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Indoor Environment and Energy Efficiency in Higher Schools

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Indoor Environment and Energy Efficiency in Higher Schools

Memoria presentada para optar al Grado de Doctor

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UNIVERSIDAD DE SALAMANCA

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Salamanca, 20 de septiembre de 2011

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RESUMEN

Los edificios representan el 40% del consumo total de energía en la Unión Europea. Por lo tanto, la reducción del consumo energético y el uso de energía procedente de fuentes renovables en el sector de la construcción son medidas importantes que se necesitan para reducir la dependencia de la energía y las emisiones de gases de efecto invernadero.

Las medidas para mejorar la eficiencia energética y ambiental de los edificios deben tener en cuenta las condiciones climáticas y locales, el tipo de ocupación, así como el entorno ambiental interior y la rentabilidad. Estas medidas no deben afectar a otras características de los demás requisitos para los edificios, tales como la accesibilidad, la seguridad y el uso previsto del edificio.

El consumo energético de los edificios depende en gran medida de los criterios utilizados para la calidad ambiental interior (confort térmico, confort visual, confort acústico y la calidad del aire interior), y los criterios para la construcción (incluidos los materiales, diseños, orientación, sistemas de energéticos, operación y mantenimiento). La calidad ambiental interior afecta a la productividad, la salud y el confort de los ocupantes, por lo general, la mejora de la calidad del ambiente interior puede mejorar el aprendizaje y el rendimiento, reduciendo el ausentismo.

Un compromiso con la eficiencia energética no tiene por qué poner en peligro la calidad del ambiente interior. Por consiguiente, es necesario especificar los criterios para el ambiente interior para los cálculos de la energía, el rendimiento y el funcionamiento de los edificios.

Hay una variada legislación internacional, española y portuguesa que especifican los indicadores y los criterios de evaluación de eficiencia energética de los edificios, confort térmico, confort acústico, confort visual y la calidad del aire interior.

El propósito de esta investigación es desarrollar un estudio de evaluación del rendimiento y definir medidas específicas destinadas a optimización de la eficiencia energética y medioambiental de los edificios de educación superior. Los edificios públicos en general y en particular los edificios de enseñanza superior, deben dar el

ejemplo, debido a causa de su público, demostrando que las consideraciones ambientales y de energía deben tenerse en cuenta, por lo que deben ser objeto de auditorías periódicas y medidas de mejora continua de calidad. La divulgación pública de información relativa a la auditoría, debería reforzarse en este caso, para que los estudiantes tomen conciencia y participen en esta cuestión.

El estudio de la calidad ambiental interior y la eficiencia energética de los edificios de educación superior se hace cada vez más importante, no sólo por su complejidad debido a muchos y variados factores, que influyen en el rendimiento, ya que debido a su naturaleza subjetiva y al hecho de que los edificios son lugares diseñados con frecuencia con diferentes propósitos en general, y al elevado número de usuarios. Debido a la complejidad de esta investigación consideramos en ella dos puntos de análisis:

1. Análisis energética

   El análisis energética consiste en un análisis del proyecto, incluido la caracterización del edificio, análisis mediante termografía y el análisis del consumo de energía mediante la recogida de datos de los analizadores de redes parciales, el poder de carga, el cálculo del indicador de eficiencia energética, consumo específico de energía, factor de forma. Para estimar el consumo energético se procedió a una serie de simulaciones mediante modelos de dinámica física-matemática (*DesignBuilder/EnergyPlus*).

2. Análisis de la calidad del ambiente interior

   Análisis de la calidad del ambiente interior consistió en un estudio local con miras a la evaluación del confort acústico, confort visual, confort térmico (en el que incluimos la temperatura absoluta, la temperatura radiante, la humedad relativa, y la velocidad del aire) y la calidad del aire interior (en la que consideramos la concentración de PM_{10}, dióxido de carbono, monóxido de carbono, ozono, formaldehido, compuestos orgánicos volátiles y el análisis microbiológico).

ABSTRACT

Buildings account for 40% of total energy consumption in the European Union. Therefore, the reduction of energy consumption and energy use from renewable sources in the building sector are important measures needed to reduce dependence on energy and emissions of greenhouse gases.

Measures to improve the energy and environmental performance of buildings should take into account the climatic and local conditions, as well as indoor climate environment and cost-effectiveness. These measures should not affect other requirements for buildings such as accessibility, safety and intended use of the building.

The energy consumption of buildings depends significantly on the criteria used for indoor environmental quality as thermal comfort, visual comfort, acoustic comfort, indoor air quality, and construction criteria (including materials, direction, design, energetic systems, operation and maintenance). The indoor environmental quality affects productivity, health and comfort of occupants, so overall; improving the quality of indoor environment can improve learning and performance, reducing absenteeism.

A commitment to energy efficiency does not make sense to compromise the quality of indoor air. There is therefore a need to specify criteria for the indoor environment for energy calculations, performance and operation of buildings.

There is many international legislation as well as Portuguese and Spanish, which specify the criteria indicators for evaluation of energy performance of buildings, thermal comfort, acoustic comfort, visual comfort and indoor air quality.

The purpose of this research was to develop a study of performance evaluation and consequently defining specific measures with the aim of maximizing energy efficiency and environmental performance of higher education buildings. Public buildings in general, and in specific higher education buildings should be the example, because of its audience, showing that the environmental and energy considerations are taken into account, so they should be subject to regular audits. Public disclosure of information on audits and measures of continuous improvement of quality, should be strengthened in this case, so that students become aware and involved in this issue.

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 is divided into two points of analysis:

1. Energy analysis

The energy analysis consisted in a characterization of the environment of a specific building in a Campus of the Higher School (including a characterization project study, construction solutions and one thermograph inspection). Energetic systems characterization present and analysis of energy consumption through collection of data from partial power analysers, load power, calculating the energy efficiency indicator, specific energy consumption and shape factor. To an estimated energy performance of the building proceeded to further a simulation using dynamic models physical-mathematical (*DesignBuilder / EnergyPlus*).

2. Analysis of indoor environment quality

Analysis of indoor environment quality consisted of a local study aiming at the evaluation of acoustical comfort, visual comfort and thermal comfort. Thus, this evaluation consisted of an experimental component, based on measurements with specific analyzers, as well as perceptions of occupants' behaviour, based on questionnaires.

“We make our buildings and afterwards they make us.”

Winston Churchill (1874-1965)

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LIST OF ACRONYMS AND ABBREVIATIONS

ACH	Air changes per hour
ADENE	Portuguese energy agency
AHU	Air handling units
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAT	Best available technology
BMS	Building Management System
BPT	Best practice technology
c	Contaminant concentration (ppm, mg/m^3, Bq/m^3, CFU/m^3, CFU/L H_2O)
CAV	Constant air volume
CC	Combined cycle
CCGT	Combined-cycle gas turbine
CCHP	Combined cooling heat and power
CCS CO_2	Carbon capture and storage
CFC	Chlorofluorocarbon
CFD	Computational fluid dynamic(s)
CFL	Compact fluorescent lamps
CFU	Colony forming unit's
CH_4	Methane
CHP	Combined heat and power
CIEMAT	Spanish National Research Centre for Energy, Environment and Technology
CLO	Average clothing, clo (clo-value)
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2 eq	Carbon dioxide equivalent
COP	Coefficient of performance
CRT	Monitor cathode ray tube
CSICE	Spain Council for Building Sustainability Innovation and Quality
CSP	Concentration solar power
dB(A)	Decibel in (A)
DCV	Demand controlled ventilation
DHW	Domestic hot water
DR	Draught risk
DTU	Technical University of Denmark
EDP	Energies of Portugal
EE	Electric energy
EEI	Energy efficiency index
ELV	Emission limit value
EPA	Environmental protection agency (US)
EPBD	Energy Performance of Buildings Directive
ESTG	School of Technology and Management of Leiria
ETS	Emissions trading scheme

EU	European Union
EUR	Euro
G8	Group of Eight; member countries are Canada, France, Germany, Italy, Japan, Russia, United Kingdom and the United States
GHG	Greenhouse gases
GHP	Geothermal (or ground-source) heat pump
H	Length of room (m)
HCFC	Hydrochlorofluorocarbon
HCHO	Formaldehyde
HL	Halogen lamp
HVAC	Heating, ventilation, air-conditioning
IAEA	International atomic energy agency
IAQ	Indoor Air Quality
ICIEE	International Centre for Indoor Environment and Energy of Denmark
IEA	International Energy Agency; member countries are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States
IEQ	Indoor Environmental Quality
INESC Coimbra	Institute of Engineering and Computers Systems of Coimbra
IPAC	Portuguese Accreditation Institute
IPCC	Intergovernmental Panel on Climate Change
IPLeiria	Polytechnic Institute of Leiria (Leiria’s Polytechnic Institute)
ISO	International organization for standardization
L	Room length (m)
LAI	Laboratory of Computer Applications
LCD	Liquid crystal display
LEB	Low energy building
LED	Light emitting diode
Leq	Equivalent continuous sound level
MET	Metabolic rate (met)
MR	Maximum recommend
MSW	Municipal solid waste
N	Nominal air change rate
NA	Not available
NEA	Nuclear energy agency
NG	Natural gas
NO_2	Nitrogen dioxide
O_3	Ozone
ºC	Degree Celsius
OECD	Organisation for Economic Co-operation and Development
OECD European	Organisation for Economic Co-operation and Development, member countries are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway,

	Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom
OECD International	Member countries are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and the United States
OECD Pacific	Member countries are Australia, Japan, the Republic of Korea, New Zealand
PAEE	Energy Saving and Efficiency Plan - Spain
PC	Computer
PFC	Power factor compensation
PFER	Plan for the Promotion of Renewable Energy - Spain
PM	Particulate matter
PM_{10}	Particulate matter with a diameter less than or equal to 10 microns (micrometres)
PMV	Predicted mean vote
PNAEE	National Action Plan for Energy Efficiency - Portugal
PPD	Predicted percentage dissatisfied
ppm	Parts per million
Pr	Pressure (hpa)
PT	Power station
Pv	Photovoltaic’s
PV	Personalized ventilation
R	Real air change rate
R&D	Research and Development
RCCTE	Regulation of the characteristics of thermal performance of buildings, Decree Law n. 80/2006
REDI	Renewable energy deployment initiative
REHC	Renewable Energy Heating and Cooling
RES	Renewable energy sources
RETs	Renewable energy technologies
RH	Relative humidity (%)
RSECE	Regulation of energy systems or air conditioning in buildings, Decree Law n. 79/2006
RT	Reverberation time
SBS	Sick building syndrome
SCE	System of Energy Certification, Decree Law n. 78/2006
SEC m^2	Specific energy consumption per square meter (m^2)
SEC m^3	Specific energy consumption per cubic meter(m^3)
SECIL	General Company for Cement and Lime, SA
SECU m^2	Specific energy consumption per user (m^2)
SF	Shape factor
SO_2	Sulphur dioxide
T	Theoretical air change rate
T5	Tubular fluorescent lamps for high yield
Ta	Air temperature (ºC)
TC	Thermal comfort
TES	Thermal energy storage

TFT	Thin-film transistor
Tg	Mean radiant temperature (°C)
TLV	Threshold limit value
Tw	Wet temperature (°C)
U	Equivalent thermal transmittance of building element (k) W/(m²·K)
UEC	Unit energy consumption
UFRRJ	Rio de Janeiro University
UPS	Uninterruptible power supply
USA	United States of America
USAL	University of Salamanca
USD	United states dollar
Va	Relative air velocity (m/s)
VAT	Value-added tax
VAV	Variable air volume or variable air velocity
VEEI	Value of energy efficiency of the installation
VOC	Volatile organic compounds
WHO	World Health Organization
ZEBs	Zero emission buildings
ε	Emissivity
λ	Thermal conductivity W/(m·K)
ν	Air velocity (m/s)

CONCEPTS AND DEFINITIONS

[Parameter] - Concentration of each pollutant to be measured in the building.

[Parameter] Ext - Temporal mean concentration of pollutant analysis measured outside the building.

[Parameter] Max - Maximum value of all the temporal averages of pollutant obtained for all areas of the building.

[Parameter] MaxT0 - Maximum value of the pollutant, obtained from all measurements in all areas of the building.

[Parameter] MedT - Average time of the pollutant measurements made at each point of sampling / measurement of the building.

[Parameter] MR – Threshold limit value or maximum of reference for the pollutant.

[Parameter] VLE - Value exposure limit for the pollutant.

Air Bounce or exhaust air - Air that is extracted by the local climate system and is released abroad. It may be all or only part of the exhaust air (see definition of ventilation).

Air Conditioning - HVAC form that allows you to control temperature, humidity, air quality and the speed of a location. You can also designate, by simplifying current, a cooling system serving only a space.

Air infiltration - Outdoor air that enters the air-conditioned place on a natural through cracks or other openings in all areas of informal surroundings, under the pressure differences that develop between the outer and inner faces of the different environment depending on its orientation relative to wind direction. Also referred to as the infiltration.

Area - The sum of the areas measured in the plant inside the perimeter walls, all compartments of a building or a condominium unit, including halls, corridors, internal plumbing, interior storage space to living area and other compartments of similar function, including in cupboards.

Audit - Method of evaluating the energy situation or indoor air quality in an existing building or building unit.

Boiler - Machine in which a thermal fluid is heated, with or without phase change, using the burning of solid fuel, liquid or gas or electricity.

Building management system (BMS) - Electronic system for management of the HVAC system, including supervision, monitoring, control and maintenance of equipment and energy use.

Building related illness - A disease-specific known cause, resulting from exposure to an agent in an interior space. Examples are the Legionnaires' disease and Pontiac fever.

Climate - A generic term to describe the treatment process of air or way to make change alone or jointly with its temperature, humidity, speed or quality on site. It is possible, therefore, respectively, with the functions heating or cooling, humidification or dehumidification and ventilation. In case all the functions are likely to be activated in a coherent way, has air conditioning.

Cooling - Type of cooling, which lets you control the maximum temperature of a place.

Dehumidification - Process of reducing the specific humidity of air.

Exhaust air - Air that is extracted from the site by the HVAC system.

Great rehabilitative care - Is an intervention in the environment or on the premises, or other energy, building, whose cost exceeds 25% of the building.

Health - A state of complete physical, mental and social and not merely the absence of disease or infirmity.

Heat pump - Thermal machine, using the principle of the refrigeration unit, which extracts heat at low temperature (cooling) and rejects the heat to higher temperature (heat), making possible the use of a useful or of those two effects simultaneously.

Heating - Way of cooling in which you can control the minimum temperature at one location.

Humidification - Process of increasing the specific humidity of air.

HVAC system - A set of equipment combined coherently in order to satisfy one or more of the objectives of climate control (ventilation, heating, cooling, humidification, dehumidification and air purification). In the event that satisfy everyone, we have air conditioning.

Hybrid ventilation - Renovation of indoor air for fresh air outside atmosphere using natural ventilation whenever conditions allow sufficient flow of renewal, and mechanical ventilation where natural ventilation is inadequate, alternative or complementary. It is common case to have the outside air supply by natural means stimulated by mechanical extraction of air (exhaust).

Indoor air quality (IAQ) - The chemical, physical and biological characteristics of indoor air, not including indoors or in the presence of industrial operations which may affect the comfort or health of the occupant.

Indoor Environmental Quality (IEQ) - Refers to all environmental factors that affect the health and wellbeing of building occupants. IEQ includes such factors as indoor air quality (IAQ), thermal comfort (TC), acoustics comfort and visual comfort.

Insufflation of air - Air that is introduced by the cooling system in air-conditioned place.

Large buildings - Building services with a useful floor area over 1000 m^2.

Mechanical ventilation - Renovation of indoor air by exhaust air space (air extraction) and air insufflation of air treated outside or in a mixture of fresh air from outside and return air using a system of ducts and fans as the drivers of air.

Monitoring - Monitoring the performance of a building or a system through a program of regular periodic readings and records relevant characteristic parameters in real time.

Natural ventilation - Renovation of indoor air for fresh air outside using only atmospheric openings in the surrounding area with appropriate self-controlled or manual adjustment and the natural mechanisms of wind and temperature differences that cause air movement.

New Air - Outdoor air that is introduced in air conditioning system for air renewal site for purposes of hygiene and health. Identifies itself in whole or in part with air insufflation.

Outdoor air - Air outside the conditioned space or location and that identifies itself with the general ambient air.

Return air - Air extraction not rejected abroad and mixed with fresh air, for after treatment, becoming the air insufflation.

Sick building syndrome (SBS) - A collection of symptoms associated with exposure to chemicals, particulate matter or biological material that cannot be related to any specific cause, but is relieved when the occupant leaves the building. Individuals report symptoms such as headaches, nausea, fatigue, drowsiness, irritation of eyes, nose, throat, etc…

Small building - Building with an area below the threshold that defines them as large buildings.

Thermal resign - A state of mind in which a person feels satisfaction with the thermal environment. The factors affecting thermal comfort are air temperature, mean radiant temperature, stratification, air movement, relative humidity, the level of activity and clothing.

Ventilation - Process of fresh air in a given space by natural means or mechanical.

Ventilation rate - Number of outside air that is supplied to the interior space over a period of time, usually one hour.

Indoor Environment and Energy Efficiency in Higher Schools

1 INTRODUCTION

1.1 Motivation

The Buildings Sector is one of the major consumers of final energy. Besides, the world population is predicted to continue growing, making it indispensable to reach a Sustainable Development as well as to mitigate problems related to weather changing and pollution. The need to ensure that the Buildings Sector improves its energy and environmental performance becomes obvious.

In particular, School Buildings are currently preferential targets for the optimization of its operation in relation to its energy intensity and its occupation type. Therefore, this project intends to measure, through simulations and auditing, the practicality of implementing innovative technologies in these Buildings, using both monitoring and the definition of a characteristic numeric model from the point of view of environmental comfort, energy efficiency and the incorporation of renewable energies and energy recovery systems.

1.2 Objectives

This tesis is done in association with the study of environmental and energy efficiency optimization in a School Building. In order to do that, one of the Buildings from *Campus 2* from Polytechnic Institute of Leiria (IPLeiria) is the study case –Leiria's Management and Technology Higher School (ESTG), *Building D*.

This study motivation lays on the need to characterize the energy and environmental performance of *Building D* and find and measure high energy efficiency systems and competitive energy sources, including renewable energy sources that add to the rational use of energy, thermal and environmental comfort as well as to the improvement in energy efficiency in the Buildings Sector, which is responsible for a similar consumption as in the Industry and Transport Sectors in Portugal.

In order to do that, a performance analysis will be made through a number of auditings. The objective is to obtain enough markers that can allow and characterize a parametric sensitivity study using simulations that can measure energy consumption rationalization and the introduction of different types of renewable energies that can translate in viable technical and economical solutions, ensuring an adequate indoor environmental quality.

Simulating and analyzing energetic performance, indoor air quality and indoor environmental quality of the building by testing the use of alternative energy systems, different renewable energy sources and its relation to the climate and to the building use type will allow the definition of a School Buildings Optimization Model.

This research intends to serve as a tool to evaluate multiple aspects of the building, which include construction aspects, energy analysis, indoor air quality and comfort conditions (thermal, noise, lights, etc). This study is oriented towards the performance analysis of ***Building D*** belonging to Campus 2 of Polytechnic Institute of Leiria. However, the approach used in the specification and development of this study may, in a generic way, favour the extension of the model to other types of buildings.

This study of buildings performance is intended to be a tool to analyze and collect data and to enable the use of that information by the Institution. Data collection and processing will allow the development of tools that can confirm the implementation of solutions in environmental and energy performance improvement in the building and its ways of function, in the existing environmental greatness and local comfort levels. This way it is possible to get a detailed description of the *Building D* performance studied. The research results will allow the implementation of future solutions both in construction and in energy, as well as in indoor air quality with the purpose to reach pre-established comfort levels.

The study of building performance becomes quite complex due to a number of factors (from which can be stressed the great number of variables) that influence it, due to its subjective nature and to the fact that these buildings are organized in areas with very distinctive purposes and have a high number of users. Due to the study complexity, the research will be divided in two major analysis topics:

- Energy Analysis;
- Indoor Environmental Quality Analysis.

It is this study purpose to evaluate the building performance at its construction level, through the building's features and its measurement of energy needs to preserve comfort, indoor air quality and energy efficiency conditions. Therefore, several indicators will be measured, highlighting, Energy Efficiency Indicator (EEI), Specific Energy Consumption (SEC), Specific Energy Consumption by User (SECU), Shape Factor (SF), Contribution of energy, natural lighting and integration of other ways of energy recovery based on new technological solutions.

Consumption analysis will allow the creation of an inventory of the building consumption. These records will be done in two ways: through historical data (accounting documents) and measurements using three-phase energy analyzers from the Building's Transformer Station and diverse portable devices. Consumption records will allow not only the analysis of consumption evolution over the building's function period (charge diagram), as well as the validation of a numeric model.

Using the consumption analysis it will be possible to reach the energy use efficiency level which will be obtained by the ratio between energy consumption and comfort levels. Thorough analysis of the consumption will justify, whenever necessary, the implementation of alternative solutions to the energy consumption. These solutions may include the use of other forms of energy, consumption deviation, use of efficient equipments, etc.

In relation to the Indoor Air Quality (IAQ) analysis, it is predicted to be using portable and stationary equipment in order to make individual and continuous measurements of different physicochemical and biological parameters (Temperature, Relative Humidity, Carbon Monoxide, Carbon Dioxide, Formaldehyde, Ozone, Particulate Matter, Bacteria, Fungi and *Legionella*). IAQ analysis will allow the creation of an inventory of the building performance in different situations, characterizing it from a healthiness point of view.

The evaluation of Indoor Environmental Quality (IEQ) will allow the measurement of comfort levels obtained in the building. This analysis will be based on measurements done with analyzer equipment for thermal comfort and true questionnaires. This way it will be possible to obtain data related to Predicted Mean Vote (PMV) and Predict Percentage Dissatisfied (PPD), amongst other parameters. An Integrating Sound Level meter and Lux meter will be used to measure existing sound level indicators and illumination level inside the building.

So, it is intended to start a research through a preparatory study as a way to evaluate the building's current status in energy consumption and indoor environmental quality. Data collection and several measurements and auditing will be performed. A diagnosis will be made based on data gathering and bibliographic review, this way entering the evaluation phase and data analysis.

The aspects of environmental sustainability such as available resources management or a set of energy efficiency strategies will enable a remarkable economic and environmental asset, thus contributing to a better and sustainable future.

1.3 State of Art

Large space buildings are attracting more attention of researchers in recent years. However, the absence in training and awareness of the buildings users in matters such as energy/efficient use of energy management, indoor environmental quality, comfort and buildings use/maintenance. Generally speaking, buildings show not only a lack in construction quality but also bad orientation, misconceived spaces, badly ventilated, which imposes right away the need for heating/cooling systems and ventilation [4], [14], [24], [28], [53], [56], [58], [93], [98], [140], [168], [195], [200], [228], [272], [301], [304].

A significant amount of research has been conducted on active control of ventilation systems to improve multi-zone ventilation effect. The required fresh air fraction of each room is usually different, which is determined by the internal load, occupation behaviour and occupant number. As a result, energy waste and poor indoor air quality occur with over ventilation and under ventilation. A significant amount of research has been conducted on optimal control to improve multi-zone ventilation effect. However, no solution to this problem was reached yet [8], [21], [51], [133], [147], [244], [246], [282], [291], [315], [317], [319], [320], [323].

EN 7730 Standard [75] , EN 15251 Standard [81] and ASHRAE 55 Standard [25] allow for increase of the room air temperature above the upper limit of comfortable temperature, it is important to explore ways of minimizing the active energy consumption in the cooling and dehumidification process and also recovering the “cool” energy from the exhaust air. The issue is how far can we go, so that good air quality is achievable with low, standardized outside air volume flow.

Air improvement may be achieved using ventilation systems controlled by signals from sensors, which should be installed in the point of expected maximum contaminant concentration. The issue is which parameter should be controlled [113], [130], [144].

The CO_2 concentration control is one method that is being explored as well as the possibility of CO_2 absorbers application for decreasing energy consumption of ventilation system and an estimation of energy savings on the example of application of CO_2 absorbers in building ventilation system [131], [186], [291]. Demand controlled ventilation (DCV) systems may allow energy consumption in adequacy with the energy requirements [31], [63], [132], [152].

Numerous studies have shown that personalized ventilation (PV) may improve occupants health, comfort and performance in comparison with traditional total volume air distribution used today. The potential of PV for energy saving has been studied little [188], [284], [324], [328].

Sustainable buildings need to take advantage of renewable and waste energy to approach nearly zero energy buildings or nearly zero emission buildings. Such buildings will need to apply thermal energy storage (TES) techniques customized for smaller loads and community based thermal sources. Lower energy heating and cooling sources will be more common. Utilization of low-energy heating and cooling sources requires that energy storage is intimately integrated into sustainable building design [48], [50], [61], [124], [126], [140], [222].

Thermal energy storage is advanced energy technology and there has been increasing interest in using it for thermal applications such as domestic hot water and space heating/cooling. TES has often been applied in standard buildings with the objective to demonstrate that the energy storage techniques could be successfully applied rather than to optimize the building performance [150], [325].

Typically, heat pipes are seen as sensible heat recovery devices; however, they can also be used for latent cooling applications. Long term energy storage the surplus heat of heat pumps in the summer and the surplus of cold in the winter are stored below ground level in the aquifer. The stored heat us used through heat pumps to warm the building in the winter, and the stored cold to cool in the summer [322].

There are a growing interest in passive cooling techniques, especially night ventilation. In fact, at night, natural or mechanical ventilation cools down the building and have lower peak demands.. The following day, the thermal mass absorbs the heat – reducing and putting off peak temperatures. Night cooling is a building management strategy using low-temperature night air to cool the structural elements of the building itself, allowing them to remove the heat load and pollutants stored the day before [134], [184].

In the field of Physical and Mathematical Modelling of transfer phenomena in buildings, new areas of research and development are emerging, showing new ways of facing problems difficult to solve until then, and new computer simulation tools which allow the prediction of indoor air temperature, thermal comfort conditions and energy consumption according to outdoor weather conditions, buildings occupation and energy systems selected. The interaction between user and numeric codes takes on new forms that consist in qualitative analysis tools rather important in the current reality and context of energy and environmental analysis in buildings [102], [114], [158].

Energy simulation programs have progressed very slowly. In more than three decades, progress in terms of mathematical models and prediction algorithms, but the approach to estimating the energy are still the same and are based on multi-room modelling assumptions [168], [305], [323].

Until now, all the models and computer programs predict heating and cooling loads based on a multi-room modelling approach, in which only one inside temperature is predicted. Besides the building envelope, outside weather, people activities and internal loads, the temperature distribution is another important factor in the building energy calculation, and should be considered in future work, because indoor environment have a three-dimensional spatial distribution caused by three-dimensional airflow. To understand building performance, we must integrate these spatial distributions into building simulations. In present days it is possible to make simulations but occasionally it come time expensive (The simulation of large buildings can take several days) [19], [46], [47], [138], [326], [329].

Recent European projects such as “Energy-Toolset for improving the energy performance of existing buildings (E-TOOL)” wit Spain, Austria, Greece, Slovenia and Bulgaria as partners intend to develop tools to increase the number of researchers with a knowledge in high energy efficiency systems and in implementing the European Guidelines for Buildings. Another project ongoing, “GreenBuilding”, with several countries as partners – Germany, France, Portugal, Austria, Greece, Spain, Italy, Sweden, Slovenia and Finland, aims to increase energy efficiency and the use of renewable energies in non-residential buildings, promoting simulations in energy efficiency. Another projects such as “Building Advanced Ventilation Technological Examples to Demonstrate Materialized Energy Savings for Acceptable Indoor Air Quality and Thermal Comfort in Different European Climatic Regions (Building Advent)” with United Kingdom, Greece, Finland, Denmark, Portugal and Belgium as its partners aims to decrease energy consumption without affecting indoor air quality, keeping an efficient ventilation in non-domestic buildings, promoting a low power consumption. However these are no specific strategies or design guidelines for achieving nearly zero energy building designs.

Research teams with high recognition at international level such as American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Swegon Air Academy (Swegon), the International Centre for Indoor Environment and Energy (ICIEE), the Research Centre for Energy, Environment and Technology (CIEMAT), the United States Environmental Protection Agency (EPA), the department of Heating, Ventilation and Air Conditioning, Hermann - Rietschel - Institut at Technische Universität Berlin and others continue to explore new techniques and solutions in fields such as energy efficiency and indoor environmental quality, emerging new ways every day challenges.

The ventilation of nearly zero energy buildings leads to specific requirements for which researchers should bring appropriate solutions in order to both guaranteeing lower energy consumption and good indoor environment quality [4], [50], [55], [177], [327].

Research and knowledge in environmental sustainability, available resource management together with strategies in buildings will allow considerable economical and environmental improvements, thus contributing to a better future.

1.4 Organization

This study is divided in nine chapters, the first one being about guidelines and motivation that led to it. State of Art and Organization are also introduced in chapter 1.

Chapters 2, 3 and 4 refer comprehensively to environmental issues, introducing the definition of sustainable development and characterizing the energy sector, mainly the buildings sector. It also refers to the importance of sustainable construction and closely related concepts such as Energy and Indoor Environmental Quality (IEQ).

The Chapter 5 consists in the study case, procedures, methodologies and equipment used to prepare the study.

Chapter 6 present the study results and discussion analysis. Finally chapter 7 and 8 are the conclusion of the study.

2 SUSTAINABILITY

"In nature, nothing is created, nothing is destroyed, everything is transformed."

(Lavoisier)

2.1 Sustainable Development

The concept of *"Sustainable Development"* is usually defined as the development that seeks to satisfy the needs of the current generation, without compromising the ability of future generations to satisfy their own needs. This was the definition presented by the World Commission on Environment and Development in 1987 in the *Brundtland* report *"Our Common Future..."* [17], [34], [182], [223], [230].

Sustainable development means to enable people, not only nowadays but also in the future, to reach a satisfactory level of social and economical development and human and cultural accomplishment, at the same time making a reasonable use of Earth's resources and preserving species and natural habitats [18], [34], [36], [99], [141].

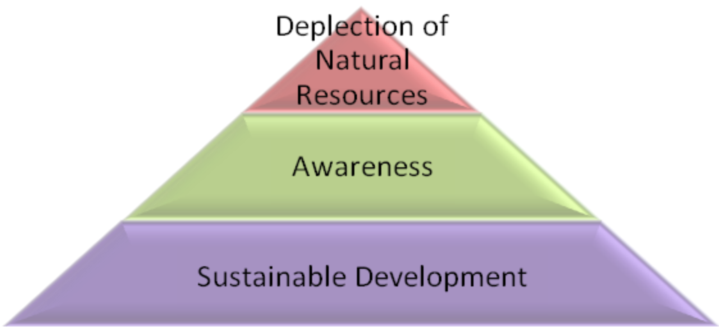


Figure 1 - Sustainable Development [182]

The United Nations Conference for Environment and Development, also known as *ECO 92*, took place in Rio de Janeiro between 3rd and 14th June 1992. This conference's objective was to reconcile economic development with environment protection, awakening in the involved nations a deep awareness for environmental issues. The attendance of 117 heads of state (the biggest leaders meeting ever) proved the highest level of political interest in the defence of the planet.

Despite some differences between theory and practice (confirming that some ecological principles focused on Summit *ECO 92* have not been understood with the same seriousness), it is confirmed that several countries began to consider sustainable development as part of their political strategy combining environment, economy and social aspects.

Agenda 21 was one of the main results from the conference *ECO 92*, that took place in Rio de Janeiro, Brazil, in 1992. It is a document whose objective was to determine the importance of each country's commitment in thinking over, either globally or locally, the way in which governments, non-governmental organizations and companies from all the sectors in the society could cooperate in studying solutions for the social-environmental problems [219].

Since the implementation of *Kyoto Protocol* in 1995, all the signatory countries have tried to cooperate with each other to reduce carbon dioxide emissions, resorting to a series of basic actions and promoting the use of alternative energies. *United Nations Conference on Climate Changes from 2009*, also known as the *Copenhagen Conference (COP 15)*, came to remind everyone of the consequences of the continuous consumption of fossil energies and the increase in carbon dioxide production in the surrounding environment [222].

Alternative energies are the ones that offer an alternative to fossil energies (exhaustible) using natural sources capable of self-regenerating such as the sun, wind, water and earth. A guided research to their use includes a wide area, serving since the great producers to the individual users, which is reflected in agriculture and engineering [118], [206], [207].

Climate changing is a fact. It is necessary and urgent to act in order to prevent an irreversible accumulation of greenhouse gases (GHG) and global warming without a potentially huge cost for the world economy and society [165], [208].

Global emissions of GHG virtually doubled since the beginning of the 70's and with current policies they could increase more than 70% between 2008 and 2050. Historically speaking, GHG emissions in the Energy sector were predominant in the richest developed countries so that the increase in GHG concentration in the industrial era was responsible for the economic activity in those countries. Nowadays, however, two thirds of new emissions to the atmosphere come from developing countries without new energy policies, thus being expected a continuous percentage increase until 2050 [230].

When confronted with the consequences and costs of inaction, governments have come to reach an international consensus on the need for global emissions to be cut off and controlled significantly.

With the package of measures adopted in 2007, European Union has just launched the foundation of a true common energy policy. Through tax measures, European Union seeks to ensure a higher sustainability of the energy market. In 2007, European Union established as a goal to reach until 2020 that 20% of European energy consumption is ensured by renewable sources. To do that, measures were adopted to promote renewable energy sources and to develop the market of those energies, namely in the biomass and biofuel sectors [230].

The International Energy Agency (IEA) recognizes that energy efficiency is vital to achieve an energy sustainable future [237].

The energy perspective in the world today is plain and unsustainable. Despite all the talks on climate changes over the recent years, energy consumption and CO_2 emissions keep rising. At the same time, concerns on energy have risen in importing countries about oil, gas and their price has reached high records [235].

The world energy system will be transformed, but not necessarily in the way it should be. Some tendencies stand out for sure: the increasing weight of China, India, Middle East and other regions in energy markets and CO_2 emissions, the increasing domination of national oil companies and the emergence of low carbon energy technologies. And while market instability could cause a temporary price drop, it is becoming clear that the cheap oil era is over. But many of the main political lines (not to mention other external factors) are still in doubt. It is of every government's competence, individually or together, to lead the world towards a cleaner, more intelligent and more competitive energy system. Time is running out and time for action is now.

Population growth affects both in quantity and in composition the direct demand for energy, through its impact on the economic development growth. World population is estimated to grow at a rate from 6,5 billions in 2006 to about 8,2 billions in 2030 – an average growth rate of 1% a year. In 2030, China will continue to be the most populous country in the world, with over 1460 million people [236].

As a result of these changes, the growth of the demand for fossil fuels is faster and faster (Figure 2).

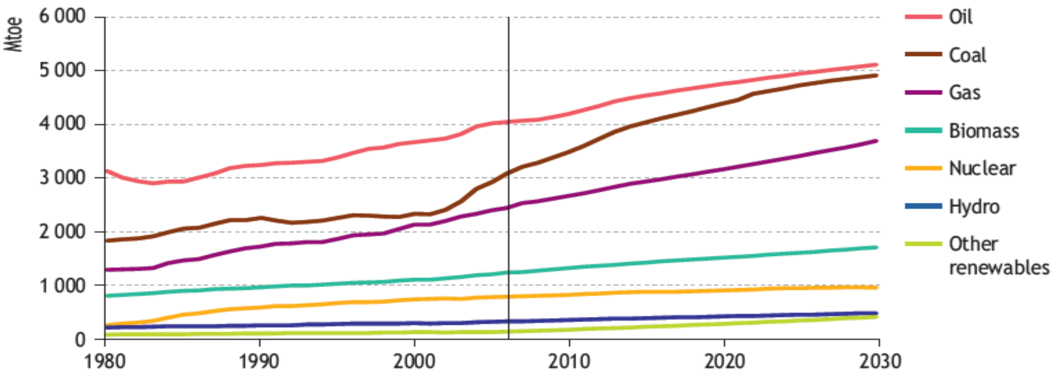


Figure 2 - World primary energy demand by fuel in Reference Scenario [235]

On the reference scenario, the total share on fossil fuels demand increases now from 80% to 84% in 2050, despite the absolute growth of nuclear and renewable energies. The outcome is an increase in the concerns on energy safety and continued significant weather changes will be a consequence [235].

As can be seen on Figure 3, in 2030 the discrepancies in energy consumption per capita amongst regions remain the same.

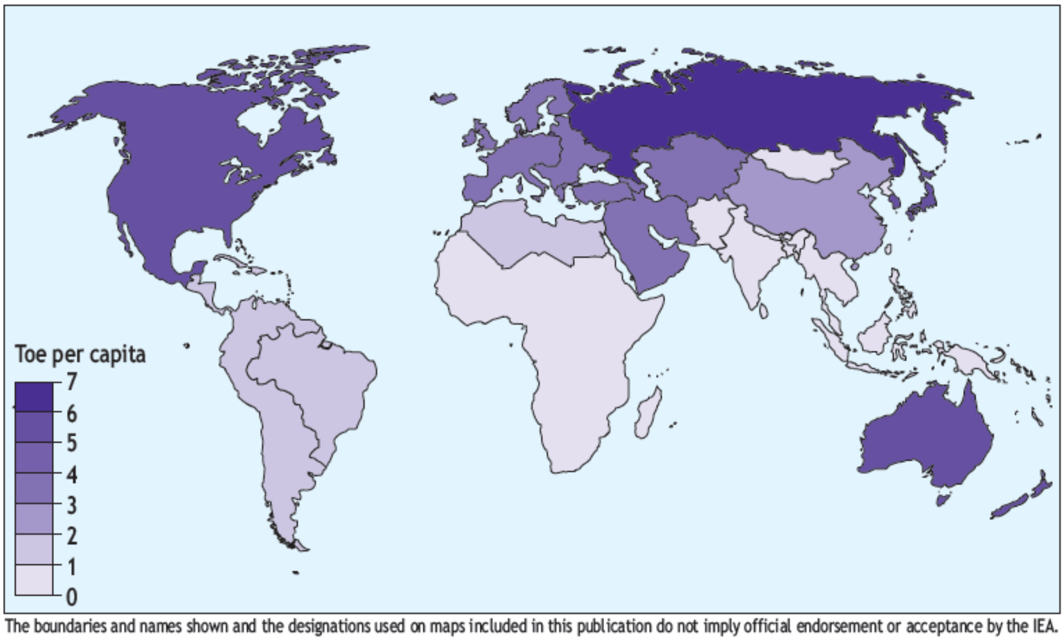


Figure 3 - Per capita primary energy demand by region, 2030 [235]

In 1980, global emissions of CO_2 rose more slowly than primary energy demand, but this decarbonisation of the energy sector began decreasing and reversing in 1990, when part of nuclear energy dropped. The reference scenario estimated keeps wagering on decarbonisation until after 2020, before the energy demand growth overcomes once more the emission growth (Figure 4).

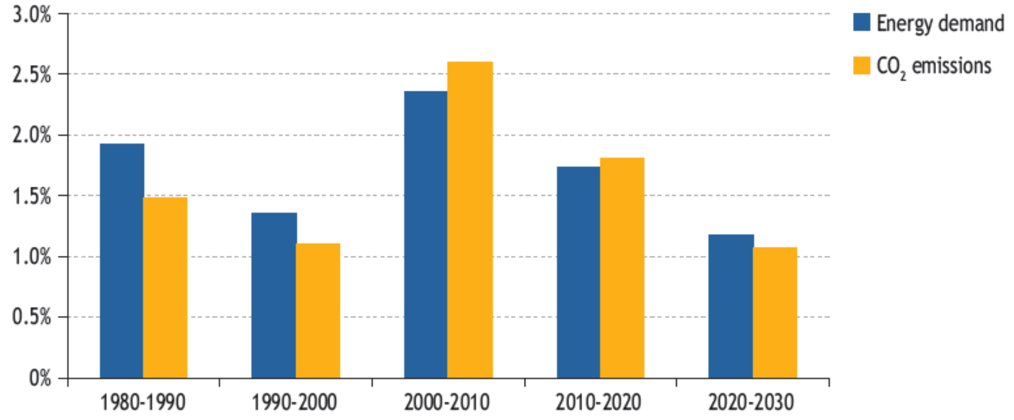


Figure 4 - Average annual growth in world primary energy demand and energy-related CO_2 emissions in the Reference Scenario [235]

Coal, oil and gas burn should be the main growth source of CO_2 emissions over the next decades. However, there are other emissions beyond CO_2, all with a great importance. Together, those emissions represent nowadays 39% of the total greenhouse gas emissions (Figure 5).

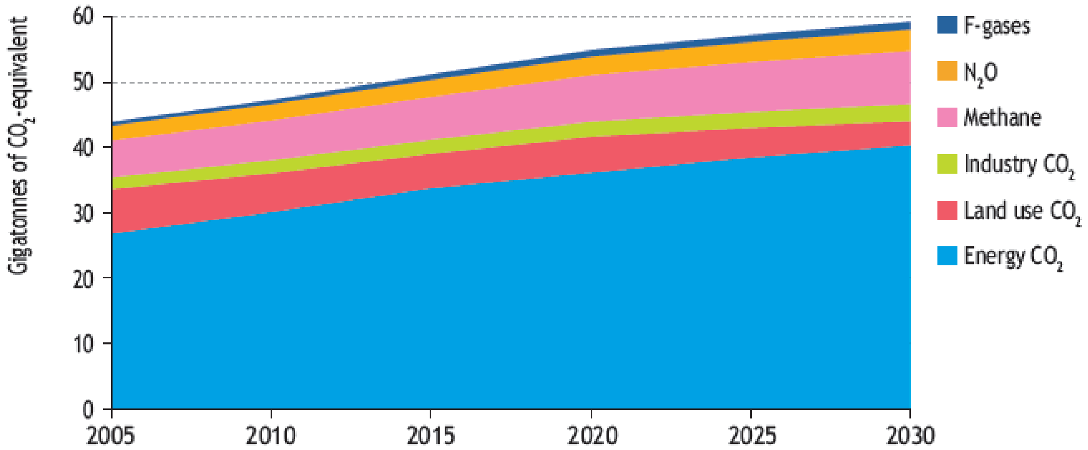


Figure 5 - World anthropogenic greenhouse-gas emissions by source in the Reference Scenario, 2005-2030 [235]

The concentration of CO_2 in the atmosphere increased from about 280 ppm in the pre-industrial era to 385 ppm and is still rising. This level is by far the highest in the last 650.000 years (180-300 ppm), as determined in ice nuclei, deep sea sediments and tree rings records. Methane concentrations increased from 715 to 1774 parts per billion in the same period. The total of CO_2 equivalent in the concentration of all the long lasting greenhouse gases, considering the Earth use, is currently of about 455 ppm. It is about 60% higher than the pre-industrial era one [235].

The increase in energy consumption, mobility and continuous dependence on fossil fuels are harmful to air quality in most developing countries. SO_2, NO_x, CO and particles (PM) emissions are harmful to human health, causing environmental problems such as acid rain, reduced visibility and troposphere ozone generation, although they might also decrease the global warming impact of greenhouse gases (GHG).

Air pollution is still a serious public health problem in developing cities around the world, namely in China and India, where the air quality keeps deteriorating [232].

The total energy consumption in the construction industry was about 40% of the world's final energy consumption. With some few interventions in buildings, it is possible to save about 30 to 35% of energy, keeping the same comfort conditions.

With a view to energy efficiency, it is urgent to encourage the integration of rational energy principles in buildings under construction and rehabilitation in order to prevent energy consumptions to decrease drastically.

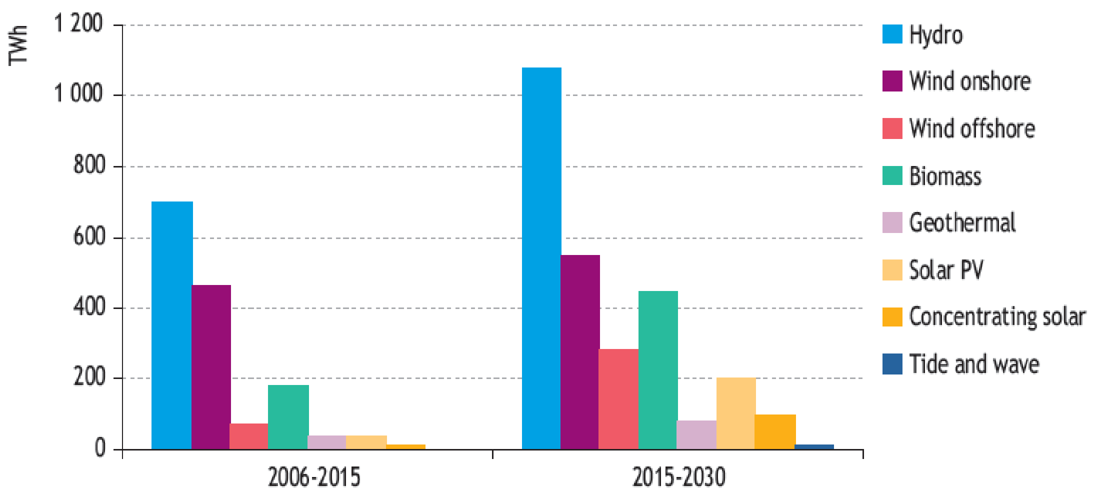


Figure 6 - Increase in world electricity generation from renewable in Reference Scenario [235]

The improvement in energy efficiency (Figure 6) is one of the common policy goals of many governments. The benefits of a more efficient use of energy are well known and include a minor dependence on fossil fuels, the increase in competitiveness and user comfort. Efficiency gains can also be understood as environmental benefits by reducing greenhouse gas emissions and local pollution [235].

2.1.1 The new Directive

The new Directive in buildings has arrived (Directive 2010/31/EU) [257] and should be implemented in February 2012. The two main goals for 2020 are to reduce CO_2 emissions in 70% from all Europe and the *"Nearly Zero Energy Buildings"*.

In order to reach them, energy efficiency should be reinforced, the weight of "in house" renewable energies should be close to 100% and new requirements should be introduced to reinforce the concept of cost/benefit, where the building is a rentable investment from an energy point of view throughout its life-cycle. A new way of designing buildings that demands an urgent review on Portuguese, Spanish and international thermal regulation is required.

Nowadays, buildings assimilate more than 40% of the final energy consumption and are responsible for 36% of CO_2 emissions to the atmosphere from the entire Europe. As an answer to that problem, the Directive on buildings (Directive 2002/91/EC) [251] which in 2006 gave origin to the ambitious Portuguese thermal regulation, is now replaced by an even more divisive one from the perspective of what have been the construction practices of the last decades. It is estimated that, by reinforcing the Directive on buildings, Europe can obtain a reduction in gases responsible for the greenhouse effect in about 70%. Even more, these improvements may result, according to EC, in an average saving of 300 Euros per year per household in every saving.

The *Energy Performance of Buildings Directive* (EPBD) [251] still running is focused on building energy performance promotion through the creation of several methodologies referring to design, comfort, construction, installation, … based on weather conditions, cost-effectiveness criteria, etc… The first step was given and the issue of energy certificates, in the case of Portugal, by the Energy certification and Air Quality System has proved to be very positive and a determinant turning point in this energy rationalization logic with the increase of the quality of the facilities, since it was one of the pioneering countries in the implementation of IAQ regulations.

With the new Directive, only now the goals are followed by the demand, excellence and inescapable force of the requirements! And in parallel, environmental demands and buildings importance for the goal achievement of the recent Directive on Renewable Energies, where there is a clear bet on the great contribution of renewable energies for the production of its needs [22], [257].

What was expected to come true in design is now a certainty for the next decade. In 2020 all the new buildings of the EU will be **“*Nearly Zero Energy Buildings*”**. But in reality what does this concept mean and what significant changes will it have in design, construction and HVAC systems in buildings?

At this moment a service building can be seen as having consumptions close to **“0”**, with appropriate construction and orientation, with passive systems that guarantee its users needs… According to experts, this is beyond any question the starting point for the design of any building, but not always enough.

The efficiency of several building parts and its HVAC system components play an important role in the efficiency of their energy use. But the design and the way all of these individual components interact is also important. There is an increasing interest in buildings with low energy consumptions and extremely low CO_2 emission profiles, like passive houses, zero energy buildings and zero carbon buildings. Many times these are developed as integrated projects, where special attention is given to efficiency in every phase of building design and construction. Actually, this is necessary for the additional investment cost of these buildings to be affordable [234].

There are many barriers concerning passive buildings, zero energy and zero carbon construction. Like many energy efficient technologies, initial costs are high and the building owners can realize that long-term benefits are unreliable if the additional investment does not reflect itself on resale values. Very few information is available for decision-makers on the benefits and potential of passive, zero energy and zero carbon buildings.

Passive construction solutions that provide a suitable integration of renewable energy sources are required for passive buildings to be developed until a real zero energy and zero carbon building. In particular, there is a need to develop intelligent solutions to equip such buildings with their small but essential energy needs for ventilation, heating, cooling and hot water [50].

Projects should be implemented as a way of displaying that technology, namely in school buildings. Schools offer the opportunity to promote relevant technologies, because they are used by a “special” community and can increase the awareness on the potential of passive buildings more widely.

2.1.2 The Portuguese reality

In Portugal, the external energy dependence is extremely high. During the 90´s, Portugal was importing 80% of the primary energy consumed. There are no current records in Portugal of any fossil energy product exploitation. This way, renewable energies begin to assume an extremely important role as they represent the entire domestic production of energy [182].

In October 2005, the Government approved a new *National Strategy of Energy*, which replaced the 2003 strategy. The new one set up a number of measures to reach the government goals to ensure the energy supply, environment protection and economic competitiveness. The key policies to reach those goals were identified as market liberalization, renewable energies promotion and higher energy and innovation efficiency [166].

In 2007, the Government defined three great goals for renewable energies until 2010: a 45% share of renewable energy in the gross consumption of electricity, a 10% share of biofuels in the total consumption of fuel by biomass or residues consumption in two power stations (Sines and Pego). The country is making progresses concerning the development of new skills on electricity production of renewable sources and, between 2004 and 2008, the capacity increased more than 2.400 MW, mainly from wind energy. Policies to encourage the biofuels development have been implemented, such as partial tax exemption and total exemption for biofuels produced by certain small projects and pilot projects, imposition of a biofuels share in transport fuels, and the establishment of voluntary agreements for passengers of public transport fleets. Until the end of 2007, biomass contributed with 1.510 GW of electricity generation at a time when electricity generation from coal was declining.

Between 1990 and 2007, total CO_2 emissions from fuel burn increased 41%, going from 39,28 million tons to 55,19 million tons. This growth is not linear, but CO_2 emissions have been decreasing since they reached a peak in 2003. In 2006, fuel burn was responsible for 87% of the CO_2 emissions in Portugal. In 2007, most of the CO_2 emissions came from two sectors, road transports and electricity generation, responsible for 38,19 million tons or 69% of the emissions. Manufacturing and construction industries also contribute significantly with a production of 9,35 million tons or 16,96% of the emissions.

Portugal is strongly committed in developing renewable energy sources in conformity with its National Strategy for Energy. Improving energy efficiency, reducing CO_2 emissions and increasing the use of renewable energies are amongst the main goals of this strategy. The promotion of renewable energy technologies market development can be considered as one of the main political goals, thus contributing to increase the security of supply through energy sources diversification while it reduces the environmental impact associated with the energy system [207].

So far, Portugal has been wagering on reducing CO_2 emissions and its dependence on energy import through the promotion of investments on renewable sources, energy saving and clean technologies. Portugal's commitment for the EU responsibility share agreement on *Kyoto Protocol* is to restrict the greenhouse gas emissions increase in 27% between 1990 and the first commitment period (2008-2012) [209].

Portugal's strategy to achieve its legally binding goal to *Kyoto Protocol* depends a lot on supply side measures, like changing the mix electricity generation and making it more environmentally friendly. The main strategies established in the *National Strategy for Energy and in the National Program of Weather Changes* (PNAC 2006/NPWC) updated in 2007 comprehend a growing dependence on renewable sources and the modernization and replacement of the current diesel or fuel oil stations with new and more efficient technologies thus generating more reduced CO_2 emissions [208], [223].

Renewable energy supply measures are the cornerstone of the recent Portuguese energy policies. As a potentially dependent country on imported fossil fuels, Portugal has been making remarkable progresses in exploring and using its endogenous sources of renewable energy. In 2008, renewable energies provided 18,5% or 4,42 million toe (tons of oil equivalent) of the total primary energy supply in the country [165].

Energy consumption in residential and commercial buildings was responsible for about 30% of the total energy consumption in Portugal at the end of 2007. With the Sustainable Urban Rehabilitation Program, the government wants that one in 15 families matches an optimized energy class (ie, greater than or equal to B-) and an equal proportion of buildings equipped with thermal solar panels.

Portugal took action to transpose into national legislation the Community Directive (Directive 2002/91/EC) concerning the energy performance in buildings (EPBD). This includes the publication of the following decrees:

- **Decree-Law no. 78/2006** [203]: SCE – National System of Energy Certification and Indoor Air Quality in Buildings.

One of the main goals of SCE is not only to control the energy consumption vital for reaching Kyoto's objectives, but also to inform the users that buy or rent a house about energy consumptions associated with a certain choice.

- **Decree-Law no. 79/2006** [204]: RSECE – Regulation of Energy and HVAC Systems in Buildings – it reviews the HVAC system regulations, including the commitment of periodic inspection to boilers and air conditionings (under the previous decree).

  The basic concern of this diploma is to act on HVAC buildings with high energy consumptions in order to improve the quality of their energy systems. It also establishes that new buildings to be constructed must be fitted with natural, mechanical or hybrid means that can ensure indoor air quality (IAQ). To do that, it lists rules on the HVAC mechanic installation designs, mainly on the installed power limits.
- **Decree-Law no. 80/2006** [205]: RCCTE – Regulation of Thermal Behaviour Features on Buildings – reviews thermal regulations in buildings.

  This regulation is more demanding regarding heating and cooling needs calculation and effective and systematic verification of regulatory requirements.

  In July 2007 the energy certification system and indoor air quality in buildings became mandatory, which forces all buildings to have an energy certificate that shows the energy consumption and the measures proposed for its reduction where necessary.

2.1.3 The Spanish reality

In 2007, the total final energy consumption in Spain was 103 million toe, being registered an increase of 69% since 1990. The transports sector was the greater user, representing 37% of the total. In the industry sector a 33% rate was recorded and the other sectors (residential, services, primary) used 30% of the total energy consumption [167].

Regarding the distribution of the total final energy consumption in 2007 in terms of energy sources, oil represented 57%, electricity 22%, natural gas 16%, biomass and residues 4% and other sources 1%. The use of natural gas doubled since 1990 and electricity grew substantially from 18% in the mid 1990´s. In government projections made before the financial crisis, it was expected a 17% increase in the total consumption of final energy between 2007 and 2016, with almost all the growth from the use of natural gas, electricity and biofuels.

In relation to fuels, the use of oil is still the main CO_2 emitting source. In 2007, it represented 55% of the emissions, a relatively stable percentage since 1990. The emissions resulting from coal use (23% of the total) were slightly higher than the ones of natural gas use (23%). Natural gas grew strongly over the last years after becoming the chosen fuel foe energy generation, in part due to the *Emissions Trading Scheme* (ETS) of the EU, while emissions coming from the use of coal have a wide but stable range of fluctuation according to the availability of other energy sources, mainly hydroelectric. However, data on the use of fuel for energy generation indicate a decline on the CO_2 emissions from the use of coal since 2007.

The energy policy in Spain tries hard to support sustainable development and to ensure energy supply that allows economic growth and competitiveness while reducing the impact of generation, transformation and final use of energy on the environment [7].

Spain's aim for the EU burden-sharing agreement related to Kyoto Protocol is to reduce GHG emissions for an average of 15% above their 1990 level from 2008 to 2012. In 2007, emissions were 53% higher than in 1990. More reductions will be necessary from 2012 onwards: emissions from sectors not covered by EU-ETS should be 10% lower than the 2005 levels until the year 2020. For the ETS sector in the EU, the reduction goal is to be 21% lower than 2005 levels until 2020 [217].

The energy efficiency policy in Spain is defined on the Energy Saving 2004-2012, on the *Efficiency Strategy (E4)* and on the *Action Plan 2008-2012*. Measures planned on the Action Plan consist on the improvement of energy efficiency in all sectors. The full implementation of the plan will save a total of 60 million toe on the total consumption of final energy and 88 million toe on the total primary energy between 2008-2012. This would also prevent 238 Mt (metric ton) of CO_2 eq (equivalent) emissions. In 2012 savings would amount to 24,8 million toe of final energy (13,7% of the final energy total consumption) and to 16,9 million toe of final energy (12,4% of the final energy total consumption) related to business-as-usual. Half of these savings would come from the transports sector, 29% from industry, 13% from construction and the rest from the changes of equipments in houses or offices and the implementation of measures in agriculture and public sector [190].

In 2008, the total energy production in Spain reached 306 TWh, above the 38% recorded in 2000. Energy production by natural gas was of 39% while nuclear energy provided 19%, coal 15%, wind energy 10%, hydro-energy 8%, 6% of oil and 2% was from solar, biomass and residues energy [167].

The mix of energy production in Spain has evolved significantly since 1990, when coal, oil, nuclear and hydro energies generated 99% of all the electricity. In 2008, these four fuels were responsible for only about 48% of the total production. The fastest development of combined cycle gas turbines (CCGT) and wind energy have come to diversify the mix of production. Since 2000 energy generation through gas has grown 101 TWh, originally driven by the need of a fast capacity increase, but after that also by the EU-ETS and by the need of spare capacity for wind energy. Wind energy was responsible for almost all of the increases in the renewable electricity generation – it increased from 5 TWh in 2000 to 23 TWh in 2008. CHP (combined heat and power) is a major production component of 35 TWh in 2008 and an increase of 3% from 2007. Coal and oil, in turn, are declining, penalized by EU-ETS.

The framework for energy efficiency in buildings is established by three laws: **Royal Decree 314/2006** from 17th March that approves the **technical building code (CTE)** [215]; **Royal Decree 47/2007** from January, on the basic procedures for **energy development certification** in new buildings [213]; and **Royal Decree 1027/2007** from 20th July, that approves the review of current **regulations for thermal installations in buildings (RITE)** [216].

The measures to be implemented on existing buildings focus on renewing the building in order to reduce the demand for energy from heating and cooling and on light, heating, cooling and hot water systems improving. Government is subsidizing renewal energies with a thousand million Euros between 2008 and 2021. Subsidies can be used to cover up to 35% of the eligible costs [167].

Energy consumption in buildings can be reduced by means of construction features when energy needs for heating and cooling are lower, namely by using energy efficient equipments.

As a way to replace fossil energy consumption by renewable energies, there are now easily accessible technologies of electric energy microgeneration and of solar central heating.

Spain and Portugal launched the market of all-Iberic electricity **(MIBEL)** on 1st July 2007 with the goal of improving the safety of supply and economic efficiency. The price of common electricity for both communities applies when interconnection capacity allows it. When congestion exists, the market is divided in two price areas.

MIBEL will allow any user in the Iberic region to obtain electricity in a system of free competition, from any producer or distributor in Portugal or Spain. The functioning of MIBEL market, as explained above, is operated by OMEL (Operador del Mercado Ibérico de Energía). In the future MIBEL market, standardized contracts will be listed by the managing body of the Portuguese market OMIP, located in Lisbon. Currently base contracts are marked and the daily settlement price usually matches the price of the last market operation. Energy bought in the future market can be physically settled (in the spot market) or financially settled [165], [166], [167].

Portugal and Spain are two of the countries with the highest sun exposure (the average annual number of sun hours is 2500). However, Portugal is one of the countries that least takes advantage of that potential! [202].

3 SUSTAINABLE CONSTRUCTION

Sustainable construction is the use of sustainable development ideas applied to the construction field. It is not possible to think of a better world without taking into account sustainability in construction works. Its heavy weight can be measured by its impacts:

- Greater demand on energy requirements (buildings represent about 40% of the energy consumption);
- It is responsible for 58% of the use of natural resources;
- It generates about 50% of residues.

It is clearly an area where the integration of sustainable development principles can make a difference, with an emphasis on energy efficiency and natural resources preservation, as well as on the use of new types of construction material with a lower environmental impact [182].

Modern sustainable construction is no more than a constructive system that promotes interventions on the environment, adapting it to the needs of use, production and consumption, but without running out of natural resources on that intervention, thus preserving them so that they can be used by future generations [48], [91], [139], [307].

In the year 2050, world population is estimated to reach about 10.000 million inhabitants, which will cause a huge environmental impact, approximately eight times bigger than the current one [232], [234].

Over the years, several strategies have been implemented in order to make constructions more efficient and advantageous. So, certain aspects have been taken into account [55], [59], [261], [274], [307]:

- Changes in buildings geometry;
- Concern for the building observation and orientation;
- Analysis of the best type of facades;
- Respect for the natural environment;
- Use of natural resources (energy, water, earth) as a productive resource.

The environmental problems faced nowadays, specially the weather changes, and the increase of energy costs to bear are now major concerns for everyone. Citizens do not know how to act, even when alerted for those problems. The efficient use of energy and the use of renewable energy sources in buildings are key-solutions to face the problem, but they depend a lot on the direct and active involvement of the users.

However, the users' commitment for a change in behaviour and to make the necessary investments on that area faces some difficulties.

Usually the solutions proposed to final users do not contemplate a proposal for integration of the different existing equipments.

There are countless solutions to improve energy efficiency in buildings. It would be enough to use the technologies with the best price/efficiency relation available to reach significant savings and recover the investment cost in a few years [202].

Building construction and rehabilitation must be accepted as a philosophy in order to be able to respond to new challenges concerning indoor environment quality (IEQ) and thus ensuring thermal, visual and acoustic comfort and indoor air quality [272].

Unlike consumer goods, buildings can last for decades or even centuries. More than half of the stock of buildings will still be standing in 2050. Buildings are much more frequently renewed than replaced. A substantial portion of buildings changed in much shorter periods than the building's lifespan. Lighting systems and diverse equipments for heating, ventilation and air conditioning (HVAC) systems are often replaced after 15 to 20 years. Even facades and windows need a renovation. Office equipment is often changed after 3-5 years while household appliances are usually chanced after a period of 5 to 15 years. Consumables such as light bulbs are replaced after shorter periods.

Choosing the best technologies available at the renovation or acquisition moment is important for decreasing the energy demand in buildings at lower costs [234].

The emissions in buildings are growing rapidly due to the fact that expansion both in buildings area and in energy consuming equipments properties is rising. New policies to improve energy efficiency in new and existing buildings must be designed to ensure that new structures are built with the highest efficiency standards for the defined political goal. These policies should promote new technologies both for buildings themselves and for energy consuming equipments inside.

A wide range of technologies already available can reduce significantly CO_2 emissions in new and existing buildings. Many of those technologies are already economical, based on the lifecycle total cost. But economic barriers can delay their penetration significantly on the absence of well conceived public policies.

Several technologies recently developed (for example, high performance windows with vacuum insulation, high performance panels, reversible heat pumps) when combined with an integrated passive solar design can reach reductions of 80% in energy consumption and GHG emissions. Many other technologies are being developed (for example, integrated intelligent control systems) and, with new researches, development and demonstration, they could have a greater impact over the next two decades. The massive adoption of many of these technologies will depend on the fast commercial demonstration and implementation. This will have to include the training of professionals with an integrated approach for the design and use of technology combinations [234].

The efficiency of the building surroundings depends on insulation levels and thermal characteristics of the walls, ceiling and floor or basement. Improvements can decrease the heating needs by a 2/4 factor compared with standard practice. This can be obtained with only a small percentage of the total cost of residential buildings, and little or no marginal net cost in the buildings and services sector. In countries with soft winters but still in need of heating (including developing countries), small amounts of insulation can easily decrease the need for heating a two or more factor, as well as lower indoor temperatures in the summer substantially [1], [274].

In many cases, improvements on the building surroundings can get the owner net cost savings, even in the short term. But usually initial investments are required, while economic returns are reached after a few years. This creates a need for funding.

The cost difference between renovation and construction after demolition is not often big. Reconstruction often provides better opportunities to improve energy efficiency and the value of the land/building. However, it often generates higher CO_2 emissions because of the works and those will not be recovered fast enough with a lower energy consumption in the building if this is not built for a high energy efficiency standard [222].

3.1 Renewable Energies

The old world energy condition of the last two centuries, based on non renewable energies, mostly fossil, is literally untenable. The so-called renewable energies are an endless world of opportunities to which we can look at with excitement and hope: from solar to wind energy, from geothermal and ocean energy to hydropower; from biogas and biomass to biofuels not used for food. It is not only necessary to combine natural and technological resources with favourable economic and political circumstances, but also to accept the social dimensions of their implementation [124].

3.1.1 Solar energy

Solar energy is the title given to any capture of light energy (and, in a sense, of thermal energy) from the sun and the further process of that captured energy into something useful for men, weather for water heating or even for electric or mechanic energy [281].

Resorting to solar energy is one of Portugal's wagers to decrease the energy dependence on oil and decrease carbon dioxide emissions. This type of energy covers 75% of annual needs in a private house, being the main source of renewable energy [182].

The methods for solar energy capture are classified as:

- Direct: it means that there is only one transformation to be done so that solar energy becomes a usable energy by men;
- Indirect: it means that there must be more that one transformation so that it becomes usable energy.

Can also be classified as:

- Passive systems: these are often direct, even though they sometimes involve convection flow that is technically a conversion of heat in mechanic energy;
- Active systems: these are systems that call for help Pv electric, mechanic or chemical devices to increase the collection effectiveness. Indirect systems are also almost always active.

Even during the heating season, the solar energy available is enough to fulfil about 60% of the needs for the preparation of domestic hot water systems in a house. Solar thermal collectors are equally used for acclimatization, not only for heating (air, pool waters) but also for cooling – in this case the radiation works as a heat source for refrigerating, combining solar energy and absorption refrigerators or hybrid systems (solar-gas) [222].

The solar photovoltaic technology (Pv) converts solar energy directly into electrical energy captured. The modules can be easily integrated into the architectural solution, either in coverage or on the facades. Electricity produced in excess can be integrated into the electricity distribution network. Although considerable investment, but with a return attractive to any home or service.

When solar heating is combined with energy efficiency measures, energy savings can be even more meaningful. However, to reach solar fractions above 90%, massive solar storage technologies, seasonal thermal storage technologies and more advanced small-scale ones with a high thermal capacity are necessary [233].

New promising projects of "combined systems" combining water and cooling (Figure 7) amplify the working period, thus improving their reliability. Heating systems usually need an energy back-up and a water tank/cylinder system to supply enough amounts of hot water during low insulation periods. These back-ups add costs to the system. New solar-assisted technology combines a heating system with a heat pump, thus resulting in an "*ultra-high efficiency*" system between 125 and 145% compared with the common condensing boiler around 107%.

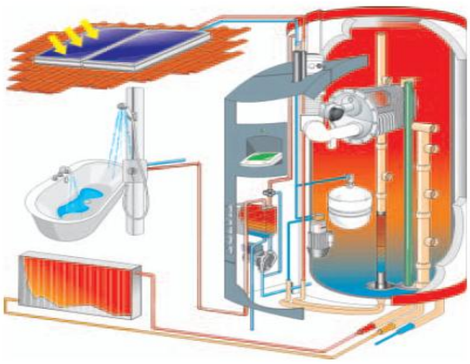


Figure 7 - A solar heater combi-system, combining water heating and space heating through room radiators (www.solvis.com) [233]

3.1.1.1 Solar cooling

Solar cooling systems use Sun radiation as an indirect energy source for the production of cold, only needing a heat source so that chemical reactions necessary to the thermodynamic processes that endure their functioning principles can be processed. It can be obtained almost totally through renewable energies (Figure 8). Cooling can be defined as the process of taking heat out of a fluid through chemical or thermodynamic processes and releasing it in the environment, whether they are vapour compression processes or absorption cycles processes. This way an efficiency ratio of the coefficient of performance (COP) can be defined as the ratio between the energy withdrawn and the energy spent to that effect [222].

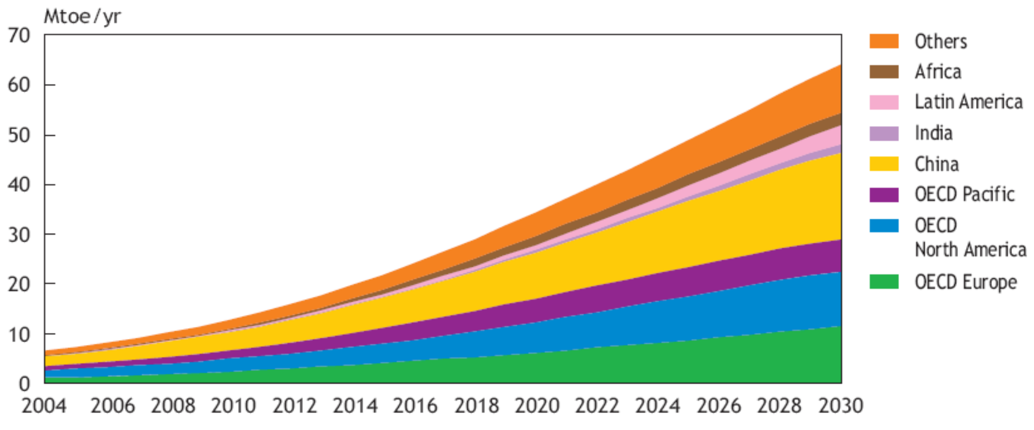


Figure 8 - Deployment of solar thermal collectors in terms of energy outputs projected out to 2030 by region [233]

One of the biggest motivations for the use of solar energy in cold production comes from the fact that the needs and availabilities are directly connected, because the periods of higher solar radiation correspond to the greater cooling needs in the building.

The choice of the most adequate refrigerating unit for a certain cooling need depends on the available energy form and the temperature level necessary. From the energetic point of view, a refrigerating unit that makes use of the solar energy to work may need a total of about 25 to 40% less of electric energy when compared with a classic system – the cooled water production machine by absorption has a very little or null electricity consumption [142], [222], [281].

Parabolic collectors or evacuated tube collectors can be used, depending on the temperature levels demanded for the production of hot water destined to the cooled water generator.

In particular, the ammonia/water or lithium bromide/water absorption chillers, fed by solar energy, uses the heat produced by solar collectors through chemical reactions taking place inside the machines – absorption chillers helped by other mechanisms – to create the thermodynamic effect necessary to make the thermal transfer and produce cooled water.

The installation is made up of solar panels, the absorption chillers, the cooling tower, the backup boiler, the storage water heater and the fan convectors; these equipments form the equipment capable of using solar energy for heating in the winter and for cooling in the summer resorting to renewable energies, only with little resort to conventional energies, thus being a preferred installation in single-family houses and in small service buildings.

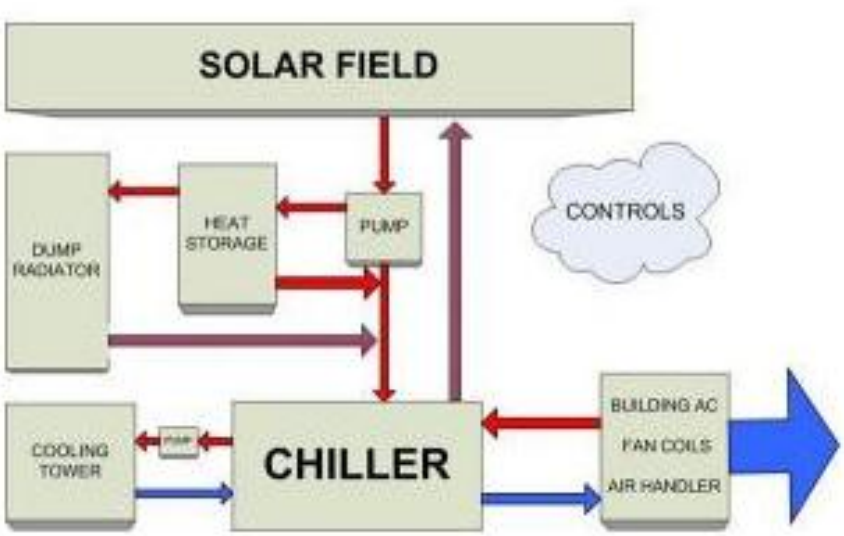


Figure 9 - Basic Principle of solar cooling [232]

3.1.2 Wind energy

Wind energy works from the movement of air masses due to pressure differences in atmospheric pressure between two distinct areas. Besides solar radiation, other geophysical phenomena such as earth rotation, tides, etc. also have a role in its generation. For over 30 years, countries like Germany or Denmark have clear conscience of the importance of wind energy as a substitute of oil, coal or gas burn with environmental advantages.

Portugal and Spain have been increasing the installed wind power level. However, these values are still inadequate, mainly for Portugal, a country highly dependent on fossil fuels import. The first wind farm in Portugal was created in 1988 in Santa Maria, Açores [266].

Figure 10 - Wind Energy [266]

This type of energy has some benefits, namely:

- It allows the effective use of wind for electricity generation;
- Low installation cost;
- Possibility of supplying energy to great networks;
- It can be used to pump water;
- Very important in places where there are no fossil fuels.

Wind energy can replace a larger part or the totality of the electric consumption in a house, through a microgenerator. Depending on the type of heating and consumption, electric energy can even be sold to the National Network. It is very advantageous in isolated or with a good wind exposure houses [222].

3.1.3 Geothermal energy

Another type of energy to resort to is called geothermal energy, very abundant, but still with low use in buildings [182].

Ambient heat stored in shallow depths (≈300m) can be a vital component of the energy/efficiency for heating and cooling in buildings. Heat is naturally stored in the underground layers. This heat source can be extracted by using heat pumps and then usefully apply it for space or water heating. Last decade increased the installation of geothermal heat pumps (GHP). These are part of a totally developed technology with relatively low cost, but that depends on the conventional fuel prices to be replaced [232].

Heat pumps can transform underground low-temperature heat or rock waters; however, a higher level can be useful for the low temperature heating as can be seen on Figure 11. In the summer, when the ground is cooler than the ambient air, shallow geothermal systems make the heat carrier fluid circulate between the building and the ground and then outlining the heat pump. Indeed, the building heat is carried to the land and is stored for the *"free cooling"* winter extraction. This way, even a geothermal system can perform heating and cooling services. Small air conditioning reversible pumps are more used for cooling and because of that they are not considered as heat from renewable sources (Figure 11).

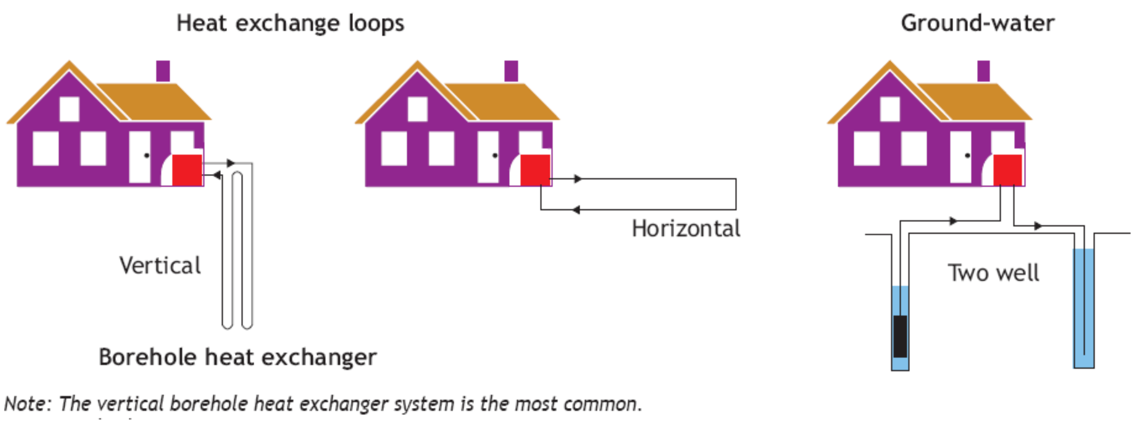


Figure 11 - Shallow geothermal systems are available in a range of types to match the local heat source whether in wet or dry ground [233]

This renewable energy source is considered as very stable, because it is not as dependent on the weather conditions as the other ones. It is a very advantageous solution for places with some volcanic activity like Açores, with appealing solutions like low depth buried piping [222].

Advantages on the use of this type of energy:

- Heating and/or cooling can be obtained through natural renewable energy;
- There is energy available underground at ± 10ºC all year long;
- Unlimited and free energy.

3.1.4 Hydro energy

This type of energy is generated by river water that flows from high altitudes to seas and oceans due to gravitational force. This flow is fed, in a reverse process, thanks to water evaporation, vapour elevation and transport in the shape of clouds naturally formed by solar radiation and winds. The phase is completed with the precipitation of rain in higher altitude areas [266].

This type of energy can be divided in two kinds, as can be seen on the following table:

Classification	*Characteristics*	*Constituent Parts*
Macro Hydro	With a power higher than l0 kW	- Dam: its role is to retain water creating a reservation; - Turbine: built with a driving shaft and paddles; - Generator: its role is to transform mechanic energy in electric energy; - Power-lines: to carry the electric energy produced.
Micro Hydro	With a power lower than 10 kW	- Canal or dike: its role is to retain water; - Water main: it carries the water to the turbine; - Turbine: built with paddles and a driving shaft; - Generator: transforms mechanic energy in electric energy.

Table 1 -Different Types of Hydro Energy [182]

In both cases, the amount of energy produced depends not only of the turbine flow but also of the height between the water surface and the turbine. It should be emphasized that small dams (micro-hydro) should be a more ecological alternative in the future.

3.1.5 Wave energy

Wave energy is generated from the exploitation of ocean waves. It is a "*clean energy*", ie, it represents no costs for the environment [232].

The idea of converting surface wave energy in other forms of energy is not recent (the first patented technique is from 1799 – *Girard & Son*, France), however the intense research and development of the wave energy conversion began after the drastic price increase in oil in 1973. It became clear since the beginning that the extraction of tidal energy is a difficult task and experiments done all over the world show just that. European Commission considered it important to help developing technologies by financing projects thus giving steps towards proving the practicality of that energy extraction. Over the last 25 years, tidal energy has gone through a cyclic process with phases of excitement, disappointment and reconsideration. However, the persistent effort on the research and development and the experience built up during those past years has constantly increased the performance energy of the attainment techniques from waves, which has made this resource closer to commercial exploitation.

3.1.6 Biomass energy

The substantial amount of organic life in our planet stores energy and chemical substances, thus being the renewable resource called biomass. Through photosynthesis, plants capture the sun energy and transform it in chemical energy. This energy can be converted in several forms of energy: electricity, fuel and heat [182].

Several natural energy sources can be considered:

- Solid biomass;
- Gaseous biofuels;
- Liquid biofuels.

Like on other types of renewable energies, the use of biomass has advantages and disadvantages, being the energy that most values the fact that its sources are virtually inexhaustible.

The use of solid biomass as a resource – through wood, pine cones, pellets or other combustion material – associated with a heat recuperating system or a boiler interconnected with heated air or water distribution pipes provide a very efficient central heating solution in a house. It is recommended for any type of accommodation, but some equipments demand some maintenance care, as they can create some sediment [222].

Biomass is by far the most important renewable energy source nowadays, representing about 9% of the total primary energy consumption. Meanwhile, most of the biomass is used in traditional house and kitchen heating. Only about 10% of the biomass is used in an industrial scale for the generation of electricity or fuels. The biomass role is expected to triple in the fuel map scenarios. According to those scenarios, bioenergy used in 2050 will reach the oil consumption existing today [232].

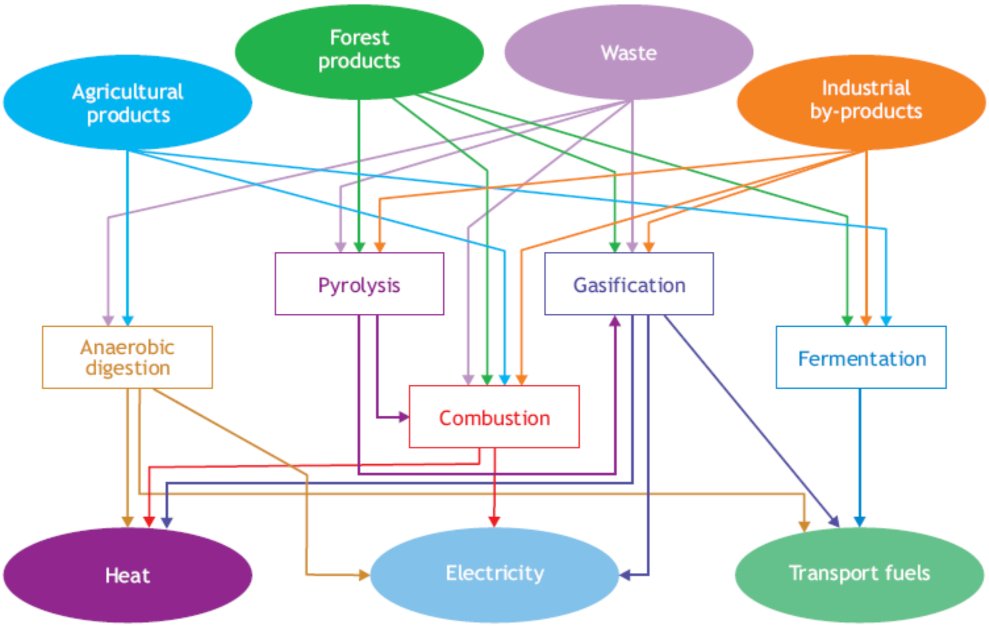


Figure 12 - Pathways for converting energy from biomass material into usable forms of heating and cooling or into other energy carriers (e.g. transport biofuels, electricity) [232]

3.2 Water

Just like energy can be obtained from natural sources with an important use, water is a resource that can and should be better exploited. Analysing sustainable techniques to be used with the objective of better taking advantage of this good is a nice place to start [182], [261], [307].

Several types of waste waters can be considered:

- Blue Water: Water from rain;

- Grey Water: from bathtub, shower, bidet, washbasin, sink and kitchen machines;
- Black Water: from toilet (responsible for about 22% of water consumption).

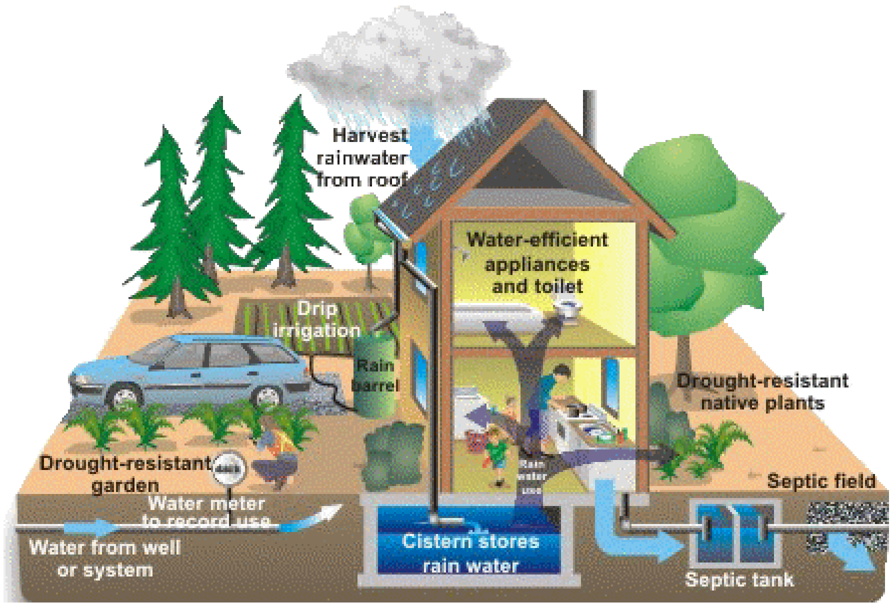


Figure 13 – Schema of waste water [182]

As it is a precious resource for the survival of the species and for the life quality of human beings, safe drinking water should only be used for tasks that lack all its qualities. Nowadays, however, drinking water is also used in functions that can be completed with water of inferior quality. The drinking water used must be recycled and reused and all the water from rain that falls on building tops should be collected in tanks, receive proper treatment and be reused in actions that do not need drinking water.

The actions that do not need drinking water are the following:

- Green spaces irrigation;
- Vehicle and outdoor spaces wash;
- Toilet flush;
- Dishwasher and washing machine.

3.3 Materials

As the health and sustainability concerns converge, going beyond plain energy saving, a new generation of materials and construction techniques begins to appear on the market [182], [261], [307].

Normally the natural materials used in construction are healthy. The problem is that the low technical performance of organic materials makes many architects choose artificial products. However, those materials that have been progressively replaced are now beginning to show up again, being revalue by their inexhaustible healthiness.

As these materials get a new boost, new techniques are being developed to reuse them differently from their traditional use.

The energy crisis, the environment degradation, the alarming increase of desertification, global warming and the more and more limited existence of raw materials suggest that the idea of a planet with an ***"endless resource"*** offer is not correct.

It is defined as "development" because of the possibility of improving the current skills or to obtain a higher degree in the situation progress; ***"sustainable"*** stands for the possibility of keeping the existence of an entity without compromising the quality or quantity of the services used. The concept of ***"sustainable development"*** is thus understood as a responsible design and an environmentally efficient maintenance based on ecological resources and principles [276].

The evaluation of a project sustainability is not possible unless three main dimensions are taken into consideration [182], [139], [261]:

1. Socio-environmental dimension;
2. Eco-efficiency dimension;
3. Socio-economic dimension.

As can be understood, it is not an easy task to combine all of these sustainability criteria in the same project, but practice shows that some steps are being given towards being closer to sustainability. The current performance should be more and more directed towards being closer to a construction type that can at least be sensitive to the presented aspects. In many countries there is a clear and growing concern by building in a more sustainable way [94], [274], [307].

4 INDOOR ENVIRONMENTAL QUALITY

The World Health Organization (WHO) defines health as ***“a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”***. We can relate this to the indoor environmental quality (IEQ), considering that this quality doesn’t represent any risk to health, comfort and well-being to the users of a certain space, while they are working.

Nowadays, we spent most of our time inside buildings. In developed countries the users spent, in average, around 90% of their lives inside buildings. This means that the air quality that we breathe is very important to our health, well-being and life quality, becoming more necessary to answer to questions of hygiene and comfort [23], [24], [244], [276], [277], [278], [304].

The indoor environmental quality is related to the coexistence of thermal comfort, visual, acoustic and indoor air quality (IAQ). In the last years we have observed a biggest preoccupation with the global comfort occupational, not only with questions related to health and productivity, but also with the associated energy consumption [272], [316].

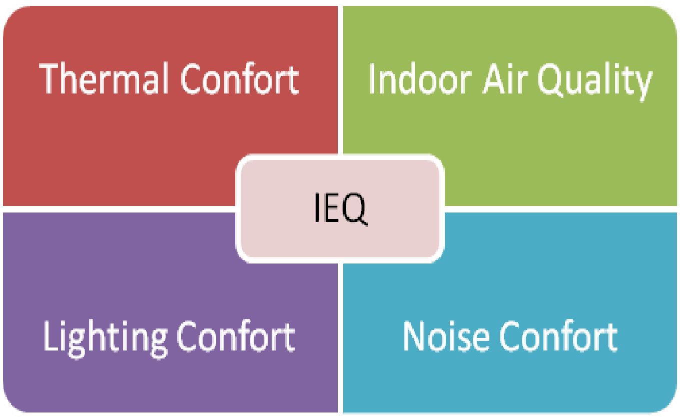


Figure 14 - Indoor Environmental Quality [272]

The IEQ depends on several factors, which can be subdivided into the following categories:

Figure 15 - Factors which influence the Indoor Environmental Quality [272]

As we can observe in Figure 15, a good IEQ can only be reached by a good design of buildings and systems. It is necessary a correct management and maintenance of the equipments to protect their users [272].

It is important to the health and comfort of the occupants to provide a place with an appropriate indoor air quality, allowing a better performance and productivity. Yet it is necessary to control important aspects of the IEQ, which will inevitably result in extra cost of energy and maybe other resources [276].

The European directive EPBD [251] specifies several requirements to save energy in buildings, repeating through the all text that the comfort of the occupants should not be neglected. This means that each choice made to save energy might influence the indoor environmental quality (IEQ) and consequently the comfort of the occupants. To support the implementation of EPBD, the European Committee for Standardization (CEN) published the EN 15251 Standard [81] that defines the indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. This standard was created to non industrial buildings, where the criteria to the environment are defined by the occupants.

The EN 15251 Standard [81] specifies the indoor environmental parameters which have impact on the energy performance of buildings. It defines how to establish indoor environmental parameters that should be considered to the project of systems to the building and the calculations of the energy performance. The environments are divided in four categories, as we can observe in Table 2.

Category	*Explanation*
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	Normal level of expectation and should be used for new buildings and renovations
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

Table 2 - Description of the applicability of the categories [81]

Category	*Thermal state of the body as a whole*	
	PPD (%)	*PMV*
I	< 6	-0.2 < PMV < + 0.2
II	< 10	-0.5 < PMV < + 0.5
III	< 15	-0.7 < PMV < + 0.7
IV	> 15	PMV < -0.7 or + 0.7 < PMV

Table 3 - Example of categories for design of mechanical heated and cooled buildings [81]

Building / space	*Category*	*Operative temperature (ºC)*	
		Minimum for heating (winter season), ≈ 1,0 clo	*Maximum for cooling (summer season), ≈ 0,5 clo*
Classroom Sedentary ≈ 1,2 met	**I**	21,0	25,0
	II	20,0	26,0
	III	19,0	27,0

Table 4 - Recommended design values of the indoor temperature for design of school buildings and HVAC systems [81]

Building / space	*Category*	*Temperature range for heating (ºC)*	*Temperature range for cooling (ºC)*
Classroom Sedentary ≈ 1,2 met	**I**	21,0 – 23,0	23,5 - 25,5
	II	20,0 – 24,0	23,0 - 26,0
	III	19,0 – 25,0	22,0 - 27,0

Table 5 -Temperature ranges for hourly calculation of cooling (Icl = 0,5clo) and heating (Icl = 1,0 clo) energy in three categories of indoor environment [81]

Type of building or space	*Category*	*Floor area m^2/person*
Classroom	**I**	2,0
	II	2,0
	III	2,0
Single office	**I**	10,0
	II	10,0
	III	10,0

Table 6 -Recommended ventilation rates for school spaces with default occupant density for the categories of pollution from building itself [81]

Category	*Airflow per person l/(s pers)*	*Airflow for buildings emissions pollutions l/ (s m^2)*		
		Very low polluting building	*Low polluting building*	*Non low polluting building*
I	10	0,5	1	2
II	7	0,35	0,7	1,4
III	4	0,2	0,4	0,8

Table 7 - Recommended design values of the indoor temperature for design of school buildings and HVAC systems [81]

Category	*Corresponding CO_2 above outdoors in ppm for energy calculations*
I	350
II	500
III	800
IV	> 800

Table 8 - Examples of recommended CO_2 concentrations above outdoor concentration for energy calculations and demand control [81]

Type of building or space	*Category*	*Design relative humidity for dehumidification (%)*	*Design relative humidity for humidification (%)*
Spaces where humidity criteria are set by human occupancy. Special spaces (museums, churches, etc) may require other limits	**I**	50	30
	II	60	25
	III	70	20
	IV	> 70	< 20

Table 9 - Example of recommended design criteria for the humidity in occupied spaces if humidification or dehumidification systems are installed [81]

Building	*Space*	*Maintained luminance, E_m, at working areas, lux*	*Remarks*
Educational buildings	**Classrooms**	300	at 0,8 m
	Classrooms for adult education	500	at 0,8 m
	Lectures hall	500	at 0,8 m

Table 10 -Example of design illumination levels for school spaces [81]

Building	*Space*	*Sound pressure level dB(A)*	
		Typical range	*Default design value*
Schools	**Classrooms**	30-40	35
	Corridors	35-50	40
	Gymnasiums	35-45	40
	Teacher rooms	30-40	35

Table 11 - Recommended design values of the indoor temperature for design of school buildings and HVAC systems [81]

To sum up, we should take into account the economic profitability and the indoor environment quality and power efficiency to ensure a proper environment Figure 16.

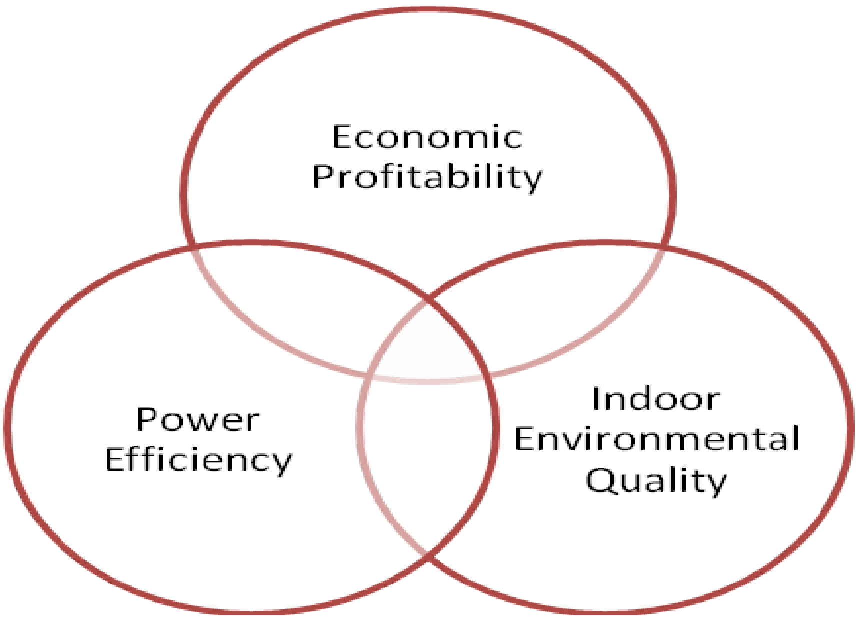


Figure 16 - Sustainable Development [278]

4.1 Indoor Air Quality

The growing concern with the air pollution show up as a result of the development of modern technology and the growing of gas emissions to the atmosphere, changing the natural balance between the different ecosystems, affecting human being health and goods and changing the earth's climate [276].

The environment is finite and its capacity of self-purification seems to have limits too. The high quantities of gas emissions to the atmosphere are a result of the human population growth and the industrial development. All this are risk factors to human health.

The air pollution is becoming more important in Europe and the rest of the world. A clean, healthy and without pollution air, is considered a basic requirement to the health and human well-being. The WHO has set an objective to Europe, that in 2015 they live in a safer physical environment, with a level of exposure and dangerous contaminants that don't exceed the international standards.

All over the years the number of complains related to the indoor air quality has growing. This happens due to the increasing of buildings, the use of new products and synthetic materials, as well as the introduction of measures to save the energy costs that reduce the supply of outdoor air. The level of indoor contamination can raise due to copiers, laser printers, computers, excessive use of products (pesticides, disinfectants, cleaning products and wax, painting, glues), gas (kitchens, canteens, laboratories), the presence of microorganisms and air contaminants from the outside [199], [200], [262].

The effect between indoor pollution causes and outdoor lead to the contamination inside the buildings, when values are superior to the ones existent outside them, they affect the health and productivity of the occupants [269].

Despite decades of research and scientific studies, problems still exist. The symptoms associated to indoor environments in different kind of buildings are connected. This is also connected to a diminution of productivity by the user. The scientific information available is too complex, isn't enough or specific to identify or connect the exposure with the symptoms, or even how to match the different contaminants. It becomes much more difficult to establish acceptable levels of some exposures. In the meantime, it has been developed some standards, which have been applied to prevent the symptoms associated to indoor environments in buildings.

On the other hand, we should not forget that the air that we breathe is related to outside air (outdoor air). The exposure to environmental pollutants, indoors and outdoors may cause a huge variety of effects on human health, according to:

- Type of contaminant;
- Magnitude, frequency and duration of exposure;
- Specific toxicity associated with the contaminant.

The composition of the indoor air might be affected by the presence of several contaminants, which belong to outdoor air and indoor sources. The outdoor air enters in the buildings through ventilation, giving origin to the contaminants found in closed environments, together with different materials used inside the buildings, furniture, equipment, people, a poor maintenance of the ventilation systems, cleaning products, and so on. All these can be the cause of the indoor pollution.

Acceptable indoor air quality (IAQ) is defined as air in which there are no known contaminants at harmful concentrations determined by the Authorities and the substantial majority (80% or more) of the people exposed do not express dissatisfaction [26].

4.1.1 Indoor air conditions

The working conditions are connected to the indoor air quality. During the 70's, ventilation requirements were changed and begin to show up buildings hermetically closed. At the same time we observed a revolution inside the office work. This happened due to computers and new technologies. The air quality inside a building depends on several parameters, including the outdoor air quality, the partition of divisions, the instalment of the air conditioning system, the conditions under which the system works and its maintenance, the presence of pollution sources and its magnitude [32], [261], [311].

The air inside the buildings should not contain high concentrations of contaminants harmful to the health or uncomfortable to the occupants. Those pollutants include those which can be visible in the outdoor air that enters in the building, furniture, construction materials, surface coatings and air treatments. The most frequent situations of risk to their occupants are: exposure to toxic or radioactive substances, infections or allergies, uncomfortable conditions and odours. Domestic pollution and pollutant gases (including allergic), inside the buildings, especially smokes produced by combustion, with the emission of carbon monoxide, nitrogen oxides, PM, COV and SO_2. The kitchen gases may also produce respiratory symptoms especially in atopic individuals. The indoor pollutants like formaldehyde and the isocyanides are released from furniture.

The IAQ affects directly and indirectly human health. The most common complaint has to do with temperature: the air is too hot or too cold. The second complaint has to do with the movement of the air, or is on or is off. Other complaints are related to humidity: the air is too dry or too wet, or even the odours [199].

Some symptoms are usually similar to flu or problems with cold: headaches, sinusitis, congestion, dizziness, nausea, fatigue, eyes, nose and sore throat. Such symptoms are difficult to associate with the physical space, like work or house. They never suspect that the indoor environment is the cause of the symptoms, unless the symptoms are shared by several occupants [200].

The contaminants might be caused by a variety of sources inside and outside the building. Physical, chemical or microbiologic pollutants may contribute to the problem.

We have a bad indoor air quality when the ventilation is not enough to maintain the concentration of pollutants at levels non harmful to the occupants. The climatization system must control the pollutants and provide a comfortable environment. When we realised that the air doesn´t circulate, when it’s cold or wet we feel uncomfortable [282].

The factors that affect the air quality in closed environments are: inappropriate ventilation, indoor air pollution, atmospheric pollution and biological contamination due to due to materials used in construction [276].

Inappropriate ventilation

The ventilation is inappropriate due to:

- An inappropriate supply of fresh air, as a result of recirculation of the air flux or low movement;
- Bad distribution and consequently an incomplete mixture with the outdoor air, causing the air stratification and differences of pressure among the different domains and construction areas;
- Air filtering, incorrect maintenance or a filtering system inadequate;
- Air temperature and humidity extreme or floating;

Indoor contamination

The indoor pollution may have origin in the individual, work, inappropriate use of products (insecticides, disinfectants, cleaning products, polish products), combustion gases (smoke, coffee, laboratories) and crossed contamination from other areas with poor ventilation. We should also consider the occupants of the building a possible source of contamination.

Outdoor contamination

Some gases can enter the building, gases from vehicles, construction, and air from the air conditioning. Another origin can be the infiltration of petrol steam, sewer, fertilizers, insecticides, including dioxins and radon.

The use of inadequate materials, as well as technical defects can be a common cause of indoor air pollution. Although it might have some overlap between the different contaminants of the indoor environment, they can be classified in three categories:

1. Physical;
2. Chemical;
3. Biological.

Type of Agent	Contaminant
Physical	Particles
	Noise
	Vibrations
	Thermal Conditions
	Radiations
Chemical	Carbon Dioxide (CO_2)
	Carbon Monoxide (CO)
	Ozone (O_3)
	Formaldehyde (HCHO)
	Total Volatile Organic Compounds (VOCs)
Biological	Bacteria
	Fungi
	Mite
	Pollen

Table 12 - Different types of contaminants

Each category has many subcategories and sometimes we can combine certain elements.

4.1.2 Pollution causes

The environment pollutants might derive from forms of energy, it might be chemical or biological and they can cause different symptoms. Some important chemical pollutants are carbon dioxide, carbon monoxide, organic vapours, fibbers and dust. The odours, lighting problems and noise may also contribute to discomfort and the arising of some symptoms. The temperature and humidity are the responsible for the usual problems, due to differences between some areas in the same building, probably because its distribution is not the same.

Most of the pollution causes occur in indoor environments, such as adhesives, carpeting, carpets, photocopiers, wood treatment products, cleansers and pesticides that issue volatile organic compounds, such as formaldehyde. Research shows that some organic compounds in volatile conditions may cause chronicle and acute diseases, when they are highly concentrated, some become carcinogenic. Low concentrations can cause acute diseases.

Besides, the ionization of the atmosphere of the buildings has been mentioned in some articles. The presence of positive electrical charges, the lack of negative ions in a closed place can be the cause of some symptoms, according to some experts.

The measurement of CO_2 is a good parameter to measure the air quality. When the renewals of air aren't enough, a concentration of CO_2 superior to 1000 ppm can indicate a bad functioning of the ventilation system. This causes some changes that are realised by the occupants and can also be object of proper measures like: total temperature, radiant temperature, humidity, CO_2, CO, formaldehyde, ozone, VOC's, particles and parameters that require more sophisticated techniques. The occupants of a building, as human beings, are a cause of contamination, producing naturally carbon dioxide, water vapour, particles and biological aerosols.

Each year, *Legionella*, is responsible for lots of deaths. It is a bacterium that can survive in different environments, relating to chemical-physical conditions. It can grow in a temperature between 35-37 ºC, which is the human body temperature, where it has the perfect conditions to its proliferation. This bacterium has 39 species and more than 50 sub-groups. Its ecological niche is the water. It can colonize the supplying systems of cities, through the distribution system of water. The most common contaminations with *Legionella* are the equipment systems of water distribution at houses, hot and cold, water refrigeration by evaporation, like cooling towers and evaporation condensers. It can be very difficult to quantify with certainty these contaminants, because sometimes its evaluation is subjective [24], [130], [131], [133], [174], [199], [200], [244], [262], [276], [277][278], [291], [304].

Once we know the effect of certain compounds to human health, we should also know the concentrations of those substances in the indoor environment air, so that we can protect the exposed occupants. This is the only way to compare the existent concentrations and the maximum concentrations that are acceptable [135].

There are different ways to obtain the pollutant concentrations in indoor atmosphere, like for example: direct measure, in situ, or we can calculate those concentrations, with some equations. We can also calculate the air renewal or the internal production of CO_2.

The concentration of organic contaminants in indoor air does not follow a model of mass balance expressed in the following equation:

$$\frac{dCi}{dt} = \frac{Q}{V} + N * C_0 - a * C_i - N * C_i \quad (1)$$

Where:

Ci - Pollutant concentration in indoor air (mg/m^3);

Q - Rate of emission (mg/h);

V - Indoor space volume (m^3);

C_0 - Pollutant concentration in atmosphere (mg/m^3);

N - Renewal rate of ventilation per hour (Air changes per hour);

a - degradation rate of the pollutant per hour.

The concentration of contaminants will only depend on the quantity of the compound released on air by the cause of contamination, by the concentration on the atmospheric air and by the different mechanisms through which we can remove the pollutant. Those mechanisms are: removal by dilution, or "disappearing" all over the years. It can be established all the rules and standards to reduce pollution, considering these possibilities.

4.1.3 Parameters that influence the indoor air quality

The indoor air quality refers to the concentration of contaminants and thermal conditions that have effect on health, comfort and on the behaviour of the occupants of a building. It must be assured certain conditions so that we don't put on risk the occupants, because most people spent most of their time indoors (transports, houses, work, schools). We must control the causes of contamination, like, heat, humidity, ventilation and air conditioning systems.

According to many authors, the first thing to do when we are analysing the air quality is to find out which are the potential contaminants that we can find and which are the origin sources [130], [131], [133], [174], [192], [199], [200], [244], [262], [276], [277][278], [291], [304], [317].

The ventilation systems are one of the most important parameters to obtain a clean air. Not only allow to expel to the outside the contaminants issued by a fixed source, but they also dilute the contaminants issued by all the sources inside a space [268].

When we have a good project and maintenance of ventilation system of a building, we can control the concentrations of contaminants under the limits considered acceptable to the type of building, obtaining this way a good indoor air quality.

The minimum rate of ventilation necessary to a place should be chosen according to the total charge of contamination, considering all types of contaminants, whether they are physical, chemical or biologic, which can affect the air quality. It should also be done a study of the potential contamination sources.

The air quality inside a building depends on many factors, from the outdoor air quality, to the design of the ventilation system and air conditioning that will determine the performance of the efficient ventilation and the system maintenance [276], [282].

The concentration level of a contaminant in an indoor space is determined by the mass balance between the generation of the pollutant and its removal rate.

The concentration of pollutants inside a building will depend on the following factors:

1. Emission rate of pollutants from internal sources
2. Ventilation variables:
    - Natural ventilation;
    - Mechanic ventilation;
    - Hybrid ventilation.

The mechanic ventilation was developed gradually to the detriment of natural ventilation, to have a biggest capacity of air exchange.

The quantity of air necessary to make adequate ventilation might depend on local factors, like:

- Local characteristics and dimensions;
- Activity performed;
- Heat emitted or thermal charge.

The air renewal of a place can be defined as the quantity of air necessary to completely renew the air that occupies and the volume of a place. When we use this concept we are referring to the number of renewals/hour.

Local	*Air renewals/ Hour*
Cabinets	4-6
Big stores	4-6
Laboratories	5-15
Toilets	10-15
Laundries	20-30
Libraries	4-5
Coffees and Bars	10-12
Kitchens	15-20
Floors	3-5

Table 13 -Number of air renewals per hour set in Spain by RITE [216]

The air flow is another variable to characterize the ventilation. The Portuguese law only refers that it should be maintained minimum flows of new air, according to the type of activity [m^3/(hour.occupant)].

Local	*Minimum flow of new air*	
	[m^3/(hour.occupant)]	**[m^3/(hour.m^2)]**
Corridor / hall	-	5
Cabinets	35	5
Conference rooms	35	20
Class rooms	30	-
Laboratories	35	-
Auditoriums	30	-
Libraries	30	-
Bars	35	-

Table 14 -Minimum flow of new air referent to school buildings in Portugal [215]

The efficacy of ventilation depends on the air distribution and the localization of pollution causes in the local. So it can have different values to different pollutants.

It depends on many factors:

- Distribution system of used air;
- Localization of pollution sources;

- Characteristics of air entry and exit;
- The difference between the temperature of the air injected, the environmental air and the flow of forced air.

The **Natural Ventilation** occurs when an air renewal of a place is made using the natural characteristics of air, that’s why the natural ventilation varies with the air velocity and the difference of temperature. The infiltrations and the air extractions through walls of buildings are also part of this process. Basic factors of natural ventilation are [8], [9], [268], [276], [278], [282], [304]:

- Difference of height
- Difference of indoor and outdoor temperature
- Difference of pressure
- Wind action
- Thermal charge

Advantages:

- No energy consumption;
- Has less problems of maintenance than any other ventilation systems;
- Any noise;
- Less filth in the air entry and exit.

Disadvantages:

- It shows sensibility to the external conditions;
- It’s not possible to create big volumes;
- The size of the facilities is bigger than the other systems, which affects the air entry and exit;
- External noises coming from the openings;
- Thermal discomfort;

- Be very careful when we open the windows;
- Total inadequacy of fluxes according to the needs;
- The occupants can't act with freedom;
- There is dust where the entries are placed.

The decay method of concentration is made through a certain concentration of marker gas at the place, where a dose is inserted, leading to the measure period of F (t) = 0. On the other hand, the concentration of marker gas decreases with time. It represents a natural logarithm of gas concentration, obtaining a straight line, being the dip of the line the velocity of the air renewal in the room.

So the number of air exchanges is calculated by:

$$N = \frac{\ln C_0 - \ln C_t}{t} \qquad (2)$$

Where:

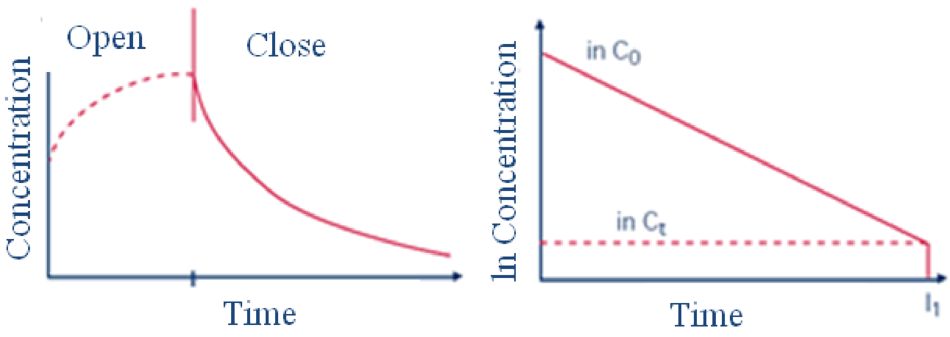
N - Air changes per hour (h^{-1});

C_0 - Concentration of marker gas at zero time (the moment it starts);

C_t - Concentration on t time, which is usually the time the measure ends;

t (h) - Total time used to calculate the air renewal rate (measure period).

To confirm if the test is reliable or not, the graphic of concentrations at logarithm scale (Graph 1) should be in straight line. If it isn't like that, it has determined that the environmental air isn't well mixed.



Graph 1 - Decay method of concentration [278]

Measuring the ventilation using carbon dioxide

The measure of the ventilation volume can be done through carbon dioxide measures. The carbon dioxide is used as marker gas, using the ones that exist in the environment or through the addition of a controlled flux. There are several methods to measure the ventilation volume, using the carbon dioxide level, like for example **the decay method of CO_2 concentration**.

We can measure the decreasing of the carbon dioxide concentration through a period of time. The calculation of the ventilation flow is given by the number of renewals (N) according to the equation:

$$N = \frac{1}{t}\log\frac{C_i - C_0}{C_t - C_0} \qquad (3)$$

Where:

C_0 - Outdoor concentration of carbon dioxide;

C_t - Final concentration of carbon dioxide;

C_i - Initial concentration of carbon dioxide;

t - Time (h).

From N it can be calculated the ventilation flow ($Q_{Ventilation}$) by:

$$Q_{Ventilation} = N * (Volume\ of\ local) \qquad (4)$$

The conditions of the indoor air quality are very important, because poor environments can affect health, productivity and comfort. Besides all this, it can cause the SBS syndrome, where the occupants show symptoms like: headaches, apathy, loss of concentration, nauseas, dry throat and skin and eyes irritation. The SBS exists when all this symptoms are identified by 20% of the occupants for a minimum period of two weeks. Recent studies didn’t identify a solid cause for SBS [315], [316], but the significant elements can be: poor ventilation, poor filtration, the presence of contaminants (asbestos, carbon monoxide, formaldehyde, inadequate humidity, radon, smoke), a pre-disposition of the occupants, a poor IEQ, psychological aspects [272].

4.2 Thermal Comfort

The interactions between the air features and the hygrometric conditions are very important to the IAQ problems. If temperature or humidity changes, that can affect human answer but also a perception of the chemical contaminants. According to different studies, people tend to describe the air more congested, perfumed and with poor quality when the temperature or humidity are higher [26], [26], [244], [268], [278], [282], [304].

The changes in the thermal environment influence the air quality. For example, high temperatures can raise the emissions of volatile organic compounds, the evaporation of volatile chemical substances and semi-volatile of surfaces. It can also affect the distribution of particles between surfaces and the surrounding air. High concentrations of humidity can affect chemical products that can be dissolved in water or the presence of biologic aerosols. More humidity leads to a higher concentration of formaldehyde and other substances highly dissolved in water. They can change the chemical composition of air and the human answer to the thermal environment. For example, higher concentrations of CO_2 can cause vasoconstriction, the flow of blood decreases.

The answer of the human body to temperature depends of a very complex balance between the level of heat production and the level of heat losses. The human body tries to maintain a mean temperature, which in normal conditions varies between 36,1 ºC and 37,2 ºC, but it is lost by radiation, convection and evaporation. The exposure to environmental conditions should not constitute a risk to health, not even discomfort to the occupants of a building. It should be avoided extreme temperatures and humidity, sudden changes of temperature, air stream, and excessive radiation, especially the one that comes from windows, lights or glass panels.

The balance between the parameters involved in the thermal comfort, relative humidity of the air, dry temperature, mean radiant temperature and air velocity, determine the environment of comfort or not. Yet we should take into account the needs of each person, considering the activity, clothing features, age and physiology [122], [295].

The heat produced in the body is determined by the level of activity of each person. It varies with age and sex. This heat is exchanged with the outdoor environment by conduction, convection, radiation and evaporation. Conduction isn't so relevant. Convection depends on temperature and the velocity of the outdoor air.

Radiation depends on mean radiant temperature. Evaporation depends on the humidity of air and its velocity.

The set of parameters that influence directly the thermal comfort are divided in:

1. Individual parameters

   - Activity;

   - Clothing.

2. Environmental Parameters

   - Air temperature;

   - Air humidity;

   - Air speed;

   - Mean radiant temperature.

The EN 7730 Standard [75] considers that a space presents thermal comfort conditions if less than 10% of the occupants don't feel uncomfortable.

Some studies with 1300 people were made to quantify the percentage of discomfort [122]. These studies allow us to establish a connection between the result of the heat balance of an individual and his dissatisfaction, designed by ***Predicted Percentage of Dissatisfied*** **(**PPD**)**. Dissatisfaction: percentage of people dissatisfied with thermal environment. PPD is determined by ***Predicted Mean Vote*** **(**PMV**)**. PMV is calculated with the value of the human body energy and metabolism. So PMV is just a scale to quantify the hot and cold sensation.

Activity and Metabolism

Metabolism is the rate at which a person processes calories and uses them for energy to be active throughout the day. To the same activity it varies according to the surface area, which is defined by units W/m^2, where the value 1.8 m^2 is the surface area of an adult. The metabolism is often given in the unit "met", where 1 met is equal to the metabolism for a seated, resting person (1 met = 58.15 W/m^2).

Activity	Metabolism (W/person)	Metabolism (W/met)	Metabolism (W/m^2)
Laying down	85	0.8	47
Seated quietly	104	1.0	58
Sedentary activity	126	1.2	70
Standing, light activity	167	1.6	93
Standing, medium activity	210	2.0	117
High activity	315	3.0	175

Table 15 - Metabolic rate for various activities [75]

Clothing

Clothing is characterized by its thermal resistance, I_{cl}, units m^2K/W. Like metabolism, it has its own unit, clo, which is the thermal resistance of 0.155 m^2K/W. in Table 16 are shown the values of thermal resistance, I_{cl}, from different types of clothing.

Clothing	Thermal resistance (I_{cl}) (clo)	Thermal resistance (I_{cl}) (m^2K/W)
Naked	0.8	47
Shorts	1.0	58
Tropical Clothing	1.2	70
Summer Clothing	1.6	93
Working clothes	2.0	117
Indoor winter clothing	1.0	0.155

Table 16 - Clothing thermal resistance [75]

Thermal Comfort Equation

This equation allow us to calculate the accumulated energy of the human body, S, which corresponds to the difference between the metabolism developed in the body and the hot transferred to the environment, presented on Equation 5.

$$\begin{aligned}
&M - W && \text{(Metabolism and Work)}\\
&- 3.05 \times 10^{-3} (5733 - 6.99 (M - W) - p_a) && \text{(Vapour diffusion)}\\
&- 0.42 \left((M - W) - 58.15\right) && \text{(Sweating)}\\
&-1.7 \times 10^{-5} M (5867 - p_a) && \text{(Breath latent)} \qquad (5)\\
&- 0.0014 \times M (34 - T_a) && \text{(Breath sensitive)}\\
&- 3.96 \times 10^{-8} f_{cl}((T_{cl} + 273)^4) - ((T_r + 273)^4) && \text{(Radiation)}\\
&- f_{cl} \times h \times (T_{cl} - T_a) = && \text{(Convection)}\\
&+ S && \text{(Heat accumulation)}
\end{aligned}$$

In this equation:

M - Metabolism, in W/m^2 (body area)

W - External work, in W/m^2 (body area)

p_a - Water vapour pressure, Pa

T_a - Air temperature, ºC

F_{cl} - Clothing, dimensional

T_{cl} - Surface temperature of clothing, °C

T_r - Mean radiant temperature of the mat elements from space, in ºC

h - Coefficient of convection between the external clothing surface and the outdoor air in W/m^{2}K

S - Energy of the human body in W/m^2 (surface area)

Surface Temperature of Clothing

The surface temperature of clothing is obtained by the energetic balance, equal to the transfer of skin conduction to clothing, to the transfer of heating by convection and radiation. This will give us the equation presented:

$$\begin{aligned}
T_{cl} &= 35.7 - 0.0275 \times (M - W)\\
&\quad -I_{cl}\{3.96 \times 10^{-8} \times f_{cl} \times ((T_{cl} + 273)^4 - (T_r + 273)^4) + f_{cl} h (T_{cl} - T_a)\}
\end{aligned} \qquad (6)$$

Clothing Factor

The clothing factor is defined by the reason between the external surface clothing and the body surface, being consequently a dimensional and superior value to the unit.

Convective Coefficient

The EN 7730 Standard [75] defines the calculation of the coefficient of free and forced convection with the following equations:

$$h_c = 2.38 \times |t_{cl} - t_a|^{0.25} \quad \text{, para } h_c > 12.1\sqrt{v_{ar}} \tag{7}$$

$$h_c = 12.1\sqrt{v_{ar}} \quad , para\ h_c < 12.1\sqrt{v_{ar}} \tag{8}$$

PMV

The PMV value has the following meanings:

Vote	Corresponding Sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Table 17 -PMV [75]

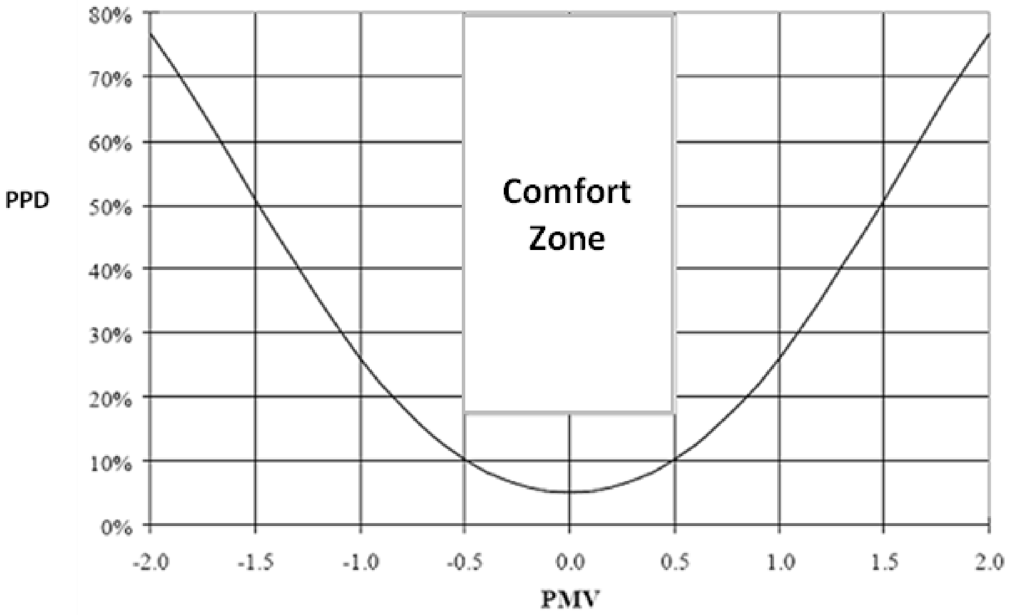
It is determined by the correlation between human body energy and the metabolism:

$$PMV = \left[0.303 \times e^{(-0.036 \times M)} + 0.028\right] \times S \tag{9}$$

When we have the value of *PMV*, to calculate the *PPD*, Predicted Percentage of Dissatisfied we use the following equation:

$$PPD = 100 - 95 \times e^{\left(-0.03353 \times PMV^4 - 0.2179 \times PMV^2\right)} \tag{10}$$

Also represented in this graphic:



Graph 2 - PPD/PMV [75]

Based on this, the EN 7730 Standard [75] admits being acceptable thermal environments with -0.5 <PMV< 0.5, which means that less than 10% of the occupants aren't satisfied.

Besides the thermal comfort of the body, a person can be in a comfortable environment, adequate or intolerable. It can be influenced by the asymmetric radiation, due to high air velocities, the difference of the vertical air temperature or contact with hot or cold surfaces. They find out that people with light activities (sedentary or standing) are sensitive to air streams, an undesirable local freezing of the human body caused by the air movement. Air streams are the most usual reason for complains in locals with air conditioning. Occupants submitted to Draught on winter tend to increase the temperature in the room to neutralize the freezing, raising the energy consumption. In extreme cases, the ventilation systems are switched off or they simply block the supplying points, leading to a bad indoor air quality. *Fanger* developed a mathematic model to quantify the ***draught risk*** (DR) in terms of the percentage of dissatisfied people. It is calculated like this:

$$DR = (34 - ta)(va - 0.005)^{0.62}(0.37 * va * Tu + 3.14) \tag{11}$$

for *va* < 0,05 m/s: use *va* = 0,05 m/s
for *DR* > 100 %: use *DR* = 100 %

Where

t_a - Local air temperature, in degrees Celsius, 20 °C to 26 °C;

v_a - Local mean air velocity, in meters per second, < 0,5 m/s;

Tu - Local turbulence intensity, in percent, 10% to 60% (if unknown, 40% may be used).

PMV e PPD are useful to evaluate conditions of comfort or discomfort. The local thermal can happen due to [272]:

- Draught;
- Vertical air temperature differences;
- Warm and cool floors;
- Radiant temperature asymmetry.

Country	*Temperature (ºC)*	*Relative Humidity (%)*	*Type of Building*
Winter			
Spain	21	Non	Houses, hospitals and hotels
	20	35	Offices, workshops, and schools
	14-18	Non	Sports gyms
Portugal	20	48	All except industrial
Summer			
Spain	25	50	All
Portugal	25	50	All except industrial

Table 18 - Values of Temperature and Humidity in Spain and Portugal [204], [214]

According to the Portuguese Decree-Law nº 79/2006, the temperature in the buildings should be between 20 and 25 ºC and the relative humidity should be around 50%, while the air velocity shouldn't be more than 0,2 m/s.

In Spain, the Royal Decree 486/97 (Attachment III), says that the temperature in places where the work is sedentary should be between 17 and 25 ºC, places with light work should be between 14 to 25 ºC and relative humidity between 30 and 70%.

Workers should be continually exposed to air streams, whose velocity exceeds the limits:

1.Hot Environments: 0.25 m/s;

2.Sedentary work in hot environments: 0.5 m/s;

3.Non-sedentary work in hot environments: 0.75 m/s.

These limits aren't applicable to projects to avoid stress, in expositions to air conditioning streams, to which the Spanish limit is 0,25 m/s, to sedentary works, and 0,35 m/s to the others.

4.3 Acoustic Comfort

"*Noise is defined as any unwanted sound, or acoustic energy which may affect the welfare of those physiological or psychological.*" [127]

According to *Chambel* [89] the human hearing capacity has different values. In average we can say that the ear picks up sounds from 20 Hz to 20 KHz, but it exist a scale of values where the hearing sensitivity is more evident: 500 Hz and 6000 Hz.

Noise is a result of the acoustic pressure, being possible to measure it with sound meters which calculate the average level to a certain pause of time. The equivalent continued sound level (Leq) is the basic indicator of noise. The measure unit is decibel (dB(A)), defined as the logarithm of the ratio of the sound intensity to some reference intensity. The decibel scale varies between 0 dB(A) (threshold of hearing) and 130 dB(A) (threshold of pain).

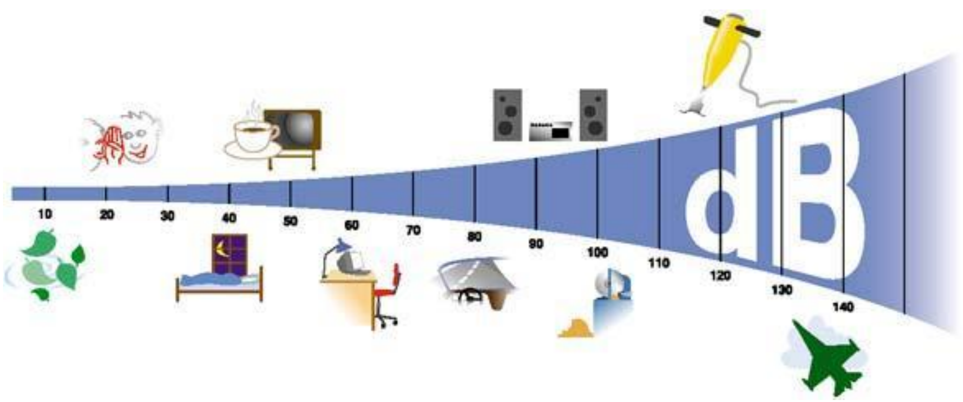


Figure 17 - dB Scale [89]

Place	dB(A)
Classrooms	40
Reading Rooms	35
Common Areas	50
Teachers Cabinets	40

Table 19 – Permitted level sounds to certain activities in Spain [216]

The Portuguese acoustic regulation [218] recommends the maximum of 45 dB(A) for school buildings. Inside those buildings the reverberation time, T, that should follow this condition: $T \leq 0{,}15\ V^{1/3}$ (V is the volume of the room).

Acoustic of the Rooms

There are too many causes to create noise inside a classroom. The noise that comes from the outside, like human activities, road traffic, air transportation, trains and other fixed or movable causes. Besides the noise inside the building can contribute to the acoustic indoor environment. The noise coming from the inside of the classroom and from the human activities are an important cause of stress noise. As well as noise coming from technological equipments, HVAC systems can be very intolerable [272].

When we are building a school we should take into account the security, health and well-being of the people who work there. During the initial phase, the acoustic features should be adequate to the building (envelope, indoors, HVAC or systems from other services). These aspects are also connected with energy saving. On one hand the right choice of equipments and materials can help to optimize the HVAC systems, on the other hand it can control the thermal wastes through the surrounding of the building.

A bad project or/and a wrong construction of the acoustic isolation and noise control can create problems related to the exposure to higher levels of noise, not only for students but also for teachers. Problems like symptoms of discomfort and some cases of serious hearing deficiencies. Besides, a bad acoustic quality of the room can cause high reverberation, causing a higher laxity on speech [127], [272], [310].

Main effects related to noise exposure

A simple but not original classification of the effects:

- Physiological effects;
- Physical effects;
- Psychological effects.

Noise effects on students

Since 1970 studies have been done, most of them about the noise effects on children, at school, trying to connect the exposure levels of noise and their performance on cognitive tasks [89], [127], [272], [310].

According to *Fonseca* [127], the room has a high importance to the way a sound is listened. There are several phenomenon created by the acoustic of the room that will change the perception of what we listen. In the open field, what we listen is mainly the sound coming from the sound source. It can exist some reflections originated by certain surfaces (floor, buildings, etc) but usually don't have much influence to the person who is listening. When we are inside a room, this is much different, because we have more reflections, which will have an important role to the way we hear a sound. This is known as **Reverberation Time** (RT).

One of the advantages or reverberation is that the room reflections reinforce the intensity of the direct sound, this is, and a certain sound coming from a room will be listened with more intensity than the same sound heard outdoors.

Indicators

According to what was said above, the simple basic indicators are: *A -weighted equivalent sound pressure level and reverberation time*. Other criteria based on the walls isolation, acoustic isolation of the impact and other is useful not only in the conception phase but also to verify the construction after being done.

The weighted equivalent sound pressure level

The A-weighted sound pressure level of a noise fluctuating over a period of time T, expressed as the amount of average energy. It is expressed as:

$$L_{Aeq} = 10 \log \left[\frac{1}{T} \int_{T} \frac{p_A^2(t)}{p_0^2} dt \right] \quad (12)$$

Where:

LA_{eq} - Equivalent continuous A-weighted sound pressure level, dB (A);

$p_A (t)$ - A-weighted instantaneous sound pressure, PA;

p_0 - Reference value of sound pressure, equal to 20 ILPA;

T - Measurement time, s.

To achieve an adequate acoustic comfort inside classrooms it is necessary to have a good knowledge of the noise coming from outdoor sources (outside the classroom and outdoors). This allows us to choose an acoustic isolation of the walls and floors, which will guaranty an adequate background noise. They should predict the HVAC noise.

Reverberation Time

RT is the time taken for a continuous sound within a room to decay by 60 dB after being abruptly switched off. According to a simple theory it depends on the volume of the room and its features of sound absorption and limits.

$$RT = 0{,}16 \frac{V}{A} = 0{,}16 \frac{V}{\sum_i \alpha_i S_i} \quad (13)$$

Where:

RT - Reverberation time, s;

V - Volume of the room, m^3

A - Sound absorption area, m^2;

αi - Absorption coefficient of surfaces, Si;

S – Surface area, m^2.

The RT is related to speech perception, being very useful as a simple indicator of the acoustic quality at schools. A short time of reverberation can favour the understanding of the speech in a classroom, while high values lead to misunderstandings of the speech. Anything that interferes with communication brings negative consequences to learning. It is important to remember that speech perception is also connected with background noise levels, especially the relation Signal –Noise (S/N). It is defined as the difference in decibels between the speech level and the background noise level. Usually T and S/N depend not only from the noise source but also from the places of the receptor.

The RT can be controlled by the correct choice of the materials, set on the limits of the room and indoor furniture. The desirable values depend on the using of the space (classroom, music room, canteen, gym). The RT measures should be done according to the EN 3382-2 Standard [83].

The quantity of reverberation depends on the rate to which the sound falls. The fall is faster when the volume of space is small, because the sound waves around the constant velocity should suffer more absorptive shocks in a certain period of time. It is also faster where the limits of a space and its content are more absorbents. The gradient of a fall won’t be totally regular but we can assume it will, for general purposes. A short RT favours clarity, as well as the speech; a longer RT increases “wealth”, especially to music [274].

The sound pressure levels should be between the limits of comfort to the individual (50-70 dB (A)) to avoid problems, because higher levels can cause fatigue. The cause of the noise is also an important factor, because it has proved that both high noise, monotone, intermittent, as well as constant, infrasound, low-frequency noise to pure concrete tones can cause headaches, fatigue, stress, irritability, discomfort [278] …

The room behaviour regarding to the frequency only depends on two phenomena: acoustic ways and absorption behaviour of the room materials. The first one has more influence on high frequencies; the second one has more influence on medium and low frequencies.

To avoid this situation, it is important that the room can have a similar behaviour to all the frequencies. If a certain material has more reflection in a frequency range, it should exist another material with a bigger absorption on the same range.

The connection *Source – Noise* is related to the capacity of the tone and voice power of the teacher being capable to overcome the noise in the classroom. The *Distance Teacher – Student*, the further away the student is from the teacher, the softer the teacher's voice will sound.

The reflex of the sound waves (Figure 18) on walls, floor and ceiling, increases the noise level in the classroom, becoming impossible to teach in that environment.

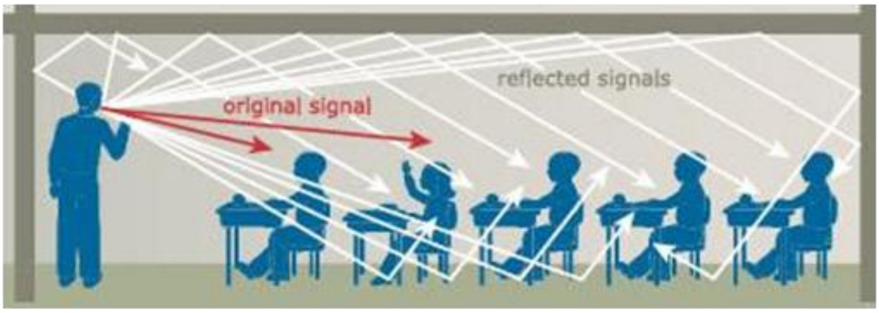


Figure 18 - Reflex of sound waves [310]

At one meter of distance (*Teacher – Student*) the energy or intensity of the voice measures around 60 dB. But every time that distance is double raised, the sound decreases 6 dB. So if a student is seat at 2 m from the professor, the intensity of sound is 54 dB, but at 4 m is only of 48 dB.

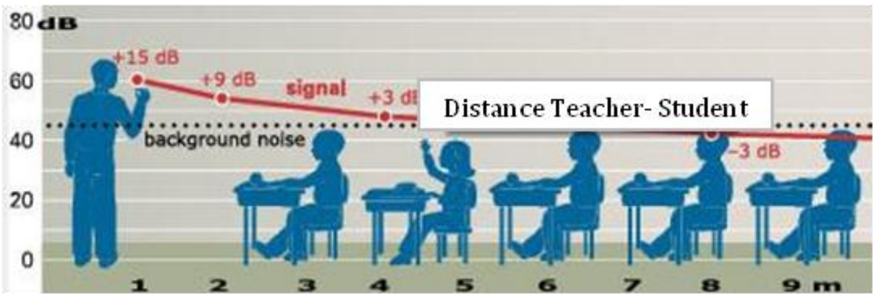


Figure 19 - Sound in a classroom [310]

The horizontal dashed line represents the background noise and the red line is the level sound of the teacher voice. To students understand what the teacher is saying, the sound should be <u>above</u> the dashed line. The values of sound intensity here are preceded by the positive signal (+ 15 dB, which means that the voice intensity of the teacher is above the line that represents the background noise). The students that are further away from the teacher won't listen the teacher so well, because the red line is below the dashed line and the signal in dB is (-3 dB). But it would be possible to hear the teacher perfectly if the red line was above the dashed line.

The RT, *Reverberation Time* adequate to classrooms is between 0,6 and 1,0 seconds.

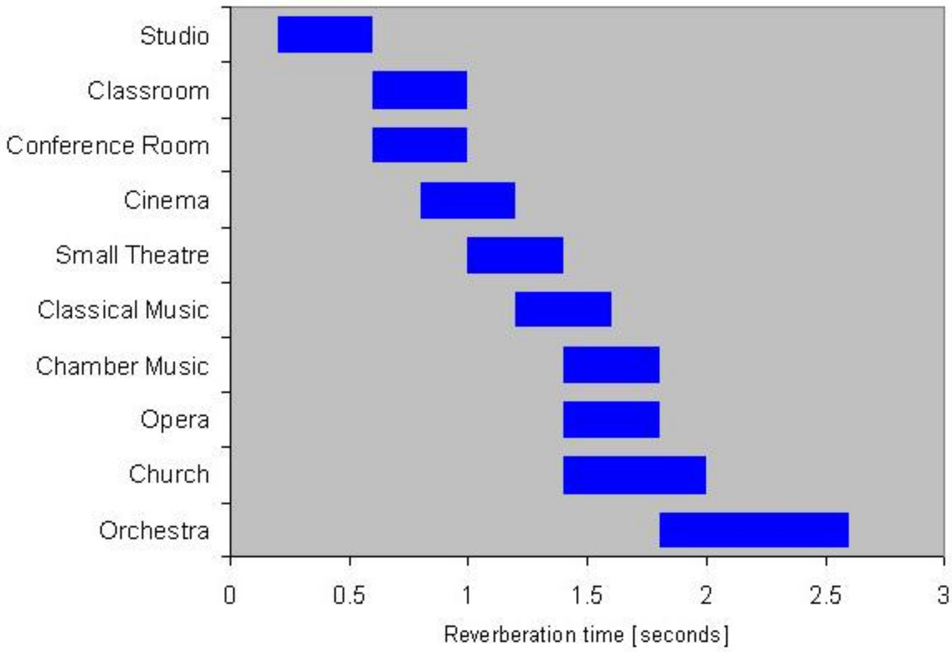


Figure 20 - Reverberation time for some typical cases of teaching [310]

The main effect of a bad acoustic in a classroom and high levels of noise is certainly a reduction on the perception of speech. This will affect communication between student and teachers and their colleagues, which will have a negative influence on the cognitive process [310].

The general effects on students due to the exposure to noise at school can be:

- To reduce the attention, not only visual but also sustained;
- To reduce hearing and perception of speech;
- To reduce long-term memory;
- A bad school performance.

Noise effects on teachers

When teachers have to work in an environment with a high background noise, they have to raise their voice. Sometimes they raise to achieve a better perception of speech. This phenomenon is known as *Lombard*. Some studies refer that the vocal behavior of teachers exposed to noisy environments, with an increase of 1dB from the background level, will cause an increase of the speech level of 0,5 dB to 0,8 dB. It becomes more difficult to understand the message when the speaker raises his voice. Besides it’s not easy to speak like this for too long. The consequences of this raising are fatigue and diseases related to phonetic system. To sum up, a bad acoustic environment has negative consequences to students and teachers.

Acoustic Materials

One of many ways to change the features of a room is to use a set of materials with certain acoustic characteristics. These materials are divided in four groups [127]:

1. Insulating materials;
2. Absorbing materials;
3. Diffusers;
4. Reflectors.

The first concern with any room is its relation with the outdoors, how to isolate it. We want to avoid the outdoors noise, to come inside the room but we also want to avoid that the sound produced in the room pass to the outdoors. The second concern, and probably the most important, is to control the reflections inside the room, from the point of view of quantity and quality.

When we are doing a project of a building, we should take into account its future utilization. This way we will know which materials should be used.

4.4 Visual Comfort

Tyrone & Nunes [307] say that the visual comfort in our houses is very important to be achieved. It will improve our well-being, health and increase our productivity. The visual discomfort is a huge motivator to change the conditions we have, when these aren't adequate to what we need.

The glazing areas, whose glasses respect the adequate techniques specifications, contribute to an optimization of the environmental energetic performance of the building, allowing the entrance of the sun radiation, benefice to the users.

The visual comfort in a building needs a system that can be used by its occupants. The dimension of the glazing areas contemplates the natural illumination necessary in cloudy days, when the radiation available at surface is much inferior to that in clear days, which in these cases can be much superior to what to need. So it is very important to project the buildings, in a way we can control the window shade, to see the landscape and avoid the sun radiation to get in.

The quantity of visible radiation emitted by a radiation source is defined as luminous flux; it is expressed in Lúmen (lm). This is defined, in terms of radiation by the sensitivity of the human eye. One of the most important parameters is luminance, measured in lux and it corresponds to lm/m^2.

The amount of visible radiation emitted by a radiation source is defined as the luminous flux and is expressed in lumen (lm):

$$lumen = fluxo\ luminoso = I\ \times d\Omega \tag{14}$$

Where,

I - Luminous intensity;

$d\Omega$ - Flux angle.

This is defined in terms of radiated power by the spectral sensitivity of the human eye. One of the most important parameters is the lighting or illumination of the surface to be illuminated which is expressed in lux, which corresponds to lm/m^2.

$$Iluminancia = E_v = lux = \frac{lm}{m^2} = \frac{d\emptyset}{dS} \quad (15)$$

Where,

$d\emptyset$ - Luminous flux, measure in lumen (lm)

dS - Surface to illuminate, measure in square meter (m^2)

The European Committee for Standardization (CEN) refer that the indoor lighting requirements are determined by the satisfaction of three basic human needs:

- **Visual comfort** - Where the workers have a feeling of well-being; in an indirect way also contributing to a high productivity level;
- **Visual performance** - Where the workers are able to perform their visual tasks, even under difficult circumstances and during longer periods;
- **Security**.

One of the most important physical characteristics at schools is lighting: the visual environment affects the students' capacity and consequently its performance. The main effect of lighting in human beings is the vision: indeed a good lighting improves the visibility of objects and helps people to better perform their activities. However, light has two more impacts on human beings: health and mood [272].

It is important to remind that the light sources can also contain visible radiation and these cannot produce several effects on human beings, according to the Directive 2006/25/EC of the European Parliament and of the Council [255], on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation).

Daylight and artificial lighting at schools

At schools, the outside view is important, not only for physiological but also psychological needs. Usually, windows may provide general illumination, enough to most of the day, providing a visual contact with the outside world, increasing the scholar environment quality. According to some researches, some people prefer to have daylight at their workplace, because it will improve their work. To quantify a potential effect of the day light, it is difficult to analyze the role of all the variables involved. Actually, windows and daylight present a very complex set of variables to be considered, such as variations of the lighting level throughout time and space, glaze, view ventilation, thermal effects and psychological state. Nowadays, it’s still necessary to study in detail the relations between quantity of light and the students answer. The daylight concept is not enough to describe properly their performance [272].

Besides, the presence of windows has effects on the energy performance of a building. It is possible to save energy through integration between the building strategy and the artificial lighting management system. The choice of the type of lighting equipment can definitely increase the energetic efficiency. Yet there are other strategies to improve the utilization of light: skylights and a drawing on the ceiling that spreads the light all over the space. These strategies don´t provide visual contact with the outside world. The daylight will only permit energy saving if the artificial light is inactive or off. So to save energy it should be installed automatic equipments or photoelectric equipments. It should be done some changes to balance the daytime efficiency and the electric light to satisfy the occupants. The automatic control with photo sensors, presence sensors, time interrupters, and the possibility to manage the different luminary groups, can reduce the energy consumption. How lighting contributes to evaluate the energy performance of buildings, according to the Directive 2002/91/EC of the European Parliament and of the Council [251], it’s the subject of the EN 15193 Standard [84]. The evaluation of the performance of Light Energy Numeric Indicator (LENI) should be done according to the EN 15193 Standard [84].

Interior surface	***Reflectance***
Ceiling	0,6 – 0,9
Walls	0,3 – 0,8
Working planes	0,2 – 0,6
Floor	0,1 – 0,5

Table 20 - Reflectance of interior surfaces [84]

The key-point is visual comfort and to supply the adequate levels of light to all the tasks and activities that happen inside a classroom. The lighting systems should allow teachers to change the lighting according to each type of activity.

Type of interior, task or activity	*In (lux)*	*Remarks*
Nursery class	300	
Nursery craft room	300	
Classrooms, tutorial rooms(*)	300	Lighting should be controllable
Classrooms for evening classes and adults	500	
Lecture hall (*)	500	
B1ack board	500	Prevent specular reflections
Demonstration table	500	In lecture halls 750 lux
Art and craft rooms	500	
Art rooms in art school	750	Tep>5000 K
Technical drawing rooms	750	
Practical rooms and laboratories	500	
Teaching workshops	500	
Music practice rooms	300	
Language laboratory	300	
Preparation rooms and workshops	500	
Student common rooms and assembly halls	200	
Computer practice rooms	500	
Teachers rooms	300	
Sports halls and gymnasiums assembly halls	300	

Table 21 - Lighting levels recommended to school facilities [84]

The indoor lighting in the classrooms, not only should reach the desired environment, but at the same time, it should satisfy other important functional and psychological needs. This is necessary to improve students' performance, because a poor lighting leads to discomfort and hyperactivity, while a good lighting leads to productivity. Lighting also affects teachers' efficiency, as well as their capacity to deal with stress. That's why it should always support the learning process and use different types of lighting according to the methods used by teachers [272].

In any project, one of the environmental factors we should take into account is the visual relation indoor/outdoor and the maximization of daylight, which contributes to the diminution of the artificial light consumption. However, when this isn't possible, we should use lighting of high energetic efficiency.

One way to evaluate the efficiency of installation is through the EEVI (Energy efficiency value of installation).

$$EEVI = \frac{Installed\ Power \times 100}{Surface\ iluminated(m^2) \times average\ manteined\ iluminance} \quad (16)$$

The units are: W/m^2 per 100 lux

According to *Rey Martínez* [278] the effects of poor lighting can be:

- Increase of sight anomalies, not allowing a clear sight, comfortable and fast that needs to be continually adjusted;
- Increase the risk of accidents;
- Increase of mistakes during the activities;
- Increase the time it takes to do a task;
- The worker isn’t very interested in the task because he doesn’t feel comfortable doing it;
- Increase the mental and physical fatigue, because the worker spends more energy reaching his objectives.

5 METHODOLOGY

5.1 Procedures

The energetic and environmental auditing work was executed from June 2009 until December 2010.

The School of Technology and Management of Leiria – Is in the Campus 2 of the Polytechnic Institute of Leiria consists of modern buildings (Building A, Building B, Building C, ***Building D*** and Building E). The Campus 2 also has two canteens and a library *José Saramago*.

The *Building D* has 8851 m^2, is a recent building (2004), presents a deployment L-shaped and has plenty of glazed areas. The building has the highest prevalence for this type of use, numerous classrooms, laboratories, computer rooms, amphitheatres, halls, storage rooms, toilets, teachers cabinets, meeting rooms and crossing areas. The ventilation is provided by HVAC system (Appendix A).

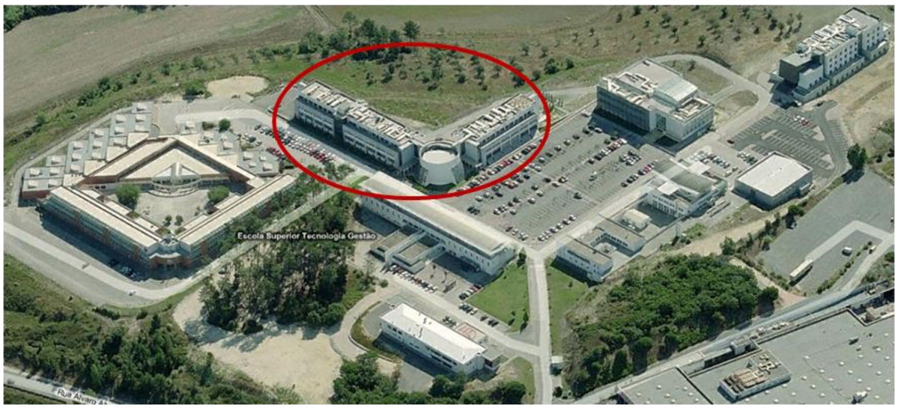


Figure 21 - *Building D* location [*Bing Maps*, 2010]

The auditing objective is the identification of physical-chemical microbiological and energy conditions in order to evaluate indoor environmental quality and energy efficiency in *IPLeiria - Building D.*

Adding to the final results observed, this report mentions auditing methodology, Indoor Environment Quality and the Energy adopted in the making of the study, as well as the legislation and technical standards recommended.

The methodology adopted for the auditing and the sampling and recording equipments used in monitoring are described in detail in **5.2 Measurement and Operation Methods** and were defined according to the objectives of the auditing process.

5.1.1 Methodology for evaluate the indoor environmental quality

Indoor Environmental Quality (IEQ) is connected to the coexistence of thermal comfort, visual comfort, indoor air quality and acoustic comfort. In some long term measurements, students used questionnaires (subjective evaluation – Appendix E) to evaluate the indoor environmental quality in the classroom a few moments before the end of the class to get a better perception of the environment to which they were exposed. To do a subjective evaluation of these parameters the following methodology was used:

The evaluation of acoustic comfort was prepared by isolated and continuous measurements of instantaneous noise pressure levels and the spectral analysis of 1/3 octave frequency range resorting to sound level meters. The Reverberation Time was also evaluated according to Sabine's formula. All the acoustic comfort measurements were done and evaluated according to International Standards [62], [70], [81], [83].

Visual comfort is one of the most critical features in school environments, because it affects the students' faculties and therefore their performance. In order to evaluate visual comfort several isolated measurements were done in different areas of the Building using a lux meter. Visual comfort measurements and evaluation were done also according to International Standards [69], [78], [84], [85].

Indoor Air Quality (IAQ) evaluation was done through data consultation and observation, using an information collection cycle, hypothesis and tests elaboration until a solution was reached. In order to do that, the monitoring of physical-chemical conditions was considered relevant with a regular capacity similar to its usual operating conditions.

Employees, teachers and students were notified to open the windows and doors as usual, not to alter the activity plan for the class, to ensure that the learning environment and daily routines would remain as normal as possible.

IAQ auditing will allow the inspection of IAQ requirements that include maximum concentration values of physical-chemical pollutants (particulate matter (PM_{10}), carbon dioxide, carbon monoxide, ozone and formaldehyde particles and volatile organic compounds) steadily or in continuous (air temperature, humidity and carbon dioxide).

Early in the auditing process, each one of the buildings involved was visited in order to collect all the useful material about the building itself, to know if the users complained or showed any symptoms, as well as all the information concerning the identification of possible pollutants and their origin. A circular letter was sent to each one of the Higher Schools Directors participating in the auditing process, as well as to the Social Services Manager in order to get information concerning complaints from casual occupants or some space in need to be described priority to proceed accordingly.

IAQ and Thermal Comfort (TC) measurements were based on the “Technical Note (TN) SCE-02 from 2009” [2] and other Standards [63], [65], [66], [67], [68], [71], [72], [73], [74], [75], [76], [77], [79], [80], [81], [82], [86], [87], in an attempt to describe the maximum spaces and areas of private use. Indoor and Outdoor air samples were collected to evaluate the presence of several pollutants, according to the methodology that follows:

Physical-chemical isolated measurements (sampling) are done in 5-minute takings, with exception to the Formaldehyde 2-minute takings, and considering the criteria of a minimal number of sampling location spots that the Technical Standard [2] refers to.

$$\mathrm{N_i} = 0{,}15 \times \sqrt{\mathrm{A_i}} \tag{17}$$

Where:

Ni – Number of points measured in the area i ($Ni \geq 1$)

Ai – Area i (m^2)

Continuous measurements are done in long periods (typically 24-hour periods). Measurement spots are chosen randomly in each location, but always taking into consideration the air circulation features and the occupation time of the locations.

Microbiological measurements of indoor and outdoor air are done in 2-minute takings, thus ensuring a volume of 200 L/min of air, with a flow of 100 L/min, taking into account the criteria of minimal number of sampling spots of the Portuguese Technical Standard [2]. Samples were collected in duplicate for each spot as a way to minimize the fluctuation effects that the values usually suffer and consolidate the results. The final result is the average calculated between both samples. Before each collection, the sampler was cleaned with sterile gauze soaked in 70% ethyl alcohol. Duplicate samples were collected each day using a "field blank" outdoors. Water sampling as a way to hold and quantify *Legionella* bacteria in the Domestic Hot Water (DHW) networks was done both in storage tanks deposit valves and in thermal units of that same water consumption.

During the water samples collection moment, as a way to research and quantify *Legionella* species, the sample origin and volume and the water temperature were registered in detail. Later, the samples were cooled down and, on the same day, carried in thermal bags to the Analysis Laboratory of the Higher Technical Institute accredited by IPAC (Portuguese Accreditation Institute) according to the method EN 11731 Standard [64].

External measurements are isolated measurements (sampling) done in 5-minute takings and considering the technical standards criteria, the parameters described are PM_{10}, carbon dioxide, temperature, humidity and microbiological particles. Outdoor air samples are taken at 1,0 ± 0,5 m above ground level or next to Air Handling Units (AHU) entries when there is an Heating, Ventilation and Air Conditioning (HVAC) system in the building.

Sampling locations to evaluate IAQ were selected this way:

- Areas powered by the same AHU – air inlet and end duct;
- Areas powered by individual HVAC;
- Types of complaint by the occupants when they exist;

- Paying attention to contaminant sources (cafeterias, bars, laboratories, workshops, cleaning activities, garages, storages, warehouses, printer rooms, copy machine rooms, etc);
- Randomly in some rooms ventilated by natural convection.

During data collection, equipments were installed based on the following criteria:

- Monitoring / sampling in locations that could represent working occupational activities;
- Equipments were placed at 0,5 m from corners and windows, walls, partitions and other vertical surfaces (ex: hangers);
- Keeping away from locations directly under or in front of air supply diffusers, fans or heaters, etc;
- Equipments were placed at a distance greater than 1 m from pollutant sources such as copy machines, printers, etc;
- Equipment placement didn’t block nor interfere with the exits of the study area in usual emergency situations;

Readings of high concentration values may be considered as evidence that allows conclusions about the problem. Air samplings make it possible to:

- Compare indoor and outdoor air quality;
- Test the hypothesis on the source of the problem;
- Confirm that a control procedure has the wanted effect of reducing the concentration of pollutants or improving the ventilation;
- Reveal the existence of compounds associated with specific problems in buildings (a carbon dioxide reading higher than 1000 ppm indicates low ventilation, carbon monoxide readings higher that 5 ppm indicate the existence of non-ventilated combustion products or the dragging of products from the vehicle exhaustion pipes);

- Compare measurement values with established concentration limits and/or with specific public health and comfort Standards for specific pollutants;
- Evaluate indoor air changes and new air floods.

All the measurements were registered in individual record sheets (Appendix B and C) organized by building. In these sheets locations and measurement spots are identified.

Table 22 lists the physical-chemical and microbiological pollutants that were subject to compliance check under the IAQ auditing and indicates the threshold limit value (TLV) concentrations of reference in Portuguese Law and Spanish Law.

	Spain			*Portugal*		
	[mg/m³]	*[ppm]*	*Time*	*[mg/m³]*	*[ppm]*	*Time*
PM₁₀	---	---	---	0,15	---	MR
CO_2	9000 1800	5000 ELV 1000 MR	2-8 hours	1800	984	MR
CO	40 10	35 9	1 hour 8 hours	12.5	10.7	MR
NO_2	0.1	0.055	1 year	---	---	---
SO_2	0.37 0.078	0.14 0.03	24 hours 1 year	---	---	---
O_3	0.24	0.12	1 hour	0.2	0.10	MR
HCHO	---	---	---	0,1	0.08	MR
VOC's	---	---	---	0,6	0.26 0.16	MR
Radon	400 Bq/m³ 200 Bq/m³		MR	400 Bq/m³		MR
Fungi	800 CFU/m³		MR	500 CFU/m³		MR
Bacteria	800 CFU/m³		MR	500 CFU/m³		MR
Legionella	100 CFU L/H_2O		MR	100 CFU L/H_2O		MR

Table 22 - TLV for contaminants in Spain and Portugal

ELV – Emission Limit Value
MR - Maximum Recommend

Note: In relation to Radon gas, Portuguese Law only imposes the research in granite areas, namely in the districts of Braga, Vila Real, Porto, Guarda, Viseu and Castelo Branco.

5.1.1.1 Physical indicators

The indoor thermal comfort level is measured using a thermal comfort analyser that permitted the measurement of the room temperature, radiant temperature (black globe), airspeed and relative humidity. The concentration of particles suspended in the air was also measured (PM_{10}: for particles with a size of 10 mm or less).

5.1.1.2 Chemical indicators

Isolated chemical monitoring of Carbon Dioxide (CO_2), Carbon Monoxide (CO), Formaldehyde (HCHO), Total Volatile Organic Compounds (TVOCs), Ozone (O_3) was done using pre-determined sampling spots inside each area or group of rooms for a period of about 5-minutes in each spot.

Continuous chemical monitoring of Carbon Dioxide (CO_2) and Carbon Monoxide (CO) was also done in pre-determined sampling spots inside each location or group of rooms for periods representative of the space use (typically 24-hour periods).

Air renewal rate in the room was measured using a CO_2 concentration decay technique. Carbon Dioxide tracking is introduced naturally through the room user's breath. Air renewal rate is determined after the tracer's concentration decay in the room. The measurement of air renewal efficiency in the building is crucial, as it supplies information about the air distribution system's ability to supply ventilated air to a building.

5.1.1.3 Biological indicators

In order to measure air contamination by microorganisms, a portable and calibrated air sampling pump was used with a direct impact in semi-solid environment (petri plates with agar), with a constant flow rate of 100 L/min, as a way to determine bacteria and fungi concentration in the air. The most used means of collecting the bacterial culture was Nutrient Agar, while the fungi collection was done with *Malt Extract Agar*. Each of these procedures was taken in a 2-minute period as a way to get air samples of 200 L each. After incubation in laboratory under specific conditions and temperatures (bacteria plates were incubated between 35 and 37 ºC, because the majority of the isolated bacteria was originated from human beings; fungi plates between 25 and 27 ºC), each plate was analysed and the counting results were expressed in colony forming units by cubic meter (CFU/m^3).

So that the research and quantification of *Legionella species* could be done, the collection of 2 samples was done in 1-liter polyethylene containers in each sampling location in Domestic Hot Water (DHW) networks, namely in dump valves of each storage tank and in terminal units of that water consumption (taps and showers).

5.1.2 Methodology to evaluate energy consumption

The energy auditing was developed through consultation of the *Building D* record. All the energy measurements were done and evaluated according to the Standards [63], [67], [78], [79], [81], [82], [84], [85], [86].

The monitoring of energy parameters was done in normal operation conditions. Employees, teachers and students were told to use electrical equipments as usual, not to alter the activity plans for the class, to ensure that the teaching environment and daily routines remain as normal as possible.

The intervention in this area will be developed through the following phases:

- Project Analysis concerning construction solutions, energy systems adopted and regulatory framework. An overall characterization of buildings or fractions, energy systems installed, their operation scheme and construction solutions will be elaborated (Appendix A).
- Energy Auditing, consisting in a local analysis of the building operation conditions and its energy systems, with the purpose of characterizing the global and disaggregated energy consumption by the main end uses of the building and of checking comfort levels.

  Due to the importance of electric energy consumption in the service buildings, it will be installed a significant amount of measurements and records of electric energy consumptions. This way, it is possible to get electric charge diagrams of the electric energy consumption daily and simultaneously to the global installation of the electric circuits of the main energy equipments or areas.

- Dynamic Simulation predicted for the fractions or buildings is destined to allow the disintegration of the consumption structure by the end uses, taking into account the building's construction and installed systems features, weather influence and its types of use (occupation, lighting and equipments), the Energy Efficiency Indicator (EEI) value (fundamental for the building certification) is determined based on the dynamic simulation models.

  The objective of the dynamic simulation in buildings is to quantify as accurately as possible annual energy consumption times required to maintain indoor comfort conditions stipulated by the user in a specified period, taking into consideration the surrounding features and the active systems installed and the local weather conditions. Another objective is to evaluate the impact of introducing certain changes in the surroundings, the HVAC systems or in use or control patterns, economically and energetically speaking.

Both Portuguese and Spanish Legislation predict resorting to multizone dynamic simulation models to support auditing in large service buildings, and the use of more simple methodologies (unizone models) for small service buildings.

In order to proceed with the computation simulation in a building using these programs, it is necessary to do a detailed survey of the geometric and construction features, of their internal space organization by areas, the existing HVAC systems, including heat generation and chilled water, and also systems that represent intense heat gains (lighting and other equipments). Besides these elements, it is necessary to know the load and use factors ("schedules") of the introduced systems and occupation itself. At last, it is also necessary to have the weather file for the entire location (city) where the building is (Appendix D).

All the data input must be as accurate as possible in order to get reliable results. Once the data referring to the characterization of systems and equipments is introduced, the model must be "calibrated", i.e., "schedule" adjustments should be made so that the results obtained are conform to the measurements done in the area [102], [114].

One of the great advantages in using dynamic building simulation tools is the previous evaluation of the impact of changes in terms of building characteristics or in terms of energy systems and the behaviour of occupants [44], [46], [47], [120], [305], [313].

Although there is a great variety of simulation programs available, the basic operation and the geometry of this software type is common, being represented by mathematical modelling.

5.1.2.1 Thermal behaviour modelling in buildings

From a thermal point of view, a building can be attached to a complex system of capacitances and thermal resistances, this way connecting different regions and respectively representing storage processes and heat transmission that occur there. The way this model is dealt with mathematically will determine the flexibility and accuracy of the technique used – not considering some regions for the energy balance, setting values of some variables or simplifying certain boundary conditions are some of the options that the various techniques can resort to in order to overcome difficulties on the resolution of certain problems.

Basically speaking, and not intending to enter into details foreign to this study, the calculation techniques used in the buildings thermal field can be divided in 5 main categories: permanent status, simplified dynamic simulation, response functions, numeric methods and analogue methods [168], [279], [282].

Permanent status

In these methods, as their name shows, heat flows are treated as a permanent status (invariant temperature over time) and do not have any mechanism that allows an accurate evaluation of solar gains, internal gains, long wave radiation exchanges, or that allows the experiment of strategies on equipment uses. Simplifications admitted by these methods have great application on early stages of building design, when the magnitude of values is concerned, not very rigorous or long measurements.

Simplified dynamic simulation

In recent years several simplified methods have appeared and can provide, without any excessive additional work, much more accurate results than those gotten exclusively with the permanent status. Such methods are an extension of the permanent status due to parameters input that are the result of using regression techniques in parametric studies done from more elaborate techniques.

Response functions

The differential equation that rules the heat flow by conduction inside solid elements can be analytically solved in an elegant way through techniques that use Laplace transforms. Through a careful specification of the several elements boundary conditions, it is possible to shape the building's dynamic response to the thermal requests in it. This technique is known for its response functions and is divided in two great branches: response factors, where the system requests (temperature, solar radiation, etc) are represented by impulses in time (stimulus functions); and frequency factors represented by Fourier series.

Numeric methods

The resolution of high complexity problems is only possible, in most of the cases, through numeric methods. With the development and expansion of digital computing, the implementation of these methods using automatic calculation has allowed researchers to solve problems in a time period and with an accuracy unthinkable a few years ago. That is the reason why, nowadays, the use of these methods on the building's thermal field is really expanding. Two major groups can be considered in this class: finite differences (or finite volumes) and finite elements.

The finite differences method works directly with the heat equation, by approximation of its derivatives to one of a truncate Taylor series, or indirectly by applying the energy preservation principle to small control volumes (a process known, in this case, as finite volumes method).

The finite elements method is fundamentally the domain discretization and the application of a variation method – the *Rayleigh-Ritz* method – or a heavy residues method such as the *Galerkin* method to the segments of the secrete domain. The big advantage of the finite elements method over the finite differences is the ease with which it adapts to the most diverse boundary geometries. In the buildings thermal field, the most publicized technique is the one of finite differences due to its implementation simplicity and ease. The response factors technique, classified in the response functions, is in practice very similar to a numeric method, but it is not included in that class because, unlike what happens with finite differences and finite elements, it can only be applied to equation systems that follow the condition of being linear and steady.

Expansion of the Taylor series

Consider the Figure 22 that presents a continuous function $f(\gamma)$ in the entire range $(\gamma - \partial\gamma) \leq \gamma \leq (\gamma + \partial\gamma)$. The replacement of the derivatives of $f(\gamma)$ by finite differences implies approximating those derivatives to the ones of a truncate Taylor series. Taylor's theorem applied to that function is

$$f(\gamma + \delta\gamma) = f(\gamma) + \delta\gamma f^1(\gamma) + \frac{(\delta\gamma)^2}{2} f^2(\gamma) + \frac{(\delta\gamma)^3}{6} f^3(\gamma) + \cdots \quad (18)$$

and

$$f(\gamma - \delta\gamma) = f(\gamma) - \delta\gamma f^1(\gamma) + \frac{(\delta\gamma)^2}{2} f^2(\gamma) - \frac{(\delta\gamma)^3}{6} f^3(\gamma) + \cdots \quad (19)$$

where $f^n(\gamma)$ is $d^n f(\gamma)/d\gamma^n$. Adding these equations using those terms that involve $(\delta\gamma)^3$ it is obtained

$$f^2(\gamma) = \frac{f(\gamma + \delta\gamma) - 2f(\gamma) + f(\gamma - \delta\gamma)}{(\delta\gamma)^2} + \varepsilon[(\delta\gamma)^2] \quad (20)$$

where $\varepsilon[(\delta\gamma)^2]$ shows that the truncation error resulting from the approximate representation of the second derivative is of range $(\delta\gamma)^2$. By subtracting the Equation (19) from the Equation (18) through the terms involving $(\delta\gamma)^2$ it is obtained

$$f^1(\gamma) = \frac{f(\gamma + \delta\gamma) - f(\gamma - \delta\gamma)}{2\delta\gamma} + \varepsilon[(\delta\gamma)^2] \quad (21)$$

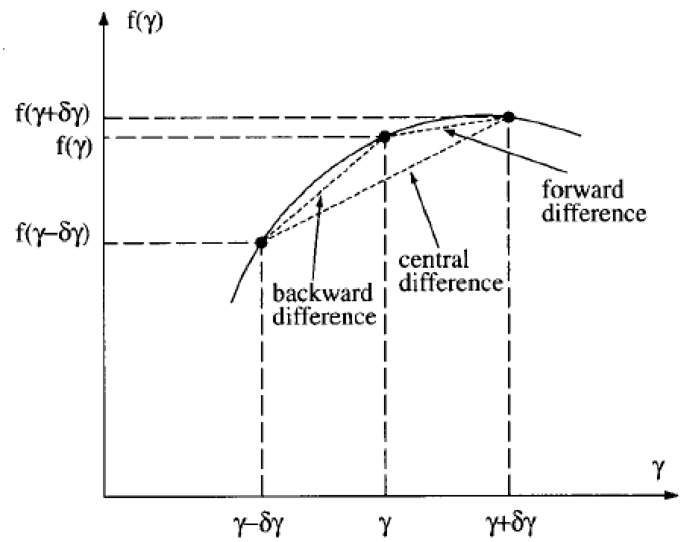


Figure 22 – A continuous function of γ

Equations (20) and (21) are respectively called central differences approximations to the second and first derivatives. The truncation of Equation (18) after the term involving $\delta\gamma$ provides the representation of the first difference forward:

$$f^1(\gamma) = \frac{f(\gamma + \delta\gamma) - f(\gamma)}{\delta\gamma} + \varepsilon[(\delta\gamma)] \qquad (22)$$

And the application of a similar truncation to Equation (19) provides the representation of the first difference backwards:

$$f^1(\gamma) = \frac{f(\gamma) - f(\gamma - \delta\gamma)}{\delta\gamma} + \varepsilon[(\delta\gamma)] \qquad (23)$$

The truncation error in equations (22) and (23) is of δγ range, ie, reducing to half the discretization step will only reduce the error to about half. On the other hand, the central difference approximation shows a truncation error of $(\delta\gamma)^2$ range, so that reducing the discretization step to half will only reduce the error to approximately a quarter.

The alternated mixture of these approximation schemes used can lead to the formulation of explicit and implicit differences. Consider Fourier's heat equation in a space variable and with a heat generation as derivative:

$$\frac{\partial^2\theta(X,t)}{\partial X^2} = \frac{1}{\alpha}\frac{\partial\theta(X,t)}{\delta t} - \frac{q}{k} \qquad (24)$$

Figure 23 shows a layer of homogeneous material randomly located inside a large homogeneous region. Two finite differences schemes are possible: explicit and implicit. An explicit enumeration scheme is obtained by representing the second derivative of Equation (24) as the central difference in Equation (20) and the first derivative as the first difference forward, like in Equation (22). By ignoring the error term and assuming (for now) that physical term properties are independent from time, it is obtained for knot I in moment t,

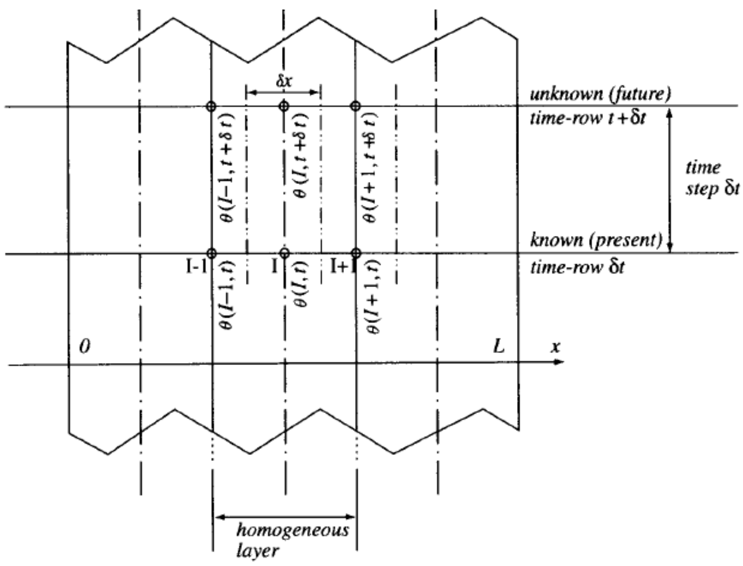


Figure 23 – Homogeneous layer: space and time nodal scheme

$$\frac{\theta(\mathrm{I}+1,\mathrm{t})-2\theta(\mathrm{I},\mathrm{t})+\theta(\mathrm{I}-1,\mathrm{t})}{\partial \mathrm{X}^2}=\frac{1}{\alpha}\frac{\theta(\mathrm{I},\mathrm{t}+\partial \mathrm{t})-\theta(\mathrm{I},\mathrm{t})}{\delta \mathrm{t}}-\frac{\mathrm{q}(\mathrm{I},\mathrm{t})}{\mathrm{k}} \tag{25}$$

$$\theta(\mathrm{I},\mathrm{t}+\partial \mathrm{t})=\frac{\mathrm{k}\,\partial \mathrm{t}}{\rho \mathrm{C}(\partial \mathrm{X})^2}\theta(\mathrm{I}+1,\mathrm{t})+\left(1-\frac{2\mathrm{k}\,\partial \mathrm{t}}{\rho \mathrm{C}(\partial \mathrm{X})^2}\right)\theta(\mathrm{I},\mathrm{t})+\frac{\mathrm{k}\,\partial \mathrm{t}}{\rho \mathrm{C}(\partial \mathrm{X})^2}\theta(\mathrm{I}-1,\mathrm{t})+\frac{\mathrm{q}(\mathrm{I},\mathrm{t})\,\partial \mathrm{t}}{\rho \mathrm{C}} \tag{26}$$

Note that the sum of the coefficients of the timeline temperature is unitary. This implies that, in the absence of heat generation, the future timeline nodal temperature of the region and the temperatures of the adjacent regions in thermal contact. If one equation like this can be described for every region, within a system, the temperature history can be determined during a discrete period, given the initial and outline condition. Explicit schemes of this type are relatively easy to formulate and solve, but they can become unstable in certain circumstances. Consider the temperature coefficient of the timeline in any region I. If this coefficient should be negative, which is

$$1-\frac{2\mathrm{k}\,\partial \mathrm{t}}{\rho \mathrm{C}(\partial \mathrm{X})^2}<0 \tag{27}$$

that would imply that the warmer the region I is now, the colder it will be after a $\partial \mathrm{t}$ time. To avoid such nonsense, a stability criterion is introduced:

$$\frac{2\mathrm{k}\,\partial \mathrm{t}}{\rho \mathrm{C}(\partial \mathrm{X})^2}\leq 1 \tag{28}$$

Usually represented by:

$$\frac{\alpha\,\partial \mathrm{t}}{(\partial \mathrm{X})^2}\leq\frac{1}{2}\qquad \text{ou}\qquad \mathrm{F}\leq\frac{1}{2} \tag{29}$$

Where F is the *Fourier* number that defined the relation between the heat conduction rate and the heat storage rate. High values express good conductors with a relatively low storage potential; low values express the opposite: bad conductors with a relatively good storage potential.

The application of simple operations on Equation (26) allows the formulation of rudimentary graphic techniques to the evaluation of transient condition in homogeneous systems. Ignoring the heat source term, Equation (26) can be rewritten this way

$$\theta(\mathrm{I},\mathrm{t}+\partial \mathrm{t})=\mathrm{F}\left[\theta(\mathrm{I}+1,\mathrm{t})+\left(\frac{1}{\mathrm{F}}-2\right)\theta(\mathrm{I},\mathrm{t})+\theta(\mathrm{I}-1,\mathrm{t})\right] \tag{30}$$

Considering that F=1/2 which, according to the stability criterion, is the highest value allowed, it is obtained:

$$\theta(\mathrm{I},\mathrm{t}+\partial\mathrm{t}) = \frac{1}{2}[\theta(\mathrm{I}+1,\mathrm{t}) + \theta(\mathrm{I}-1,\mathrm{t})] \qquad (31)$$

An implicit enumeration case happens when the unknown temperature $\theta(\mathrm{I},\mathrm{t}+\partial\mathrm{t})$ is expressed according to the temperatures of current and future timelines, predominant in every region in thermal contact. A certain system will, this way, be represented by a series of algebraic equations that should be solved simultaneously for each time step. The second derivative of Equation (24) is replaced by the formulation of the central difference of Equation (20), but using unknown temperature values in the future timeline instead of the known values of the current timeline, like in the explicit formulation. The first derivative is expressed on the first earlier version of the Equation (23) formulation. Ignoring once more the error and assuming the physical term properties are constant, it is obtained:

$$\frac{\theta(\mathrm{I}+1,\mathrm{t}+\partial\mathrm{t}) - 2\theta(\mathrm{I},\mathrm{t}+\partial\mathrm{t}) + \theta(\mathrm{I}-1,\mathrm{t}+\partial\mathrm{t})}{(\partial\mathrm{X})^2} = \frac{1}{\alpha}\frac{\theta(\mathrm{I},\mathrm{t}+\partial\mathrm{t}) - \theta(\mathrm{I},\mathrm{t})}{\delta\mathrm{t}} - \frac{\mathrm{q}(\mathrm{I},\mathrm{t}+\partial\mathrm{t})}{\mathrm{k}} \qquad (32)$$

Reformulating, it comes

$$\left(1 + \frac{2\mathrm{k}\,\partial\mathrm{t}}{\rho\mathrm{C}(\partial\mathrm{X})^2}\right)\theta(\mathrm{I},\mathrm{t}+\partial\mathrm{t}) = \theta(\mathrm{I},\mathrm{t}) + \frac{\mathrm{k}\,\partial\mathrm{t}}{\rho\mathrm{C}(\partial\mathrm{X})^2}[\theta(\mathrm{I}+1,\mathrm{t}+\partial\mathrm{t}) + \theta(\mathrm{I}-1,\mathrm{t}+\partial\mathrm{t})] + \frac{\mathrm{q}(\mathrm{I},\mathrm{t}+\partial\mathrm{t})\,\partial\mathrm{t}}{\rho\mathrm{C}} \qquad (33)$$

Implicit formulations are unconditionally stable for all the space and time and discretization policy, although great space and time steps result in excessive discretization errors.

The weighted average of Equations (26) and (33) can now be used in the construction of a general formulation. Multiplying Equation (26) by (1-W) and adding the result to Equation (33), when multiplied by (W), it can be obtained:

$$(1+2\mathrm{WF})\theta(\mathrm{I},\mathrm{t}+\partial\mathrm{t}) = \mathrm{WF}[\theta(\mathrm{I}+1,\mathrm{t}+\partial\mathrm{t}) + \theta(\mathrm{I}-1,\mathrm{t}+\partial\mathrm{t})] + [1-2\mathrm{F}(1-\mathrm{W})]\theta(\mathrm{I},\mathrm{t}) + (1-\mathrm{W})\mathrm{F}[\theta(\mathrm{I}+1,\mathrm{t}) + \theta(\mathrm{I}-1,\mathrm{t})] + \frac{\partial\mathrm{t}}{\rho\mathrm{C}}[\mathrm{Wq}(\mathrm{I},\mathrm{t}+\partial\mathrm{t}) + (1-\mathrm{W})\mathrm{q}(\mathrm{I},\mathrm{t})] \qquad (34)$$

Establishing that W<0,5, an explicit scheme is obtained, whose stability criterion is

$$F \leq \frac{1}{2}\left(\frac{1}{1-W}\right) \tag{35}$$

when taking into consideration that W≥0,5, it results in an implicit scheme, with W=0 the commonly use formulation of *Crank-Nicolson* is obtained, very favourable by its combination of stability and accuracy.

Using a similar logic, it is possible to elaborate finite differences formulas for more than one space dimension.

Numerical Resolution Principle (modal or finite volumes method)

From the models shown earlier, it is now developed the numeric approach to the thermal simulation in buildings by finite differences, mainly because it follows the application of the energy storage principle to control regions or volumes. In fact, one of the most admittedly simple processes, and the most used because of that, of shaping the thermal behaviour in a building area is to consider it is divided in a finite set of control volumes, each one representing a physical system with certain properties and where temperature can be considered uniform, that interact thermally using one or more heat transmission processes. The imposed condition to the energy balance for each control volume is the accomplishment, for each time instant, of the energy storage principle, even if the time step is high or the volume numbers are low (in these cases some important errors may happen by insufficient time or space discretization) [168].

Consider the generic control volume I in thermal contact with its boundary regions with which heat transmission processes occur. This volume may represent a construction element, a layer of that element or the indoor air volume, for example. For clarity and representation ease, each control volume is identified by a knot – whence the name nodal method – where all the physical term features needed to the problem formulation are condensed: temperature, volume, specific mass, specific heat. Thermal interaction among the several knots of the net domain is done by thermal connection L coefficients, changeable according to the heat transmission process concerned – conduction, convection, radiation.

The energy storage principle relative to volume I can be formulated as follows:

$$\left|\begin{matrix} \textit{Storage energy} \\ \textit{in volume I} \\ \textit{in a} \\ \textit{time unit} \end{matrix}\right| = \left|\begin{matrix} \text{Liquid thermal exchanges} \\ \text{between control volume I} \\ \text{and its surrounding} \\ \text{regions in a time unit} \end{matrix}\right| + \left|\begin{matrix} \text{Thermal energy} \\ \text{generated in volume I} \\ \text{in a time unit} \end{matrix}\right|$$

In the differential form, this energy storage principle applied to volume I (Vi), assuming that ρ and cp are constant, is described as:

$$\rho_I c_{pI} v_I \frac{d\theta_I}{dt} = \sum_{J=1}^{N} Q_{J,I} + Q_I \tag{36}$$

where $Q_{J,I} = L_{J,I}(\theta_J - \theta_I)$ are heat flows exchanged by volume I with volumes with which it thermally interacts (being the input direction in volume I positive), $L_{J,I}(W/°C)$ are their respective thermal connection linear coefficients and Q_I is the thermal energy rate generated in volume I.

By integrating Equation (36) in time order, it is successfully obtained:

$$\rho_I c_{pI} v_I \int_{t_0}^{t} \frac{d\theta_I}{dt} = \sum_{J=1}^{N} \int_{t_0}^{t} Q_{J,I} + \int_{t_0}^{t} Q_I \tag{37}$$

$$\rho_I c_{pI} v_I \int_{t_0}^{t} d\theta_I = \sum_{J=1}^{N} \int_{t_0}^{t} Q_{J,I}\, dt + \int_{t_0}^{t} Q_I dt \tag{38}$$

$$\rho_I c_{pI} v_I \left(\theta_I^{(t)} - \theta_I^{(t_0)}\right) \approx \sum_{J=1}^{N} Q_{J,I}^{(t')} \Delta t + Q_I^{(t')} \Delta t \tag{39}$$

where $\Delta t = t - t_0$ and $t_0 \leq t' \leq t$. Also to mention that Equation (39) is only approximate. In fact, in order to record an equality between both parts it would be necessary that the value of t' chosen was such that the ones of $Q_{J,I}^{(t')}$ and $Q_I^{(t')}$ matched their average values $Q_{J,I}^{m}$ and Q_I^{m}. Because it was not possible, during simulation, to predict that t' value, there will always be room for error, which will be higher or lower depending on the t' of choice.

As observed, *Crank-Nicholson* formulation is the one that leads to better results accuracy. This way, in short, volume I equation can be numerically translated by

$$\rho_I c_{pI} v_I \left(\theta_I^{(t)} - \theta_I^{(t_0)}\right) = \sum_{J=1}^{N} L_{J,I}^{(t')} \left[\theta_J^{(t')} - \theta_I^{(t')}\right] \Delta t + Q_I^{(t')} \Delta t + \varepsilon \qquad t_0 \leq t' \leq t \tag{40}$$

The formulation resulting from the evaluation of both equation parts for present time $t' = t_0$ is called explicit, while its evaluation for future instant t'=t is known as totally implicit. Generally speaking, such evaluation can be done in a generic instant $t' = f\, t_0 + (1 - f)t$. The formulation is implicit for f≠1. For the particular case of f=0,5 *Crank-*

Nicholson formulation is obtained – it combines previous formulations (explicit and implicit) and is accepted as unconditionally stable.

The establishment of thermal balance for each knot resulting from the discretization domain in control volumes provides a set of equations where future instant temperatures and present instant temperatures appear. If these two are known, knot temperatures in future instant can be obtained by solving the equations system.

So that the simulation process begins, the temperatures field in the initial instant t=0 must be known. If explicit formulation is chosen, the acquisition of knot temperatures in each instant is direct, without needing to solve the equations set simultaneously. This happens because the equation concerning each future knot temperatures do not show up. Otherwise, in implicit formulation, each nodal equation has terms with present and future temperatures, not only from their own knot, but also from knots thermally attached to them. This fact demands each equation to be solved simultaneously with the others in each step in time.

Nodal Equations

By assimilating the building, or part of it, to a nodal system representing the regions knots as previously mentioned, the thermal connection type between them must be acknowledged, ie, which heat transmission phenomena are established together, as a way to make possible the specification of the general formulation of heat storage principle and the consequent equations system to be solved in each step in time [168], [279], [282].

In a more general case, a location is made of several areas relative to its partitioning. This means that, accurately speaking, the simulation model should be extended to all of those areas, with the creation of a set of knots for each one, demanded by their modelling. As it is easy to understand, this type of modelling – named multizone – is much heavier, in terms of the number of equations involved, than the one that considers the area is divided in one single zone – monozone or unizone modelling. Furthermore, the amount of results produced is such that its interpretation becomes hard and, because of that, understanding the most conditioning phenomena of the global thermal behaviour is less clear. Multizone modelling is recommended when there is the perception that very different thermal behaviours can occur amongst the several location parts. Otherwise, the construction of a single zone is usually enough for the results accuracy demanded by sizing.

The criterion followed for the knots numeration is the ascending order from the outside surface of the element. The indoor air in the area is represented by a single layer and, therefore, by a single knot (fi).

Outdoor conditions are not true knots, since they should be known in each simulation instant, not constituting unknown terms of the equations system. Outdoor conditions are generally associated to outdoor environment – air (fe) and ground (fs) temperature and solar radiation. Anyway, some situations may occur when it is necessary to specify and shape other type of conditions. A common example emerges when it is admitted, by simplification, that there are no heat exchanges between two locations with similar thermal environments. In this case it is necessary to establish specific equations for the indoor boundary knots of the locations parting elements.

The establishment of balance equations for all the discretization knots provides the system:

$$[A]\left[\theta^{(t)}\right] = [B]\left[\theta^{(t_0)}\right] + [C] \tag{41}$$

that should be solved in order to $\theta^{(t)}$, when the previous instant temperatures $\theta^{(t_0)}$ are already known – for this particular example, the form of these matrices, with the designation of their non-null elements. Equation (41) presents the equations system in a linear way. However it is important to mention that, given the existence of thermal connection coefficients dependant on the temperature – like, for example, the ones associated with radiation –, there are terms from matrix [A] whose correct value is only obtained in instant t, which makes the equations system non linear. The way in which this obstacle is overcome by linear system calculating the connection coefficients in instant t0, which does not imply significant errors in the model for short time intervals.

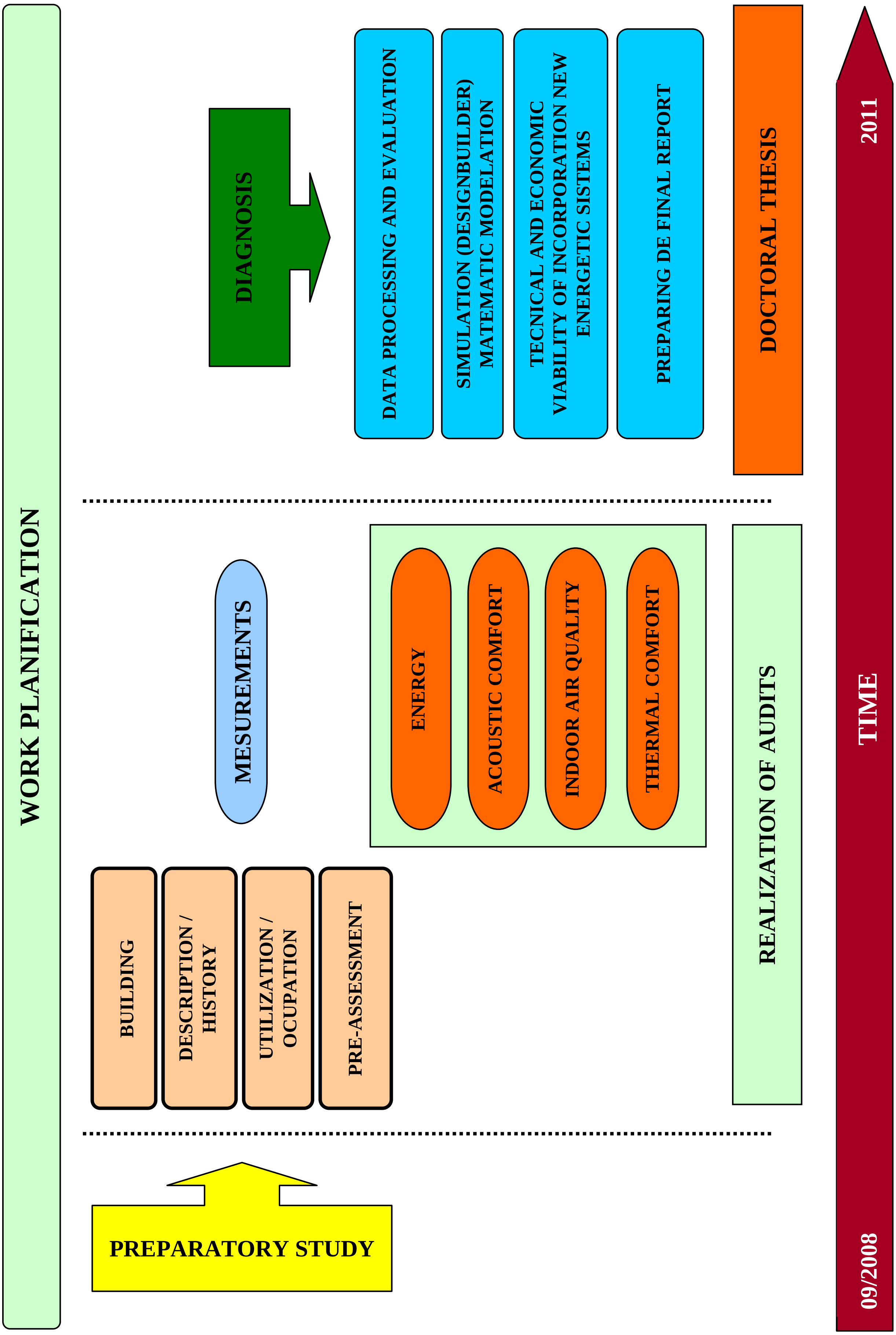


Figure 24 – Schedule of work

5.2 Measurement and Operation Methods

The selection of locations for data collection must lay on the probability that the sampling monitoring is done in an area that represents occupational activities.

The methods adopted for the measurements of indoor environment quality and energy efficiency follow the Portuguese Legislation and the International Standards related.

The following pictures show example photos of different measurements, locations and equipments.

Figure 25 - LAI V

Figure 26 - Electric Machines Lab (D.S.00.11)

Figure 27 - Robotics Lab

Figure 28 - Electric Machines Lab (D.S.00.11)

Figure 29 - Hall (next to Classroom D.S.-1.12)

Figure 30 - Computer Centre

Figure 31 - Amphitheatre 1

Figure 32 - Amphitheatre 1

Figure 33 - Teachers Cabinet (D.S.2.19)

Figure 34 - Classroom (D.S.0.1)

Figure 35 - Classroom (D.S.0.1)

Figure 36 - Classroom (A.S.2.5)

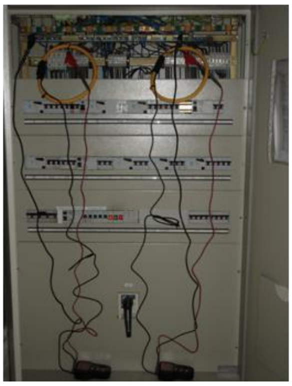


Figure 37 – Switchboard

Figure 38 – Transformer Station

Figure 39 - Picture of *Building D*

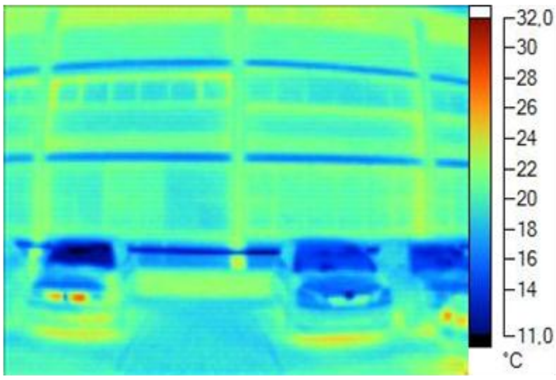


Figure 40 - Thermal picture of *Building D*

The equipments calibration was done every day before measurements.

NOTE: All equipment are certified.

The methods and equipments used are shown Table 23.

Equipment	Brand	Model	Measurement	Sensitivity/Error	Analytic Method	Equipment
Analyser for Thermal Comfort	Delta OHM	HD 32.1 Thermal Microclimate	Long Term	Temperature ± 0,01 ºC Black Globe - Class 1/3 DIN Air speed ± 0,02 m/s Temperature and bulb humidity - Class A Relative Humidity ± 0,1 %	PT100 temperature sensors Unidirectional hot wire probes Capacitive RH Sensors	
Temperature and HR Analyser	LogTag	HAXO-8	Long Term	± 0,1 %	Temperature - Thermocouple sensor type Relative Humidity - capacitive type sensor	
Analyser multifunction	Testo	Testo 435-4	Sampling Point and Long Term	± 1 %	Carbon Monoxide - electrochemical sensor Carbon dioxide sensor - NDIR (non dispersive infrared)	
Analyser multifunction	Fluke	975	Sampling Point and Long Term	± 1 %	Temperature - sensor thermistor type Relative Humidity - capacitive type sensor Carbon Monoxide - electrochemical sensor Carbon dioxide sensor - NDIR (non dispersive infrared)	
Analyser multifunction	SENSOTRON	PS32	Long Term	± 3 %	Carbon dioxide sensor - NDIR (non dispersive infrared)	

Table 23- Measurements and Operation Methods

Equipment	Brand	Model	Measurement	Sensitivity/Error	Analytic Method	Equipment
Ozone Analyser	aeroQUAL	Series 500	Sampling Point	± 10 %	Technology GSS (Gas Sensitive Semiconductor) - High correlation with the reference method UV Photometry	
PM_{10} Analyser	DUSTTRAKII Aerosol Monitor	8530	Sampling Point	± 0,1 %	Metering real time laser / NIOSH 0600	
Formaldehyde Analyser	htV-m	Formaldemeter htv-m	Sampling Point	± 2 %	Electrochemical cell in real time	
VOCs level detector	Photovac	202ppbPRO	Sampling Point	± 1 %	PID Detector (standard 10.6 eV lamp UV) Photo-ionizing detector	
Diffuser flow rate measure	TSI	AccuBalance 8375	Sampling Point	± 3 %	Barometric Sensor / Air Flow Methodology	
Microbiologic Analyser	SAS QAI	SUPER 90593	Sampling Point	---	Method of impact on Agar	

Table 24 - Measurements and Operation Methods (Cont.)

Equipment	Brand	Model	Measurement	Sensitivity/Error	Analytic Method	Equipment
Tree-phase Power Analyser	Dossena	MULTIVER 3SN	Long Term	± 0,1 %	Electromagnetic Induction	
Tree-phase Power Analyser	Fluke	Fluke 43B	Sampling Point and Long Term	± 2 %	Electromagnetic Induction	
Tree-phase Power Analyser	Aflex	Clamps Aflex	Long Term	± 2 %	Electromagnetic Induction	
Power and energy quality analyser	Chauvin Arnoux Group	C.A. 8335	Long Term	± 2 %	Electromagnetic Induction	
Portable energy audit analyser	CIRCUTOR	CIR- E3	Long Term	0.5 – 2 %	The analyser has four voltage sensor inputs and three current sensor inputs.	
Thermal Camera	FLIR Systems	PM 575 PAL	Sampling Point	0,10 – 30 ºC	Infrared thermograph	

Table 25 - Measurements and Operation Methods (Cont.)

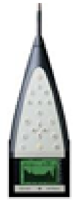
Equipment	Brand	Model	Measurement	Sensitivity/Error	Analytic Method	Equipment
Analyser of luminance	KOBAN	KL 1330	Sampling Point	± 2 %	Silicon photodiode with filter	
Sound Level Meter	Brüel & Kjaer	2260 Investigator	Sampling Point and Long Term	± 0,5 %	Equipment for measurement of spectral analysis for the frequency range of 1/3 of the eighth Pre-polarized Free-field ½" Microphone	
Sound Level Meter	RION	NL-31	Sampling Point and Long Term	± 0,1 %	Equipment for measurement of instantaneous sound pressure level (Lp, Leq, LE, Lmax, Lmin and 5 values of Ln) UC-53A Pre-polarized microphone with ½" capacitor	
Measuring the Length of Reverberation	Bertram Schapal	Dodecahedral Loudspeaker DO 12	Sampling Point	± 1 %	Equipment used for obtain the reverberation time (*RT*)	
DesignBuilder Software	*DesignBuilder* is a user-friendly modelling environment. It provides a range of environmental performance data such as: energy consumption, carbon emissions, comfort conditions, maximum summertime temperatures and HVAC component sizes.			---	Physical mathematical dynamic models	DesignBuilder SOFTWARE

Table 26 - Measurements and Operation Methods (Cont.)

6 RESULTS / DISCUSSION ANALYSIS

The research was done with commitment as this is an urgent issue nowadays and it is vital for the achievement of a sustainable development, as it seeks to reconcile harmoniously the economy, environment and sustainability vectors and above all the building sector, that has such a major impact on economy.

This thesis is done in association with a study of environmental and energy efficiency optimization in a Portuguese Higher School Building. The methodology adopted for the auditing and the sampling and recording equipments used in monitoring are were defined according to the objectives of the auditing process, as well as the legislation and technical standards recommended. The identification of physical-chemical microbiological and energy conditions in order to evaluate indoor environmental quality (IEQ) and energy efficiency in *IPLeiria - Building D* were done.

The different types of measurements included: objective results (room temperature, radiant temperature, airspeed, relative humidity, particles suspended in the air, Carbon Dioxide, Carbon Monoxide, Formaldehyde, Total Volatile Organic Compounds, Ozone, Bacteria, Fungi, *Legionella*, characterization of the building, thermograph inspection, load power, energy systems installed, energy efficiency indicator, specific energy consumption, shape factor, checking visual and acoustic comfort levels) and subjective results (questionnaires).

As a way to get results about the *Building D*, different types of collecting and measurements were done, leading to a data processing, whose conclusive results were presented in this chapter. From the analysis of these results appear a set of guidelines (improvement opportunities) to promote the energy efficiency and the indoor environmental quality at the university buildings.

Each data point collected cost time, resources and money to acquire, and if the work is not necessary, it is a waste of time during the investigation, resulting in an excessive amount of data to process and analyse. Changes in the occupation during a follow-up period may have an important effect on the evaluation, and if that is not taking into account the conclusions may be wrong.

This chapter refers to the results obtained after the data treatment, concluded in December 2010. These results show the reality of *Building D*, with respect to energy, indoor air quality, thermal, acoustic and visual comfort.

6.1 Water

IPLeiria with respect to water consumption is supplied by public network. The water consumption has domestic purposes, such as toilets.

As a way to reduce water consumption, it could be installed a water treatment station, so we can use the different types of water, for cleaning, watering the gardens, as well as, install an automatic system of watering, that stops water in days of high humidity.

6.2 Energy

As this building doesn't have an energy counter, it was necessary to establish the type of collection, measures to be done, to obtain the best results. All this was done to dissociate the consumption of the building, according to the total Campus billing of electric energy, because it wasn't viable technically to collect data of each equipment or energy consumption system.

Currently the building depends on electricity and natural gas, as energy sources. The average annual energy consumption, costs and equivalent CO_2 emissions is indicated in the table:

Types of energy	Final Energy [kWh]	Primary Energy [kgep]	Costs[€]	Emissions CO_2 [t(CO_2)e]
Electric Energy	844.130	244.798	62.550	294
Natural Gas	341.703	29.386	14.038	35
TOTAL	**1.185.833**	**274.184**	**76.588**	**329**

Table 27 - Average annual energy consumption on *Building D*

The electric energy provided to *Building D* is consumed namely in lighting systems, HVAC, laboratories machines, computer and electrical equipments. Its weight, in terms of energy is 71, 2%.

The natural gas is only used for heating and its weight in terms of energy is 28, 8%.

Relatively to annual consumption of all sources of energy, the building consumed 274.184 kgep, which represents a cost of 329 tCO_2e emissions.

The electric energy consumption on *Building D* was compared to one measurement in the power station. Figure 41 represents the diagram of charges in the building. The *Building D* present a full charge consumption.

It is important to make users aware of the correct use of the equipments, to avoid unnecessary energy consumption. They should disconnect stand-by button of some equipments.

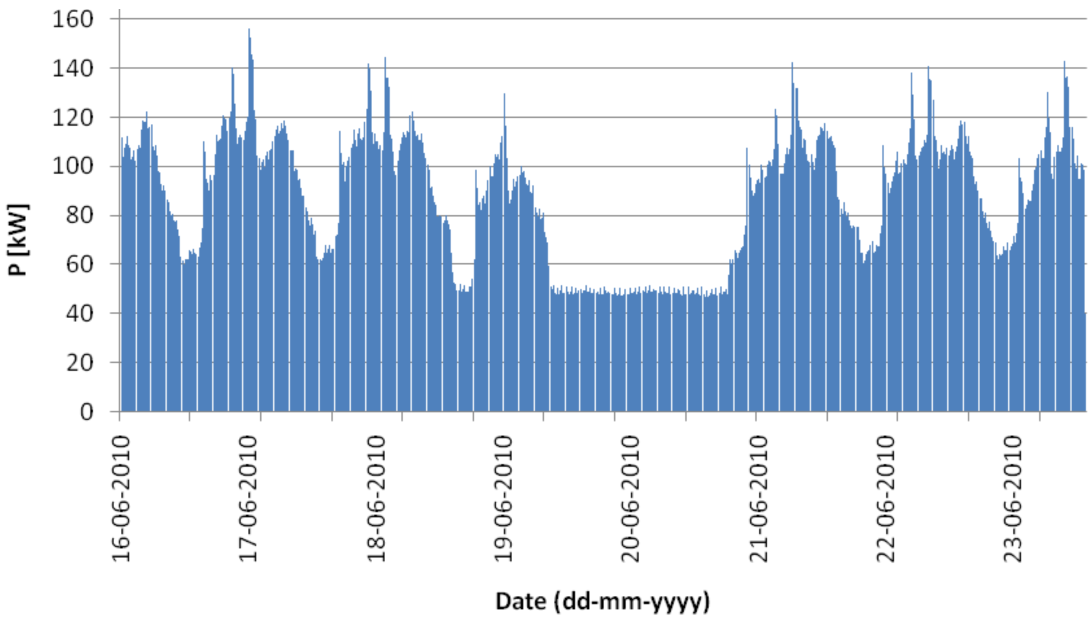


Figure 41 – Diagram of charges in the Building D

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.

6.2.1 Energetic systems characteristics and energy efficiency indicators

- Specific Consumption of Energy by m^2 ($SECm^2$) = 30.98 $kgep/m^2$
- Specific Consumption of Energy by m^3 ($SECm^3$) = 11.0 $kgep/m^3$
- Specific Consumption of Energy by User (SECUs) = 278.36 Kgep/User
- Shape Factor (SF) = 0.36 m^{-1}

Any building should be designed and constructed with the aim of energy efficiency. The power supply to the building needs to employ innovative solutions that are technically feasible, are justified in terms of costs, are acceptable from the environmental and social points of view, and on the other hand ensure a living comfort. To reduce transmission heat losses, the shape factor of the building, which represents the ratio between the surface and volume of the building, should be as low as possible. As well as the energy efficiency indicator and specific energy consumption should also be smaller.

The area with glazing causes huge thermal losses in the heating station and overheating in the cooling station, because *Building D* has a higher percentage of glazing on the northern side (Table 28).

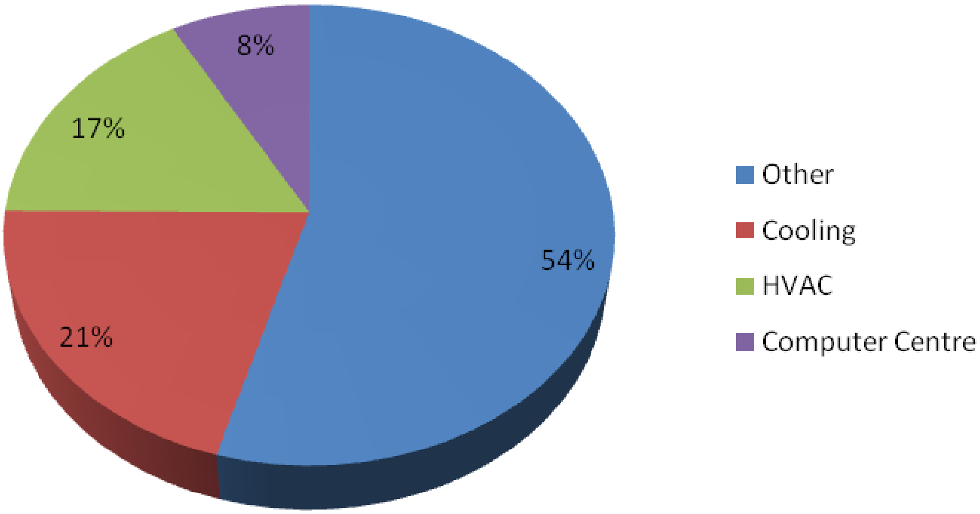
Orientation	Front Area		Glazing Area		Total Front Area	Total Glazing Area	
	(m^2)	(%)	(m^2)	(%)	(m^2)	(m^2)	(%)
NE	1373	23	607	27	5957	2243	38
SE	1830	31	406	18			
SW	1172	20	564	25			
NW	1582	26	666	30			

Table 28 - Front area according to the orientation of *Building D*

Total area with pavement (m^2)	Total Volume (m^3)
8851	24784

Table 29 - Area and volume of *Building D*

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



Graph 3 - Dissociation of *Building D* consumption

Cooling represents 21% of the global consumption of electric energy, which corresponds to the consumption made by the Chillers, producing cold to HVAC.

HVAC only corresponds to the consumption made by the distribution system of thermal energy (hot and cold), being responsible by 17% of the global consumption.

The computer centre represents 8%, being 54% associated to other systems and equipments.

When an unexpected power disruption happens, the building has a uninterruptible power supply (UPS), capable of assuring the service continuity of some specific equipments of the building, such as computers, security and communication.

At the Power Station (PT), there is a condenser, capable of storing electric charge. However there is also in that building another unit of reactive energy compensation connected to the energy supply.

The *Building D* is served by a thermal central shared with the library *José Saramago*. There are two boilers, installed in a technique space inside the library, to heat water. The chiller to cool down the water is installed in a technique area outside the buildings.

The heating is done only by one boiler, number 2, while the other one is ready to work if this one breaks down. On the following table we can see the characteristics of the boilers.

Designation	Boiler 1	Boiler 2
Brand	Lamborghini	Roca
Model	Megaprex 1050	CPA 900
Thermal power	1.046,0 kW	1.046,6 kW
Combustible	Natural Gas	Natural Gas
Burner	Lamborghini	Roca Tecno 100 GM
Year of fabrication	2006	NA
Service	DHW + Acclimatization	DHW + Acclimatization

Table 30 - Characteristics of the boilers

In Figure 42 and Figure 43 we can see the boilers.

Figure 42 - Boiler 1 (Lamborghini)

Figure 43 - Boiler 2 (Roca)

The chiller whose characteristics will be presented on Table 31, works during half of the year, to satisfy the needs of cooling of the building.

Brand	Model	Cooling Power[kW]	Refrigerant Fluid
Trane	RTAC 200	700,00	134a

Table 31 - Characteristics of the Chiller

Figure 44 - Chiller view

The system is constituted by send/return collectors. As there are thermal production equipments of heating and cooling working simultaneously, the HVAC, especially the air handling units (AHU), are fed by 2 or 4 tubes. It depends on their functions, heating and/or cooling.

The air renewal is made by the AHU that inflates the air inside the building through a pipeline network. The air extraction to the outside is made by ventilators.

The air treated is transported by a pipeline network and introduced in the spaces to heat or cool.

In all the areas where the new air is inserted, the air renewal will be heated /cooled in the AHU, so it doesn't exceed the environment temperature established to the place.

The AHU made the heating and cooling, but also renew the air of 5 floors of the building. These units are central station kind, constituted by several modules.

The air inflation system in the building is made by 21 AHU, being 18 installed on the roof, one on floor 2. The other two are inside the building, in a technical room on floor 0. This room is ventilated by an inflation ventilator. Figure 45 represents the position of each one of the AHU in the building.

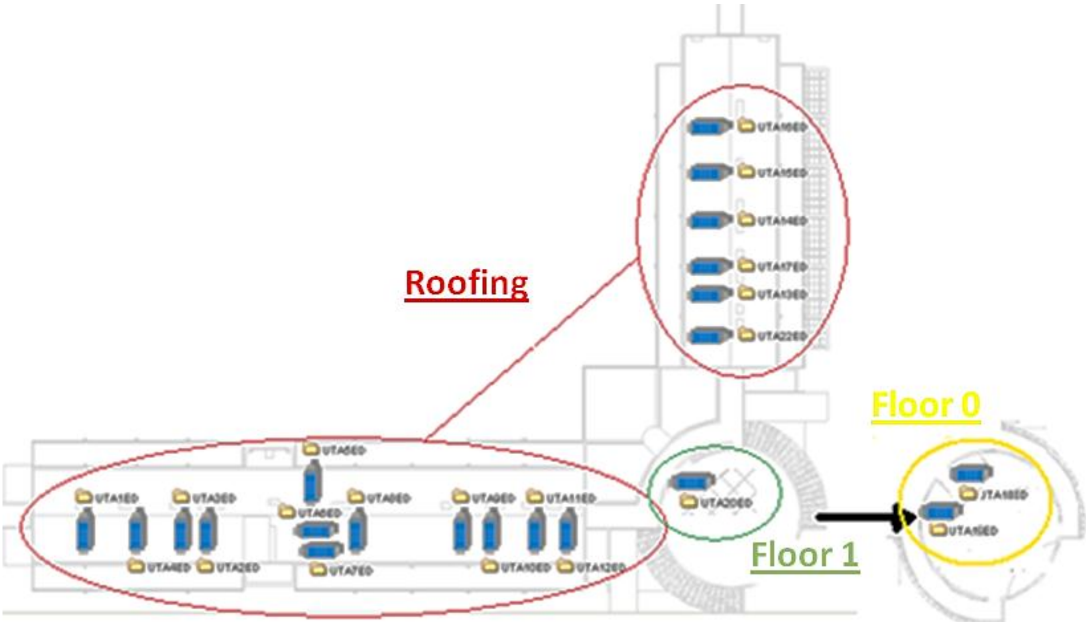


Figure 45 – Position of each AHU in the *Building D*

The behaviour of HVAC system in each single room or building is unique and depends on many factors, including the system itself, the locations, the diffusers, the thermostats, the inside design conditions, the outdoor weather conditions, the control scheme associated with the HVAC system and so on.

The energy saving potential of stratum ventilation is derived mainly from the reduction in the loads of ventilation, dehumidification and transmission, prolonged free cooling period and increased COP of chiller.

It is recommended to maintain the building with a slightly higher pressure to the one from the exterior, to reduce the energy used and to protect the indoor environmental quality.

About the installed systems, they should be better programmed, because there are energy consumptions when the building isn't working, so this should be avoided. The temperatures should also be better controlled, through the installation of sensors to optimize the control.

We should have a more efficient project of AHUs relating to the spaces they serve.

When we observe Figure 46 and Figure 47 we can see two types of air intake in the AHU.

Figure 46 - AHU with new air intake

Figure 47 - AHU with new air intake and renewed air

All AHU are equipped with the same type of pre-filters and filters, having the same efficiency.

In Figure 48 and Figure 49 we can see the pre-filters and filters of the AHU.

Figure 48 - Pre-filters class G4

Figure 49 - Filter class F8

On the basis of each battery there is a board to collect the condensers, which are connected to a drainage pipe to the exterior.

From the analysis of each AHU, it was verified that the pre-filters and filters of some units are dirty, affecting the indoor air quality. Besides all the degradation to the indoor air quality, the dust in the filters increases the electric consumption, because the ventilator has to work at a higher velocity in order to attain the values of the nominal heat requested to the system.

There are also some mistakes in the filtering system installed in some AHU, as well as too much water in the board to collect the condensers from the cooling/heating batteries, leading to a degradation of the battery and water retention, facilitating the development of microorganisms.

It should be done a preventive maintenance, by cleaning the filters, pipelines and grids, which improves the equipment efficiency. This will guaranty the correct functioning of the equipments and prevents that the HVAC contaminates the spaces occupied by people, functioning correctly with a proper thermal control and ventilation, minimizing the energy consumption. It is essential to do the maintenance of the HVAC systems, as well as to have the adequate distance and separation of the entry and exhaustion, replacing dirty filters, to clean pipelines and to prevent the accumulation of water in the reservoirs.

All the engines are controlled by variable air velocity (VAV) or demand controlled ventilation (DCV), inserted in an electric board, installed in the exterior of the AHU. So the engines function at a variable speed in a discontinuous or intermittent mode, according to the need of air inflation temperature. In Figure 50 we can see the electric board where the DCV are inserted.

Figure 50 - Variable air velocity or demand controlled ventilation

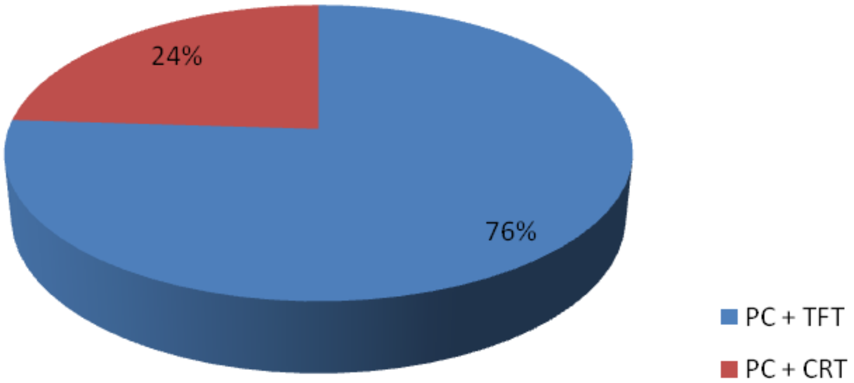
The server room of the building we are studying needs constant cooling, to guaranty a good functioning of the equipments inside it. This cooling is made through an air conditioning, from Panasonic, model CU-B43DBE8.

The computer network equipments are distributed by 19 backstage, being one in the servers' room, on floor -1, and the rest in all the circulation spaces of the building.

As there is a computer centre in the building it is necessary a permanent cooling of the servers room, which represents a higher consumption in the building. To reduce these consumptions it should be installed a *"free–cooling"*.

Most of the computers in the building have thin-film transistor monitors (TFT) that are more efficient energetically than monitors' cathode ray tube (CRT).

However it was verified that 24% of the monitors still are CRT, being the rest 76% TFT monitor. In Graph 4 we can observe the graphic of distribution of both existent monitors.



Graph 4 - Types of monitors

There are 434 computers installed in the building, especially in the computer rooms, laboratories and teachers cabinets, representing a power of 50 kW. Besides all the computers and monitors there are 66 printers.

It is advisable an effective control of energy management of all the computers, especially in the labs, to minimize the consumption when they are not being used.

There are two lifts in this building, with an independent house machines located in the roof. Each house machines, integrates the mechanic and electric system of each lift, partial and control board.

The Table 32 presents the main characteristics of the lifts and goods lifts in the building.

Description	Brand	Model	Power [kW]	Maximum Capacity [kg]	Number of people
Elevator 1	Schmitt+Sohn	VN303018	5,5	630	8
Elevator 2	Schmitt+Sohn	VN303019	7,5	2.000	26

Table 32 - Characteristics of the lifts

Besides the referred systems and equipments, there are also equipments distributed in the different spaces, equipments such as projectors and video projectors installed in the classrooms. The common spaces to the occupants of the building present some equipment such as, coffee machines, food and drink machines, among others.

Besides all this, there is a power plant of compressed air, installed on the floor -1 (Figure 51), which is constituted by a compressor, an air dehumidifier and storage of compressed air.

Brand	Model	Power [kW]	Maximum Pressure [Bar]
Atlas Copco	GA 18	18,5	7,5

Table 33 - Compressor characteristics

Figure 51 - Central of compressed air

This system gives energy to the terminal equipments installed in the various laboratories of the building.

6.2.2 Dynamic simulation of the building

The goal of buildings acclimatization is to produce conditions that allow a thermal comfort for its occupants. In addition to acclimatization is still necessary to ensure air quality and ventilation usually employing introduction of new air treated. Acclimatization is the transmission of heat and mass transfer that occurs between a thermodynamic system and its surroundings. This system is represented by the building under study, which suffers the action of three types of thermal loads:

- Internal - generated by the occupancy rate for the lighting and the operation of various equipment;
- External - caused by climate change by temperature, solar radiation, wind and humidity which promote exchanges across the boundary;
- Infiltration and fresh air - caused by the infiltration and replacement of indoor air.

All these thermal loads should be counted, because they are mechanisms of energy transfer, which will influence the heating and cooling energy consumption required for the building.

The interaction of the thermal loads types will lead to changes in temperature, humidity and indoor air quality.

The heat transfer that promotes these changes can occur in three distinct ways:

- Radiation - energy transport by electromagnetic waves, carried out independently of the environment in which transport occurs;
- Conduction - transport of energy through a solid, liquid or gaseous form;
- Convection - heat transfer between a solid surface and a moving fluid, liquid or gaseous form of forced or natural ventilation.

To counteract these changes that can lead to people discomfort, it’s necessary to have mechanical systems sized to efficiently remove thermal loads, allowing for a temperature and humidity within the range of comfort and to ensure indoor air quality.

The calculation of thermal loads and the performance of HVAC systems can be done by several simulation programs. Under the legislation, for large buildings (> 1.000 m^2) and with air-conditioning systems over 25 kW, is necessary to perform a dynamic simulation of the building thermal behaviour, using a simulation program that meets international requirements.

The *DesignBuilder / EnergyPlus* is a simulation program for physical-mathematical dynamic. *DesignBuilder* is a very intuitive program interface and easy to work. It offers a huge amount of “libraries” with presets and templates that facilitate the program data implementation and also gives the possibility to create new libraries. The range of these libraries includes the building outside data like the climate data, and the time of use of various types of area or even different types of buildings.

The computer model of *Building D* (Figure 52) 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 (Appendix D).

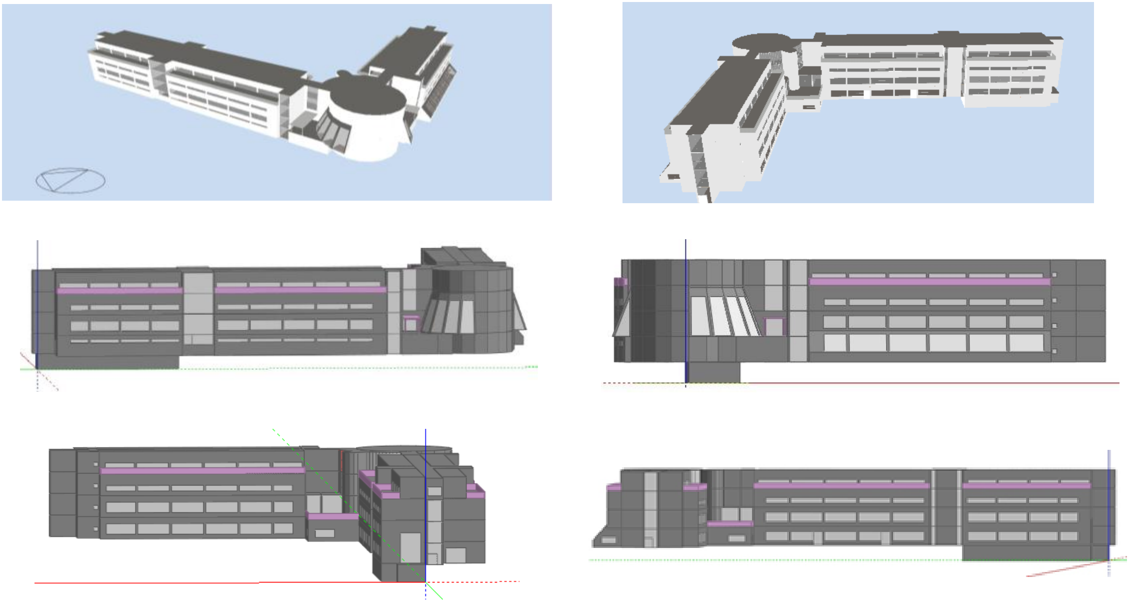


Figure 52 – Different views of *Building D* (DesignBuilder)

Model Implementation

Due to the building high dimension, the under study and the many different activities on it, set up were made to the general building.

Climate

The building under study is located in central Portugal, on the coast region. The climate data bases used by the program don't have yet the region of Leiria characterized, so it was used the climatic maps of Coimbra (weather data provided by INETI). Because of that, a inserting divergence in the results should be overlook in the observations and conclusions made.

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.

They are characterized by the following indicators:

$$Density = \frac{Occupation}{Area} = people/m^2 \quad (42)$$

$$Ilumination = \frac{Ilumination}{Area} = W/m^2 \quad (43)$$

$$DHW = \frac{Consumption\ rate}{Area} = \ l/m^2.dia \quad (44)$$

$$Minimum\ Fresh\ Air = \frac{Air\ flow\ rate}{Occupation} = l/s.person \quad (45)$$

$$Mechanical\ Ventilation = \frac{Air\ flow\ rate}{Area} = l/s.m^2 \quad (46)$$

$$Computers, Office\ Equipment, Miscellaneous, Catering\ and\ Process = \frac{Power}{Area} = W/m^2 \quad (47)$$

The general building data implementation is done through five tabs:

1. **Activity** - Activity data type performed in a certain area. Example: schedules and density, lighting, hot water consumption, amount of new air changes, etc…; (Activity template, Occupancy, Metabolic, Holidays, DHW, Environmental control (Heating temperatures set point, Cooling temperatures set point, Ventilation temperatures set point, Minimum fresh air, Lighting), Computers, Office equipment, Miscellaneous, Catering and Process).

   Metabolism

   Another common factor that will have an effect on indoor thermal loads is metabolism. Its influence is reflected on people heat released for the tasks being performed, thus increasing the interior temperature and relative humidity. The value used throughout the building, the simulation is 0.90 met and that in the winter season (cold season) value of thermal resistance used was 1.0 clo and the summer season (warm season) 0.5 clo.

2. **Construction** - Construction and materials data type;

   Materials and construction methods

   Some inputs are common to the whole building, such as the types and construction materials, and can therefore be specified in the model general options. The importance of building materials is closely linked to the thermal mass. The material thermal mass is its capacity to retain heat. Thus the building thermal inertia is its ability to counteract the temperature variations within it, or reduce the transfer or heat transmission. This is due to its ability to accumulate heat in the building elements.

   The materials were created according to the building envelope analysis (Appendix A) and considering the amount shown in ITE 50 [286].

3. **Openings** - Data relating to openings in the building. Example: glazing template, external windows, internal windows, roof windows / skylights, doors, curtains and vents).

   The windows and glazing were modelled to be as identical as possible with reality, because of its importance with regard to heat exchange. They are responsible for much of this exchange, that can occur either by radiation or by convection.

4. **Lighting** - Data relating to lighting. Examples: lighting template, general lighting, task lighting, display and lighting control, etc...;

   The lighting in Higher Education buildings has a very significant weight in the final consumption outpacing most of the time 40%. Promotes heat exchange by radiation, conduction, convection and therefore the importance of this tab.

5. **HVAC -** Data relating to air conditioning equipment, water heating and natural ventilation. Examples: HVAC template, auxiliary energy used in HVAC equipment, mechanical ventilation, heating, cooling, DHW, natural ventilation and air temperature distribution, etc...

   Ventilation

   The air flow from the building outside requires expend energy to put inflation and the temperature after the temperature of the building. As previously mentioned, all have space in the building ventilation. Based on the flow rates required and the volume of various spaces can be estimate the air flow rate (T) and based on the value obtained true measurement of the CO_2 decay method can be estimated the air changes per hour (average R is approximately 0.46 air changes per hour) according to Table 49. Apart from the forced ventilation, there is any natural ventilation due to wind action and windows opening, that are difficult to quantify (natural infiltration). It was considered a minimum value of 0.15 changes per hour due to these effects.

The value of air changes per hour by different type of use for Higher Education Buildings in Portuguese and Spanish legislation goes from 3 to 15 air changes per hour.

The program results are presented through graphs or tables, it is possible to choose the type of information that is obtained by simulation (example: total consumption, partial consumption, temperature, comfort parameters, etc…), the time intervals between calculations, the simulation time, etc…

The ***Case 3*** and ***Case 4*** consists of improvements made in the building regarding to the replacement of computer equipment, lighting, heating and cooling equipment more efficient, as well as the implementation of more effective control for HVAC system and lighting and shading.

Regarding to the lighting system is considered the replacement of:

- T8 fluorescent lamps for T5 fluorescent lamps of 35 W with electronic ballast;
- CFL fluorescent lamps for LED lamps;
- Ferromagnetic ballasts of T5 fluorescent lamps for electronic ballasts.

These measures allow a potential savings of approximately 34 kW installed power for lighting (34%).

It was implemented a system of lighting control ***Linear/Off*** that allows control of interior lighting with exterior light. Beyond this system was added a control system to shading equipment the ***Day-Cooling and Solar*** allows you to take greater advantage of the outdoor conditions.

Reactively to computers equipment, the substitution of CRT monitors type for TFT monitors, allow a potential savings of approximately 7 kW in installed power of computer equipment (8%).

The office equipment installed (as photocopying, printers, electrical machinery, etc. also had an improvement.

The HVAC system considered a set point of 19 °C for heating against the currently used 22 °C and the cooling set point of 26 °C against 25 °C currently used.

The COP for cooling have been improved as well as the efficiency of the heating system.

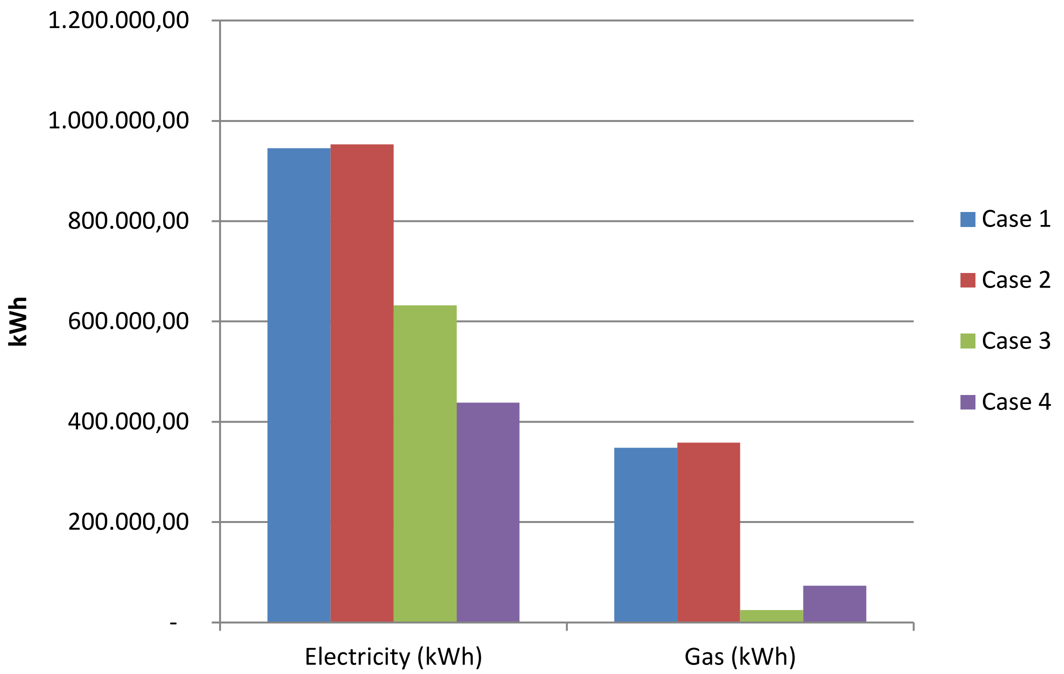
Input Parameter	Case 1	Case 2	Case 3	Case 4
Occupation [person]	985			
Area [m^2]	8851			
Volume [m^3]	26553			
Illumination [W]	101000		66740	
DHW Consumption rate [l]	0			
Air Flow rate [l/s]	3392,88			
Density [person/m^2]	0,11	0,10	0,11	
Illumination [W/m^2]	11,41		7,54	
Minimum Fresh Air [l/s.person]	3,44			
Mechanical Ventilation [l/s.m^2]	0,38			
Computers [W/m^2]	9,84	10,00	9,07	
Office Equipment [W/m^2]	6,23	10,00	2,28	
Miscellaneous	1			
Catering	0			
Process	0			
Heating	22		19	
Heating set back	16			
Cooling	25		26	
Cooling set back	50			
Shading Control	Solar		Day-Cooling and Solar	
Lighting Control	Off		Linear/Off	

Table 34 – Input parameters for the different cases

The different case simulations are performed on *DesignBuilder / EnergyPlus*. The simulation results show that appropriate operational mode could greatly improve the energy consumption.

Simulation results	Case 1	Case 2	Case 3	Case 4
Room Electricity (kWh)	523.697,47	477.372,1	378.294,41	258.592,97
Lighting (kWh)	209.535,30	250.052	123.493,34	73.830,74
System Misc (kWh)	166,86	166,86	166,86	166,86
Electricity Total (kWh)	945.707,94	953.109,9	632.366,13	437.895,50
Gas Total (kWh)	348.212,69	358.678	24.416,13	72.824,59
Heat Generation (Gas) (kWh)	348.212,69	358.678	24.416,13	72.824,59
Chillers (Electricity) (kWh)	212.308,30	225.518,9	130.411,53	105.304,94
Air Temperature (°C)	24,56	24,34	24,18	23,83
Radiant Temperature (°C)	25,46	25,26	25,2	24,86
Operative Temperature (°C)	25,01	24,8	24,69	24,34
Outside Dry-Bulb Temperature (°C)	0	0	0	0
Glazing (kWh)	-49.148,22	-34.2305	-342.055,25	-331.349,44
Walls (kWh)	-35.165,00	-228.102	-221.395,86	-208.510,31
Ceilings (int) (kWh)	7.906,75	4.986,76	42.517,24	49.492,10
Floors (int) (kWh)	-10.625,58	-7.654,21	-44.046,63	-50.835,91
Ground Floors (kWh)	-5.842,19	-5.708,65	-5.677,61	-5.431,25
Partitions (int) (kWh)	-3.318,34	-3.331,8	-1.785,06	-1.595,01
Roofs (kWh)	-31.956,03	-30.715,2	-30.500,25	-28.383,17
Doors and vents (kWh)	-18.957,11	-18.344,6	-18.031,61	-17.099,10
Floors (ext) (kWh)	-46.479,82	-45.307,8	-44.554,73	-42.308,89
External Infiltration (kWh)	-598.363,56	-582.053	-569.311,19	-543.630,50
External Vent. (kWh)	-113.949,98	-94.105,9	-110.355,25	-99.338,68
Radiant Heating (kWh)	226.338,23	233.140,7	48.832,26	66.998,62
General Lighting (kWh)	209.535,30	250.052	123.493,34	73.830,74
Miscellaneous (kWh)	30.805,73	22.732	30.805,73	21.549,41
Computer + Equip (kWh)	492.891,75	454.640,1	347.488,69	237.043,55
Occupancy (kWh)	205.521,55	160.092	206.665,67	203.880,28
Solar Gains Exterior Windows (kWh)	802.231,25	802.228,5	982.765,94	996.804,25
Zone/Sys Sensible Cooling (kWh)	-552.001,56	-563.797	-391.234,59	-315.914,81

Table 35 – Simulation results for the different cases



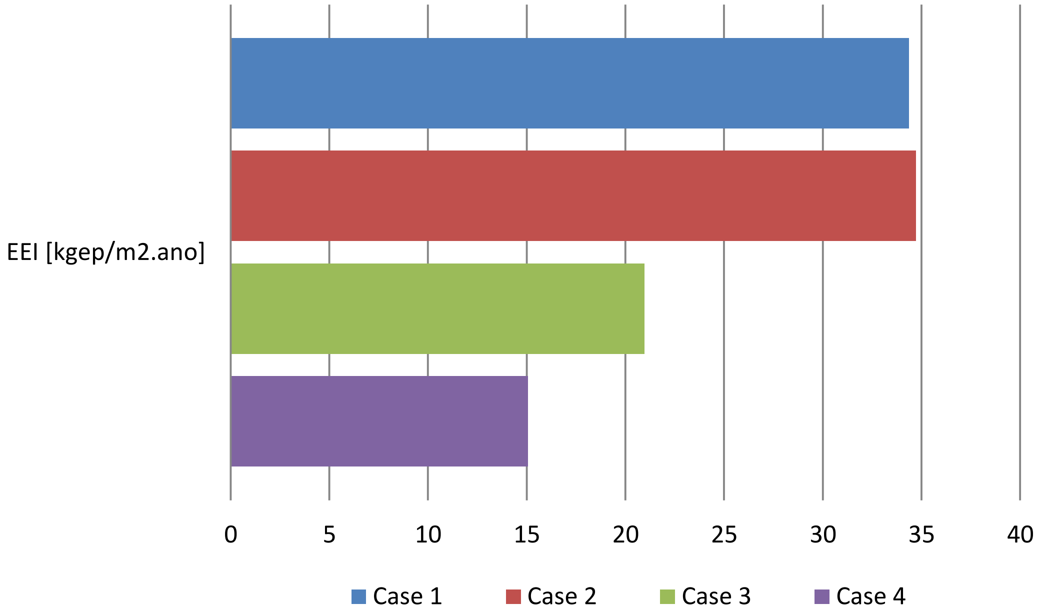
Graph 5 – The consumption for the different cases

Simulation results	Case 1	Case 2	Case 3	Case 4
CO_2 (kg)x10^3	715,71	722,824	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

Table 36 – Simulation results for the different cases (Cont.)

	Case 1	Case 2	Case 3	Case 4
Electric Deviation (%)	12,03	12,91	-25,09	-48,12
Gas Deviation (%)	1,91	4,97	-92,86	-78,688
Total Deviation (%)	9,12	10,62	-44,61	-56,93
EEI [kgep/m^2.ano]	**34,37**	**34,71**	**20,96**	**15,06**

Table 37 – Summary of simulation results for the different cases



Graph 6 – Energy efficiency index for the different cases

The evaluation as also a component of numeric calculation performance of the same building, allowing the development of a optimization tool to reduce its energy dependence and consequently reduce the greenhouse gas emissions, ensuring energy and environmental sustainability of this building. Using this methodology applied to this case study makes it possible to systematically assess the sustainability of Higher Education Buildings. The results of this research might be generalized to other buildings, where the climate, classroom conditions, degree level and educational approach, are most of the time similar to Portugal and Spain.

The thesis also had as objective to compare the efficiency of the different mechanical systems operating mode, according to the indoor environmental quality inside a typical Higher Education Building in Portugal. Construction characteristics, materials, occupant behaviour and weather conditions affect the indoor conditions. However, these variables are not independent.

The physic–mathematic simulation results show that it is possible to achieve good comfort conditions by reducing energy. What indicates that in buildings with good projects it is easier to reach good undertakings. The computer simulations show that to use correctly a building it is necessary a proper strategy of control. To know the indoor and outdoor thermal conditions is important to correctly predict the building's behaviour (schedules).

We have to rethink the use of higher education buildings, this type of buildings are large and as such have high consumption. The opening of all buildings on university campus is unthinkable for occupations minimal as shown by simulations. Good management of resources is inevitable.

Changes made in schedules, set point temperatures, increasing the efficiency of the equipments and automatic controls have an investment payback reduced and is translated into major changes at consumption.

It is very important to have the perfect notion of the occupation of the buildings of higher education, to calibrate the model because it can lead to very signifies deviations.

The *Building D* doesn't have an energy counter, it was necessary to establish a ratio between the measures done, to obtain the best results. All this can introduce a small deviation in the real consumption of the building, and because we are conscious of that, the simulation we chose to validate the model is the *Simulation D_1_7*. When compared with the other simulations reflects better the reality of the building, turning to be ***Case 1***.

Two phases can be distinguished in mathematical modelling: the choice and validation of the model. Therefore, any model must be tested and validated by existing experimental and numerical cases.

The simulations number D_1_2, D_1_3, D_1_6, D_2 e D_3 (marked with red in Appendix D) shouldn't be considered, due to an error in the programming process.

The simulations show that it is difficult to existing buildings for higher education to reach the EEI of reference (15 kgep/m^2.ano). What means that the commitment *"nearly zero energy buildings"* presents itself as a major challenge, in a short time.

New renewable energies that can be input on the *Building D* with no significant integration requirement for efficient payback.

Technology Solution	Description	Disadvantage	Energy Saving
Automated natural ventilation	Natural ventilation enhanced by automated openings in facades through the use of actuators and control systems. Openings can be controlled based on internal/external conditions such as temperature, wind speed, precipitation etc. Openings could be windows or building integrated louvres.	Control requirement and thermal comfort parameters.	5% - 20%
Standard Photovoltaic	Photovoltaic units collect solar energy and convert it into electricity for use either within the building or for distribution to public infrastructure. The units are often roof mounted.	Cost may often outweigh benefits.	1% - 5%
Combined Photovoltaic and Solar Thermal collectors (PVT)	These units collect solar energy. The first layer converts this energy to electricity. The second layer collects residual heat for use within the building.	Cost may often outweigh benefits.	5% - 20%
Night ventilation	Significant differences between daytime and night time temperatures in areas with temperate climates provide opportunities for the use of 'free' energy. Buildings that are not used overnight can be purged of heat either passively or mechanically, by using cool ambient air. This feature can significantly increase comfort levels and reduce cooling requirements and associated energy use.	Control systems required. Security levels can be compromised i.e. opening windows overnight.	1% - 5%
Flat plate solar collectors	Solar collectors are active systems that collect solar energy, which is transferred to a medium such as water for subsequent use within a building for heating or domestic hot water. A flat plate solar collector consists of an insulated box with a glass or plastic cover. Water is passed through the box via a series of pipes which are mounted adjacent to the absorber plate. Solar energy is collected during this process.	May not be effective during the winter when heating demand is highest. Can be problems with freezing in cooler climates.	5% - 20%
Thermal storage - thermo chemical	Energy can also be stored using reversible chemical reactions. For example, the dissociation of ammonia into nitrogen and hydrogen which requires a large amount of heat energy. This type of storage can only be used by solar thermal power systems which can gather large quantities of energy.	New technology. Cost.	5% - 20%
Thermal storage – ground source	The earth can act as a thermal store. Solar energy is constantly being collected by the earth. This energy can be extracted. Alternatively, heat or cold can be pumped into the ground for storage at a later time, potentially on an inter seasonal basis.	Space for below ground heat exchanger required. Complex system. Risk of system not meeting comfort requirements.	5% - 20%

Table 38 – Technology solutions

Technology Solution	Description	Disadvantage	Energy Saving
PV Glazing Panels	Photovoltaic units collect solar energy and convert it into electricity for use either within the building or for distribution to public infrastructure. In this case the Photovoltaic cells are mounted between 2 panes of glass within a laminated glazing system.	Cost.	1% - 5%
Daylight dimming	Daylight dimming allows the level of artificial lighting output to be reduced dependent upon the availability of natural light. This reduction in artificial lighting reduces energy consumption.	Cost compensate the benefits.	5% - 20%
Solar PV powered LED lighting	LED lamps are the newest addition to the list of energy efficient light sources. LED lighting systems consume 10%- 20% of the energy that 'standard' systems consume. Though still in their infancy, LED lamp technologies are rapidly progressing and show promise for the future.	Cost of LED lighting systems is still prohibitive. Colour rendering capability of LED systems is limited.	5% - 20%
Automated natural ventilation	Natural ventilation enhanced by automated openings in facades through the use of actuators and control systems. Openings can be controlled based on internal/external conditions such as temperature, wind speed, precipitation etc Openings could be windows or building integrated louvres.	Control requirements. Thermal comfort parameters.	5% - 20%

Table 39 – Technology solutions (Cont.)

However the package of new solution also can pass true other solutions. But they require various combinations of technical and economical interventions:

6.3 Visual Comfort

It was done a survey to characterize the lighting system of the building. The number of luminaries, lamps, control way and technology used in the different spaces. This survey has an objective: to characterize the technology used and also to evaluate the efficiency of the existing systems, to detect potential opportunities to improve, not only the energy consumption, but also the visual comfort to the occupants.

The main characteristics of the artificial lighting systems installed in *Building D* are presented on Table 40.

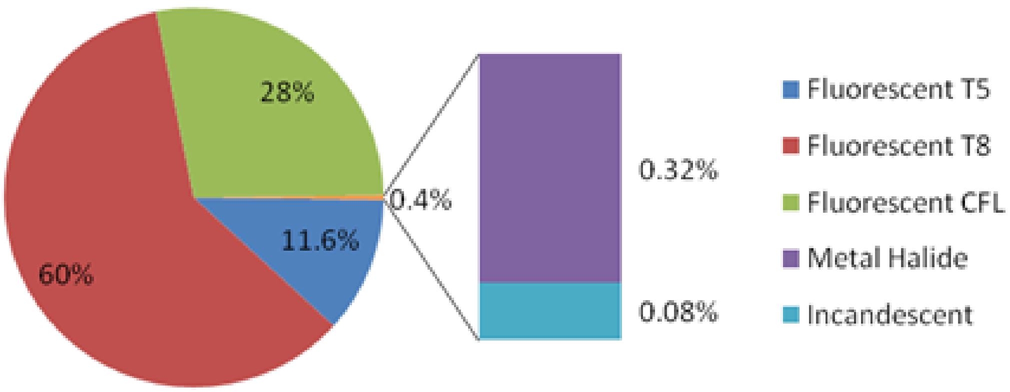
Type	Unit power [W]	Quantity	Total power [kW]
Fluorescent T5	28	216	11,69
	35	148	
Fluorescent T8	36	1425	60,23
	58	3	
Fluorescent CFL	26	637	28,75
	42	192	
Metal Halide	150	2	0,30
Incandescent	40	2	0,08
Total	**---**	**2.625**	**101,1**

Table 40 - Lighting equipment installed on *Building D*

The building has installed a power of 101,1 kW for artificial lighting, distributed by five types of light sources: tubular fluorescent lamps, type T5 and T8, compact fluorescent lamps (CFL), metal iodides and incandescent lamps.

The building presents a power density for lighting of 11,42 W/m^2, isn't very high in average, but it can be reduced, especially if we analyse the luminance in some spaces and substituting the fluorescent lamps T8 by T5, more efficient. It is very important to control lighting.

According to the characterization done, it was possible to do a distribution of the installed power by each type of technology. We can observe it in Graph 7.



Graph 7 - Distribution of the luminaries power by each type of light

With respect to energy consumption, the fluorescent lamps, type T8, are the ones which have more installed power, representing 60% of total.

The fluorescent lamps, T8 of 36 W represent 54% of the total applications, followed by the CFL and the tubular T5.

The fluorescent lamps T8 are practically installed in all the spaces, like laboratories, classrooms and teachers cabinets, among others. In Figure 53 we can see the lighting of laboratories.

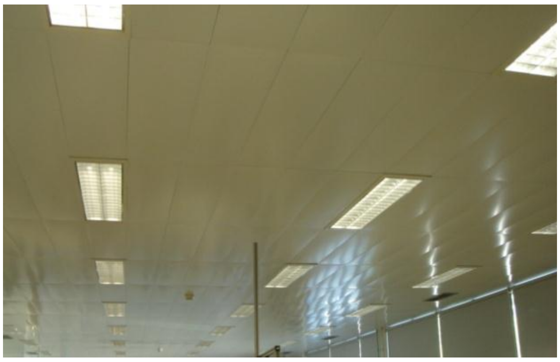


Figure 53 - Application of lamps T8

Figure 54 - Application of lamps CFL

According to fluorescent lamps T5, these are also installed in the labs and classrooms, as well as spaces to circulate.

The lamps CFL are installed in bigger spaces, such as amphitheatre, toilets and spaces to circulate, as we can see in Figure 54. The CFL are installed in a false ceiling, with opaque reflectors and acrylic refractor.

Most of the luminaries installed, type T5 and T8, are installed in a false ceiling, with reflectors mirrored by thin metal sheets. After the analysis done, it was verified that only some luminaries T5 have installed electronic ballasts, while the rest of lamps, T5, T8 and CFL are equipped with ferromagnetic ballasts.

Concerning to command systems and control of the lighting systems there are three different methods.

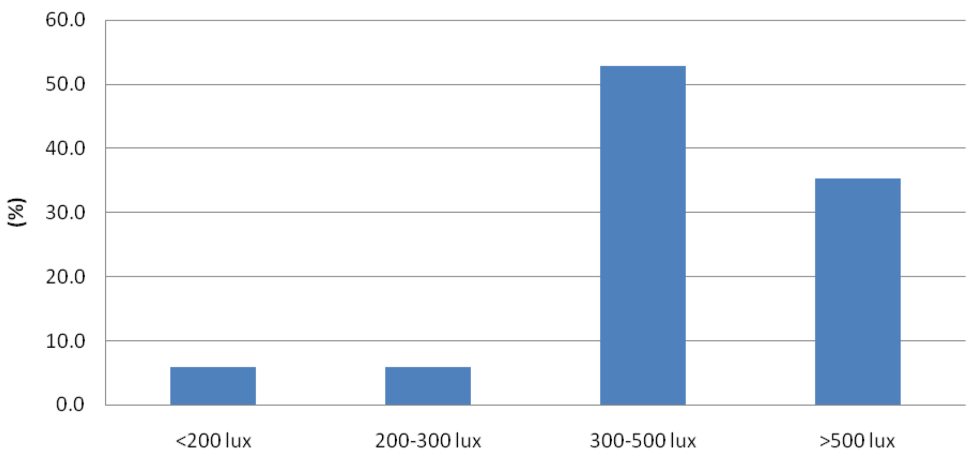
The lighting of the reading rooms, cabinets and labs is controlled mostly through switches and/or switches of lustre, controlling 1 or 2 circuits, depending on the area of the space. In some described spaces, the command is done through modular switches installed in the electric panel of each place. Concerning to circulation spaces, such as corridors, halls and toilets, the control of lighting is done mostly through presence sensors. These spaces are also controlled through time switches.

It is also important to refer that there is emergency sign luminaries in all the spaces of the building.

Place	Luminance [lux]
Laboratory of Computer Applications (LAI V)	471
Laboratory of Computer Applications (LAI IV)	477
Storage	345
Robotics Lab	807
Electric Machines Lab	466
Hydraulics Lab	398
Corridor room (D -1.12)	158
Amphitheatre I	288
Computer Centre	870
Classroom DS 0.4	557
Maintenance workshop II	408
Store room CI (DS -1.16)	370
Reprographics room DS 02.62	560
Bioscience Lab	438
Cabinet DS 2.19	575
Amphitheatre III (DS -1.01)	1107
Classroom DS 0.1	360

Table 41 - Average values of measurement of instant lighting

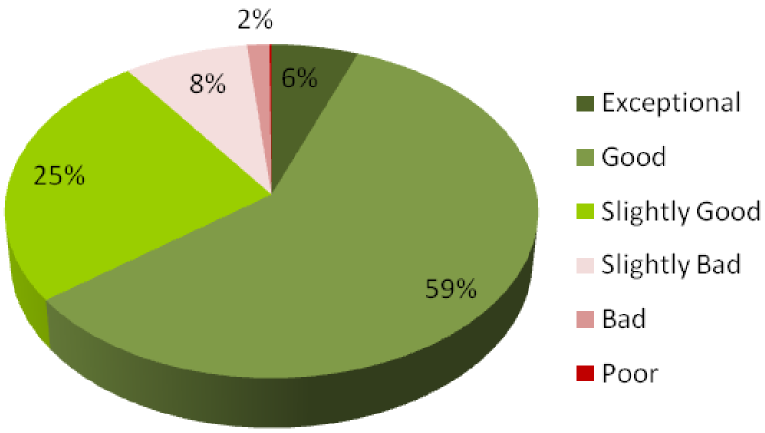
According to EN 15251 Standard [81], that recommends several levels of lighting, the following figure shows the distribution of the levels of lighting registered in the measured places. The standard says that the level of lighting to teaching adults should be 500 lux.



Graph 8 - Distribution of lighting levels registered at different measured places

The use of different lighting levels, according to the requirements of the EN 12464-1 Standard, EN 15193 Standard and EN 15251 Standard will also lead to savings.

The result of the subjective inquiries about lighting has shown a great satisfaction by most of the questioned.



Graph 9 - Result of the subjective inquiries about lighting

The school should inform the users how to use the shading systems, avoiding closing the panels totally, leading to an unnecessary increase in the energy consumption indoors.

6.4 Acoustic Comfort

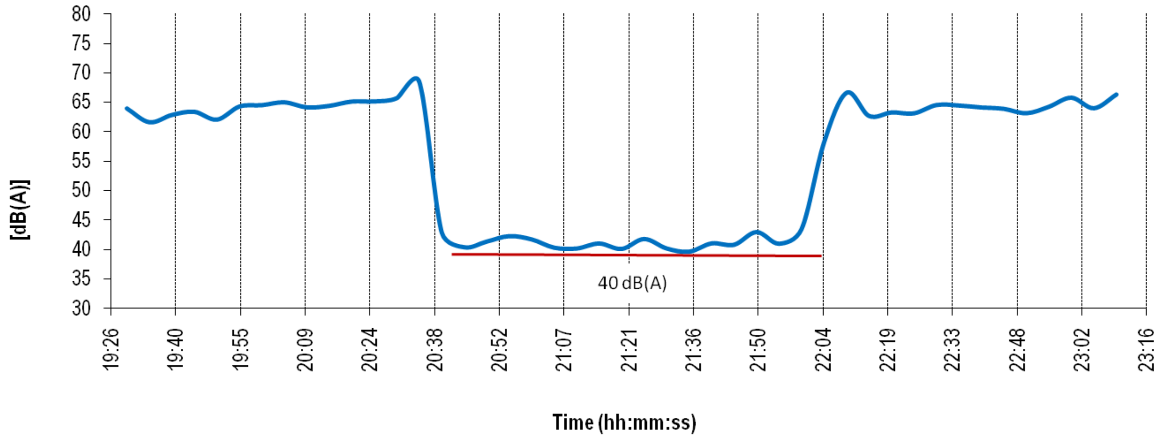
Figure 55 - Noise measurement

The Graph 10 represents the instant sound pressure level obtained in a continuous measurement, of long-term, representing a day of classes.

Graph 10 – Instant sound pressure level, dB(A)

The dB (A) values to classes are superior to 60 dB (A), but when there aren't classes are about 45 dB (A).

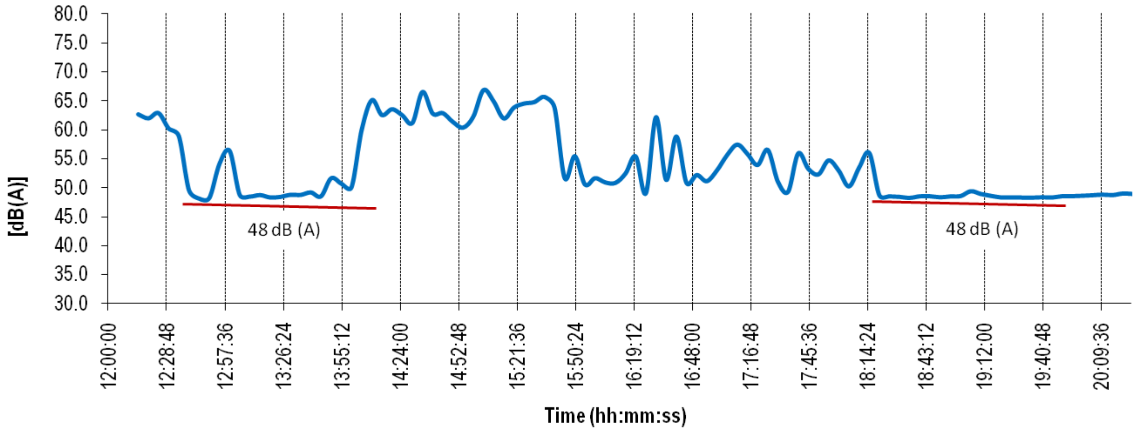
In the Graph 10 there are some fluctuations in the measurement, because the measure was done with the door open.



Graph 11 - Instant sound pressure level referent to a class, dB(A)

The dB (A) values to classes are usually superior to 60 dB (A), but when there aren't classes are about 40 dB (A).

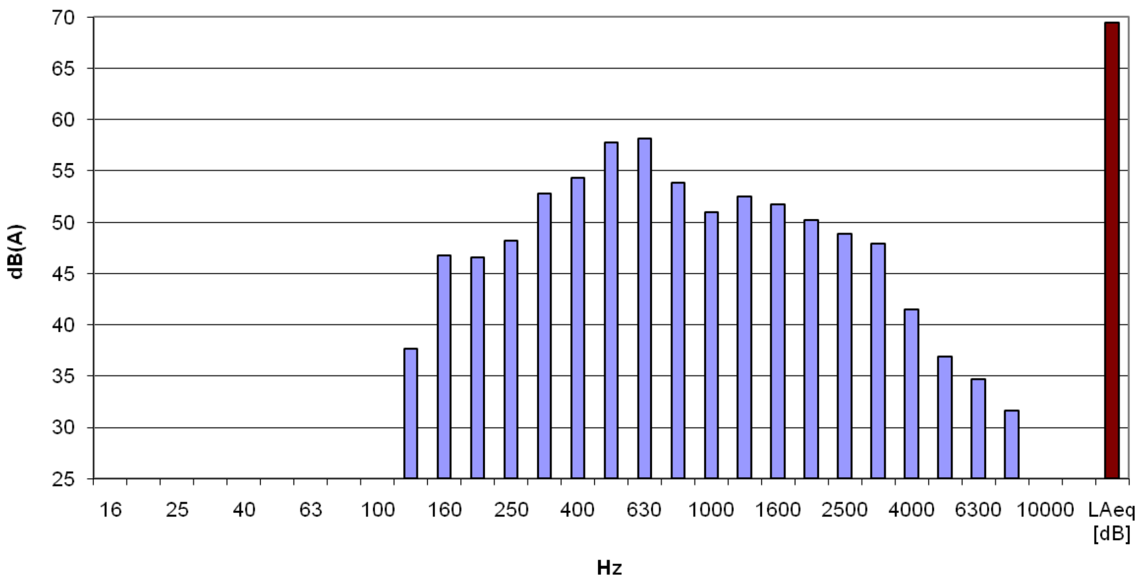
The Graph 12 represents the instant sound pressure level obtained in a continuous measurement, of long-term at the Computer Centre.



Graph 12 - Instant sound pressure level at the Computer Centre, dB(A)

The values of dB (A) to the computer centre are usually values next to 60 dB (A), and for empty times (only the noise of the equipment) are about 48 dB (A).

Graph 13 represents the spectral analysis by frequency ranges of 1/3 octave, of a classroom with a class of 2 hours. We can verify that the column of 500 and 630 Hz represent the bigger acoustic energy.

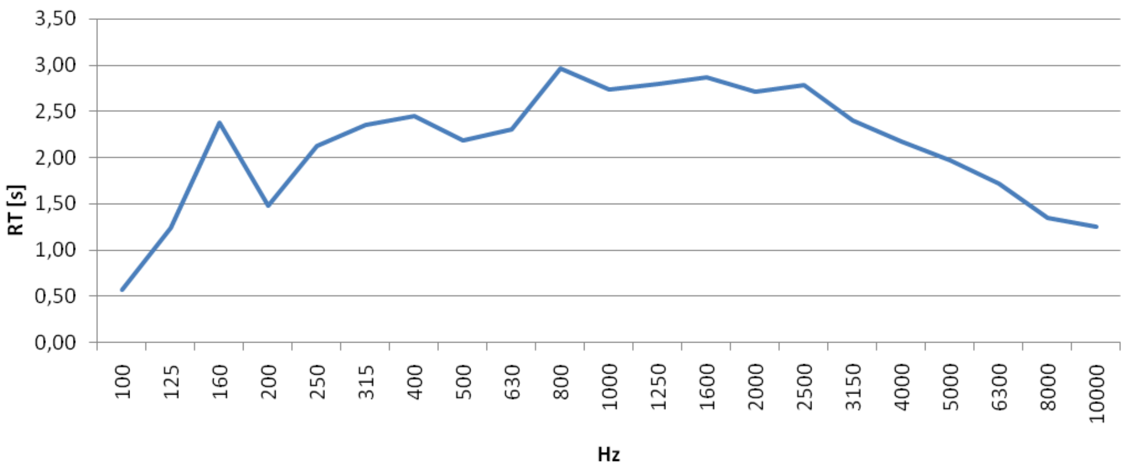


Graph 13 - Spectral analysis by frequency ranges of 1/3 octave

The value of the continuous equivalent sound pressure level, in A has an approximated value of 70 dB (A).

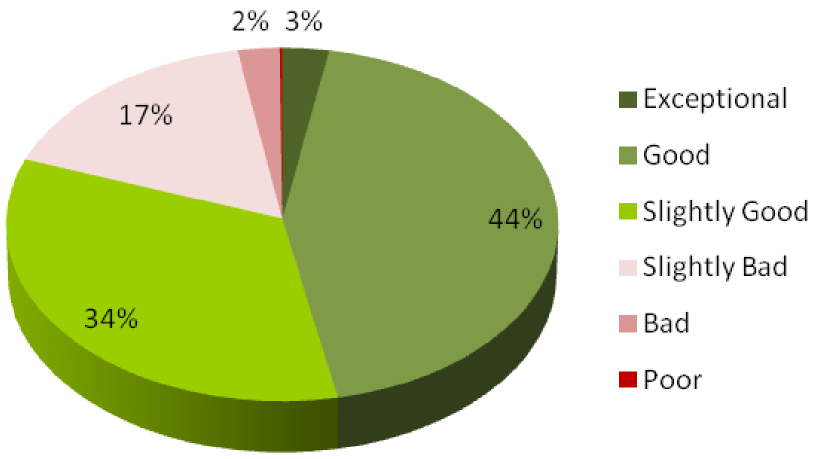
Figure 56 - Reverberation time measurement

Analysing the reverberation time (RT) in a classroom, we realized that it is necessary to think twice about the sound isolation in this building, because the decay isn't soft after the emission.



Graph 14 - Reverberation time

The RT is connected to the perception of the speech; it should be used as a simple indicator of the acoustic comfort of the building. A RT inferior to 2 seconds for octaves of 500, 1000, 2000 and 4000 Hz will favour the perception of the speech in a classroom. The Portuguese law refers to this kind of activity a $RT \leq 0.15\ V^{1/3}$, in this case $RT \leq 1$ s. About the noise, most of the respondents to the subjective inquiry seem satisfied.



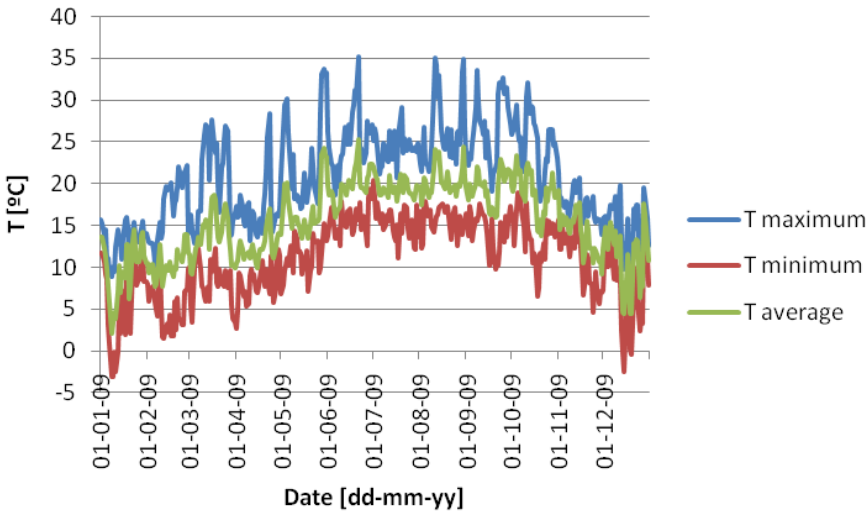
Graph 15 – Result of the subjective inquiries about noise

To adopt the necessary measures to correct uncomfortable situations, to plan structural solutions to eliminate or minimize the sound impact, such as:

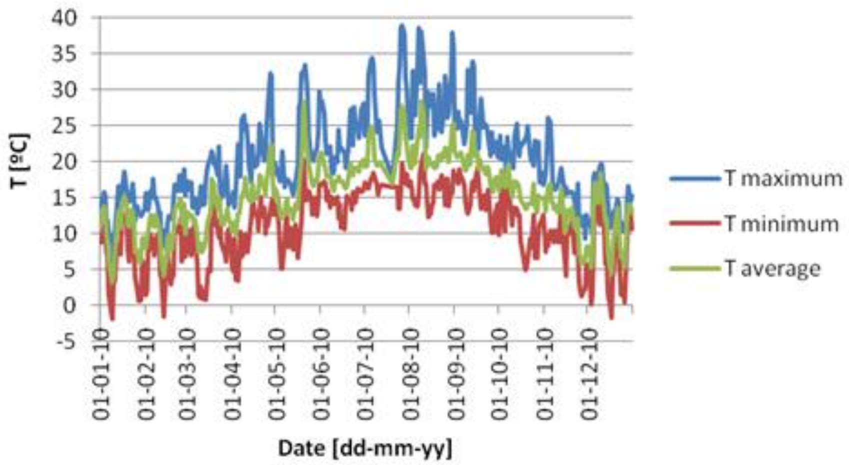
- To isolate the classrooms;
- To replace the equipments for other less noisy;
- To isolate noisy vibrating elements.

6.5 Thermal Comfort

Monitoring of outdoor temperatures, of 2009 and 2010, to validate and compare to the measurement done to *Building D*.



Graph 16 - Temperatures in 2009

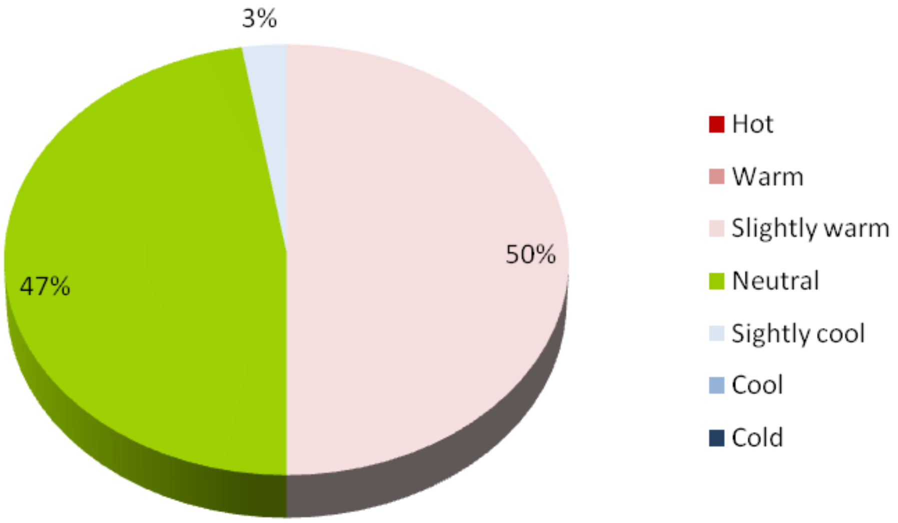


Graph 17 - Temperatures in 2010

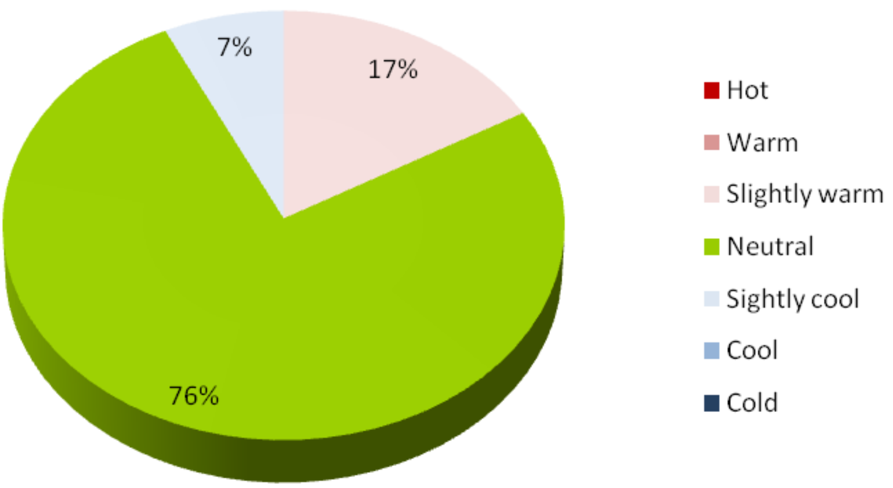
The HVAC of *Building D* is controlled by the Technique Building Management System (BMS), Siemens, model Design Insight.

About the thermal comfort conditions, the calculation of PMV indicators and PPD gives us an objective determination, according to the requirements of EN 7730 Standard [75]. The values obtained through direct measures, which were done according to the EN 7726 Standard [67], were validated by the vote of students and teachers for the same environment, through questionnaires. This way we could obtain objective and subjective results.

The subjective reaction was registered, being the average voting calculated according to the different categories of the EN 15251 Standard [81]. The graphics bellow represent comparative results, between objective and subjective values of the occupants, results obtained in different days and with different ways of ventilation system functioning.



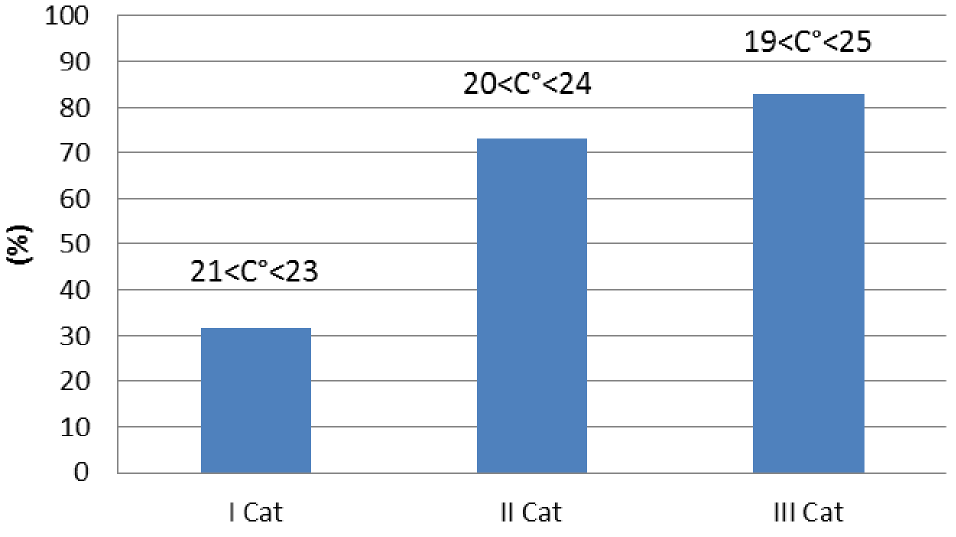
Graph 18 - Objective results referent to thermal comfort



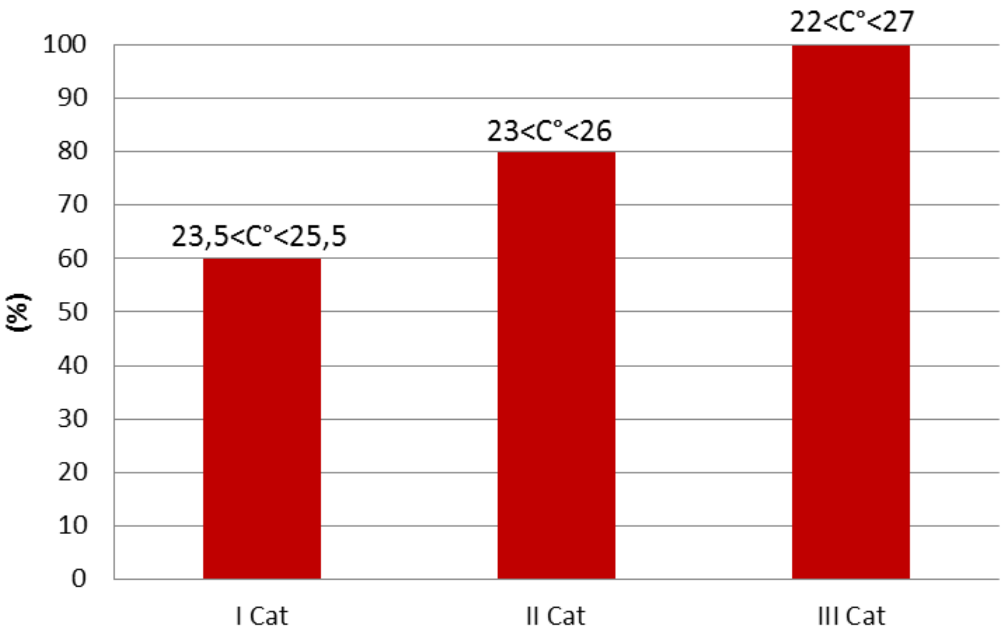
Graph 19 - Subjective result referent to thermal comfort

In many cases it is possible to observe that the subjective votes have a higher percentage of neutral sensation than the objective results.

The temperature values were registered to the winter (cold season) and to the summer (hot season) according to the different categories of EN 15251 Standard [81].

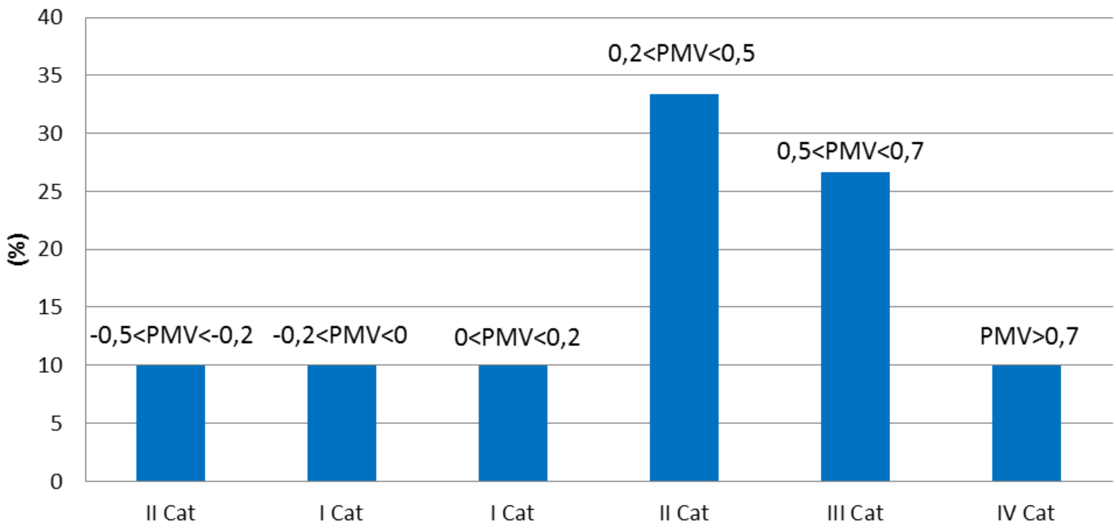


Graph 20 - Temperature values registered during Winter, in the studied environments

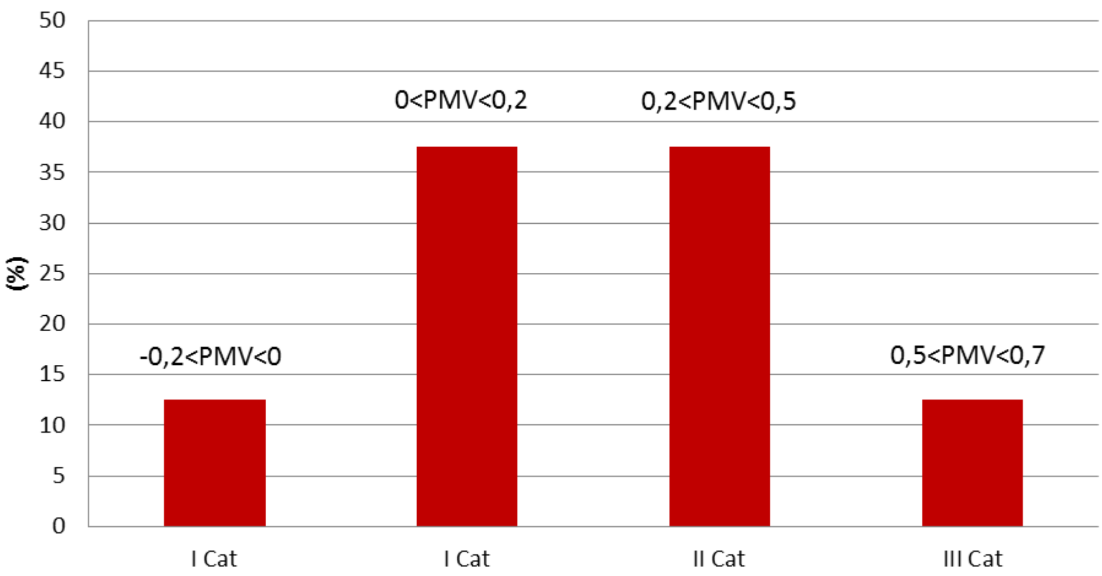


Graph 21 - Temperature values registered during Summer, in the studied environments

The PMV and PPD values were calculated with 1.2 met, depending on the type of season, 1.0 clo (cold season) or 0.5 (hot season).

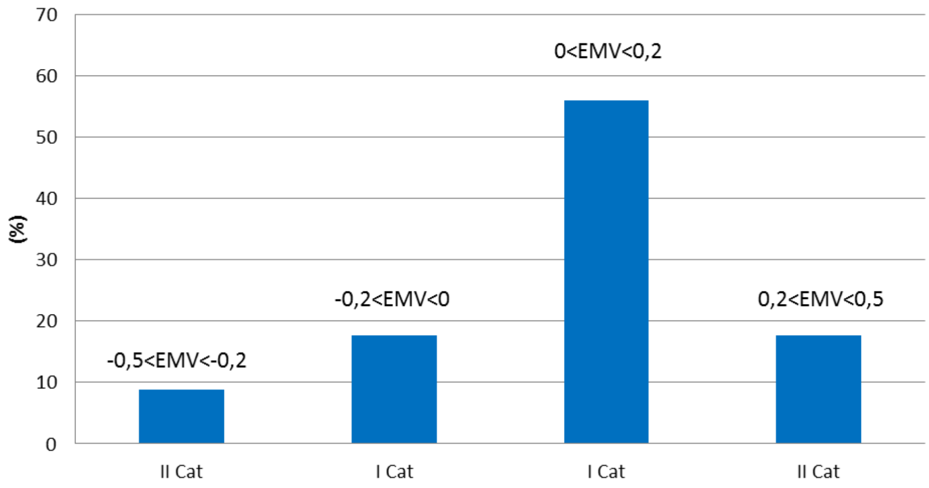


Graph 22 - PMV values registered during Winter, in the studied environments

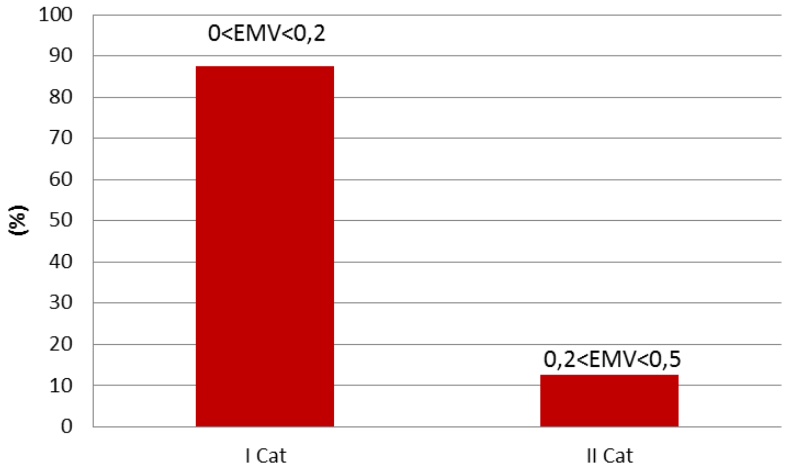


Graph 23 - PMV values registered during Summer, in the studied environments

The subjective values were registered according to the categories of EN 15251 Standard [81], called Express Median Voting (EMV).



Graph 24 - EMV values registered during Winter, in the studied environments



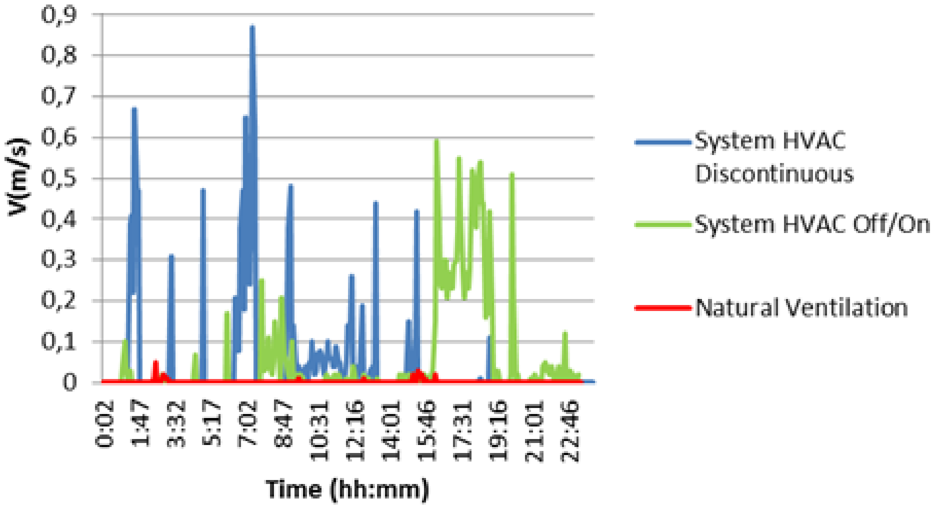
Graph 25 - EMV values registered during Summer, in the studied environments

The most important variables affecting thermal comfort are air temperature, relative humidity, air velocity, radiant exchange, level of activity (production of body heat) and the thermal resistance of clothing (clo - value). These variables are included in the model developed by *Fanger* for comfort. From PMV and PPD analysis, we observe that a high indoor comfort level follows high energy demand.

The subjective results (questionnaires) were not made in accordance with *ASHRAE Standard 62*, but they also use a continuous scale of acceptability. The measurements made in *Building D* have shown that it predicts a warmer thermal sensation than the occupants actually feel. The reason for this discrepancy could be that thermal perception is affected not only by the heat balance of the body, but also by other factors such as adjustments of behaviour and psychological and physiological adaptation.

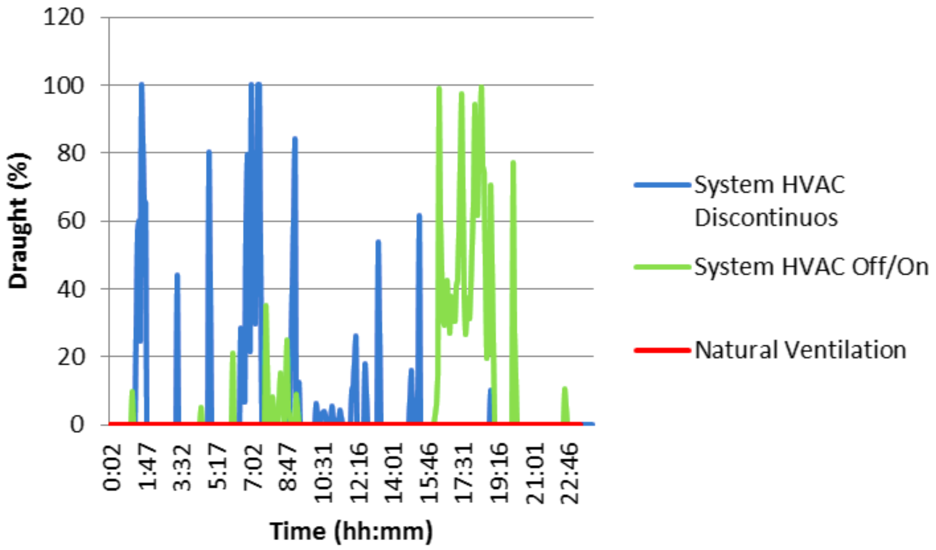
Different types of measurement were made to evaluate the local thermal comfort. This was made on the basis of the air speed, on the temperature and intensity of turbulence, used to calculate the draught risk(DR), in terms of percentage of people dissatisfied Graph 26 and

Graph 27 present an example of air speed and DR obtained in a classroom with different mode of operating HVAC systems and natural ventilation.



Graph 26 - Typical air velocity

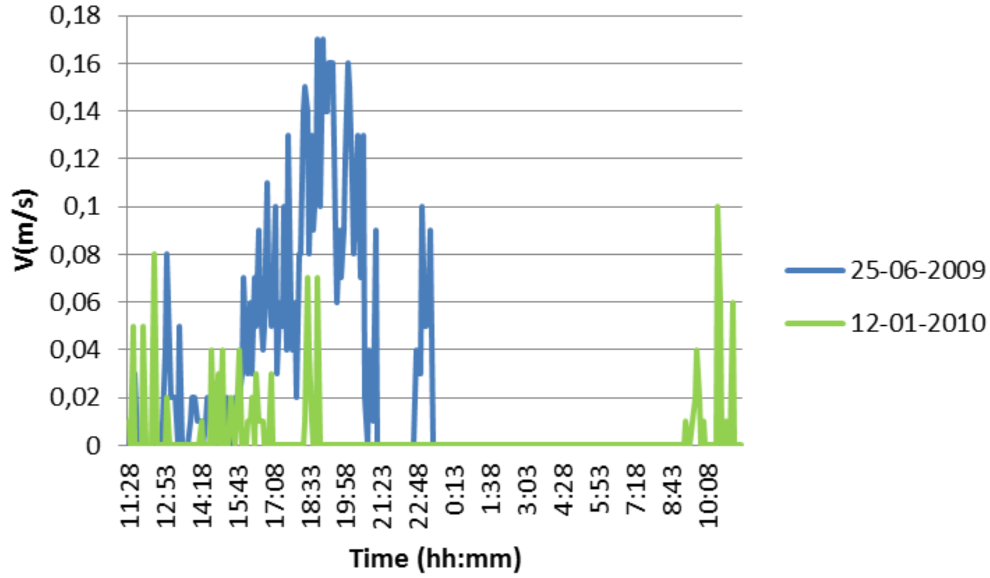
The system HVAC discontinuous or intermittent (DCV) is the one that presents higher air speeds, not being a good solution to avoid complaints. However in both cases of mechanic ventilation, the recommended values of air speed are exceeded.



Graph 27 - Percentage of dissatisfied due to draught risk

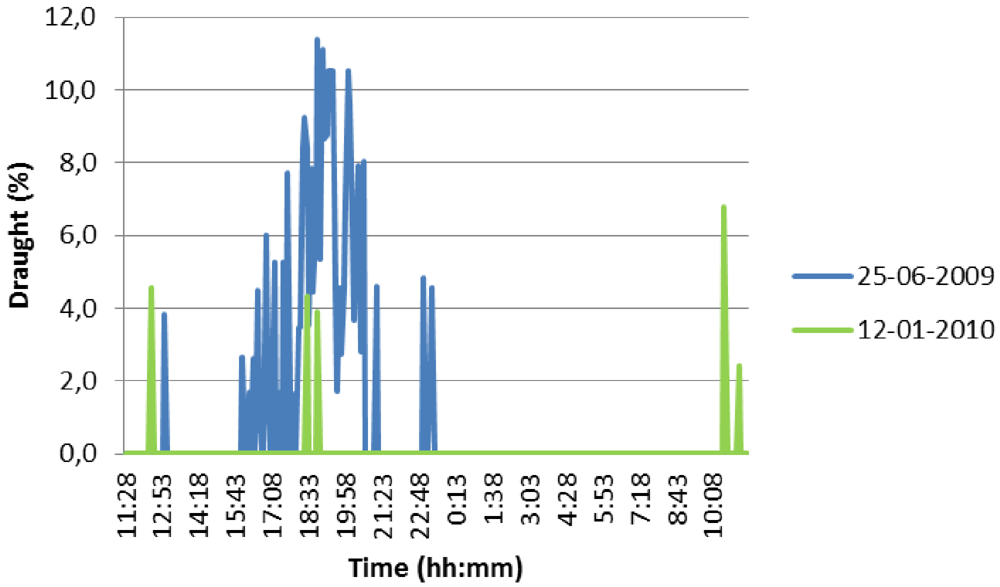
In systems HVAC we always have draught (air streams) superiors to natural ventilation.

Graph 28 and Graph 29 present an example of air velocity and DR obtained in a teacher cabinet, with system HVAC, during summer (25/06/2009) and winter (12/01/2010).



Graph 28 - Local air velocity in a room with a HVAC system

The air speed in summer is superior to winter, to assure comfort. This happens because in the winter the thermal load of the building envelope helps to maintain the necessary comfort conditions. In this case the recommended values to the air speed aren't exceeded.

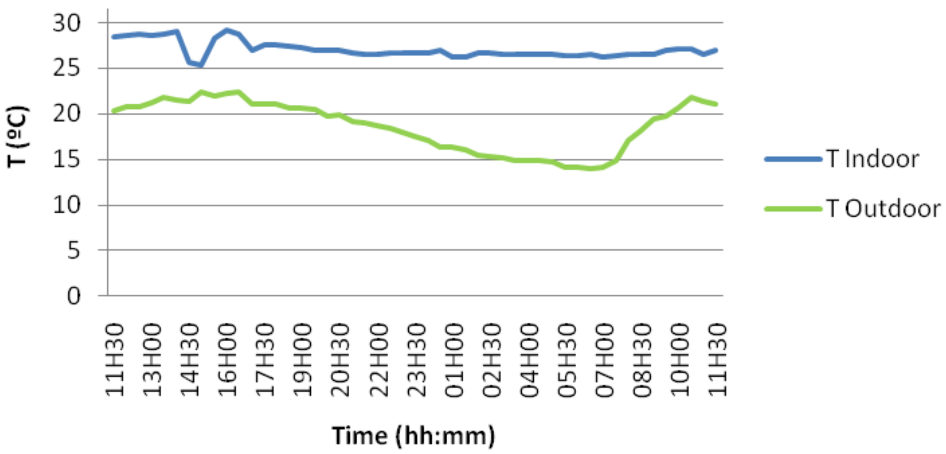


Graph 29 - Local draught in a room with a HVAC system

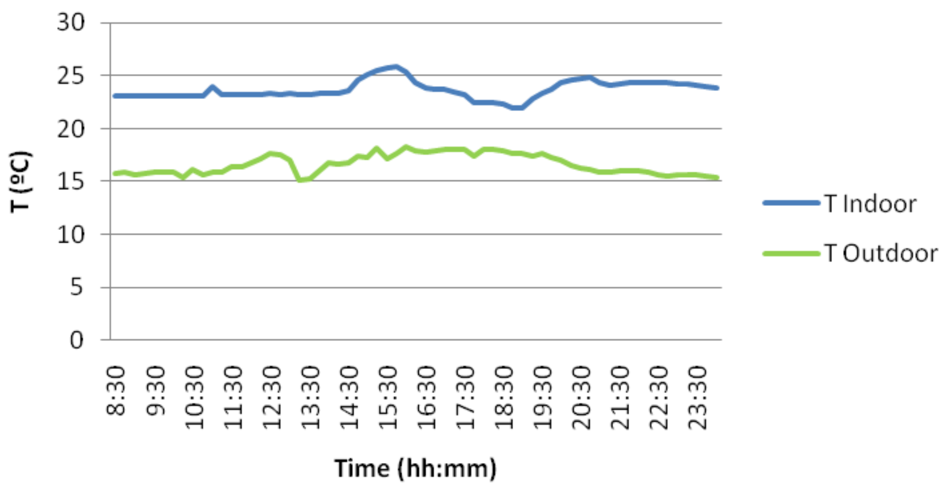
In summer the draught risk is superior to winter, so the occupants can complain about it.

The global conditions of the obtained temperatures through direct measure and calculation of the PMV and PPD indicator, at different points gave neutral results or slightly hot. The experimental values were according the subjective questionnaires results but having a higher percentage of neutral. It wasn't found a significant difference between the different types of ventilation. About the local thermal conditions, it was registered a higher percentage of dissatisfied people due to draught, in buildings with mechanical ventilation systems. People with light activities are sensitive to high air speed and turbulence intensity. The draught risk are the most common reason for complains in buildings with mechanical ventilation systems, and also the big difference between mechanic systems and natural ventilation.

Sometimes we can change the set point of the air temperature, according to the internal and external conditions, increasing the energy efficiency.



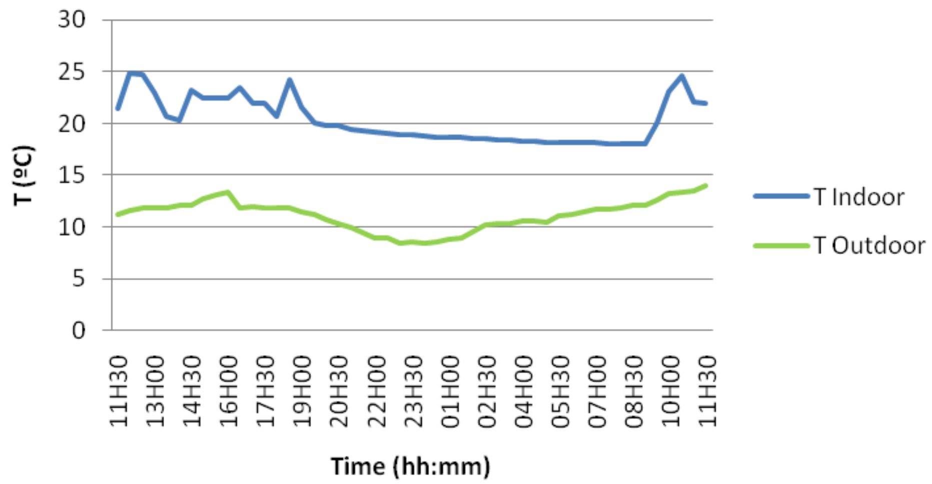
Graph 30 - Local air temperature in an office room with a HVAC system in summer season (25-06-2009)



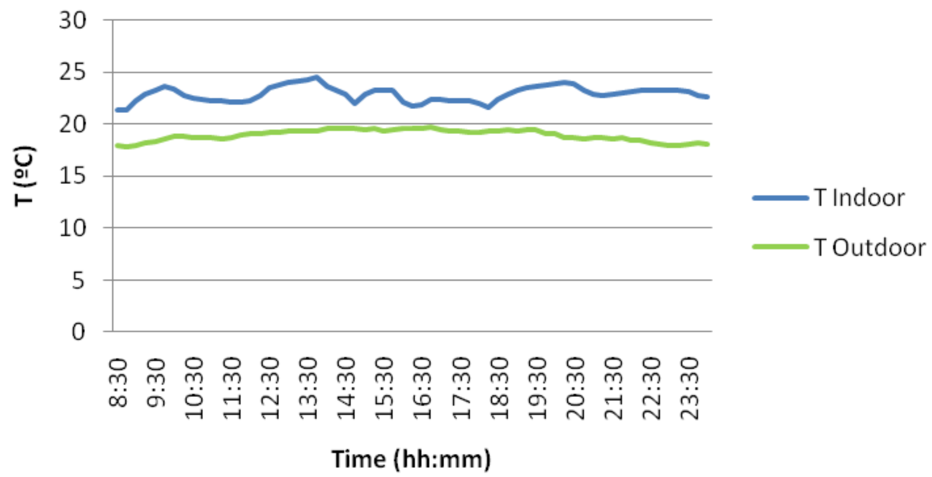
Graph 31 - Local air temperature in a classroom with a HVAC system in summer season (25-06-2010)

The mechanic system doesn't have indoor and outdoor temperature sensors. That's why it works without the outdoor characteristics.

The difference between the indoor and outdoor temperature is essential to parameterize the heat loss and to understand any heating or cooling demand in terms of meeting the occupants comfort.



Graph 32 - Local air temperature in an office room with a HVAC system in winter season (12-01-2010)



Graph 33 - Local air temperature in a classroom with a HVAC system in winter season (10-12-2010)

When there isn't a temperature sensor in the local, the system isn't controlled, so sometimes the occupants complain.

To the expected type of activity inside Higher Education Buildings, where there is sedentary work, mostly intellectual work, with high levels of occupation, it is recommended lower air temperature than the ones found in winter, from 20ºC to 25ºC, to have a better thermal comfort and consequently a higher productivity and reduce absence of fatigue.

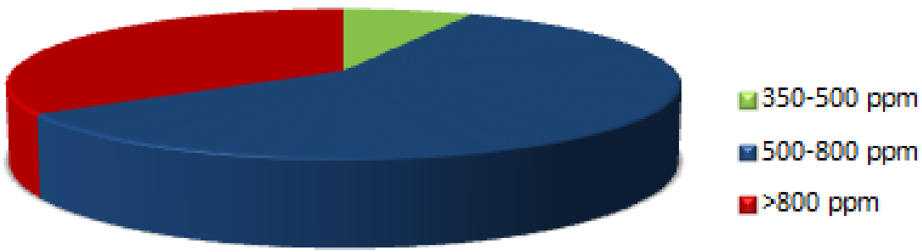
Small variations of temperature, with adequate control, gives us better results and avoid complains from the users. The control positions must be adjusted and temperatures should be lowers on winter and higher on summer, to save energy, satisfying the minimum requirements of IAQ.

6.6 Indoor Air Quality

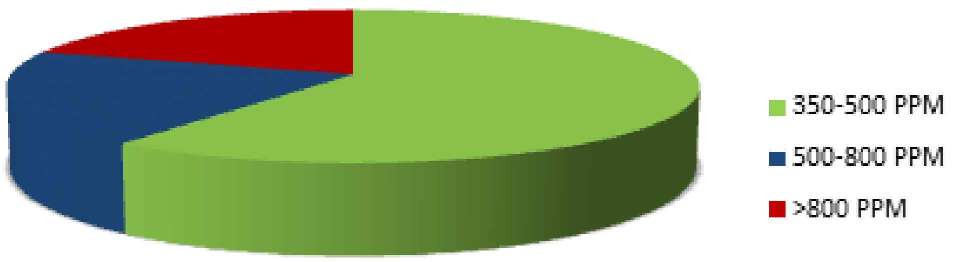
Figure 57 - Portable IAQ equipments

The direct measurements of the indoor air quality (IAQ) included the following parameters: particulate matter, carbon dioxide, carbon monoxide, ozone, formaldehyde, volatile organic compounds and microbiologic analysis. The measurements were done according to the international standards and the Portuguese and Spanish regulation.

The objective results (direct measurement) were registered according to the different categories of EN 15251 Standard [81], above the measurements of outdoors CO_2. The average of the outdoors measurements was equal to 458 ppm for the cold season (Winter), while in the hot season (Summer) it was 401ppm.

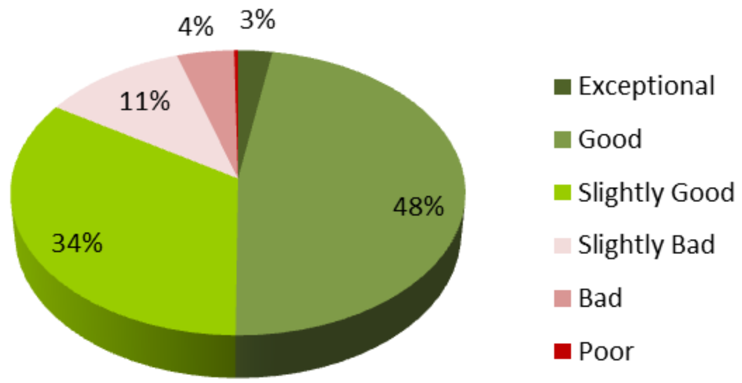


Graph 34 - Distribution of the carbon dioxide concentrations (ppm) depending on the winter, in the studied environments



Graph 35 - Distribution of the carbon dioxide concentrations (ppm) depending on the summer, in the studied environments

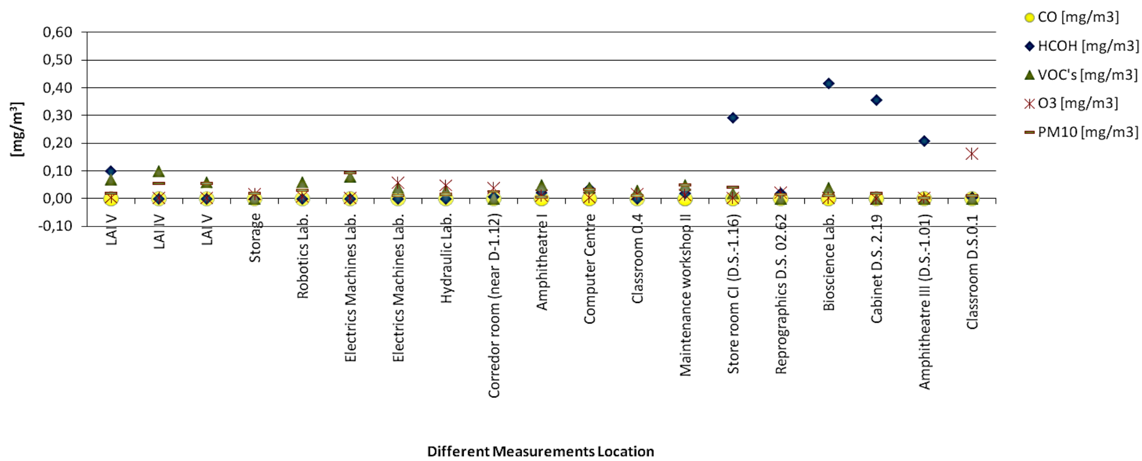
The graphic bellow represents the subjective results of the questionnaire, obtained in different days and with different modes of operating system.



Graph 36 - Results of the subjective questionnaires referent to Indoor Air Quality

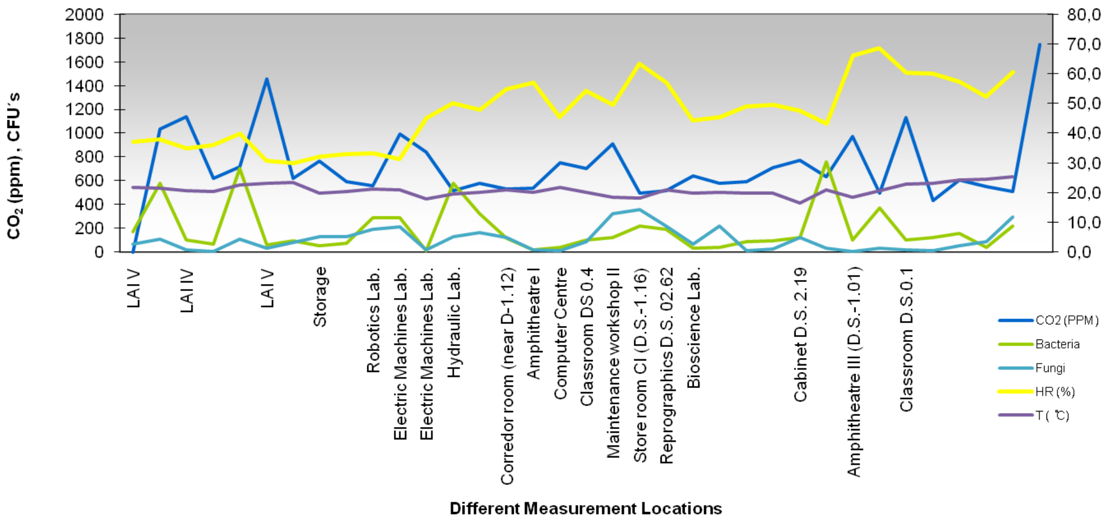
The results showed that a higher percentage of occupants are satisfied about the Indoor Air Quality.

The PM_{10} values, carbon monoxide, ozone and volatile organic compounds are below the recommended values. The formaldehyde exceeds the maximum recommended in Portugal (0.1 mg/m^3) in 4 points.



Graph 37 – Results of the direct measurement from different parameters of IAQ

The following graphic shows the parameters that are more connected to the occupation of schools (carbon dioxide, bacteria, fungi, relative humidity and temperature).



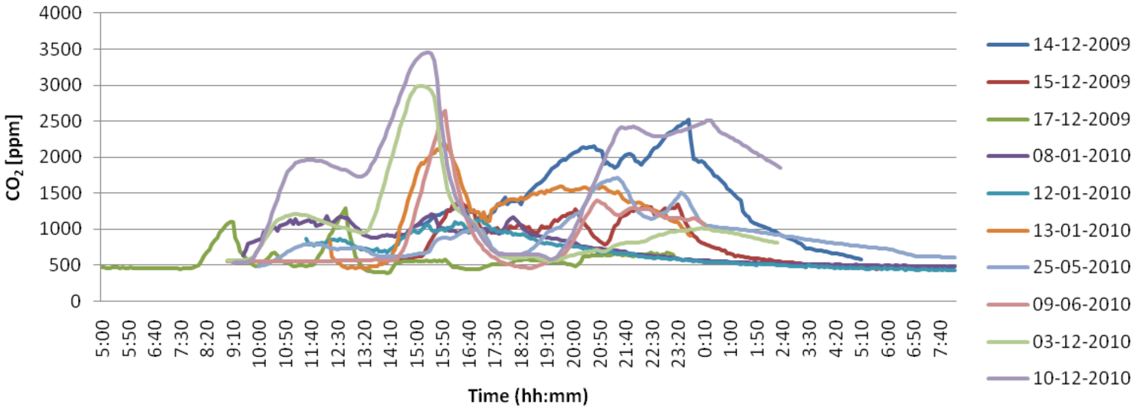
Graph 38 - Results of the direct measurement from different parameters of IAQ

The *temperature and humidity*, parameters that change to provide the thermal comfort conditions, in certain circumstances can give origin to the appearing of certain contaminants. So, high temperatures favour the appearing of some chemical substances in the environment, being present in the materials with which buildings are built. On the other side, the control of the relative humidity is important to limit the growing of certain microorganisms. That's why it is important to maintain always humidity under 30 to 70% to avoid their growing, mainly when the space isn't being used.

We can observe that the values of the bacteria are equal to the values of CO_2, felt where the measurement was done, the same way that the values of the fungi are equal to the relative humidity.

As expected, the concentration of CO_2 and relative humidity vary according to the occupation conditions (number of people and time of occupation). As CO_2, microbiologic values also vary according to the occupation conditions (number of people and time of occupation).

Concerning to the evaluation of the indoor air quality in the university buildings, a typical indicator is CO_2 level.

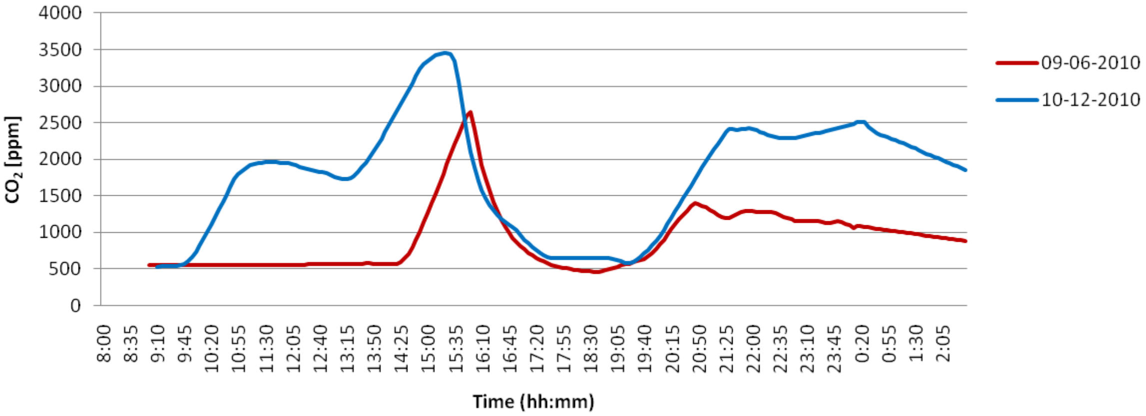


Graph 39 - Long term measurements of CO_2 in a classroom

As we can verify in the previous graphic, it is very easy to exceed the established value in Portugal and Spain.

The occupancy density and behaviour seems to be a important factor which affects the supply flow rate per person and thus may affect the energy saving. The ventilation system in Higher Education Buildings should have sensors of CO_2 in each zone, because of the occupation in this type of buildings is fluctuating. This means that a room can be full in this moment, but the next moment can only have 5 students, and the next hour can be empty.

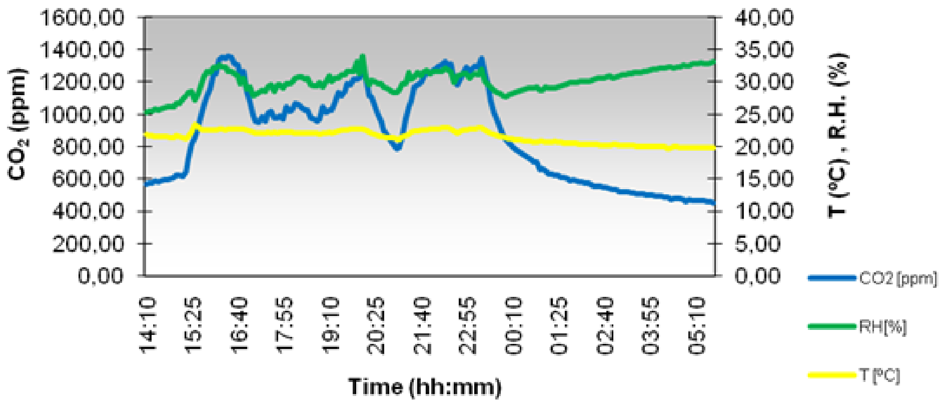
The Graph 40 presents an example of carbon dioxide concentration (CO_2) obtained in a classroom with natural ventilation, during summer (09/06/2010), and winter (10/12/2010).



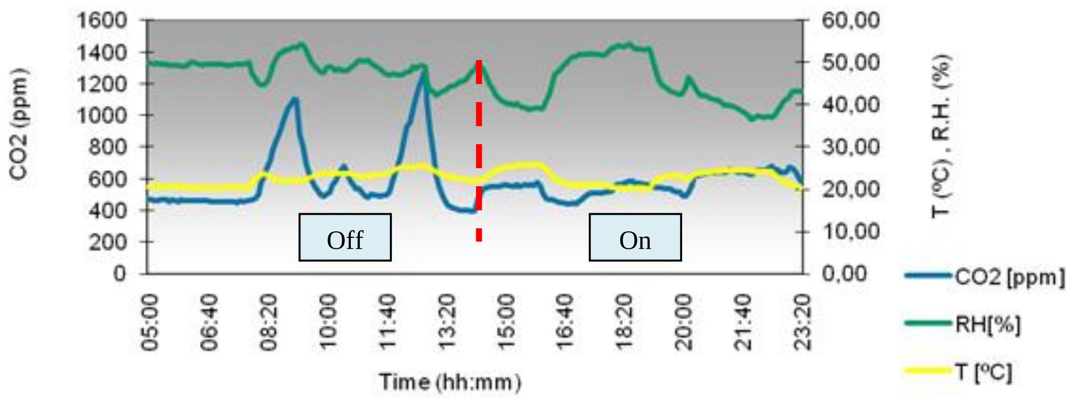
Graph 40 - Long term measurements of CO_2 in a classroom for warm and cold season

The cold season shows a higher concentration of CO_2, while the hot season shows lower values. During the hot season there is more air changes per hour from the outside.

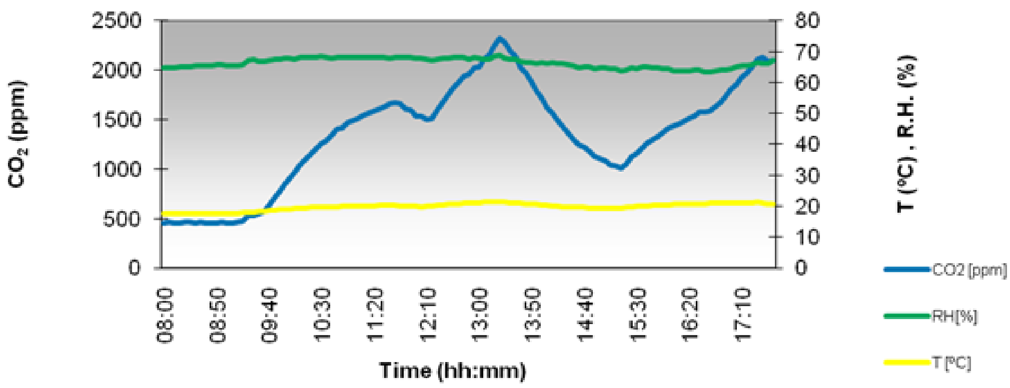
The measurements represented in the following figures, present CO_2 values, from the air temperature and relative humidity values obtained in different operating mode. Graph 41 represents demand controlled ventilation in HVAC conditions (because the system switches on and off all day (discontinuous or intermittent), trying to obtain the requested temperatures by the Technical Cabinet to the Building Management System). Graph 42 represents HVAC off/on conditions (it means the system was switched off till noon and then was always on). Graph 43 shows the result of a classroom with natural ventilation.



Graph 41 – Demand controlled ventilation



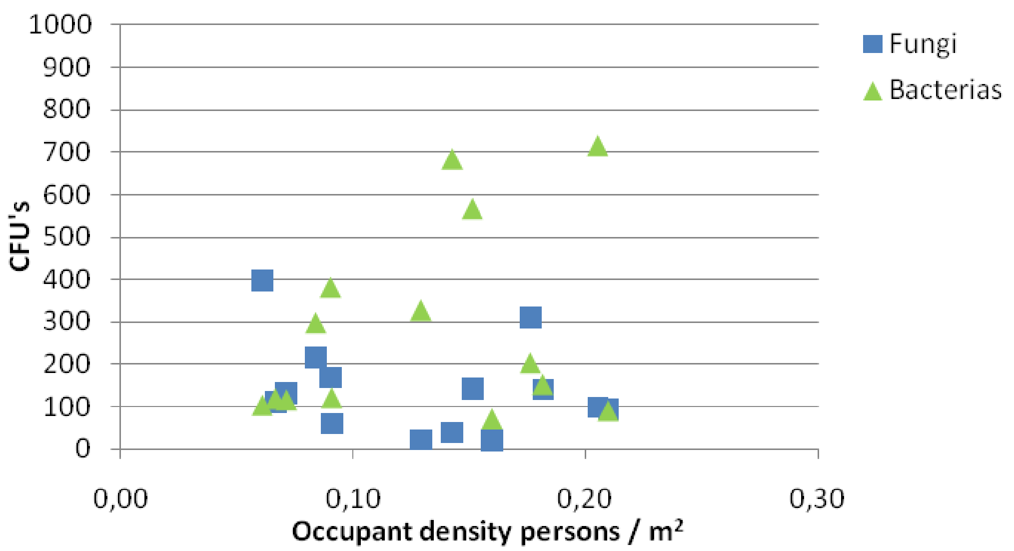
Graph 42 - HVAC Off/On conditions



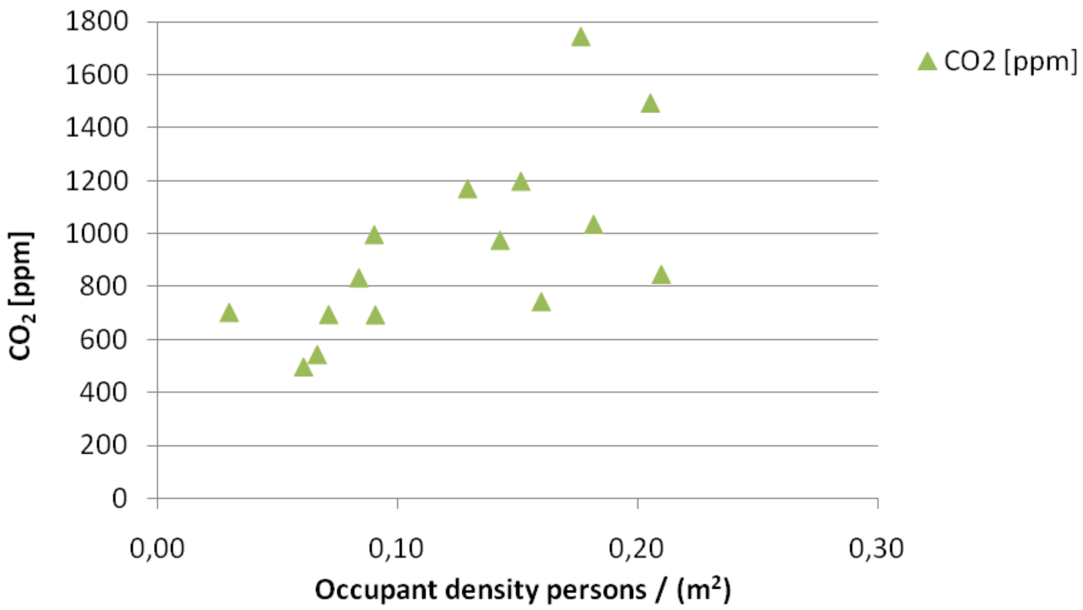
Graph 43 - Natural ventilation conditions

In general, all the pollutants evaluated inside of the buildings were of low concentration, not only in the natural ventilation but also in the mechanic ventilation. However, most of the measured values of CO_2 exceeded the values permitted by the Portuguese legislation (984 ppm) and Spanish (1000 ppm) in different rooms of the building, as a result of inadequate ventilation. After the measurements done, it was verified that the natural ventilation is not enough to guaranty a good IAQ related to CO_2 concentration. Even with mechanic ventilation, when the system is off or discontinuous (DCV), the air quality isn't assured. With the HVAC continuous we can assure a good IAQ. Usually the high percentage of people dissatisfied is due to air streams in buildings with HVAC systems. A way to change the situation is to increase the temperature in the room to neutralize the sensation of cooling, increasing the energy consumption. Another way is to switch off the ventilation systems or block the air flowing, causing a deterioration of the indoor air quality or another solution is new diffusers.

The hybrid ventilation is the best solution for this type of buildings. The mechanic ventilation systems are effectively necessary but have higher energy consumption. The building management system should be able to respond to different settings (indoor temperature, CO_2 level, automatic control for naturally ventilated building, room occupancy, relative humidity, rain detection, outside air temperature, wind speed and wind direction sensors).



Graph 44 - Fungi and Bacteria vs. occupant/m^2



Graph 45 - CO_2 vs occupant/m^2

The density of occupation has an effect over the IAQ in the classrooms. Not all the rooms follow the requirements of 2 m^2/person (0,5 persons / (m^2)).

The ventilation controlled by the CO_2 concentration used as an indicator of the occupation level, modelling the exterior air flow according to the CO_2 existent in that moment. This system can save energy in spaces with a variable occupation and where the densities of occupation can be too highs, like the university buildings.

The system should have a control to guaranty the entry of exterior air in periods of too low or any occupation, permitting the dilution of possible contaminants.

In the summer, it can be used the fresh air at night, to cool the building and save the *"free cooling"* energy, eliminating most of the contaminants accumulated, from the air renewal.

Overheating in summertime is one of the potential problems that can be ensured through the night-time cooling temperatures during periods of high ambient temperature.

Night ventilation affects internal conditions during the day, reducing the peak temperature of the air, reducing the air temperature in the morning and creating a time interval between the occurrence of maximum temperatures internal and external. The effectiveness of night ventilation cooling depends on three main parameters:

- The temperature and flow of ambient air circulated in the building during the night;
- The thermal capacity of storage;
- The quality of the heat transfer between air and the thermal mass.

However, the night ventilation must be carefully controlled to avoid overcooling of the building structure.

It is also possible to guide mark zones for natural ventilation in the building. Zones that are usually occupied for long time periods, can be natural ventilated especially on evening and night time, keeping them separately accessed and controlled. This approach ensures comfortable working conditions for the occupants at night, without compromising the night time cooling procedures of naturally ventilated areas.

Finally, for higher density areas of occupation, the cooling potential of natural ventilation may not be sufficient to prevent IAQ and the mechanical systems must support to achieve the required goals.

It is support by the monitoring data that Higher Education Buildings, to perform well, need good controls and a sound understanding of the control strategy should enter the culture of building occupants. The occupants will change the behaviour for appropriate behaviour according with the building specifications proposed, such as ventilation of the building at appropriate times.

The aspects of the internal environment, such as thermal comfort, visual comfort, acoustic comfort, indoor air quality and construction criteria, can all have an strong impact on the energy performance, but occupant satisfaction is also highly dependent on these parameters. Generally, the Higher Education Buildings have a poor IEQ, because the buildings are occupied by a large number of students. It is necessary to have adequate ventilation to remove the indoor air contaminants and to promote an adequate air changes per hour.

The following tables present the measurements done in *Building D*. The parameters that exceed the Portuguese and Spanish regulation have a colour, indicated in Table 42.

Both	*Portugal*	*Spain*
(orange)	(olive green)	(red)

Table 42 - Chromaticity diagram

Date	Location	A (m^2)	Time	Occupation		T (ºC)	RH (%)
				Number of Persons	Maximum Occupation		
14-12-2009	LAI V (Laboratory of Computer Applications)	99	14:50	18	39	21.7	37.2
			14:56			21.7	37.2
			17:55	15		21.5	37.9
			18:05			21.8	39.1
	Outdoor	-	15:43	-	-	15.9	38.3
15-12-2009	Outdoor	-	11:15	-	-	10.2	36.8
		-	19:40	-	-	8.9	45.2
	LAI IV	73	10:15	NA	39	20.7	34.8
			10:29			20.4	35.9
			14:03	15		22.6	39.9
			14:11			23.2	39.1
	LAI V	99	12:03	9	39	23.0	30.8
			12:12			23.3	30.0
	Storage	215	15:36	NA	NA	19.8	32.0
			15:45			20.3	32.8
	Robotics Lab.	177	17:07	16	24	21.1	33.3
			17:16			21.4	33.6
	Electric Machines Lab.	119	18:17	10	32	20.9	31.3
			18:27			21.2	31.8

Table 43 – Temperature and relative humidity measurements

Date	Location	A (m^2)	Time	Occupation		T (ºC)	RH (%)
				Number of Persons	Maximum Occupation		
16-12-2009	Outdoor	-	10:30	-	-	7.5	77.2
		-	13:46	-	-	11.1	71.3
	Electric Machines Lab.	119	11:20	NA	32	17.9	45.1
			11:30			17.8	45.6
	Hydraulic Lab.	214	14:19	4	30	19.5	50.2
			14:29			20.0	47.8
			15:08			20.8	48.2
	Corridor (near D-1.12)	60	17:04	NA	NA	20.9	54.9
17-12-2009	Outdoor	-	14:48	-	-	18.5	56.5
		-	15:24	-	-	15.6	64.2
	Amphitheatre I	262	17:33	43	206	20.0	57.0
			17:51			20.4	54.7
	Computer Centre	67	21:09	3	8	21.8	45.5
			21:17			20.7	45.1
18-12-2009	Outdoor	-	11:18	-	-	10.0	76.5
		-	15:46	-	-	10.9	69.4
	Classroom 0.4	100	11:45	21	82	20.2	54.2
			12:04			21.3	48.1
	Maintenance Workshop II	82	16:30	5	8	18.5	49.6
04-01-2010	Outdoor	-	10:33	-	-	14.1	74.7
	Storage CI	38	11:12	NA	NA	18.2	63.3
	Copy room D.S. 02.62	13	14:41	NA	1	20.8	57.1
06-01-2010	Bioscience Lab.	150	15:37	NA	25	19.9	44.2
			15:47			20.2	45.4
			17:32	24		-	-
			17:23			19.8	49.4
	Outdoor	-	17:03	-	-	9.1	81.9

Table 44 – Temperature and relative humidity measurements (Cont.)

Date	Location	A (m^2)	Time	Occupation		T (ºC)	RH (%)
				Number of Persons	Maximum Occupation		
08-01-2010	Outdoor	-	9:06	-	-	2.9	66.3
		-	18:29	-	-	7.0	61.8
	Cabinet. D.S. 2.19	14	9:39	1	4	16.6	47.6
			18:00	2		21.0	43.2
13-01-2010	Outdoor	-	13:13	-	-	20.5	64.4
		-	21:41	-	-	19.7	67.0
	Amphitheatre III	116	13:34	NA	105	18.3	66.2
			13:59			20.7	64.4
			22:33	15		20.5	68.6
			22:54			21.9	68.4
25-05-2010	Outdoor	-	10:37	-	-	18.7	74.5
		-	13:50	-	-	20.0	73.7
		-	21:27	-	-	16.4	79.8
	Classroom D.S.0.1	102	10:01	NA	79	22.8	60.3
			10:15			22.8	60.3
			13:08	23		23.0	60.0
			13:15			23.3	59.5
			14:14	NA		24.2	57.2
			14:23			23.9	58.0
			17:15	35		24.4	52.3
			17:25			24.8	51.8
			20:51	18		25.3	60.5
			20:58			25.1	61.3

Table 45 – Temperature and relative humidity measurements (Cont.)

In Spanish law is required to the Relative Humidity (RH) be between 30 and 70 %, and in Portuguese law the recommendation is only to be closer to 50 %. We use as reference range 30 to 70% of RH.

Date	Location	Time	HCHO [ppm]	VOC [mg/m^3]	O_3 [ppm]	PM_{10} [mg/m^3]	CO [ppm]	CO_2 [ppm]
14-12-2009	LAI V (Laboratory of Computer Applications)	14:50	0.08	0.07	0.002	0.019	0	1035
		14:56	0.08	0.07	0.002	0.019	0	1035
		17:55	0.139	0.16	0.001	0.036	0	1140
		18:05	0.073	0.08	0.001	0.028	0	1255
	Outdoor	15:43	-	-	-	0.021	-	613
15-12-2009	Outdoor	11:15	-	-	-	0.029	-	559
		19:40	-	-	-	0.042	-	405
	LAI IV	10:15	0	0.10	0.001	0.055	0	619
		10:29	0.037	0.05	0.001	0.046	0	717
		14:03	0	0.04	0.002	0.033	0	1459
		14:11	0.024	0.07	0.001	0.031	0	1529
	LAI V	12:03	0	0.06	0.001	0.055	0	619
		12:12	0.026	0.05	0.004	0.024	0	765
	Storage	15:36	0	0.00	0.008	0.020	0	595
		15:45	0	0.01	0.007	0.019	0	554
	Robotics Lab.	17:07	0	0.06	0.004	0.030	0	992
		17:16	0	0.04	0.004	0.028	0	1000
	Electric Machines Lab.	18:17	0	0.08	0.001	0.094	0	840
		18:27	0	0.04	0.001	0.058	0	826
16-12-2009	Outdoor	10:30	-	-	-	0.017	-	415
		13:46	-	-	-	0.030	-	424
	Electric Machines Lab.	11:20	0	0.04	0.029	0.010	0	513
		11:30	0	0.01	0.029	0.009	0	466
	Hydraulic Lab.	14:19	0	0.03	0.024	0.017	0	579
		14:29	0	0.04	0.022	0.017	0	528
		15:08	0	0.01	0.031	0.017	0	519
	Corridor (near D-1.12)	17:04	0.006	0.00	0.019	0.026	0	535

Table 46 - Physic - chemical measurements

Date	Location	Time	HCHO [ppm]	VOC [mg/m^3]	O_3 [ppm]	PM_{10} [mg/m^3]	CO [ppm]	CO_2 [ppm]
17-12-2009	Outdoor	14:48	-	-	-	0.016	-	459
		15:24	-	-	-	0.010	-	363
	Amphitheatre I	17:33	0.018	0.05	0.005	0.005	0	751
		17:51	0.032	0.00	0.004	0.013	0	674
	Computer Centre	21:09	0.029	0.04	0.002	0.032	0	705
		21:17	0	0.01	0.003	0.023	0	698
18-12-2009	Outdoor	11:18	-	-	-	0.019	-	460
		15:46	-	-	-	0.022	-	425
	Classroom 0.4	11:45	0	0.03	0.008	0.012	0	907
		12:04	0	0.04	0.006	0.008	0	784
	Maintenance Workshop II	16:30	0.016	0.05	0.007	0.050	0	495
04-01-2010	Outdoor	10:33	-	-	-	0.003	0	496
	Storage CI	11:12	0.234	0.02	0.001	0.041	0	518
	Copy room D.S. 02.62	14:41	0.016	0.00	0.011	0.015	0	643
06-01-2010	Bioscience. Lab.	15:37	0.333	0.04	0.001	0.012	0	577
		15:47	0.402	0.05	0.001	0.013	0	592
		17:32	0.015	0.03	0.003	0.013	0	711
		17:23	0.251	0.03	0.003	0.016	0	774
	Outdoor	17:03	-	-	-	0.074	0	475
08-01-2010	Outdoor	9:06	-	-	-	0.047	0	454
		18:29	-	-	-	0.101	0	557
	Cabinet D.S. 2.19	9:39	0.285	0.00	0.000	0.020	0	632
		18:00	0.056	0.04	0.001	0.024	0	975
13-01-2010	Outdoor	13:13	-	-	-	0.025	-	514
		21:41	-	-	-	0.076	-	411
	Amphitheatre III	13:34	0.167	0.00	0.002	0.003	0	495
		13:59	0.168	0.00	0.001	0.006	0	573
		22:33	0.339	0.02	0.000	0.026	0	1132
		22:54	0.298	0.05	0.000	0.023	0	1208

Table 47 - Physic - chemical measurements (Cont.)

Date	Location	Time	HCHO [ppm]	VOC [mg/m^3]	O_3 [ppm]	PM_{10} [mg/m^3]	CO [ppm]	CO_2 [ppm]
25-05-2010	Outdoor	10:37	-	-	-	0.033	-	385
		13:50	-	-	-	0.043	-	387
		21:27	-	-	-	0.091	-	433
	Classroom D.S.0.1	10:01	0.004	0.00	0.081	0.011	0	431
		10:15	0.004	0.00	0.081	0.011	0	431
		13:08	0.007	0.00	0.062	0.011	0	606
		13:15	0.008	0.00	0.054	0.013	0	657
		14:14	0.157	0.00	0.015	0.013	0	549
		14:23	0.166	0.00	0.020	0.012	0	533
		17:15	0.006	0.00	0.083	0.031	0	508
		17:25	0.01	0.00	0.077	0.031	0	508
		20:51	0.099	0.00	0.002	0.045	0	1745
		20:58	0.11	0.00	0.002	0.045	0	1748

Table 48 - Physic - chemical measurements (Cont.)

Date	Location	Time	V (m^3)	Q(m^3/h)	T (N/h)	R (N/h)
14-12-2009	LAI V (Laboratory of Computer Applications)	14:50	296.1	1170	3.95	0.2634
		14:56				
		17:55				
		18:05				
	Outdoor	15:43	-	-	-	-
15-12-2009	Outdoor	11:15	-	-	-	-
		19:40	-	-	-	-
	LAI IV	10:15	220.2	1170	5.31	0.4173
		10:29				
		14:03				
		14:11				
	LAI V	12:03	296.1	1170	3.95	NA
		12:12				
	Storage	15:36	643.2	1072	1.67	NA
		15:45				
	Robotics Lab.	17:07	351	840	2.39	NA
		17:16				
	Electric Machines Lab.	18:17	357.9	1120	3.13	NA
		18:27				
16-12-2009	Outdoor	10:30	-	-	-	-
		13:46	-	-	-	-
	Electric Machines Lab.	11:20	357.9	1120	3.13	NA
		11:30				
	Hydraulic Lab.	14:19	642	1050	1.64	NA
		14:29				
		15:08				
	Corridor (near D-1.12	17:04	155.6	299.3	1.92	NA

Table 49 -Measurements of the air flow rates and air changer per hour

Date	Location	Time	V (m^3)	Q(m^3/h)	T (N/h)	R (N/h)
17-12-2009	Outdoor	14:48	-	-	-	-
		15:24	-	-	-	-
	Amphitheatre I	17:33	786	6180	7.86	NA
		17:51				
	Computer Centre	21:09	200.1	280	1.40	NA
		21:17				
18-12-2009	Outdoor	11:18	-	-	-	-
		15:46	-	-	-	-
	Classroom 0.4	11:45	300	2460	8.20	NA
		12:04				
	Maintenance Workshop II	16:30	246	480	1.95	NA
04-01-2010	Outdoor	10:33	-	-	-	-
	Storage CI	11:12	135.6	191	1.41	NA
	Copy room D.S. 02.62	14:41	40.4	30	0.74	NA
06-01-2010	Bioscience Lab.	15:37	450	875	1.94	NA
		15:47				
		17:32				
		17:23				
	Outdoor	17:03	-	-	-	-
08-01-2010	Outdoor	9:06	-	-	-	-
		18:29	-	-	-	-
	Cabinet D.S. 2.19	9:39	41.3	140	3.39	0.4121
		18:00				
13-01-2010	Outdoor	13:13	-	-	-	-
		21:41	-	-	-	-
	Amphitheatre III	13:34	474	3150	6.65	0.6006
		13:59				
		22:33				
		22:54				

Table 50 -Measurements of the air flow rates and air changer per hour (Cont.)

Date	Location	Time	V (m^3)	Q(m^3/h)	T (N/h)	R (N/h)
25-05-2010	Outdoor	10:37	-	-	-	-
		13:50	-	-	-	-
		21:27	-	-	-	-
	Classroom D.S.0.1	10:01	307.2	2370	7.71	0.6091
		10:15				
		13:08				
		13:15				
		14:14				
		14:23				
		17:15				
		17:25				
		20:51				
		20:58				

Table 51 -Measurements of the air flow rates and air changes per hour (Cont.)

T - Theoretical air change rate (flow rate required to the sampling point volume).

R – Real air change rate (air changes per hour obtained true measurement of the CO_2 decay method).

All the users of the building should be aware of the need to air renewal and adopt a more efficient ventilation system, obtaining a good indoor air quality. Nowadays this is very important because most of our time is spent inside buildings.

The school buildings with natural ventilation are more ancient and were built with traditional materials. This can mean less pollution comparing to new buildings. Pollution is mainly produced by bio effluent. Besides, the natural ventilation with the opening of doors and windows can raise the air renewal rates.

The exterior new air flow must increase, to comply with the legislation in terms of air changes per hour, recommended for each type of building. The perception of the air quality increases when the ventilation rates increase.

Date	Location	Time	Bacteria (CFU)		Fungi (CFU)	
14-12-2009	LAI V (Laboratory of Computer Applications)	14:50	170	133	67	213
		17:55	577	557	110	175
	Outdoor	15:43	137	73	157	150
15-12-2009	Outdoor	11:15	40	77	173	170
	LAI IV	10:15	103	63	17	10
		10:29	67	67	3	10
		14:03	703	730	107	90
	LAI V	12:03	62	97	30	50
		12:12	93	147	80	40
	Storage	15:36	53	50	127	73
		15:45	73	63	127	87
	Robotics Lab.	17:07	290	473	193	143
	Electric Machines Lab.	18:17	290	305	213	217
16-12-2009	Outdoor	10:30	35	15	260	280
		13:46	35	55	410	395
	Electric Machines Lab.	11:20	10	25	15	25
	Hydraulic Lab.	14:19	575	395	130	160
		14:29	320	325	165	140
	Corridor (near D-1.12)	17:04	115	120	125	95
17-12-2009	Outdoor	14:48	170	155	255	290
		15:24	5	55	255	200
	Amphitheatre I	17:33	15	20	15	0
	Computer Centre	21:09	40	65	10	20
18-12-2009	Outdoor	11:18	30	25	265	215
		15:46	30	20	325	285
	Classroom 0.4	11:45	100	80	90	95
	Maintenance Workshop II	16:30	125	80	320	475
04-01-2010	Exterior	10:33	60	35	365	425
	Storage CI	11:12	215	220	360	385
	Copy room D.S. 02.62	14:41	190	255	220	270

Table 52 - Microbiologic measurements

Date	Location	Time	Bacteria (CFU)		Fungi (CFU)	
06-01-2010	Bioscience Lab.	15:37	30	45	65	85
		15:47	40	45	220	245
		17:32	90	70	10	20
		17:23	95	45	25	15
	Outdoor	17:03	25	30	340	460
08-01-2010	Outdoor	9:06	170	135	490	410
		18:29	220	270	255	330
	Cabinet. D.S. 2.19	9:39	120	110	120	145
		18:00	755	615	35	45
13-01-2010	Outdoor	13:13	60	65	385	370
		21:41	30	55	85	90
	Amphitheatre III	13:34	100	50	5	10
		22:33	370	285	30	15
25-05-2010	Outdoor	10:37	75	175	650	770
		13:50	80	45	400	290
		21:27	45	35	785	930
	Classroom D.S.0.1	10:01	100	85	15	20
		13:08	125	80	10	15
		14:14	155	115	50	65
		17:15	40	45	90	100
		20:51	215	190	295	325

Table 53 - Microbiologic measurements (Cont.)

After analysing and quantifying the bacteria *Legionella*, we verified that there isn’t contamination, the result was negative.

As we spent most of our time inside buildings, it is very important to obtain a good indoor environmental quality. It is very difficult to create an environment that assures comfort and security to all the occupants of Higher Education Buildings, because of the higher occupation, different clothes and different types of activities.

7 CONCLUSION

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

1st. The measurements made indicate that is convenient to maintain the temperature and relative humidity of the buildings on lower levels of thermal comfort. The different measurements showed that a reduction of temperature and relative humidity reduce some contaminants, therefore, also can reduce the sick building symptoms (SBS).

2nd. The dissatisfaction due to draught is caused, in many cases, by air velocity and turbulence intensity, so the cooling is caused not only by the air speed, but also by fluctuations in air flow. The cold sensation increases discomfort due to the draught. The percentage of people dissatisfied was higher in cold sensation than in neutral values. This happens because when people are in cold environments are less tolerant to air velocities, even if it is low. To minimize complaints it is necessary to reduce the air velocity, so that people don't feel cold.

3rd. 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.

4th. It is necessary to take into account, because of health risks, that in an attempt to reduce the energy consumption of buildings and, consequently, associated emissions of CO_2, the impacts of increased insulation can reduce air changes rates, and lead to a bad building designed, which produce overheating and poor indoor air quality. The level of carbon dioxide should be used as a measure of indoor air quality. Indoor CO_2 levels > 1000 ppm suggest inadequate ventilation rates in a occupied space. The outside air flow (ventilation) should be sufficient to dilute and remove indoor pollutants and moisture, and to provide an acceptable level of contaminants in indoor air. Ventilation rates should be based on pollution loads and in the use made of the building.

5th. The combined effect, in the indoor environment, of high air temperatures in the classrooms in winter, with high concentrations of CO_2, in extreme situations can cause symptoms of fatigue, headaches, and consequently less productivity.

6th. The recommended solution is the hybrid ventilation systems, where ventilation can be achieved through mechanical or natural forces or a combination of both. An important reason for using natural ventilation is the low power consumption, low CO_2 emissions and low operational maintenance.

7th. The naturally ventilated buildings tend to be more desirable to the occupants relatively to those that use mechanical ventilation only. In case of densely populated areas on Higher Education Buildings such as classrooms or conference rooms, CO_2 sensors should be used in conjunction with temperature sensors. The key problem is to provide the total control system, sufficient but not excessive ventilation, avoid drafts, etc. In addition to indoor air temperature and CO_2 sensors, should exist an automatic control of natural ventilation, occupancy sensors, relative humidity, rain detection, outside air temperature, wind speed and wind direction.

The mechanical ventilation systems are indeed necessary, but they have an higher energy consumption. The system of *Building D*, the object of our study, doesn't have temperature sensors and CO_2 sensors. This inevitably leads to increase energy consumption due to bad control of the building management system. The system doesn't count with internal loads, not even with the outside temperature. A natural ventilation system with the support of a mechanical system with indoor and outdoor temperature sensors, and CO_2 sensors, would reduce a significant percentage of energy consumption and also contribute to improve the behaviour of the occupants, like opening windows to ventilate.

8th. There are some building intrinsic properties, such as infiltration rates, which affect the internal conditions such as temperature and ventilation rates. Another key aspect is the behaviour of the occupants and their actions that affect the internal conditions - for example, adjusting the thermostat or open the windows. The relationship between the building and the final energy used is also related to the behaviour of the occupants.

Changes in occupants behaviour can be very difficult to predict and can result in a less effective performance of energy efficiency measures than expected, even to the point of lead to inappropriate results.

9th. The air flow rates are too low in the situations of natural ventilation or high density and long-term occupation. The situation where exist a system operating mode with discontinuous ventilation or intermittent (the ventilation demand controlled by temperature) does not allow us to ensure a good indoor air quality and often lead to an inadequate energy consumption. By contrast, in continuous operation mode we have a good indoor air quality (increases the number of air changes per hour), increases energy consumption, consuming a large amount of energy to over ventilate the building. The results show a large variation 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.

10th. The number of sensors required increases significantly the investment costs. However, this is compensated by ensuring a good indoor air quality, reducing the risk of sickness and increasing productivity.

11th. The acoustic conditions also play an important role in the higher education buildings, the noise-related effects are in most cases related to problems that have to do with the reverberation time. A good acoustic comfort in higher education buildings will allow students to play their roles on listening, learning and understanding with a maximum normality. An insufficient perception and a high background noise may be the cause of the decline in student performance. It might also cause health problems for occupants. Along with some of the common symptoms of the usually-called sick buildings, the *Building D* of our study, shows a high level of reverberation time, which results in an increased of fatigue and makes it hard to concentrate. It is common in such kind of buildings that exists a number of classrooms with the same architectural arrangement that allows doing previous studies for optimizing acoustic.

12th. Regarding the lighting, we conclude from our study that it represents one aspect of most importance in energy saving. Anyway, it appears that there are many activities that can be affected by poor lighting, making it necessary to change the lighting conditions in higher education buildings to obtain better results in terms of energy saving. Lighting and solar shading should be controlled by sensors of illuminance level, which will result in an improvement of energy efficiency and indoor environmental quality. The supply of natural light into a space, can replace the use of electricity for lighting, avoiding a major expense, but should be available to avoid a possible glare and an excessive solar gain.

13th. The objective results obtained in our study, allow us to state that the building has acceptable levels for different environmental factors. The temperature varied around 22 °C. The illumination level was acceptable, about 500 lux and the average noise of 60 dB. According to the questionnaires results (subjective results), the different factors have in a general way one satisfactory level.

14th. 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.

15th. The main advantage of using a simulation of airflow and thermal models on *DesignBuilder / EnergyPlus* is precisely that the internal temperature is calculated as part of the simulation. This type of software, surely, requires a new level of detail to perform a complete simulation of the thermal energy. In the light of our work, in this field, we underline that are important disadvantages of this type of modelling, the fact that the program assumes that external and internal concentrations are spatially uniforms, does not include urban planning, do not take into account the dispersion of air pollutants, wind direction, etc… This are disadvantages of high complexity, such as the complex processes of dispersion around the construction. Other environmental parameters, such as local weather, also play an important role by influencing indoor conditions in an indirect way. There is imperative need of more and better weather files. The validation is also an important issue that should have more complex requirements, to achieve similar results in all the cases.

Dynamic simulations were conducted to predict the temperature inside the building through the year, taking into account the solar protection, thermal inertia and heat gains previews.

16th. 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).

Taking in account that the effects of night cooling and exposed thermal mass were not considered in the simulations, the results could be better than expected. The simulation results indicated that the time and mode of operation are very important to maintain good indoor environmental conditions. One of the difficulties of the simulation work performed was the effort required to model the building design and the time taken to run each simulation (approximately two weeks).

17th. 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).

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.

The construction energy efficiency is each time more important, as well as the measures taken to reduce their carbon footprint. The renewable energy technologies that are considered applicable for onsite energy production, may contribute on a short-term to achieve the nearly zero energy buildings goals using solar energy and biomass.

However, the overall solution requires several combinations and technical and economic interventions that provide a more economic and sustainable scenario. The environmental sustainability, the management of the available resources as well as the energetic efficiency will allow strategies in the future to obtain an economic and environmental value added.

8 CONCLUSIONES

Las medidas realizadas a lo largo de este estudio nos permiten obtener las siguientes conclusiones:

1ª Resulta favorable mantener la temperatura y la humedad relativa de los edificios en niveles inferiores a los correspondientes al confort térmico. Las diferentes medidas mostraron, que una reducción de la temperatura y de la humedad relativa reducen la presencia de algunos contaminantes y, por supuesto, también puede reducir los síntomas de edificio enfermo.

2ª La insatisfacción de los ocupantes por corrientes de aire está causada, en muchos casos, por la velocidad del aire y la intensidad de su turbulencia, por lo que la refrigeración es consecuencia no sólo de la velocidad del aire, sino también de las fluctuaciones en el flujo del mismo. La sensación de frío aumenta el malestar. El porcentaje de personas insatisfechas es mayor cuando existe sensación de frío, más que en valores considerados neutros, esto ocurre porque la gente en ambientes fríos es menos tolerante a la velocidad del aire, incluso si ésta es baja. Para minimizar las quejas es necesario reducir la velocidad del aire para que la gente no tenga sensación de frío.

3ª Comparando las tasas de ventilación alcanzadas, representadas por las tasas de cambio de aire, con las recomendadas por las normas, y debido a errores relativos, se llegó a la *conclusión* de que, la temperatura del aire, el dióxido de carbono, los niveles de formaldehido, bacterias, hongos y las tasas de cambios de aire se encuentran en niveles muchas veces inaceptables.

4ª Que es necesario tener en cuenta, por ser riesgos para la salud, que en el intento por reducir el consumo energético de los edificios y por consiguiente las emisiones de CO_2, el aumento del aislamiento puede reducir las tasas de cambio de aire, y conducir a edificios mal diseñados, donde se produzca sobrecalentamiento y una calidad del aire interior pobre. El nivel de dióxido de carbono debe usarse como una medida de la calidad del aire interior. Así, niveles interiores de CO_2 > 1000 ppm, indican tasas de ventilación inadecuadas en espacio ocupado. El flujo de aire exterior (ventilación) debe ser suficiente para diluir y eliminar los contaminantes del interior y la humedad, y para proporcionar un nivel aceptable de contaminantes en el aire interior. Las tasas de ventilación deben ser función de la carga de contaminación y de la utilización que se haga del edificio.

5ª Que el efecto combinado, en el ambiente interior, de altas temperaturas del aire, dentro de las aulas en invierno, con altas concentraciones de CO_2, en situaciones extremas, pueden causar síntomas de cansancio, dolores de cabeza y consecuentemente menos productividad.

6ª La solución más recomendable es la ventilación híbrida de los sistemas de ventilación, que puede conseguirse mediante fuerzas mecánicas o naturales o una combinación de ambas. Una razón importante para el uso de la ventilación natural es el bajo consumo energético, bajas emisiones de CO_2 y el mantenimiento operativo.

7ª Que los edificios con ventilación natural son los más deseables para los ocupantes frente a los que utilizan exclusivamente una ventilación mecánica. En el caso de zonas densamente pobladas en los edificios de educación superior, tales como aulas o salas de conferencia, los sensores de CO_2 deben usarse conjuntamente con los sensores de temperatura. El problema clave es el control total del sistema, ventilación suficiente pero no excesiva, evitar corrientes de aire, etc.. Además de la temperatura del aire y los sensores de CO_2, deberá tenerse un control automático de la ventilación natural, sensores de ocupación, humedad relativa, detección de lluvia, temperatura del aire exterior, velocidad y dirección del viento.

Los sistemas de ventilación mecánica son efectivamente necesarios, pero tienen un mayor consumo de energía. El sistema del *Edificio D,* objeto de nuestro estudio, carece de sensores de temperatura y de CO_2. Esto lleva inevitablemente a un aumento el consumo de energía, debido al mal control del sistema de gestión del edificio. El sistema no cuenta con las cargas internas, ni siquiera con la temperatura exterior. Un sistema de ventilación natural con el apoyo de un sistema mecánico, con sensores de temperatura interior y exterior, así como sensores de CO_2, reduce en un porcentaje significativo el consumo de energía y también contribuye a mejorar el comportamiento de los ocupantes, como abrir las ventanas para ventilar.

8ª Hay propiedades intrínsecas de la construcción, tales como las tasas de infiltración, que afectan a las condiciones internas tales como: la temperatura y las tasas de ventilación. Otro aspecto fundamental es el comportamiento de los ocupantes y sus acciones que influyen en las condiciones internas - por ejemplo, ajustar el termostato o abrir las ventanas. La relación entre el edificio y el uso final de la energía está relacionada también con el comportamiento de los ocupantes. Cambios en el comportamiento de los ocupantes pueden ser difíciles de predecir y pueden conducir a resultados inadecuados.

9ª Las tasas de flujo de aire son demasiado bajas en las situaciones de ventilación natural o con alta densidad y la ocupación a largo plazo. La situación en la que tenemos un modo de funcionamiento del sistema con ventilación discontinua o intermitente (la demanda controlada de ventilación por la temperatura) no nos permite garantizar la buena calidad del aire interior y lleva en muchas ocasiones a un gasto de energía inadecuado. Por el contrario, en el modo de funcionamiento continuo tenemos una buena calidad del aire interior (aumento del número de renovaciones de aire), aumento el consumo de energía, se consume una gran cantidad de energía para ventilar todo el edificio. Los resultados muestran una gran variación se demuestra que la ventilación es un tema muy importante. Diferentes modos de funcionamiento pueden conducir a resultados diferentes y pueden llevar a tomar medidas, en muchas ocasiones, insatisfactorias.

10ª Que el número de sensores necesarios aumenta significativamente los costes de inversión. Sin embargo, esto se compensa con una buena calidad del aire interior, reduciendo el riesgo de enfermedad y el aumento de la productividad.

11ª Las condiciones acústicas juegan también un papel importante en los edificios de educación superior, los efectos relacionados con el ruido en la mayor parte de los casos responden a problemas que tienen que ver con el tiempo de reverberación. Un buen confort acústico en los edificios de enseñanza superior permitirá que los estudiantes desarrollen sus tareas de escuchar, aprender y entender con la máxima normalidad. La percepción insuficiente y un ruido de fondo elevado pueden ser la causa de la disminución del rendimiento de los estudiantes. Si el ruido es excesivo puede ser causa de problemas de salud para los ocupantes. Junto a algunos de los síntomas comunes del denominado edificio enfermo, el *Edificio D*, de nuestro estudio, presenta un alto nivel de tiempo de reverberación, lo que se traduce en un aumento de la fatiga y hace que sea difícil concentrarse. Es frecuente en este tipo de edificios que existan una serie de aulas con la misma disposición arquitectónica lo que permite hacer estudios previos de optimización acústica.

12ª En lo que se refiere a la iluminación, se concluye de nuestro estudio que, representa uno de los aspectos de mayor importancia en el ahorro energético. Se constata asimismo que hay muchas actividades que pueden estar afectadas por la mala iluminación, por lo que es necesario cambiar las condiciones de iluminación en los edificios de educación superior para obtener mejores resultados, en términos de ahorro energético. La iluminación y el sombreado solar deben ser controlados por sensores de nivel de iluminancia, lo que redundará en una mejora de la eficiencia energética y de la calidad ambiental interior. El suministro de luz natural a un espacio, puede sustituir el uso de electricidad para la iluminación, lo que evitará un gasto importante, pero debe disponerse de forma que evite posibles deslumbramientos y una ganancia solar excesiva.

13ª Los resultados objetivos obtenidos en el edificio objeto de nuestro estudio, nos permiten afirmar que el edificio posee niveles aceptables de los diferentes factores ambientales. La temperatura osciló alrededor de 22°C. El nivel de iluminación fue aceptable en torno a 500 lux y el ruido promedio de 60 dB. De acuerdo con los resultados de los cuestionarios (resultados subjetivos), los diferentes factores están en unos buenos niveles de satisfacción.

14ª Se deduce también que la modelización es una actividad de importancia en la ingeniería de construcción sostenible. A pesar de ello, continúa habiendo un conjunto de problemas importantes. La plena integración de la energía y el modelado de la calidad ambiental en interiores y el diseño de los proyectos, requiere la integración de procesos adicionales y sobre todo más investigación referente a la manera de tomar decisiones, y en la forma de cómo los resultados de los modelos pueden ayudar a la toma de decisiones en este tipo de edificios.

15ª La principal ventaja de utilizar una simulación del flujo de aire integrado y modelos térmicos, en *DesignBuilder / EnergyPlus,* es precisamente que la temperatura interna se calculará como parte de la simulación. Este tipo de software, por supuesto, supone la aportación de un nuevo nivel de detalle requerido para realizar una simulación completa de la energía térmica. Destacamos a la luz de nuestro trabajo en este campo, que son desventajas importantes de este tipo de modelos, el hecho de que el programa asume que las concentraciones externas e internas, son espacialmente uniformes no incluyen la planificación urbana, no tienen en cuenta la dispersión de los contaminantes del aire y la dirección del viento, etc. Las desventajas encierran una gran dificultad, tal como los complejos procesos de dispersión en torno a la construcción. Otros parámetros ambientales como el clima local, también juegan un papel importante al influir en las condiciones de interior de una manera indirecta. Se constata la necesidad imperiosa de más y mejores archivos meteorológicos. La validación representa también un tema importante, los requisitos deben ser más complejos, para poder llegar en todos los casos a resultados similares.

Se realizaron simulaciones dinámicas para predecir la temperatura dentro del edificio durante todo el año, teniendo en cuenta la protección solar, inercia térmica y ganancias de calor previstas.

16ª Temperaturas de referencia más eficientes pueden reducir el consumo energético de los edificios. Por lo tanto, deberían hacerse esfuerzos para llegar a nuevos valores estándar de referencia. Las simulaciones demuestran que pequeños cambios tienen reembolsos rápidos. Podemos llegar a más del 50% de mejora (Caso 4).

Teniendo en cuenta que, los efectos del enfriamiento nocturno y la masa térmica expuesta, no fueron considerados en las simulaciones, los resultados podrían ser mejores de lo esperado. Los resultados de la simulación indicaron que el tiempo y modo de operación son muy importantes para mantener unas buenas condiciones internas. Una de las dificultades del trabajo de simulación realizado fue el esfuerzo necesario para modelar el diseño del edificio y el tiempo de aplicación para cada simulación (aproximadamente dos semanas).

17ª El sistema de gestión de edificios debe ser capaz de responder a esta dinámica (la temperatura del aire interior, el nivel de CO_2, el control automático de la ventilación natural, la ocupación, la humedad, la detección de lluvia, la temperatura del aire exterior, la velocidad del viento y su dirección) y ser capaz de una resolución para operar tanto en los casos de una alta ocupación (alta densidad), Como en los casos de baja ocupación (baja densidad).

Las nuevas tecnologías energéticas eficientes son necesarias para alcanzar las nuevas directrices, el desarrollo puede requerir una comprensión de los mecanismos por los cuales la calidad de ambientes interiores afecta a los humanos.

La eficiencia energética de la construcción es cada vez más importante, así como las medidas adoptadas para reducir su huella de carbono. Las tecnologías de energía renovable que se consideran aplicables para la producción de energía in situ, pueden contribuir en el corto plazo al logro de mejores usos de energía utilizando la energía solar y la biomasa.

Sin embargo, la solución global requiere de varias combinaciones y de intervenciones técnicas y económicas que proporcionen un escenario más económico y sostenible. La sostenibilidad del medio ambiente, la gestión de los recursos disponibles, así como la eficiencia energética permitirán en el futuro estrategias para obtener un valor económico y ambiental añadido.

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Appendices