	0,63	0,63

The simulation results (Figure 5) show that appropriate operational mode could greatly improve the energy consumption.

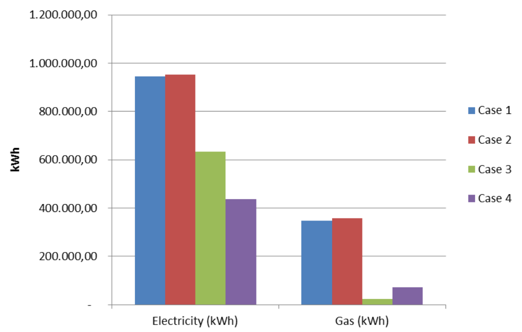

Figure 5. The consumption for the different cases

B. *Indoor Environmental Quality*

The values obtained by direct measurements were validated by the thermal votes of the students and teachers to the same environment predicted by questionnaires, obtaining subjective results. Figures 6 and 7 present air temperature results in the winter and summer season, according to EN 15251[23].

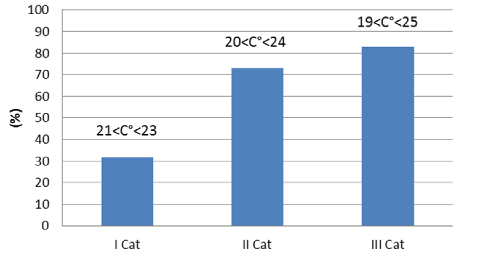

Figure 6. Temperature values recorded for winter season

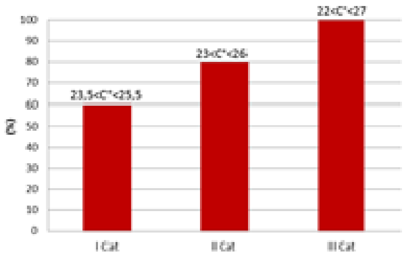

Figure 7. Temperature values recorded for summer season

Concerning the thermal comfort conditions, it enables the analytical determination and interpretation using calculation of PMV and PPD index and local thermal comfort criteria.

The values of PMV and PPD were calculated with 1.2 met and 1.0 clo (winter season) or 0.5 clo (summer season), and according to the EN 15251 [23] (Figures 8 and 9).

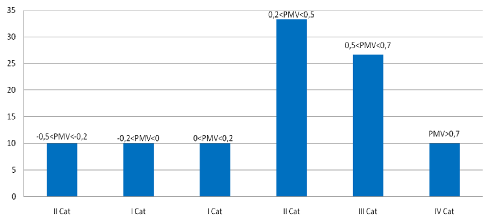

Figure 8. PMV values recorded for winter season

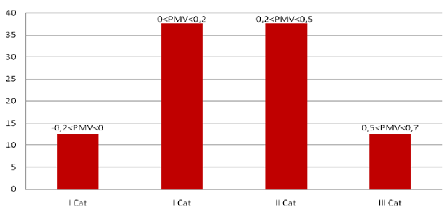

Figure 9. PMV values recorded for summer season

Figures 10 and 11 present according to EN 15251 [23], the subjective results called Expressed Mean Vote (EMV).

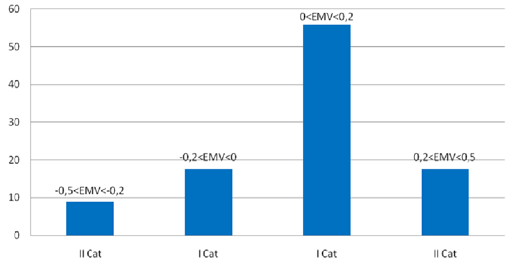

Figure 10. EMV values recorded for winter season

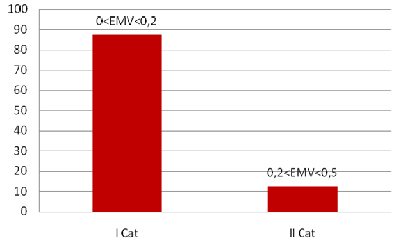

Figure 11. EMV values recorded for summer season

Field experiments of local thermal comfort criteria, based in the local air velocity, temperature and the turbulence intensity, were used to calculate the draught risk in terms of the percentage of dissatisfied people (DR). Figure 12 and 13 presents an example of air velocity and DR obtained in a classroom with different systems of ventilation.

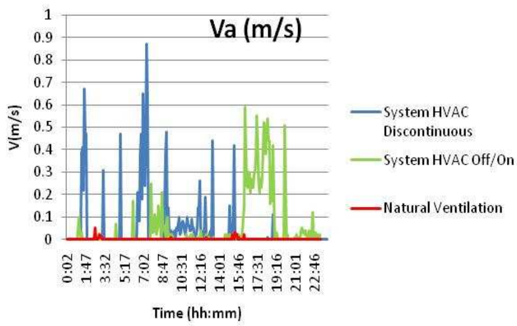

Figure 12. Typical air velocity

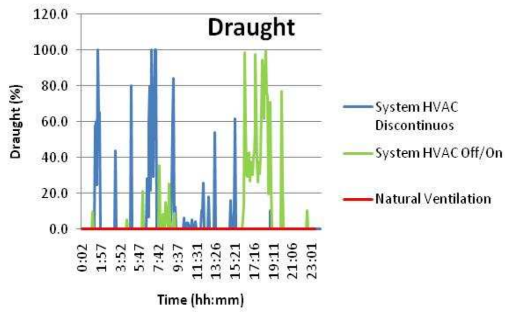

Figure 13. Percentage of dissatisfied due to draught risk

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Concerning the indoor air quality evaluations, a representative typical example of experimental CO_2 values obtained in some classrooms is presented in Figure 14 for a classroom in a building with natural ventilation, for discontinuous HVAC conditions (because the system turn on and off all day), and for a HVAC Off/On conditions (which mean that the system has off until the middle of the day and after it has turn on).

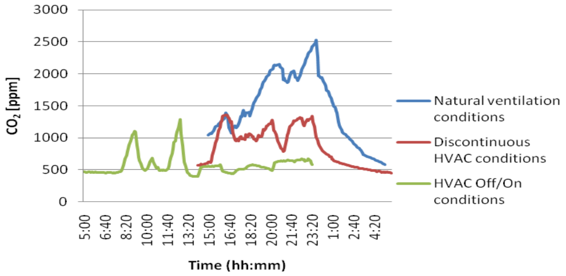

Figure 14. Experimental CO_2 values

As expected, the concentration of CO_2 and the relative humidity changes according to the occupancy conditions (number of peoples and length of time).

Furthermore, the EN 15251 [23] suggest several levels of CO_2 above outdoor, corresponding to different quality categories. For winter season the average of the measurements CO_2 outdoor was equal to 458 ppm and for summer season the average measurements of CO_2 outdoor was 401 ppm (Figures 15 and 16).

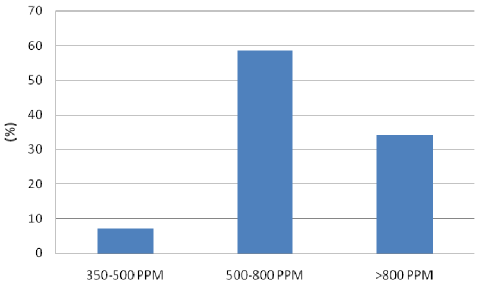

Figure 15. CO_2 values recorded for winter season

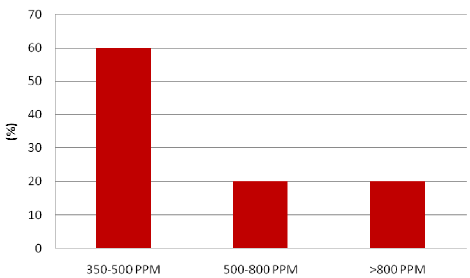

Figure 16. CO_2 values recorded for summer season

In the indoor environment of classrooms in winter, there are high concentrations of CO_2.

IV. DISCUSSION AND CONCLUSION

The measurements made during this study allow us to reach the following conclusions:

There are some building intrinsic properties, which affect the internal conditions but another key aspect is the behaviour of the occupants and their actions that affect the internal conditions.

The dissatisfaction due to draught is caused, in many cases, by air velocity and turbulence intensity.

Results show and demonstrate that ventilation is a very important issue. Different operating modes can deliver to different results which might lead to take decisions, often unsatisfactory. The recommended solution is the hybrid ventilation systems. The key problem is to provide the total control system, sufficient but not excessive ventilation, avoid drafts, etc.

Comparing the ventilation rates achieved, represented by air changes per hour, with the ones recommended by standards, and due to relative errors, it was concluded that the temperature of air, carbon dioxide levels, formaldehyde, bacteria, fungi and air change rates are many times at unacceptable levels. The measurements made indicate that is convenient to maintain the temperature and relative humidity of the buildings on lower levels of thermal comfort.

The objective and subjective results obtained in our study, allow us to state that the building has acceptable levels for different environmental factors.

Is also clear that modelling is a very important activity for sustainable construction engineering. However, there still a set of important problems. The full integration of energy and indoor environmental quality modelling and design projects, requires the integration of additional processes and especially, more research regarding how to make decisions, and in the manner of how the results of modelling can help to make choices in this type of buildings.

The Building Management System (BMS) should be able to respond to these dynamics (the indoor air temperature, CO_2 level, the automatic control of naturally ventilated building, occupancy, humidity, rain detection, outside air temperature, wind speed and wind direction sensors) and be capable of a resolution to operate both in the cases of high occupancy (high density), as in the cases of low occupancy (low density).

More efficient temperature set points can reduce the energy consumption of Higher Education Buildings. Therefore, efforts should be made to reach new reference standard values. The simulations show that small changes have quick paybacks. We can reach over the 50% of improvement (Case 4).

New energy efficient technologies are needed to achieve the new directives; the development may require an understanding of the mechanisms by which the indoor environmental quality affects humans.

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