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Master Thesis

Java Software Platform for Environmental Buildings' Management

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Many thanks for their valuable assistance to the following professors
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Kalaitzakis Konstantinos

This thesis is dedicated to my family and friends.

CONTENTS

Chapter 1 – Introduction

1.1 General

The last twenty years, there has been a great interest on environmental and energy management of buildings. Concerning the energy management of buildings, the main goal is to maintain the energy consumption into low levels and keeping the appropriate indoor environmental conditions for the occupants of the building in the same time. The environmental management of buildings is interested in the monitoring and adjustment of the indoor environmental parameters, which affect the physical and psychological health of the occupants, their productivity and their willing to remain in building's spaces. The progress in the domain of automation and electronics allow the usage of smart electrological installations, which allow to monitor and manage these parameters easily, from a simple house until a great industry. The control and the adjustment of these parameters, is a complex procedure, because the parameters interact and their changes affect each human in a different way.

The contemporary design of buildings aims to achieve the best possible indoor conditions, by regarding the type of usage of the indoor spaces. The indoor spaces should provide the best possible thermal, optical, acoustic and indoor quality conditions. The human factor has a great influence in the effort to control the conditions mentioned before, because the occupants tend to adjust the indoor climate with correspondence to their needs, ignoring all the parameters the might affect. For the designers of the buildings and the embedded systems, guidelines are needed in order to design spaces, which can be occupied without problems.

In the recent years, general guidelines and standards for the designing of buildings have been developed in international and national level, in order to improve the quality of the indoor environment. The guidelines aim to offer the basic information to the governments and the several scientific/researching organizations in order to take the necessary decisions, mainly for the determination of standards. Standards comprise legal criteria which consider the related guidelines for the determination of the limits for the indoor environmental quality. They depend both on the populations' characteristics and the environment's attributes. That's why they differ from country to country. They provide arithmetic designing values for several environmental parameters (e.g. indoor temperature, illuminace, ventilation rate) in order to achieve the proper dimensioning of several embedded systems (e.g. ventilation systems, humidification systems). The standards concern new unconstructed buildings and old ones. Moreover, they provide information for the classification methods of several types of buildings in order to examine the level of achievement of the proposed values. Within 2008 – 2009, in Greece, it is scheduled to announce the national standards for the buildings' designing, concerning their environmental behaviour.

Finally, classification mechanisms are essential for the energy and the environmental behaviour of the buildings. For each building, there must be a certification which refers to the environmental and energy class (like the electrical devises) and the possible solutions to improve each parameter, so it can reach a higher class.

1.2 Thesis' contribution

The present thesis's goal is to develop a software platform which evaluates and performs environmental classification for different types of buildings. The classification mechanism is depended on international standards (LEED rating system, CEN standards) and examines several environmental parameters for indoor spaces. Two categories of standards are selected: a) Standard which evaluates the total environmental behavior of the building based on information that describes the physical and technological characteristics of the building, b) Standard which separate each building into several zones and evaluates each zone's environmental behavior. Thermal comfort, relative humidity, indoor air quality (carbon dioxide concentration), optical comfort (illuminance levels) parameters are examined for each zone of the building. A classification rank is resulted for each environmental parameter and for each zone. Measurement data of the above parameters, that describes the environmental performance of each zone, are required.

The platform was developed in Java programming language by giving an open source character to the application. Anyone can change and adjust very easily the embedded methodologies in order to convert them and meet national standards. A special attention was given to the development of the platforms' interface. A user friendly interface is provided, so the majority of people can understand and operate the application. The collection of data mechanism was implemented in order that the application could easily cooperate with several building management systems. The format of the data imported in the platform follows the majority of measurement data formats, exported by building management systems.

The software application platform was tested and evaluated, using real data provided by a building management system installed in a building with office usage. Results of all methodologies and for all environmental parameters were validated in order to improve the classification mechanisms. The aim of platform's evaluation was the production of a completed application software, which can be used by the majority of building designers and environmental inspectors for the classification of many types of buildings.

1.3 Chapters' description

Chapter 2 presents some of the latest implementations related to the environmental classification of buildings.

Chapter 3 describes the CEN standard's specifications and requirements of the methodology, which is used for the environmental classification. A general description and the standard's scope are given. The classification methodology is provided for the following environmental parameters: Thermal comfort (a new adaptive perception), Relative humidity, Carbon dioxide concentration (indoor air quality), Lighting (optic comfort). The design values and the related classes and categories are also indicated.

Chapter 4 provides the presentation of the LEED Building Green Rating system. An analytic description of the methodology is provided within the resulted categories.

Chapter 5 presents a synoptic description of the software application platform. The tools, where application was developed, the database system and an application's flow chart are presented.

Chapter 6 contains the validation and evaluation process of the software platform. A description of the building, which was classified, is given. The classification results for each methodology, building's zone and environmental parameter are presented escorted by graphic charts, produced by the application.

Chapter 7 includes the conclusions for the classification results provided by the software platform. The classification results are analyzed and discussed for each environmental parameter and methodology. Comparison between the three zones is performed, when necessary. Furthermore, future platform's extensions and changes are provided.

Finally, the bibliography and several appendices follow.

Chapter 2 – State of the art

2.1 TOBUS – a European diagnosis and decision-making tool for office buildings upgrading

The TOBUS methodology [17] and software have been developed as a result of a 2-year European research project, involving the eight European institutions, in the frame of JOULE III programme of the European Commission (EC), Directorate General XII. A structured diagnosis scheme enables architects and engineers to simultaneously handle the entire complex progress of office building refurbishment or retrofit with respect to deterioration, functional obsolescence of building services, energy consumption and indoor environmental quality. The software tool can then be used to define the most appropriate and cost-effective actions, to elaborate consistent refurbishment scenarios and calculate a reasonable investment budget in the early stages of a refurbishment project.

Concerning the indoor environmental quality (IEQ), TOBUS makes an inventory of employee complaints about IEQ by processing the responses collected from checklist and employee questionnaires. Based on this inventory, possible actions to resolve the identified problems are given, if possible. Otherwise, a warning or an advice to hire a specialist for further investigations is issued. TOBUS treats the following issues: thermal comfort, indoor air quality (humidity, pollutants and ventilation), lighting, noise. Psycho-social factors, personal characteristics and ergonomics are used in the analysis. The approach is based on three types of data collection:

1. A *checklist* is used to collect information on building structure and services from the building manager and technical staff.
2. A *questionnaire* is used to collect information on perceived comfort and complaints from the building occupants.
3. A *checklist* with information to be collected by the auditor(s) during the visit to the building is also available.

Based on the analysis of the complaints different possible causes for the problems can be identified and possible actions for the improvement selected. Indoor environmental quality improvement measures can have a negative impact on other issues. TOBUS includes an indoor environmental quality evaluation procedure that results in the following qualitative expressions.

- For each IEQ issue (thermal comfort, acoustics, light and air quality) it is possible, based on the data collected from the questionnaire, to define a number or qualitative expressions to describe the situation before the refurbishment/retrofit, according to the occupants.
- Building symptom index (mean number of symptoms reported by occupants) based on the data from the questionnaires.
- During the diagnosis, it is checked whether certain complaints/symptoms are related to objects (types). The number of objects related to a complaint/symptom is an indicator about the seriousness of the complaint/symptom.

TOBUS software is a research prototype and its databases include information based on limited national data from the participating countries. However, its open structure allows the software to be easily adapted to the different European counties.

2.2 E-Building, a completed system for the electronic management of internal environment and energy in the buildings

E-building system [18] has been developed as a result of a 2-year research project, involving the Technical University of Crete, the National and Kapodistrian University of Athens and the Byte Computer S.A, in the frame of General Secretary of Research and Technology (GSRT) concerted program "Renewable Energy Sources and Energy Saving". E-building is based on the software platform IBM LOTUS DOMINO and has been developed using Java programming language. It consists a completed modern electronic platform which enables the following tasks:

- The improvement of the acceptance's level by the occupants of a building for the indoor air quality, the thermal and optical comfort.
- The definition and the evaluation of possible problems and the proposal of scenarios for the improvement or total solution for these problems.
- The appliance of strategies related to energy savings and localization of highly energy consumption sources.
- The reduction of energy costs for heating or cooling.

- The energy and the environmental classification of buildings, according to Greek and international standards.

The electronic system e-building requires the existence of a building management system, which provides data about the energy consumptions for lighting, cooling and heating, and measurements for indoor and outdoor temperatures, carbon dioxide concentrations, humidity e.t.c.

The indoor environmental quality classification is based on the LEED methodology which is the official methodology for the environmental classification of buildings in U.S. The system implements an adaptation of LEED methodology in Greek standards. The ranking and the classification results for each building largely depend on several structural, technical, geographical characteristics that describe the environmental behaviour of the building.

The criteria of the proposition mechanism, which introduces possible scenarios for the improvement of the environmental and energy performance, depend on the energy consumption values, the thermal, optical and indoor air quality classification results. The system has the capability to evaluate and calculate the distinct contribution of each solution activity for the improvement of indoor environmental conditions and energy consumption.

Chapter 3 - Environmental Classification, CEN prEN 15251:2006

3.1 General

Energy consumption of buildings depends significantly on the criteria used for the indoor environment (temperature, ventilation and lighting) and building (including systems) design and operation. Indoor environment also affects health, productivity and comfort of the occupants. Recent studies have shown that costs of poor indoor environment for the employer, the building owner and for society, as a whole are often considerable higher than the cost of the energy used in the same building. It has also been shown that good indoor environmental quality can improve overall work and learning performance and reduce absenteeism. In addition, uncomfortable occupants tend to act so they feel comfortable, which may have energy implications. There is therefore a need for specifying criteria for the indoor environment for design, energy calculations, performance and operation of buildings.

There are national and international standards, and technical reports, which specify criteria for thermal comfort and indoor air quality (EN ISO 7730, ANSI/ASHRAE 55-2004). These documents specify different types and categories of criteria, which may have a significant influence on the energy demand. These criteria are, however, mainly for dimensioning of building, heating, cooling and ventilation systems and not directly for energy calculations and year-round evaluation of the indoor thermal environment. New results have shown that occupant expectations in natural ventilated buildings may differ from conditioned buildings. These issues are not dealt with in detail in the above mentioned standards.

CEN's (Centre Europeen de Normalization) standard PrEN 15251:2006 [1] (Criteria for the indoor environment including thermal, indoor air quality, light and noise) specifies how design criteria can be established and used for dimensioning of systems. It defines how to establish and define the main parameters to be used as input for building energy calculation and long term evaluation of the indoor environment. Different categories of criteria may be used depending on type of building, type of occupants, type of climate and national differences. The standard specifies several different categories of indoor environment suitable for the space to be conditioned. These different categories may also be used to give an overall, yearly evaluation of the indoor environment by evaluating the percentage of time in each category.

3.2 Scope of prEN 15251:2006 standard

The scope of prEN 15251:2006 standard is described below:

- It specifies the indoor environmental parameters which have an impact on the energy performance of buildings.
- It specifies how to establish indoor environmental input parameters for building system design and energy performance calculations.
- It specifies methods for long term evaluation of the indoor environment obtained, as a result of calculations or measurements.
- It identifies parameters to be used by monitoring and displaying the indoor environment in existing buildings.
- This standard is applicable mainly in non-industrial buildings, where the criteria for indoor environment are set by human occupancy and the production or process doesn't have a major impact on indoor environment. The standard is thus applicable to the following building types: single family houses, apartment buildings, offices, educational buildings, hospitals, hotels and restaurants, sports facilities, wholesale and retail trade service buildings.
- It specifies how different categories of criteria for the indoor environment can be used. But it doesn't require certain criteria to be used. This is up to national regulations or individual project specifications.
- The criteria recommended in this standard can also be used in national calculation methods.
- The standard does not prescribe design methods; it gives input parameters to the design of buildings, heating, cooling, ventilation and lighting systems.

3.3 Thermal Comfort Classification

Whether or not users are satisfied with a building, is largely determined by the quality of the thermal indoor climate. Indoor atmosphere affects the occupants of a building, physically and psychologically. Due to this reason, the designer of the building has to create an indoor and outdoor environment, suitable for all possible human activities. Biological, emotional and physical characteristics of each occupant are considered. As a consequence, if a group of people is exposed to the same climate, it is highly unlikely that all of them will be satisfied. The aim of the designer is to create optimum thermal comfort for the group. So, she/he must ensure conditions under which the majority of people of the group will feels comfortably.

Thermal comfort in an indoor area depends on the exchange of temperature between human's body and environment. Another factor is human activity in this area. The exchange of temperature depends on many parameters like:

- Indoor temperature
- Relative humidity
- Mean radiant temperature
- Air velocity
- Clothing level
- Occupant's activity

Thermal comfort is achieved with different combinations of the parameters above. It is the combination of different portion effects of each parameter, separately and between them, in the human body. The positive or negative effect of one parameter in thermal comfort can be reinforced or compensated by changing another parameter.

3.3.1 International Standards ISO 7730 and ANSI/ASHRAE 55-2004

ISO 7730 [9] and revised ASHRAE 55-2004 [8] standards are based on the thermal comfort indices PMV-PPD (predicted mean vote - predicted percentage of dissatisfied) with assumed typical levels of activity and thermal insulation for clothing. PMV predicts the mean value of the votes of a large group of persons on the following 7-point thermal sensation scale (+3=hot, +2=warm, +1=slightly warm, 0=neural, -1=slightly cool, -2=cool, -3=cold). PPD predicts the percentage of thermally dissatisfied people. The PMV-PPD index takes in to account the influence of all 6 thermal parameters (clothing, activity, air- and mean radiant temperature, air velocity and humidity) and can be directly used as criteria. By an assumed combination of activity and clothing, an assumed 50% relative humidity and low air velocities it is possible to establish a corresponding range of operative temperatures and express the criteria as a temperature range. For the design and dimensioning further criteria for the thermal environment (draught, vertical air temperature differences, floor temperature, and radiant temperature asymmetry) should be considered.

3.3.2 CEN prEN 15251:2006 standard for thermal comfort

PrEn 15251:2006 standard has a different methodology in how it sets the buildings. Standards, mentioned before, mainly set buildings for the dimensioning of heating, cooling and ventilation systems. PrEn 15251:2006 standard takes into account recent studies which have proven that occupant's needs and expectations, towards comfort conditions, differ between buildings with HVAC systems and naturally ventilated or air-conditioned buildings. PrEn 15251:2006 buildings may be used for energy calculations and evaluation of indoor environment, besides the dimensioning of heating, cooling and ventilation systems. The comfort categories are shown in table 1.

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 1 - Description of the applicability of the categories used

For mechanically heated and/or cooled buildings, standard provides general principles and limits, for thermal comfort, like the minimum indoor temperature for winter and the maximum indoor temperature for summer. These limits depend on different outdoor conditions and indoor loads for different locations and types of buildings.

For buildings without mechanical cooling systems, standard provides measures for decreasing cooling or heating load. Some measures are the usage of solar shading, decrease of openings, increase of heat insulation and design for effective cooling with natural ventilation. The temperature limits for buildings without mechanical cooling systems are shown in figure 1.

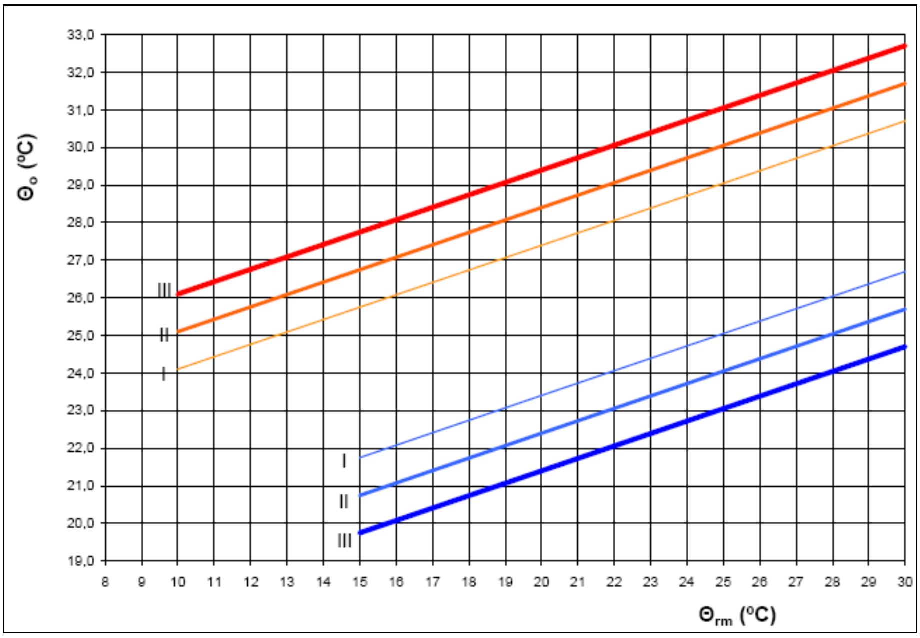

Figure 1 - Design values for the indoor operative temperature for buildings without mechanical cooling systems as a function of the exponentially-weighted running mean of the outdoor temperature.

The temperature limits presented in figure 1 are used for the dimensioning of passive cooling techniques (solar shading, thermal capacity of building, design, orientation and opening of windows) to prevent overheating in summer conditions.

Buildings without mechanical cooling systems have the same comfort criteria with mechanically heated and/or cooled buildings, in heating period. This happens because all buildings surely have a heating system.

Temperature limits of figure 1 only apply when:

- The thermal conditions in the spaces at hand are regulated primarily by the occupants through opening and closing of windows.
- Occupants are engaged in near sedentary physical activities with metabolic rates ranging from 1,0 to 1,3 met.
- Strict clothing policies inside the building are avoided, in order to allow occupants to freely adapt their clothing insulation.

3.3.3 – New Adaptive Thermal Model

Extensive field research [13] shows that people evaluate the climate differently in buildings, where they can open windows and influence the thermal indoor climate. Various adaptation mechanisms affect this phenomenon. The most important one is people's expectation of the building's climate, based on the outdoor temperature of the particular day and the preceding days. Thermal comfort models that take into account human adaptability have been developed over the years [8,12]. The concept of adaptive thermal comfort can be described as [14]: "When a change occurs causing thermal discomfort, people react in such a way that their thermal comfort is established". Unlike other models, such as PMV-model, adaptive thermal comfort model takes the effects of behavioural and psychological adaptation into account. PMV-model, for example, can only take the effects of behavioural adaptation into account: the adjustment of clothing, the level of activity, and the increase of the air velocity. Behavioural adaptation can be discerned in personal, technical, environmental, cultural and organizational adaptation. Psychological adaptation implies a changed perception of, or response to, sensory information. Thermal sensations are influenced by an individual's experiences and expectations in a direct manner.

An essential requirement of adaptive thermal comfort models is the discrimination between different types of buildings, usage and climate circumstances. An important criterion is the possibility of individual control. Occupants of naturally ventilated buildings have possibilities for increasing the air velocity in the room by operating windows. Additionally, psychological adaptation plays an important part especially in this type of buildings: because of the more direct contact to the weather outside, higher temperatures are also expected for the indoor climate.

In this thesis thermal comfort classification is based on a new approach of the adaptive thermal model of CEN standard, as referred to [2]. This new model introduces two buildings or climate types, Alpha and Beta. A Beta building is an air-conditioned building with no operable windows (Sealed Façade). An Alpha building is a free-running building (Façade with operable windows) which allows occupants to adjust temperature through active cooling, if operable windows are no accessible, and allows them to adjust clothing to outdoor and indoor conditions. Flow diagram in figure 2 shows this discrimination.

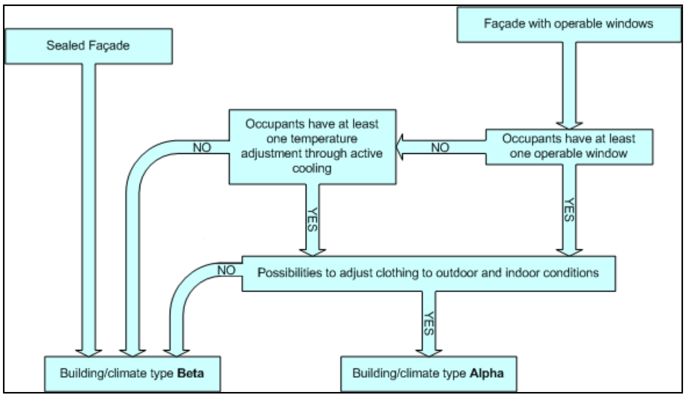

Figure 2 - Diagram determining the type of building/climate

In figures 3, 4, limits are specified for 90, 80 and 65% acceptance of the thermal indoor climate.

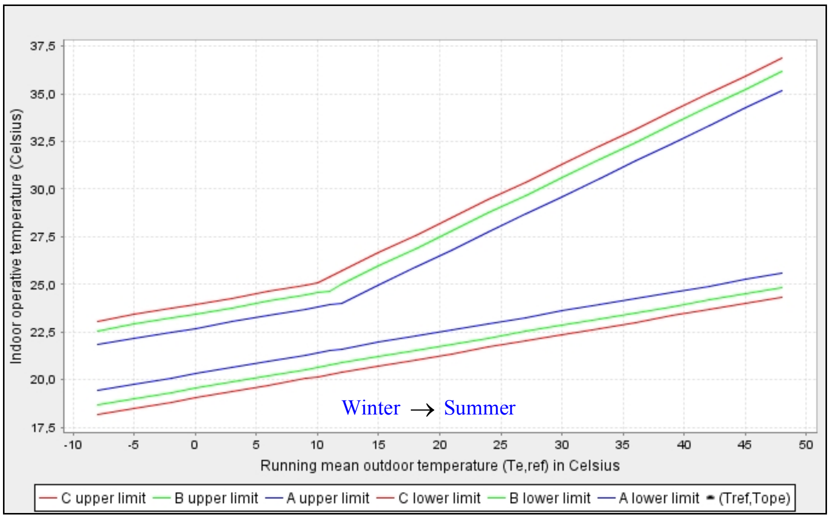

Figure 3 - Building/Climate type Alpha

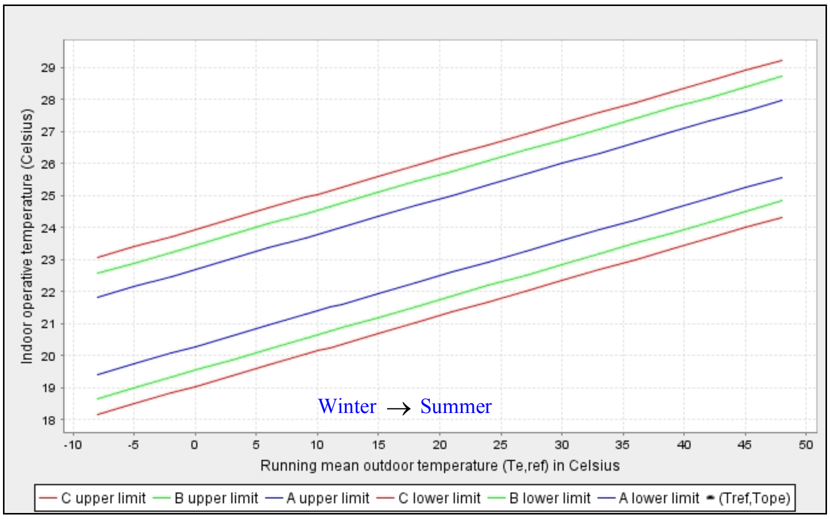

Figure 4 - Building/Climate type Beta

Vertical axis indicates the indoor operative temperature which is calculated as the arithmetic mean of the air temperature and the mean radiant temperature (MRT).

$$T_{oper} = \frac{T_{indoor} + T_r}{2} \quad (1)$$

Horizontal axis indicates an adapted version of the running mean outdoor temperature (RMOT - $T_{e,ref}$). $T_{e,ref}$ is calculated as the exponentially weighted, mean outdoor air temperature of the day under study and the three preceding days. Mean outdoor air temperature is calculated as the average of minimum and maximum daily outdoor air temperatures.

$$T_{e,ref} = \frac{T_{o,n} + 0{,}8T_{o,n-1} + 0{,}4T_{o,n-2} + 0{,}2T_{o,n-3}}{2{,}4} \quad (2)$$

$$T_{o,n} = \frac{T_{o,n,\max} + T_{o,n,\min}}{2} \quad (3)$$

During heating season and when heating is on (mean outdoor temperature below 10-15^oC) no building/climate type Alpha exists. The effect of behavioural adaptation plays some role, but psychological adaptation probably to a lesser extend. Therefore, for building/climate type Alpha at a $T_{e,ref}$ of below 10–12 ^oC the operative temperature limits are the same as Beta.

Both for building/climate type Alpha and Beta, identical lower limits have been taken. For the situation very near the lower limits, it is assumed that the user's perceptions are approximately identical for both building/climate types. In both cases, the windows will be closed most of the time.

A building/climate belongs to a category (class) when the limits of the category are not exceeded at any point in time. Each pair of of ($T_{e,ref}$,T_{oper}) must be inside the limit lines of the class. Table 2 shows the formulas belonging to the limit lines. A 'good' indoor climate is characterized by 80% acceptance (Class B). In order to meet the functional requirement of a good indoor climate, it is required that the building's performance never exceeds the limit values for 80% acceptance at a specified outdoor climate. Around Class B two classes have been defined. Class A is used for extra high quality buildings (very good) and Class C for buildings with an indoor climate that is acceptable as such. When the limit values of Class C are exceeded at any point in time, the indoor climate is inadequate (None).

Class	**Acceptance**	**Building/Climate type**			
		Alpha		Beta	
		Upper Limit	***Lower Limit***	***Upper Limit***	***Lower Limit***
A	90%	$T_{e,ref} > 12^o C$: $T_{oper} < 20{,}3 + 0{,}31 T_{e,ref}$ $T_{e,ref} < 12^o C$: $T_{oper} < 22{,}7 + 0{,}11 T_{e,ref}$	$T_{oper} > 20{,}3 + 0{,}11 T_{e,ref}$	$T_{oper} < 22{,}7 + 0{,}11 T_{e,ref}$	$T_{oper} > 20{,}3 + 0{,}11 T_{e,ref}$
B	80%	$T_{e,ref} > 11^o C$: $T_{oper} < 21{,}3 + 0{,}31 T_{e,ref}$ $T_{e,ref} < 11^o C$: $T_{oper} < 23{,}45 + 0{,}11 T_{e,ref}$	$T_{oper} > 19{,}55 + 0{,}11 T_{e,ref}$	$T_{oper} < 23{,}45 + 0{,}11 T_{e,ref}$	$T_{oper} > 19{,}55 + 0{,}11 T_{e,ref}$
C	65%	$T_{e,ref} > 10^o C$: $T_{oper} < 22 + 0{,}31 T_{e,ref}$ $T_{e,ref} < 10^o C$: $T_{oper} < 23{,}95 + 0{,}11 T_{e,ref}$	$T_{oper} > 19{,}05 + 0{,}11 T_{e,ref}$	$T_{oper} < 23{,}95 + 0{,}11 T_{e,ref}$	$T_{oper} > 19{,}05 + 0{,}11 T_{e,ref}$

Table 2 - Thermal Comfort Classes

3.4 Relative Humidity Classification

The humidification of indoor air is usually unnecessary. Humidity has only a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy, however, long term high humidity indoors will cause microbial growth, and very low humidity (<15-20%) causes dryness and irritation of eyes and air ways. Requirements for humidity influence the design of dehumidifying (cooling load) and humidifying systems and will influence energy consumption. The criteria depend partly on the requirements for thermal comfort and indoor air quality and partly on the physical requirements of the building (condensation, mould etc.) For special buildings (museums, historical buildings, churches) additional humidity requirements must be considered. Humidification or dehumidification of room air is usually not required but if used excess humidification and dehumidification avoided. Unoccupied buildings shall not be humidified (with some exceptions such as museums) but may need to be dehumidified to prevent long term moisture damage.

Standard prEN 15251:2006 recommends design values of indoor relative humidity for occupied spaces for dimensioning of dehumidification and humidification systems. Table 3 shows the categories of relative humidity classification and the limits of each category.

Category	Relative Humidity Limits, %	
	Upper (dehumidification)	*Lower (humidification)*
I	50	30
II	60	25
III	70	20
IV	>70	<20

Table 3 - Relative Humidity Classification Categories

Indoor air shall not be dehumidified to a lower relative humidity than the design value and not be humidified into higher relative humidity than the design values. In figure 5, limits are specified for all humidity classification categories.

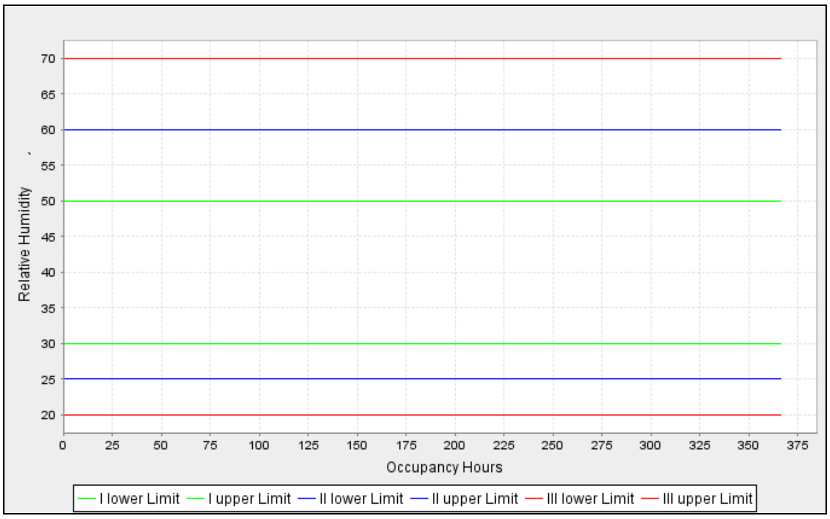

Figure 5 – Relative humidity classification limit lines

The classification of a building is based on the process of daily hourly measured values of relative humidity for a sufficient number of days. Relative humidity measurements (vertical axis) are selected only for the time where building is occupied (occupancy hours - horizontal axis). In case two categories have equal percentages of hours, then the worse category is the one that dominates. This is because the goal of the classification is to improve building indoor conditions.

3.5 Lighting Classification

The indoor adequate lighting levels allow to residents perform visual tasks efficiently and accurately (without side effects like glare and blinding). The design luminance levels can be secured by means of daylight, artificial light or a combination of both. In most cases, the use of daylight instead of artificial is preferred due to health, comfort and energy. This depends on many factors like standard occupancy hours, the portion of occupancy time during which there is enough daylight, location of the building (latitude), amount of daylight hours during summer and winter, etc.

In this thesis, lighting classification is based on the CEN standard prEN 12464-1:2002 (Light and lighting - Lighting of work places - Indoor work places) which is referenced at prEN 15251:2006. Standard recommends design illumination levels at working areas for many buildings/spaces types. These levels are defined and detailed in EN 12464-1 and some of them are presented in Annex A table 19. Recommended design levels are not suitable for residential buildings. Three types of buildings/spaces are supported in this thesis and are shown in table 4.

Category	**Building Type**		
	Office	***School***	***Shop***
Adequate	≥ 500 lx	≥ 300 lx	≥ 300 lx
Inadequate	< 500 lx	< 300 lx	< 300 lx

Table 4 - Categories and limits of lighting classification

In figure 6, classification limits are specified for supported types of buildings/spaces.

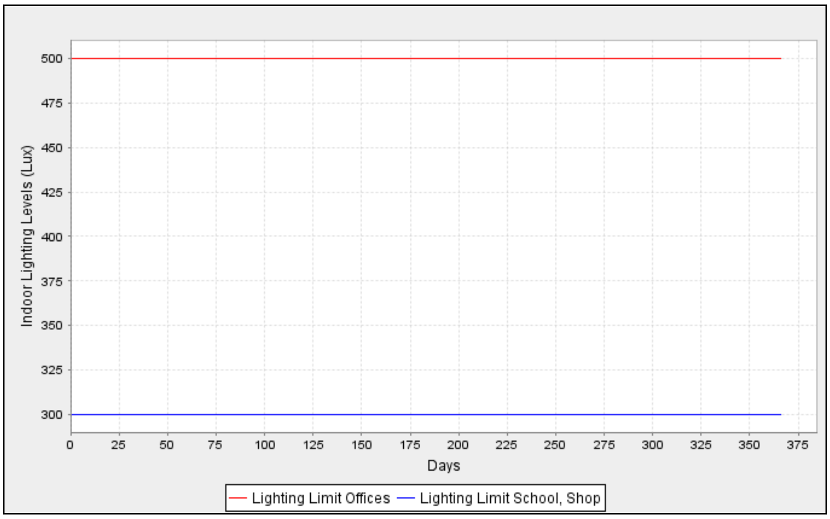

Figure 6 – Lighting classification limit lines

The classification of a building is based on the process of daily hourly measured values of illuminance, for a sufficient number of days. Illuminance measurements (vertical axis) are selected only for the time where building is occupied (occupancy hours - horizontal axis). A building belongs to the category with the greater percentage of occupied hours inside its limits. In case two categories have equal percentages of days, then inadequate category is the one that dominates.

3.6 Indoor Air Quality - Carbon Dioxide Classification

In modern societies people spend most of their daily time at indoor spaces like residential buildings, offices, libraries, malls, restaurants etc. Due to this reason, indoor air quality constitutes a major issue for buildings' and systems' designing. Basic chemical pollutant factors, which affect the indoor air quality, are generated by many indoor and outdoor sources. Indoor pollutant factors depend on occupancy (time of occupation), indoor activity (smoking, cooking, cleaning…), processes (like copiers in schools), emissions from buildings materials as well as furniture.

In this thesis indoor air quality classification is related to carbon dioxide concentration. Carbon dioxide is a gas which exists naturally in the atmosphere. Its standard outdoor concentration (300 ppm – 400 ppm) doesn't affect human's health. In indoor spaces occupied by people, the carbon dioxide concentration will reach higher levels than in pure outdoor air. High concentrations levels will cause discomfort in more than 20% of occupants, and the discomfort will increase with increasing CO_2 concentration. At 2,000 ppm the majority of occupants will feel a significant degree of discomfort, and many will develop nausea and headaches.

PrEN 15251:2006 standard relates directly carbon dioxide concentration with ventilation rates of ventilations systems, embedded in buildings. In systems with variable air flow control and demand controlled ventilation, the ventilation rate may vary between maximum for full occupancy or demand and minimum for non occupied space. CO_2 concentration is a factor for human occupancy in a building and should not exceed the design values. Table 5 shows standard's recommended categories and values for the excess of CO_2 concentration above outdoor CO_2 concentration.

Category	CO_2 Limits, ppm
Accepted	≤ 700
Marginal	>700 and ≤ 800
Unaccepted	>800

Table 5 - Carbon Dioxide Classification Categories

In figure 7, limits are specified for all CO_2 concentration classification categories.

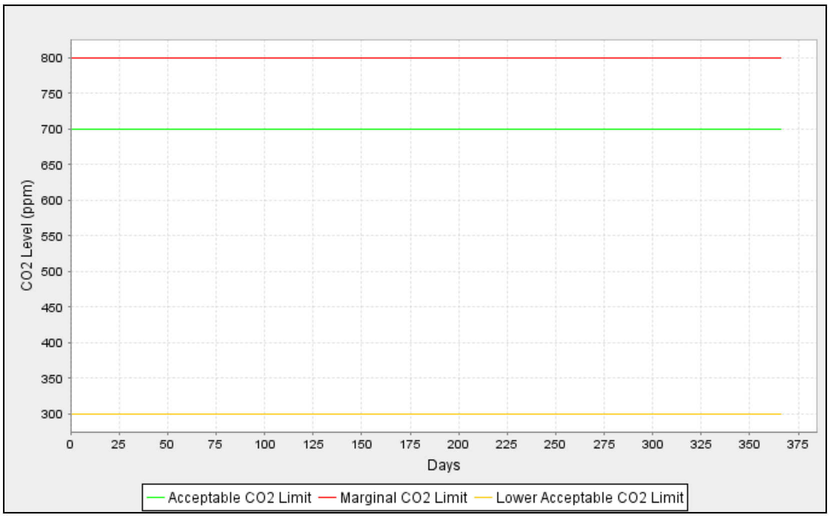

Figure 7 – CO_2 classification limit lines

The classification of a building is based on the process of daily hourly measured values of carbon dioxide concentration, for a sufficient number of days. The average carbon dioxide concentration (vertical axis) is calculated for each day of study (horizontal axis), as the sum of hourly concentration values (during occupancy time) divided by the occupancy hours.

$$CO_{2_{day,avg}} = \frac{\sum_1^n CO_{2_{hourly}}}{\sum_1^n hours}$$, where n is the number of occupancy hours (4)

A building belongs to the category with the greater percentage of days inside its limits. In case two categories have equal percentages of days, then the worse category is the one that dominates.

An additional concentration level has been introduced at 300 ppm (outdoor fresh air concentration). This level does not represent a category, but it is essential for the validation of measurements. If a daily average CO_2 concentration is lower than 300 ppm, then this measurement is invalid and is excluded from the classification mechanism. This may mean a problem in the CO_2 sensor.

3.7 Standard's Measurement Guideline

In existing buildings measurements might be used to check whether the performance of a building and it's building service systems (ventilation system, heating and cooling devices, artificial lighting) accord to design requirements. Standard prEN 15251:2006 provide how such measurements can be conducted for each indoor environmental quality parameter described in previous sections.

3.7.1 Thermal Environment

Measurements shall be made where occupants are known to spend most of their time and under representative weather condition of cold and warm season. For the winter (heating season) measurements at or below mean outside temperatures for the 3 coldest months of the year, and for the summer (cooling season) measurements at or above statistic average outside temperatures for the 3 warmest months of the year with clear sky. The measurement period for all measured parameters should be long enough to be representative, for example 10 days. Air temperature in a room can be used in long term measurements and corrected for large hot or cold surfaces to estimate the operative temperature of the room. Measurement instrumentation used for evaluation of the thermal environment shall meet the requirements given in EN ISO 7726 [11] standard.

3.7.2 Indoor Air Quality - CO_2 concentration

In buildings where people are the main pollution sources, the ventilation rates can be derived using CO_2 measurement. Measurements shall be made where occupants are known to spend most of their time, preferably at head level during typical high load conditions. CO_2 measurements should preferably be made under winter conditions, as normally fresh air supply is lowest during the colder months (limited use of operable windows, partly closed facade shutters due to draught risk). In some cases, momentary measurements at 'worst case times' (e.g. end of the morning or end of the afternoon in for example an office or school) might be sufficient. In larger buildings, not all rooms need to be evaluated and measurements in only 5 or 10% of the rooms (representatively chosen) might be enough. In mechanically ventilated buildings measurement of the amount of fresh air supply is often more practical and precise than the measurement of CO_2 concentrations. Measurement instrumentation used for evaluation of the air supply shall meet the requirements given in EN 12599 [7] standard.

3.7.3 Lighting

Light quality measurements are based on measuring illuminance. The illuminance shall be measured on the task area to conform to values recommended in EN 12464-1 [5] standard at all operational times. Measurements of lighting levels are carried out without the presence of daylight. Preferably also measurements are carried out during an average cloudy day. The maintained luminance level shall be measured on the horizontal plane in the occupational zone at approximately 0,8 meter for regular occupied spaces and at 0,1 meter in circulation areas and sports halls.

Chapter 4 - Environmental Classification, LEED Green Building Rating System

4.1 Description of the LEED methodology

The Leadership in Energy and Environmental Design (LEED) [3,4] Green Building Rating System represents the U.S. Green Building Council's effort to provide a national standard for what consistitutes a "green building." Through its use as a design guideline and third-party certification tool, it aims to improve occupant well-being, environmental performance and economic returns of buildings using established and innovative practices, standards and technologies. This thesis implements an adaptation of LEED methodology in Greek and European standards. The certification is based on a point ("credit") rating system. The amount of points achieved will determine, which level of LEED certification the building is awarded. Building's projects earn one or more points toward certification by meeting or exceeding each credit's technical requirements. Appendix B states the basic intent and requirements, necessary to achieve each "credit". A short description of technologies and strategies is also included. There are 71 possible points and five certification levels (A-E). The available credits are organized into five broad categories: a) Sustainable Sites, b) Water Efficiency, c) Energy and Atmosphere, d) Materials and Resources and e) Indoor Environmental Quality. These categories contain requirements that describe the environmental behaviour of the building. Tables 5-9 present the credits for each category and the points that earned when meeting each credit's technical requirements.

Sustainable Sites [SS]		
1	Erosion & Sedimentation Control	2 points
2	Site Selection	1 point
3	Development Density	1 point
4	Reconfiguration of Contaminated Areas	1 point
5.1	Alternative Transport Ways [*Public Transportation Access*]	1 point
5.2	Alternative Transport Ways [*Bicycle Storage & Changing Rooms*]	1 point
5.3	Alternative Transport Ways [*Alternative Fuel Vehicles*]	1 point
5.4	Alternative Transport Ways [*Parking Capacity*]	1 point
6	Reduced Site Disturbance [*Protect or Restore Open Space*]	1 point
7.1	Stormwater Management [*Rate and Quantity*]	1 point
7.2	Stormwater Management [*Treatment*]	1 point
8.1	Heat Island Effect [*Non-Roof*]	1 point
8.2	Heat Island Effect [*Roof*]	1 point
9	Light Pollution Reduction	1 point
		Maximum Total Points: 15

Table 5 - Sustainable Sites

Water Efficiency [WE]		
1.1	Water Efficient Landscaping [*Reduce by 50%*]	1 points
1.2	Water Efficient Landscaping [*No Potable Use or No Irrigation*]	1 point
2	Innovative Wastewater Technologies	1 point
3.1	Water Use Reduction [*20% Reduction*]	1 point
3.2	Water Use Reduction [*30% Reduction*]	1 point
		Maximum Total Points: 5

Table 6 - Water Efficiency

Energy and Atmosphere [EA]		
1	Fundamental Building Systems Commissioning	2 points
2	Minimum Energy Performance	2 points
3	CFC Reduction in HVAC&R Equipment	2 points
4	Optimization of Energy Performance	1-10 points
5.1	Renewable Energy Sources [*5%*]	1 point
5.2	Renewable Energy Sources [*10%*]	1 point
5.3	Renewable Energy Sources [*20%*]	1 point
6	Ozone Depletion	1 point
7	Measurement & Verification	1 point
8	Green Power	1 point
		Maximum Total Points: 22

Table 7 - Energy and Atmosphere

Materials and Resources [MR]		
1	Storage & Collection of Recyclables	2 points
2.1	Building Reuse [*Maintain 75% of Existing Shell*]	1 point
2.2	Building Reuse [*Maintain 100% of Shell*]	1 point
2.3	Building Reuse [*Maintain 100% Shell & 50% Non-Shell*]	1 point
3.1	Construction Waste Management [*Divert 50%*]	1 point
3.2	Construction Waste Management [*Divert 75%*]	1 point
4.1	Resource Reuse [*Percentage 5%]*	1 point
4.2	Resource Reuse [*Percentage 10%]*	1 point
5.1	Recycled Content [*Percentage 5%*]	1 point
5.2	Recycled Content [*Percentage 10%*]	1 point
6.1	Local/Regional Materials [*20% Manufactured Locally*]	1 point
6.2	Local/Regional Materials [*35% Manufactured Locally*]	1 point
7	Rapidly Renewable Materials	1 point
		Maximum Total Points: 14

Table 8 - Materials and Resources

Indoor Environmental Quality [QE]		
1	Minimum IAQ Performance	2 points
2	Environmental Tobacco Smoke (ETS) Control	2 points
3	Carbon Dioxide (CO2) Monitoring	1 point
4	Ventilation Effectiveness	1 point
5.1	Low-Emitting Materials [*Adhesives & Sealants*]	1 point
5.2	Low-Emitting Materials [*Paints, Coverings*]	1 point
5.3	Low-Emitting Materials [*Carpet, Moquetes*]	1 point
5.4	Low-Emitting Materials [*Composite Wood*]	1 point
6	Indoor Chemical & Pollutant Source Control	1 point
7.1	Thermal Comfort, Based on international Standards	1 point
7.2	Thermal Comfort, Permanent Monitoring System	1 point
8.1	Daylight & Views, Daylight 75% of Spaces	1 point
8.2	Daylight & Views, Views for 90% of Spaces	1 point
		Maximum Total Points: 15

Table 9 - Indoor Environmental Quality

Table 10 presents the five certification levels and the amounts of points that determine them.

Certification Levels	Points
A - *Platinum*	54-71
B - *Gold*	41-53
C - *Silver*	31-40
D - *Certified*	19-30
E - *Certified*	0-18

Table 10 - Certification levels

The LEED system can be used in three ways to improve the “green-ness” of a building design:

1. LEED can serve as a *design guide* for a design team. The LEED credit system is a systematic way of ensuring that the most important environmental issues are considered during the design of a building.
2. LEED reports are valuable means of showing the client and other interested parties that the design has *effectively addressed environmental issues*.
3. Building's design *certification* by national and international authorities.

The larger benefit of LEED buildings is an improved indoor environment (lower absenteeism, greater productivity, better thermal comfort), lower maintenance costs (commissioned building, more durable materials, smaller or eliminated building systems), higher corporate profile (increase product sales, marketing advantage, improved employee morale), and reduced risk of remedial measures (deal with sick building syndrome or environmental contaminants).

Chapter 5 - Java Application Platform

5.1 General

A major part of this thesis was the development of a software platform which evaluates and performs environmental classification for buildings, based on standards described in chapters 3, 4. The software application was developed in Java programming language using Netbeans IDE under Linux operating system.

5.1.1 Why using Java

Java is a programming language originally developed by Sun Microsystems and released in 1995 as a core of Sun Microsystems' Java platform. The language derives much of its syntax from C and C++, but id has a simpler object model and fewer low-level facilities. Java applications are typically compiled to bytecode that can run on any java virtual machine (JVM). In May 2007 Sun made available most of their Java technologies as free software under General Public License. Basic advantages of using java language follow:

- It uses *object-oriented* programming methodology.
- *Platform independence*: Programs written in the Java language run similarly on any supported hardware/operating system platform (Widows, UNIX, Macintosh and Solaris).
- *Automatic memory management*: Programmers don't need to perform manual memory allocation for the creation of objects and later deallocating that memory. Avoidance of memory leakages which result to arbitrarily large amount of memory consumption by the application.

An additional reason of selecting java language for the classification platform was that java helps on developing open source applications. The idea of an open source application allows the improvement and expansion of the application by other members of the scientific community.

5.2 Description of the java platform

The application is divided in two major sections. The first is responsible for the gathering of building's information that describes the physical characteristics and the environmental behavior of the building. The second implements the classification mechanism, based on standards described on chapters 3, 4, and processes the data of the building. A detailed flow chart of application's structure and operations is presented in figure 7.

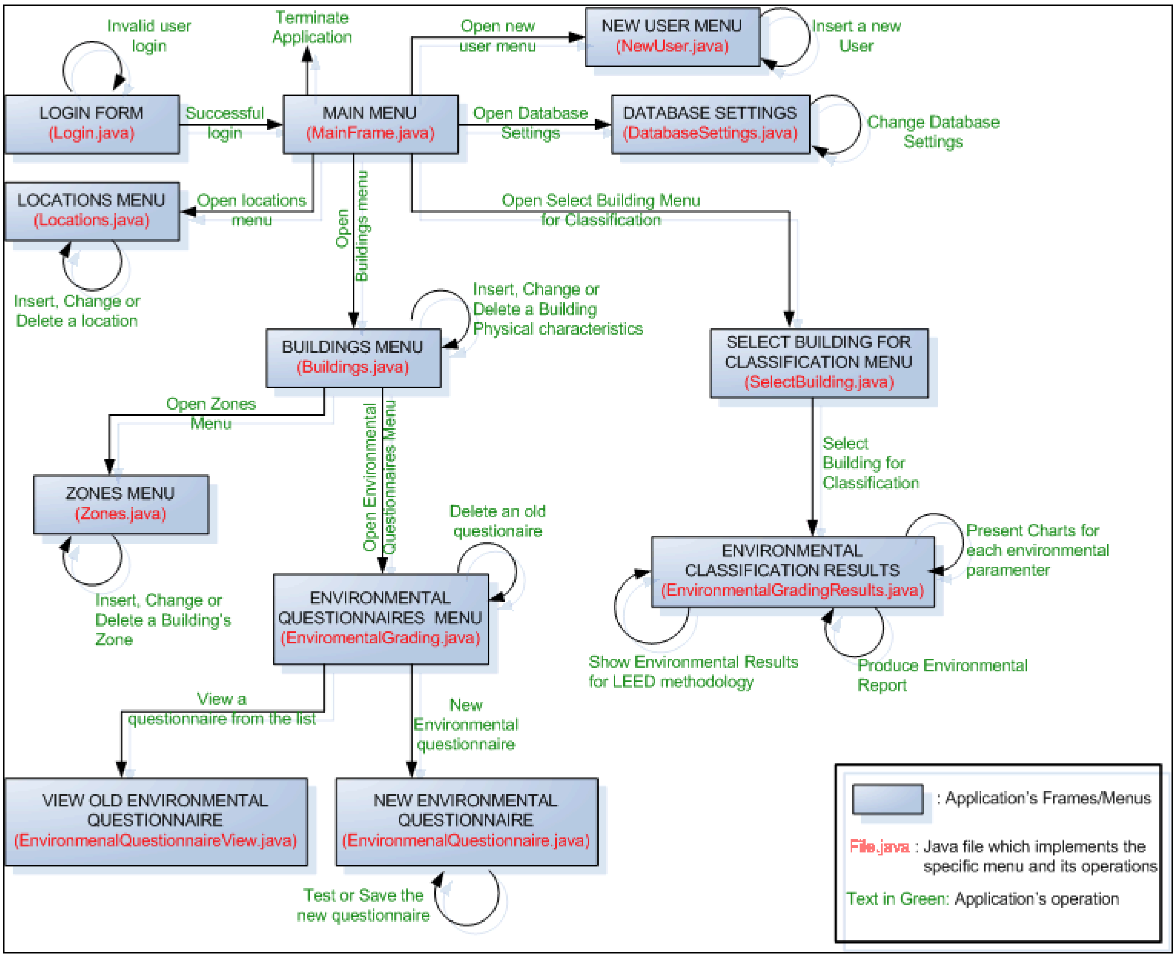

Figure 7 - Application's flow chart

Blue boxes represent the application's menus and frames. Red text indicates the java files which implement the specific menus and its operations. Green text indicates application's operations and options.

5.2.1 Authentication Mechanism

Application contains an authentication mechanism in order to protect buildings' data from unauthorized users. Only authorized users have access to the application and can perform buildings' insertions and classifications. New users can be inserted into the application from the *users menu* after a successful login.

5.2.2 Database Settings

An authorized user may change database connection settings from the *database settings menu*. By changing the database name, username and password, application can operate with different databases of the same structure. Using the same interface, a user may interact with many different databases and organize the classified buildings according to her/his favor.

5.2.3 Stored Locations

Application has the capability of storing known locations, where buildings may be located. Each location is escorted by geographical and statistical data which may be used in several classification methods. Each user may insert, change or delete a location from *locations menu*.

5.2.4 Buildings Input Data

As mentioned before, the buildings information is divided into 1) physical characteristics and 2) data that describe the environmental behavior of the building. *Buildings Menu* is responsible for gathering the physical characteristics of a building. These characteristics consist of two categories:

- Basic information – Identity of the building: like building's description, address and floors.
- Physical entity characteristics: like insulation, conditioned surface, building's condition (old or new) and type, air-condition's existence. This information is valuable for the classification mechanism.

Four types of buildings are supported: Offices, Hotel, School and Shop. A text file which contains hourly measurements of outdoor air temperature is inserted in this menu for each building. This file is essential for the thermal comfort classification (calculation of running mean outdoor temperature, $T_{e,ref}$). From Buildings Menu user may insert, change or delete a building within its characteristics.

Each building is divided into several zones and each zone's environmental performance is described by several parameters:

- Indoor Air Temperature
- Mean Radiant Temperature
- Relative Humidity
- CO_2 concentration
- Illuminance

Zones menu is responsible for the insertion, change or deletion of a zone for a building. Outdoor Air Temperature is missing from zones menu, as it is supposed that outdoor temperature is the same for all indoor zones (given in Buildings Menu). A text file is stored for each parameter which contains hourly measurements taken by a Building Energy Management System. These hourly measurements are processed in the classification mechanism. For each zone, the occupancy period (Starting hour – Ending hour) during the day is also stored. This is useful in the classification mechanism as the classification takes place during the occupancy period of the building.

All files must contain hourly values and agree the following format for a successful zone's insertion:

Date Time Value (e.g.: 13/05/2008)

5.2.5 LEED Green Building Rating System Implementation

The application implements the LEED methodology as a questionnaire. The questionnaire is divided into five sections (tabs), one for each LEED category. Each section contains the requirements of the specific category (in a Yes/No form) that must be fulfilled in order to earn all possible category points. The classification of the building results from the addition of points (credits) of positive fulfilled requirements. More than one questionnaire can be assigned to each building. The last one (in time) is considered in the final classification results of the building. Each time a user fills in a questionnaire, he has the option to test it before saving it. When a questionnaire is saved (the filled answers), the total score (points achieved) and the resulted category are also saved. The user can view a filled questionnaire and its results at any time by choosing it from the list of questionnaires for a certain building.

5.2.6 CEN based environmental classification

A building is ready for environmental classification, when all its data are inserted in the application. Each user has to select the building from the list of available buildings and wait the classification results. All environmental parameters (Thermal comfort, Relative Humidity, Lighting, CO_2 concentration) are classified, according to standard presented in chapter 3. Environmental parameters' files are processed and the classification results are presented separately for each zone. The application produces measurement and statistic graphic charts (standard based) for each zone and for each parameter. LEED classification results (total score and resulted category) are also presented if a questionnaire is available for the specific building. Finally, the application is able to produce an environmental classification report which contains the classification results for all zones and methodologies.

5.2.7 Java open source class libraries

For the generation of the charts and the production of the environmental report two open source java class libraries were used: JFreeChart and JasperReports respectively. JFreeChart is a free chart library for the Java(tm) platform. It is designed for use in applications, applets, servlets and JSP. JFreeChart is distributed with complete source code subject to the terms of the GNU Lesser General Public Licence, which permits JFreeChart to be used in proprietary or free software applications [26]. JasperReports is an open-source Java class library designed to aid developers with the task of adding reporting capabilities to Java applications by providing an API to facilitate the ability to generate reports from any kind of Java application. Though it is primarily used to add reporting capabilities to web-based applications, it can also be used to create standalone desktop or command-line Java applications for report generation [27].

Appendix C provides a short application manual and forms/menus description.

Appendix D gives a small description of the most significant java classes and their methods, used for the operation of the platform.

5.3 Database System Implementation

5.3.1 General

The application manages a large amount of data, which are collected and stored for each building. Data must be organized and stored in such a way, so that their extraction and usage are easy and quick. The application must include a database mechanism which implements the efficient management of building's information. The information, stored into the database, concerns:

- Authentication data for the application's users.
- Physical characteristics of buildings (e.g. category, area, location).
- Measurements of specific sensors' types for every zone of the building.
- Data related with the environmental behavior of the building, according to the LEED Green Building Rating system.

This information is used for the extraction of the environmental grading results.

5.3.2 Selection of Database System Tool – Java DB

For the implementation of the database, several tools could be used such as Java DB, MySQL, Microsoft SQL Server and Oracle environment. Java DB was selected for the following reasons:

- It is an open source project.
- It efficiently collaborates with the application as it is implemented in Java language.
- It is ideal for desktop applications: a) it doesn't consume many system resources b) is fast and c) secure
- It is portable and it comes within the application (embedded database system).

Java DB is Sun's supported distribution of the open source Apache Derby 100% Java technology database. It is fully transactional, secure, easy-to-use, standards-based (SQL, JDBC API, and Java EE). Java DB's embedded mode makes it simple to develop, deploy, and use applications, while allowing easy migration to client/server mode. It is 100% pure Java, so it fits seamlessly with the Java development model (just putting the derby jar file on application's classpath). It can be run in the familiar client/server configuration, as well as embedded in an application, allowing any number of clients to connect. It is easy to use and easy to deploy for departmental client/server applications, with minimal tuning required. Java DB technology adheres to database standards such as JDBC and ANSI SQL standards. This means Java DB provides the functionality expected of a sophisticated relational database, including SQL syntax, transaction management, concurrency, triggers, and backups. It also means that it is easy to migrate an application using Java DB to and from other standards-based databases, such as PostgreSQL, Oracle and DB2. Finally, Java DB provides a number of security mechanisms including database file encryption, authentication through either external LDAP directory or built-in repository, and authorization. In addition, access to the database can also be controlled at read-only or read-write level.

Derby is an open source, fully functional relational database management system. It supports many of the features found only in high-end, commercial database engines, such as transactions. Derby itself is written in Java, so it is amenable to the needs of Java programmers. Another important Derby attribute is its really light footprint (about 2MB RAM) that obviates the need for very powerful host machines.

5.3.3 Relation Model and Entity Relation Diagram

The main design structure of information is the entity. Entity is an object whose characteristics have discernible existence, contrary to other objects, and is described through a collection of attributes. The discretion achieved with the entities' usage, in data grouping, doesn't necessary results that data are orthogonal (foreign). This means that some records can be the same in different entities. For each entity's attribute, type, detail and the bandwidth of information must be specified. Two or more entities can be interlinked with a relationship which allows the combination of data between different entities.

A poor database design can cripple an application, producing problems with redundancy, inaccuracy, consistency, and concurrency of your data. Normalization is a process that serves to reduce, if not eliminate, these problems with data [28,29]. The benefits of normalizing a database include:

- Avoiding repetitive entries.
- Reducing required storage space.
- Preventing the need to restructure existing tables to accommodate new data.

- Increased speed and flexibility of queries.

There are five normal forms in all, each progressively building on its predecessor. In order to reach peak efficiency, it is recommended that relational databases are normalized through at least the third normal form. In order to normalize a database, each table must have a primary key field that uniquely identifies each record in that table. [28,29]

First Normal Form requires that there are no **multi-valued** attributes, and no **repeating groups**. A multi-valued attribute would contain more than one value for that field in each row. Data cannot be stored or processed in a database when it is in this form (multi-valued or repeating groups). [28,29]

Second Normal Form requires that any non-key field is depended on the **entire primary** key. Entire primary key field is one (or more logically joined) field(s) used to uniquely identify each record in a data file. A relation is in 2NF if, and only if, it is in 1NF and every non-key attribute is fully functionally depended on the entire key field. [28,29]

Third Normal Form prohibits **transitive dependencies**. A transitive dependency exists when any attribute in a table depends on any other non-key attribute in that table. A relation is in 3NF if, and only if, it is in 2NF and no non-key fields transitively depended on the key field(s). That is, no non-key field functionally depends on another non-key field. [28,29]

According to the previous rules the ER (Entity Relationship) diagram was drawn, figure 8:

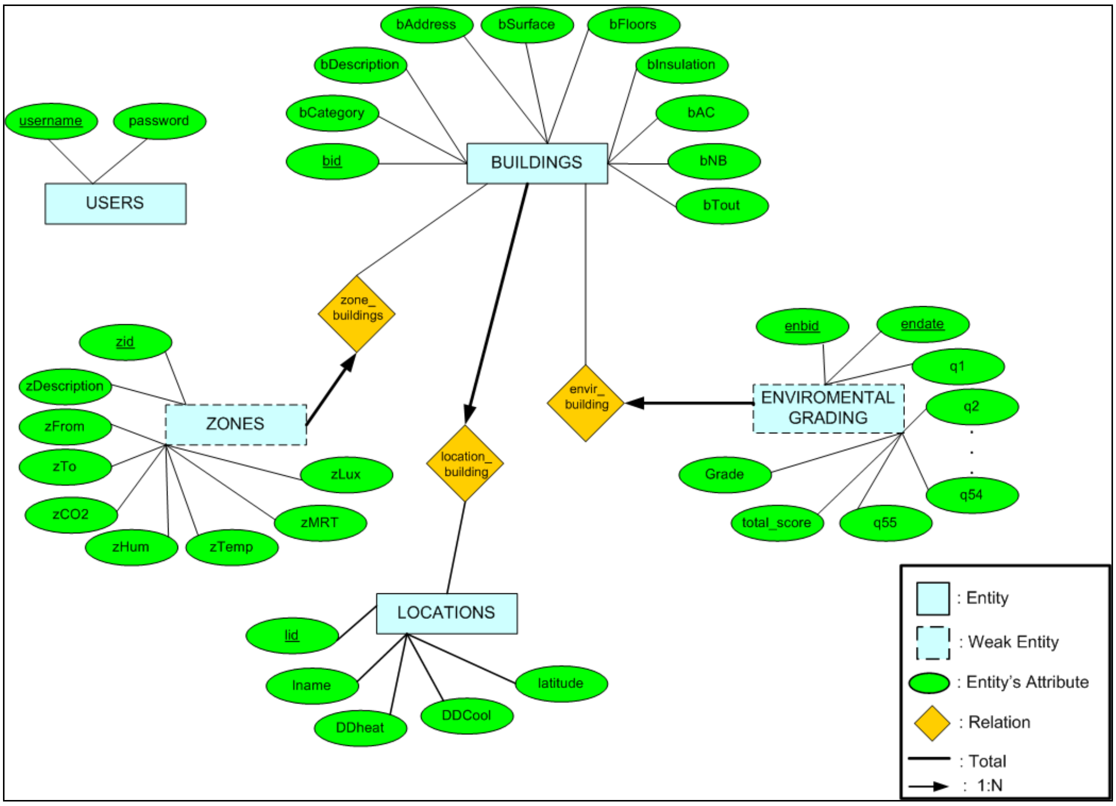

Figure 8 - Database Entity Relationship diagram

Entity **Users** has been designed to represent all registered users in the application. Two attributes that characterize a user have been selected: *Username* and *Password.* Username attribute is the primary key. Table **Users** was constructed to represent this entity and contains the above attributes.

Entity **Locations** has been designed to represent all available locations in the application. *lid* attribute is the primary key (location id). Name, latitude, Degree-Days Heat and Degree-Days Cool are entity's attributes. Table **Locations** was constructed to represent this entity and contains the above attributes.

Entity **Buildings** has been designed to represent the buildings in the database. It contains the physical characteristics of buildings. *bid* attribute is the primary key (building id). *Description*, *Address*, *Surface*, *Floors, Insulation, Location, AC (Air-condition), NB (New Building)* are attributes that characterize each building. *Category* attribute stores the category of the building (Offices, Hotel, School, Shop) and *Tout* attribute stores the name of the file which includes measurements of the external temperature. Table **Buildings** was constructed to represent this entity. It contains the above attributes and an additional one (foreign key), the primary key of the location where the building is located (Reason: relation location_building is 1:N).

Entity **Zones** has been designed to represent the zones that belong to each building. *zid* attribute is the primary key (zone id). *Description* attribute store a small description of the zone. *From* and *To* attributes store the time limits of the occupancy time. CO_2*, Humidity, Temperature, MRT, and Lux* attributes store the names of the measurements' files of the environmental parameters, respectively. Table **Zones** was constructed to represent this entity. It contains the above attributes and an additional one (foreign key), the primary key of the building which owns the zone (Reason: relation zone_building is 1:N).

Entity **Environmental Grading** has been designed to represent all available LEED Green Building Rating questionnaires for each building. Entity has two primary keys: the building id, *enbid* (foreign key) and the *date* of questionnaire completion. *Totalscore* and *grade* attributes store the total score and the environmental grading result, respectively. Attributes *q1-q55,* store the answers of the questionnaire. Table **Environmental Grading** was constructed to represent this entity.

Three relations have been designed. Relation **loation_buildings** has been designed to relate a building to the location where is located. Relation **zone_building** has been designed to relate a building to the zones it includes and **envir_building** to relate a building to the environmental questionnaires it contains.

- The relationship between BUILDINGS and LOCATION_BUILDINGS is **total** because it is necessary for a building to be located in a location.
- The relationship between LOCATIONS and LOCATION_BUILDINGS is **partial** because it is not necessary for a location to belong to a building.
- The relationship between LOCATIONS and BUILDINGS is **1:N** because one or more buildings may be located to the same location.
- The relationship between BUILDINGS and ZONE_BUILDING is **partial** because it is not necessary for a building to have a zone.
- The relationship between ZONES and ZONE_BUILDING is **total** because it is necessary for zone to belong to a building.
- The relationship between BUILDINGS and ZONES is **1:N** because one building may have more than one zone.
- The relationship between BUILDINGS and ENVIR_BUILDING is **partial** because it is not necessary for a building to have a LEED questionnaire.

- The relationship between ENVIRONMENTAL GRADING and ENVIR_BUILDING is **total** because it is necessary for questionnaire to belong to a building.
- The relationship between BUILDINGS and ENVIRONMENTAL GRADING is **1:N** because one building may have more than one questionnaires.

Below all database's tables (short form) are given.

Table Users	
username	password

Table Locations				
lid	lname	DDheat	DDCool	latitude

Table Buildings										
bid	bloc_id (FK)	bCategory	bDescription	bSurface	bFloors	bAddress	bInsulation	bAC	bNB	bTout

Table Zones									
zid	zbid (FK)	zDescription	zFrom	zTo	zCO2	zHum	zTemp	zMRT	zLux

Table Environmental Grading						
enbid	endate	q1	…	q55	total_score	grade

Appendix E contains all tables in an analytic form and the relational schema.

Chapter 6 - Experimental Results, Evaluation and Validation of the application

6.1 General

In order to evaluate and validate the java application platform, it is necessary to perform several tests for all methodologies embedded in the application. According to application's requirements and specifications, a building which embodies a building energy management system must be found. BEM system has to record measurements and produce text files that contain hourly values of the required environmental parameters. Additionally, the selected building must be escorted by all necessary information required, to fill the LEED environmental questionnaire.

The application's evaluation was based on measurements recorded by a building management system installed in the facilities of Byte Computers S.A.

6.2 Description of Byte Computers S.A. Facilities

The building is an autonomous multi-storey construction and is located in the city of Athens in Greece. The greater part of its façade consists of extended reflective windows. Buildings' spaces are comprised mainly by offices and meeting halls. There are certain spaces with special usage: server rooms and storage rooms. Server rooms require temperature range between 18 and 22 ^{o}C, and humidity values less than 60%. Storage rooms don't have special environmental requirements. In the rest of spaces, thermal requirements are defined by international and national standards (20 - 21 ^{o}C for heating season and 26 ^{o}C for cooling season). Specifications for indoor air quality define the quantity of fresh air due to its usage. For the offices the recommended quantity is 30 $m^3/h/person$, where smoking is not allowed, and 90 $m^3/h/person$ where smoking is permitted. Lighting specifications require 500lx at working area for offices and 200lx at the rest of spaces, where the occupancy is minor.

The building embeds a central heating/cooling/ventilation system made by Daikin (VRV – Variable Refrigerant Volume). The basic characteristic of this system is that it can operate at heating and cooling mode simultaneously, for its indoor units.

A major advantage is that central units are able to interconnect with building automated control management systems.

The lighting equipment consists of lighting units with fluorescent lamps and aluminum reflectors of high performance. The absence of electronic ballast doesn't permit the continuous dimming of lighting units.

The Byte's building embeds a Building Management System based on Lontalk communication protocol, known as Lonworks Network. It is comprised of compatible, with lonworks protocol, devices made by Honeywell, Echelon, Daikin and Crompton.

6.3 Experimental Classification Results – CEN standard

The experimental procedure is based on data, recorded from three different zones in three separate floors (Zone A – Ground Floor, Zone B – First Floor, Zone C – Second Floor). Data, recorded by the installed building management system, constitutes of hourly measurements of the following environmental parameters: Outdoor and Indoor Air Temperature, Mean Radiant Temperature, Relative Humidity, CO_2 concentration and Indoor illuminance. They are organized into text files and are inserted into the application. The file's format agrees the following pattern: Date Hour Value (e.g. 01/12/2006 13:00 26.2). The measurements lasted eighty one days, starting from 01/12/2006 01:00 and ended at 19/02/2007 23:00 (during heating season). The daily occupancy hours, of spaces under consideration, were from 09:00 to 17:00 (offices mainly).

The environmental classification results and the graphic charts, produced by the application, of each classified environmental parameter and for each zone are presented below.

6.3.1 Thermal Comfort Classification Results

Thermal comfort classification mechanism processes the measurement files for the following environmental parameters: Indoor Air Temperature, Outdoor Air Temperature and Mean Radiant Temperature. Figures 9 - 14 presents the thermal comfort graphic charts for all zones. Two types of charts are produced:

- The thermal comfort model's chart which contains the categories' line limits and the pairs of ($T_{e,ref}$, T_{oper}).

- Bar chart showing the percentages of points for each sub-category.

Zone A – Ground Floor

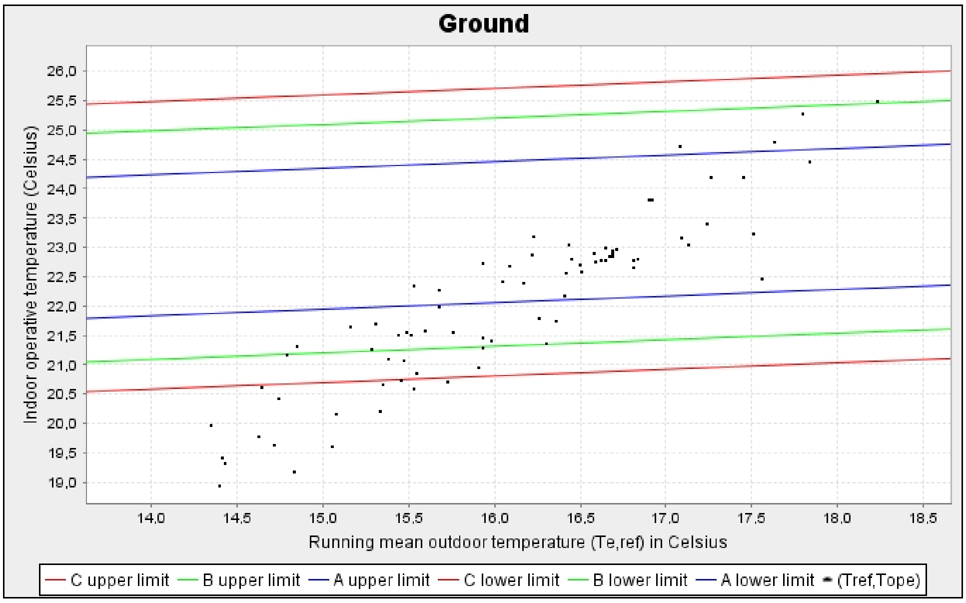

Figure 9 - Thermal Comfort Classification chart for Zone A – Ground Floor

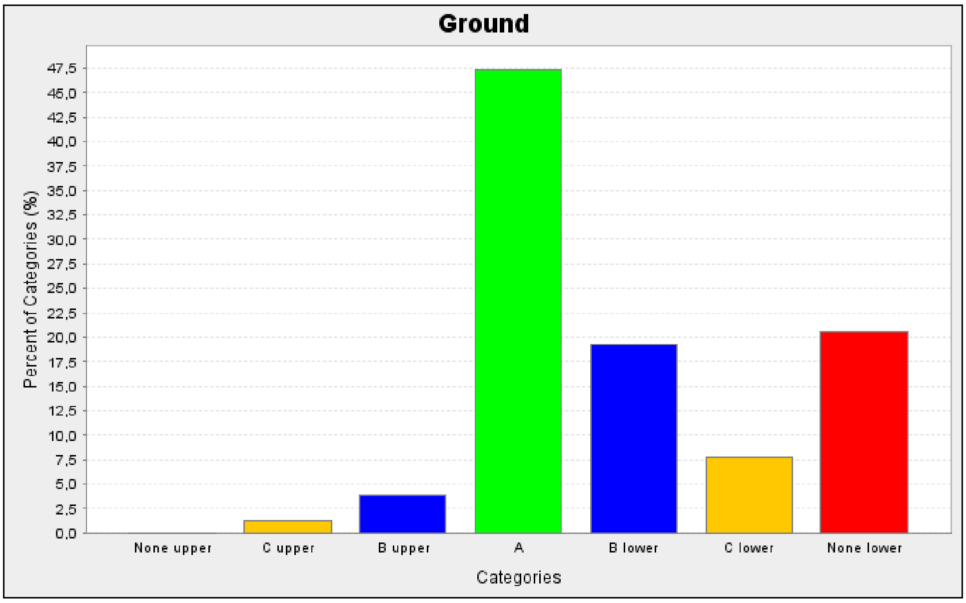

Figure 10 - Percentage of points of each sub-category for Zone A – Ground Floor

The classification's result indicates that the indoor climate of zone A – Ground Floor is inadequate. Although, many points are inside classes' limits, the zone doesn't belong to a class because several points are exceed the limit values of Class C.

Zone B – First Floor

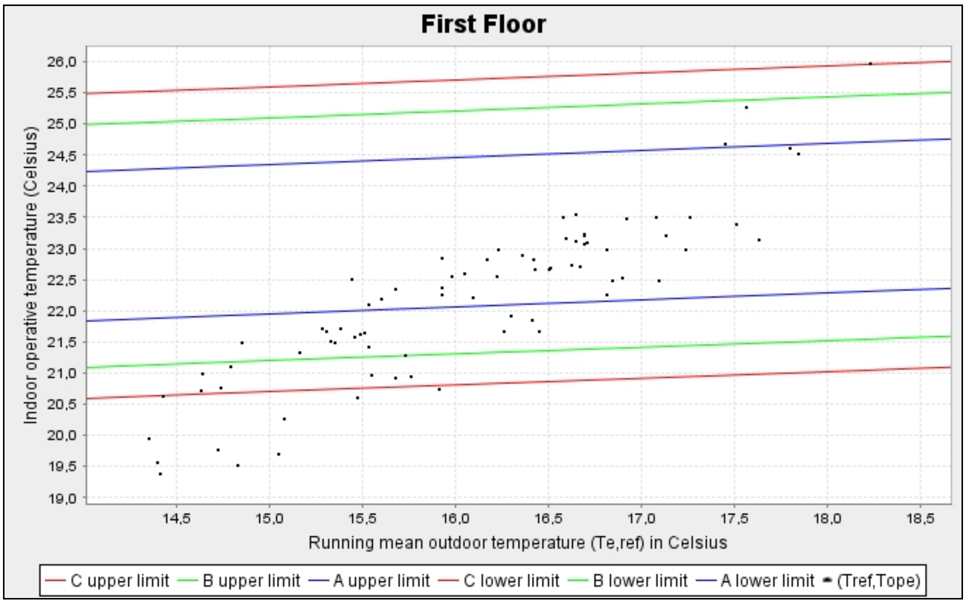

Figure 11 - Thermal Comfort Classification chart for Zone B – First Floor

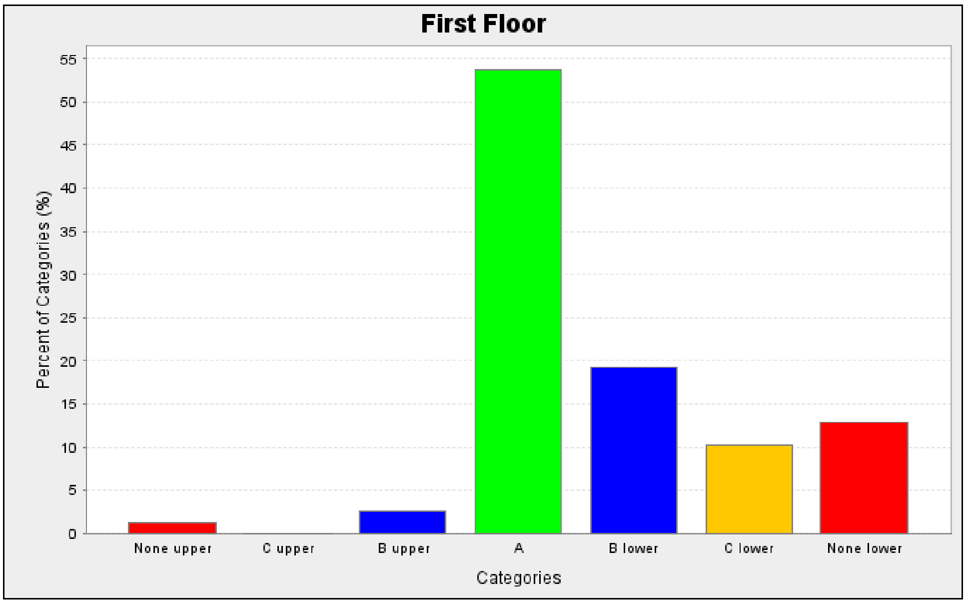

Figure 12 - Percentage of points of each sub-category for Zone A – Ground Floor

The classification's result indicates that the indoor climate of zone B – First Floor is inadequate. Although, many points are inside classes' limits, the zone doesn't belong to a class because several points are exceed the limit values of Class C.

Zone C – Second Floor

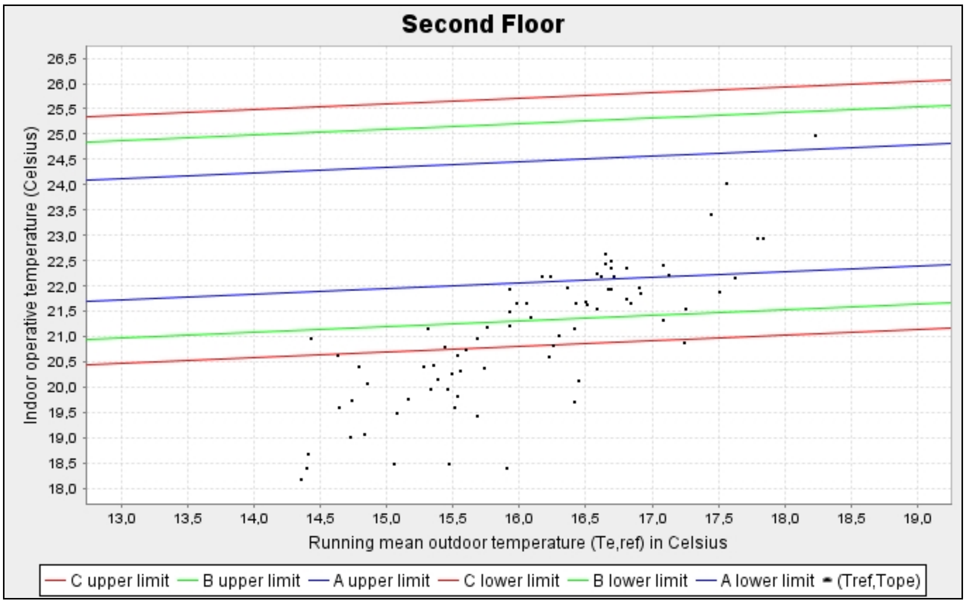

Figure 13 - Thermal Comfort Classification chart for Zone C – Second Floor

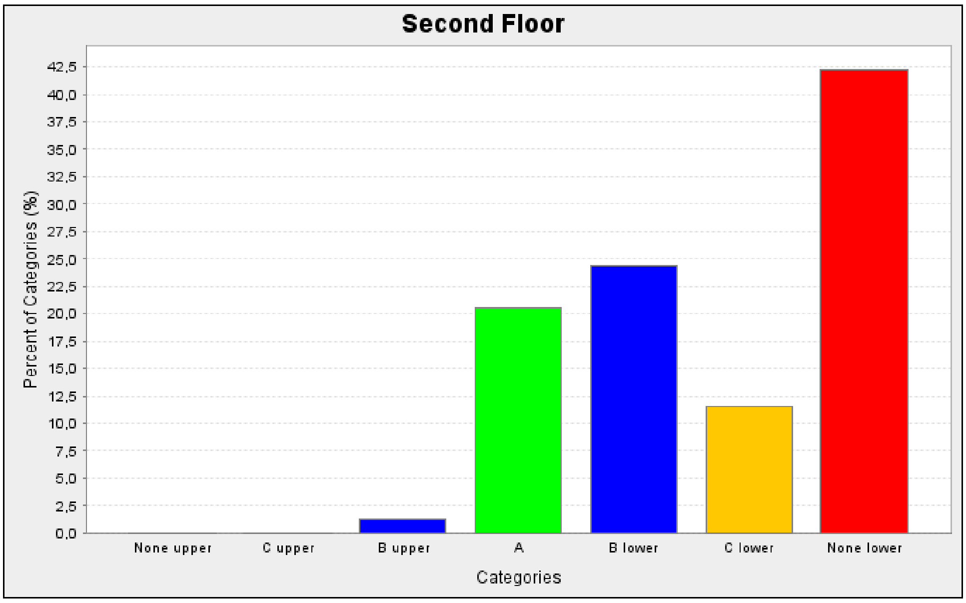

Figure 14 - Percentage of points of each sub-category for Zone A – Ground Floor

The classification's result indicates that the indoor climate of zone C – Second Floor is inadequate. Although, many points are inside classes' limits, the zone doesn't belong to a class because several points are exceed the limit values of Class C.

Table 11 presents the classification results for the three zones.

Zone	Thermal Comfort Category
Ground Floor	None
First Floor	None
Second Floor	None

Table 11 - Thermal Comfort Classification Results

6.3.2 Relative Humidity Classification Results

Relative humidity classification mechanism processes the measurement files of relative humidity parameter. Figures 15 - 20 presents the relative humidity graphic charts for all zones. Two types of charts are produced:

- Chart which contains the measurements during **occupancy time** and the line limits of each category.
- Pie chart showing the percentages of hours for each category.

<u>Zone A – Ground Floor</u>

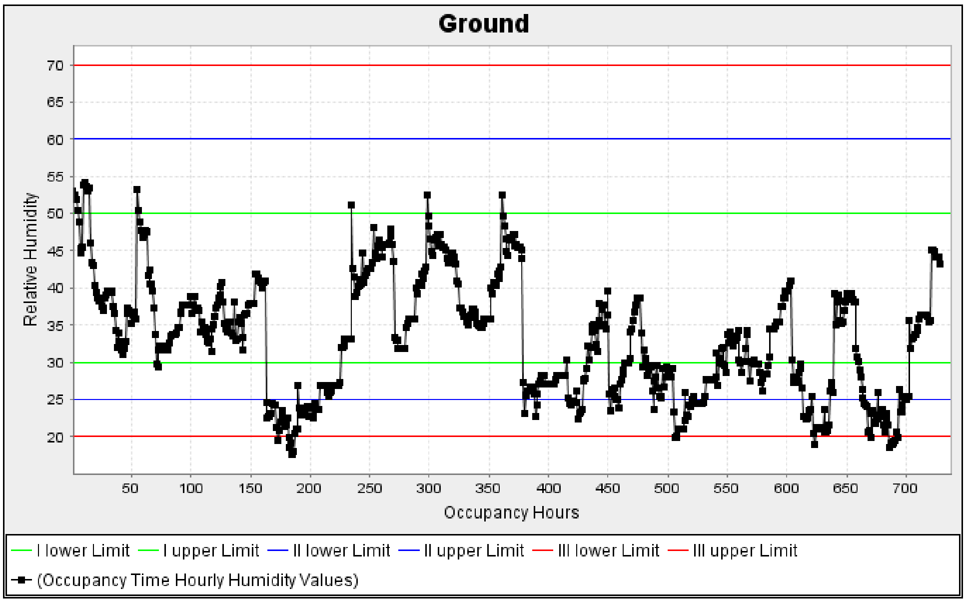

Figure 15 - Relative humidity Classification chart for Zone A – Ground Floor

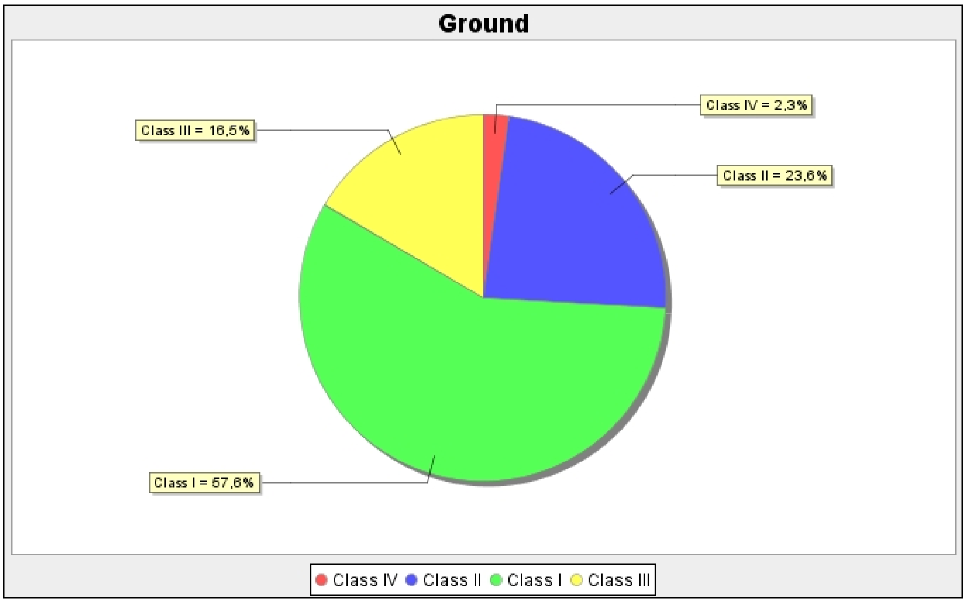

Figure 16 - Percentage of days of each category for Zone A – Ground Floor

The classification's result indicates that zone A – Ground floor belongs to category I. The greater percentage of hours belongs to category I. Relative humidity remains in acceptable limits and there is no need for dehumidification or humidification during occupancy hours.

Zone B – First Floor

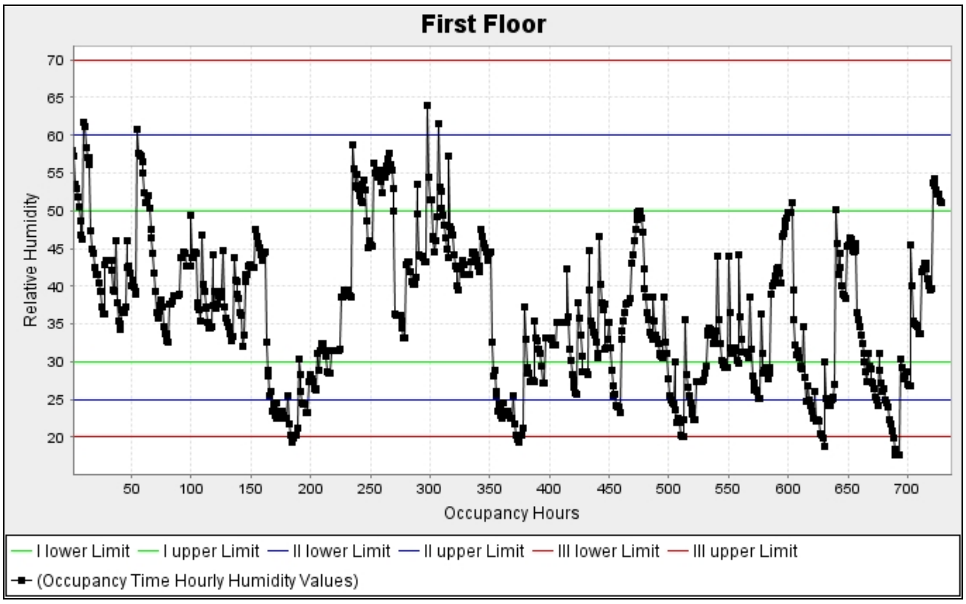

Figure 17 - Relative humidity Classification chart for Zone B – First Floor

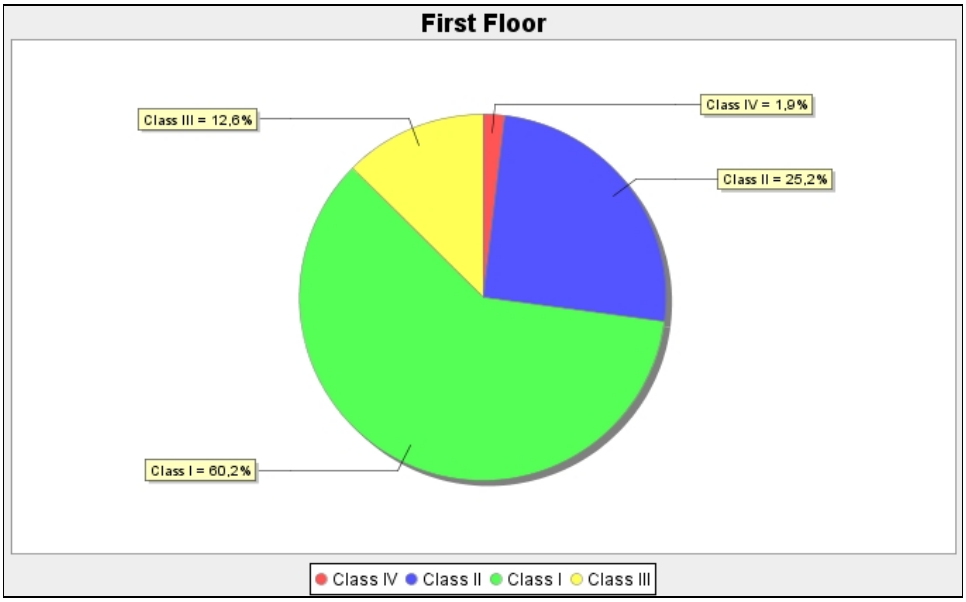

Figure 18 - Percentage of days of each category for Zone B – First Floor

The classification's result indicates that zone B – First floor belongs to category I. The greater percentage of hours belongs to category I. Relative humidity remains in acceptable limits and there is no need for dehumidification or humidification during occupancy hours.

Zone C – Second Floor

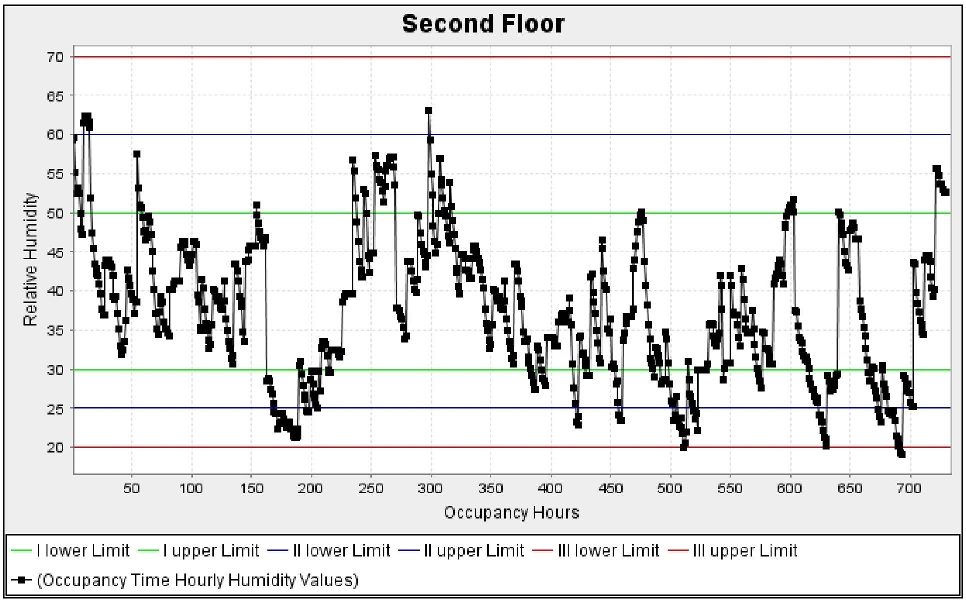

Figure 19 - Relative humidity Classification chart for Zone C – Second Floor

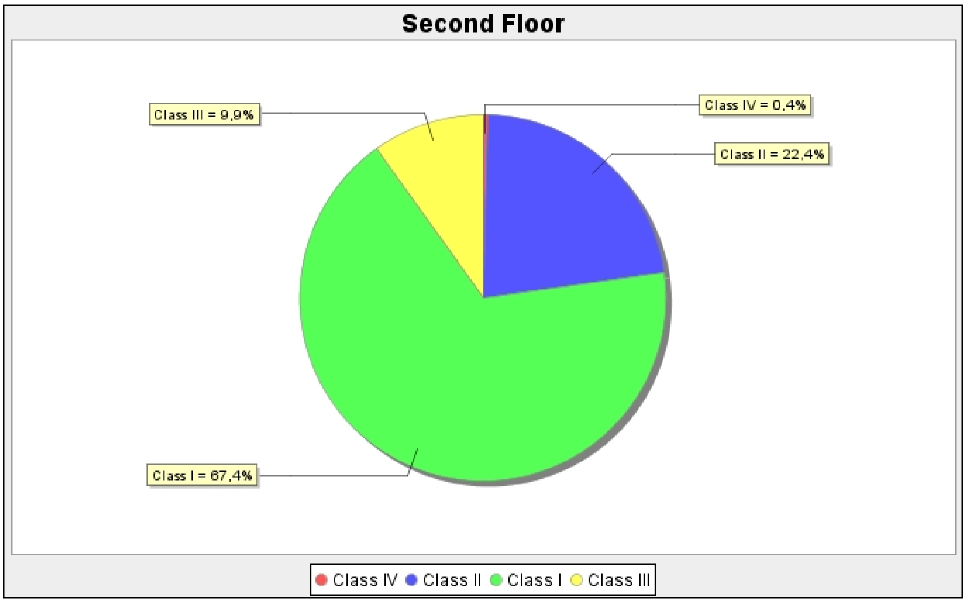

Figure 20 - Percentage of days of each category for Zone C – Second Floor

The classification's result indicates that zone C – Second floor belongs to category I. The greater percentage of hours belongs to category I. Relative humidity remains in acceptable limits and there is no need for dehumidification or humidification during occupancy hours.

Table 12 presents the classification results for the three zones.

Zone	Relative humidity Category
Ground Floor	I
First Floor	I
Second Floor	I

Table 12 - Relative humidity Classification Results

6.3.3 Carbon Dioxide Classification Results

Carbon dioxide classification mechanism processes the measurement files of CO_2 concentration parameter. Figures 21 - 26 presents the carbon dioxide graphic charts for all zones. Two types of charts are produced:

- Chart which contains the measurements during **occupancy time** and the line limits of each category.
- Pie chart showing the percentages of days for each category.

<u>Zone A – Ground Floor</u>

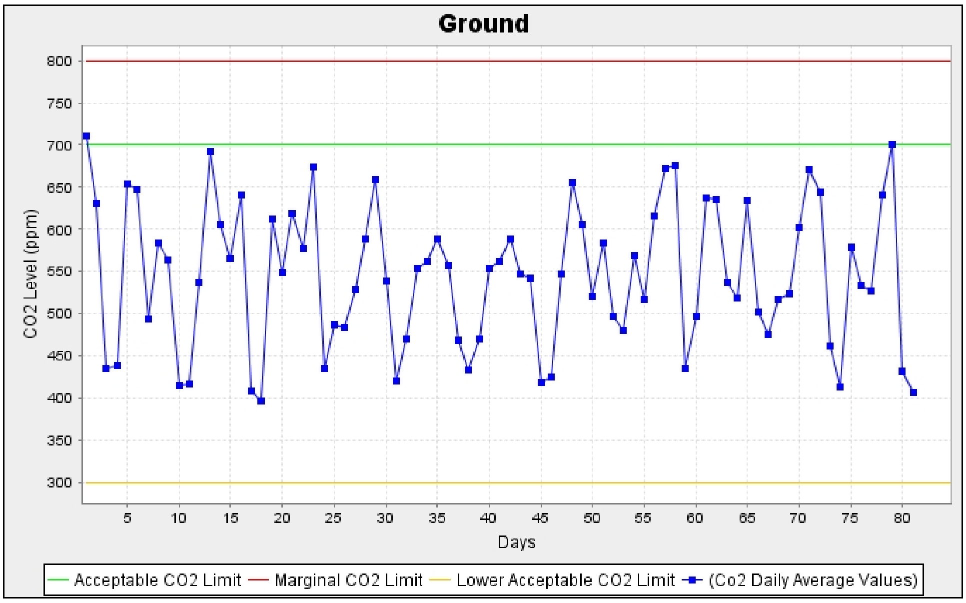

Figure 21 - Carbon Dioxide Classification chart for Zone A – Ground Floor

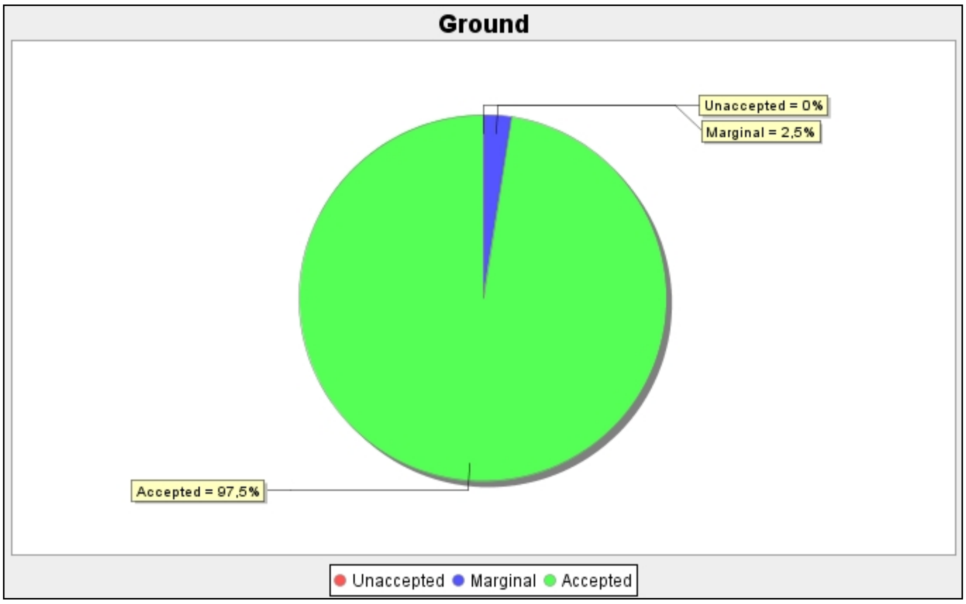

Figure 22 - Percentage of days of each category for Zone A – Ground Floor

The classification's result indicates that the levels of carbon dioxide are acceptable, during occupancy hours. The indoor air quality of zone A – Ground floor doesn't cause discomfort to the residents.

Zone B – First Floor

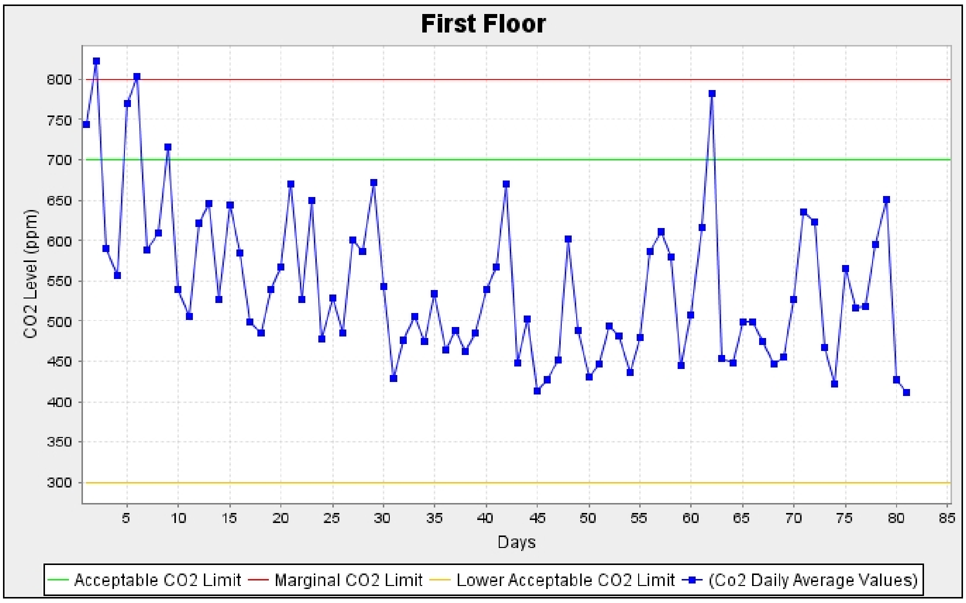

Figure 23 - Carbon Dioxide Classification chart for Zone B – First Floor

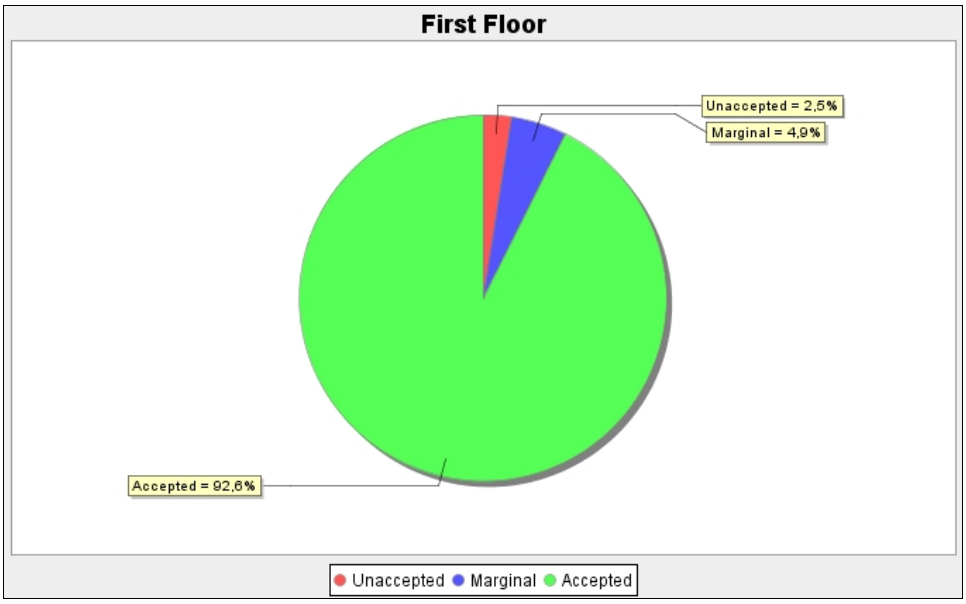

Figure 24 - Percentage of days of each category for Zone B – First Floor

The classification's result indicates that the levels of carbon dioxide are acceptable, during occupancy hours. The indoor air quality of zone B – First floor doesn't cause discomfort to the residents.

Zone C – Second Floor

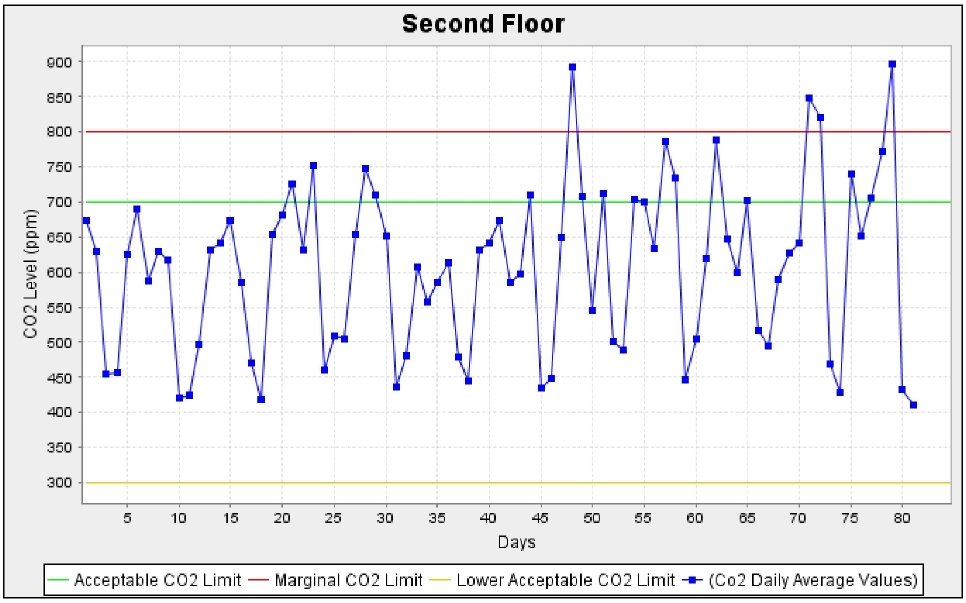

Figure 25 - Carbon Dioxide Classification chart for Zone C – Second Floor

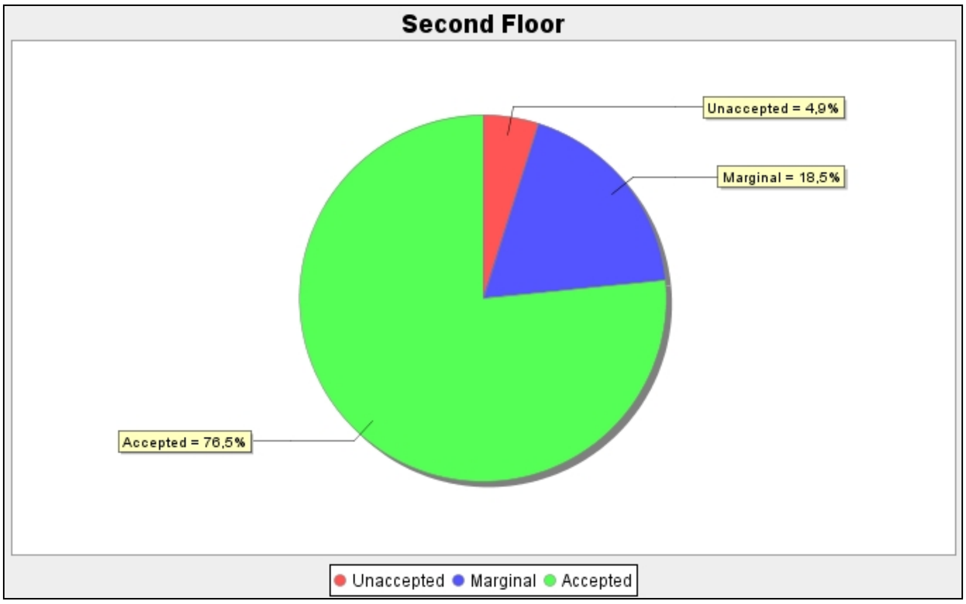

Figure 26 - Percentage of days of each category for Zone C – Second Floor

The classification's result indicates that the levels of carbon dioxide are acceptable, during occupancy hours. The indoor air quality of zone C – Second floor doesn't cause discomfort to the residents.

Table 13 presents the classification results for the three zones.

Zone	Carbon Dioxide Category
Ground Floor	Accepted
First Floor	Accepted
Second Floor	Accepted

Table 13 - Carbon Dioxide Classification Results

6.3.4 Lighting Classification Results

Lighting classification mechanism processes the measurement files of indoor illuminace parameter. Illuminnce measurements were provided only for one zone, First Floor. Figures 27, 28 presents the lighting graphic charts for zone B – First Floor. Two types of charts are produced:

- Chart which contains the measurements during **occupancy time** and the line limits of each category.
- Pie chart showing the percentages of hours for each category.

Zone B – First Floor

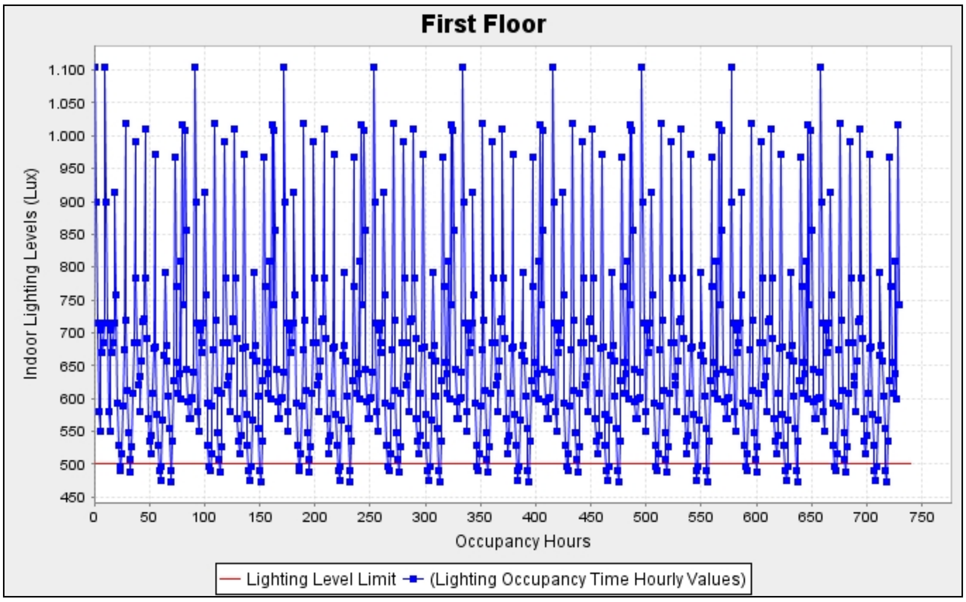

Figure 27 - Lighting Classification chart for Zone B– First Floor

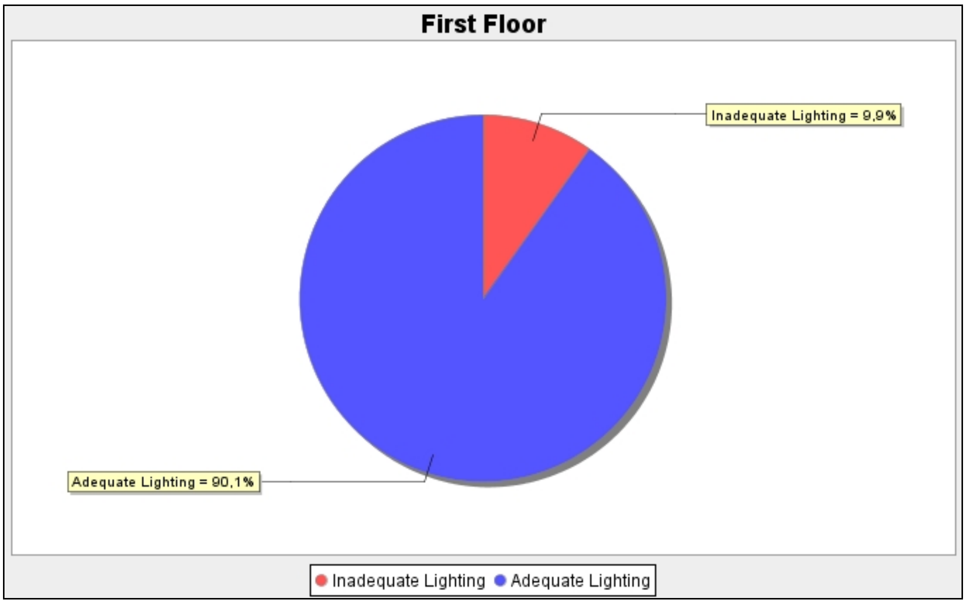

Figure 28 - Percentage of days of each category for Zone B – First Floor

The classification's result indicates that zone B – First Floor has adequate lighting during occupancy hours. The illuminace levels are secured by the proper combination of daylight and artificial light.

6.4 Experimental Classification Results – LEED Green Buildng Rating System

Beside CEN classification methodology, a LEED questionnaire was filled to classify building according to LEED Green Building Rating methodology. Table 14 presents the classification results.

LEED Categories	Earned Points
Sustainable Sites	8/15
Water Efficiency	3/5
Energy and Atmosphere	14/25
Materials and Resources	10/14
Indoor Environmental Quality	14/15
Sum of Earned Points (Total Score)	**49/71**
Classification Building's Class	**B**

Table 14 - LEED Classification Results

Appendix F presents the filled LEED questionnaire and the environmental report created by the application.

Chapter 7 - Conclusions and Future Work

7.1 Classification results' conclusions

In this section, classification results are analyzed and discussed for each environmental parameter. Comparison between the three zones is performed, when necessary. The classification results derived from measurements lasted eighty one days, during heating season. This period isn't enough to estimate the total environmental behavior of the building (a whole year usually needed). But it is ideal for the evaluation and validation of application platform.

7.1.1 Thermal Comfort Classification

According to the classification results, the indoor climate of the three zones is inadequate (Category *None*). Several points exceed the limits of C class for each zone. A great percent of points is located in the lower subclasses, as shown in table 15.

Zone	**Percentage of points in lower subclasses (B Lower, C Lower, <C Lower)**
Ground Floor	47,4%
First Floor	42,3%
Second Floor	78,2%

Table 15 - Percentages of points in lower subclasses

This means that the indoor climate is quite cold for the residents according to thermal model's class limits. The building environment may affect the occupants causing health problems, lower productivity and discomfort. The classification results may be affected by the following factors:

- The period of measurements is quite cold for the Greek standards. Higher RMOT (running mean outdoor temperature) was near $18{,}23\,^{o}C$ and lower RMOT was near $14{,}3\,^{o}C$. The greater percentage of days were fluctuated between 14,7 ^{o}C and 16,9 ^{o}C. If buildings' insulation is inefficient and thermal conductivity is relatively large, then the efficiency of thermal units, in increasing spaces' temperature, decreases with low outdoor temperature. Conduction heat flows occurs in the direction of decreasing indoor temperature.

- The classes' limits of the adaptive thermal model may be too rigorous for Greek building constructions. Limits, introduced by the model, are more suitable for buildings located in central Europe (international model). Further work must be done in order to adjust limit lines to national standards.
- Adaptive thermal model evaluates the total thermal behaviour of the building, during the day. It processes all the measurements taken during the day and doesn't study the occupancy time of spaces. This may affect the classification results, in a large portion, for a building which controls environmental parameters only for occupancy time. The indoor temperature and MRT values, for hours outside occupancy time, may be quite small (cold conditions). These values produce relatively small daily operative temperature values (arithmetic mean of the air temperature and the mean radiant temperature). Many points located outside C class limits belong to this category of measurements. An alteration of thermal model that takes into account the occupancy time may produce more fair classification results for this type of buildings.

Comparing the three classified zones, zone B – First floor proved to have the better thermal comfort performance. It has the greater percentage of points in class A and the smaller percentage of points out of C class's limits (None class). Table 16 shows the respective percentages for all zones.

Zone	Class A point's percentage	Percentage of points out of C class's limits
A – Ground Floor	47,4%	20,5%
B – First Floor	53,8%	14,1%
C – Second Floor	20,5%	42,3%

Table 16 - Compare zones' performance

7.1.2 Relative humidity Classification

According to classification results, relative humidity levels fluctuated in very acceptable limits for all zones, during occupancy time. There is no need for spaces' humidification or dehumidification. The percentages of days for category I are greater than the other categories. Table 17 shows the resulted percentages.

Zone	Category I	Category II	Category III	Category IV
A – Ground Floor	57,6%	23,6%	16,5%	2,3%
B – First Floor	60,2%	25,2%	12,6%	1,9%
C – Second Floor	67,4%	22,4%	9,9%	0,4%

Table 17 - Percentages of each category for all zones

Although the zones belong to category I, it is noticed that a great percent of measures is located near lower limits of categories. This means that the climate tends to be dry during occupancy time. If further improvement is needed, then humidification of indoor air is required.

7.1.3 Carbon Dioxide Classification

According to classification results, carbon dioxide concentrations are kept in very acceptable levels, for all zones. The results indicate that building's ventilation system efficient refreshes the indoor air, during occupancy time, without causing discomfort to the occupants. Table 18 presents the percentages of days for each category and zone.

Zone	Lower Accepted	Accepted	Marginal	Unaccepted
A – Ground Floor	0%	97,5%	2,5%	0%
B – First Floor	0%	92,6%	4,9%	2,5%
C – Second Floor	0%	76,5%	18,5%	4,9%

Table 18 - Percentages of each category for all zones

Second column of table 18 (lower acceptance limit 300ppm) indicates that the measurement equipment, for all zones, operates without any problem. All measurements are above 300 ppm which is normal for indoor spaces. As mentioned in chapter 3, carbon dioxide concentration may be related with the space's occupancy and activities. Comparing the three classified zones, zone C – Second floor has greater marginal and unaccepted percentages than the other two zones. This may be caused by greater occupancy levels or activities that produce greater carbon dioxide concentrations or both.

7.1.4 Lighting Classification

According to classification results, working areas' illuminace values for zone B – First floor were adequate (Adequate percentage: 90,1% Inadequate percentage: 9,9%). Occupants may perform visual tasks efficiently and accurately. During measurements' period (winter) the daylight hours are few. This means that illuminance levels are secured by means of daylight and artificial light for the latest hours of occupancy time (15:00 – 17:00).

7.1.5 LEED Green Building Rating System Classification Results

According to LEED questionnaire's result building is awarded with B class. Contrary to CEN standard, LEED methodology doesn't require measurement files and doesn't divide building into zones. The resulted class represents the total environmental behavior of the building. Several changes may be performed in order to improve the environmental behavior of the building according to LEED system's requirements. Improved stormwater management, efficient water landscaping techniques and usage of renewable energy sources could be applied.

7.2 Future Work

The characteristics of a java application and the flexibility of classification standards, for experimentations and extensions, allow potential changes and additions to the java application platform. Two major categories of extensions and changes exist: a) Classification methodologies additions/changes, b) Application additions/changes. Several potential additions and changes are presented below:

<u>Classification methodologies</u>

- Beside carbon dioxide, more pollutant factors (e.g.: carbon monoxide, ozone, sulphur dioxide, nitrogen dioxide e.t.c.), may be monitored and classified in order to have better evaluation of the indoor air quality. Relative tables with limits of many pollutant factors are given by several organizations' guidelines like WHO (World Health Organization), US EPA (Environmental Protection Agency) and NIOSH (National Institute for Occupational Safety and Health).
- Furthermore, ventilation rates may be classified, as proposed by standard prEN 15251:2006, for the indoor air quality. Ventilation rates are related directly to the indoor air quality. They determine the exchange of fresh air and affect the levels of pollutants in the indoor atmosphere. Ventilation rates must be specified for the design of ventilation systems and the calculation of heating and cooling loads. Standard prEN 15251:2006 provides recommended design ventilation rates for residential and non-residential buildings.
- As prEN 15251:2006 standard recommends that, indoor system noise may be monitored and classified. The noise from the HVAC systems of the building may disturb the occupants and prevent the intended use of the space or building. The noise in a space can be evaluated using A-weighted equivalent sound pressure level. Standard recommends indoor system noise criteria of some spaces and buildings. The criteria should be used to limit the sound power level from the mechanical equipment and to set sound insulation requirements for the noise from outdoors and adjacent rooms. The values can be exceeded in the case the occupant can control the operation of the equipment or the windows.
- Additional optical criteria may be considered in order to evaluate the optic comfort with more precision. Beside illuminance, the UGR (Unified Glare

Rating) and the Ra (Colour rendering index) may be monitored. The classification results will be more accurate for the indoor lighting conditions. Standard prEN 15251 provides design values for these criteria, as shown in appendix A.

- As mentioned in the previous section, thermal comfort classification model may receive several changes. Occupancy time, for each zone, may be considered in order to classify zones during occupancy period and ensure more fair classification results. Moreover, the limits of the classes must be adjusted in order to correspond with national (Greek) standards and be less rigorous for old type of buildings. Furthermore, different thermal models, like PMV-PPD, may be performed and be compared to the adaptive thermal model in order to improve the existent model.
- One unified classification category could be produced based on the weighted resulted categories of each environmental parameter (for classification methodology based on CEN standard). Each building could be characterized by a total environmental class which certifies the total environmental behaviour of the building.

<u>Java application platform</u>

- A useful extension, that could be implemented, is the proposition of solutions and scenarios for the improvement of buildings' characteristics. According to the zones' classification, specific scenarios could be proposed to the buildings' administrators. These scenarios could contain changes for:
    1. The technical equipment (e.g. change ventilation system filters).
    2. Building's physical characteristics (e.g. reinforce insulation).
    3. Operation set points for the heating/cooling systems (e.g alteration of the temperature setpoint).
- The application could embed drivers for several communication protocols (like EIB, Lonworks) and cooperate with building energy management systems directly. The future environmental behaviour could be predicted by the evaluation of real time measurements and a real time classification could be performed. Several software controllers could be embedded and adjust, in

parallel, the environmental parameters in order to achieve better classification results.

- The buildings menu could contain more physical characteristics for the buildings. This is useful for several classification methodologies, as a good estimation of the environmental behaviour could be performed. Such characteristics are: the types of materials (for the walls, floors, ceilings), the lighting equipment, the orientation of the building, the insulation type e.t.c.
- The zones' menu could request measurement files for more environmental parameters as mentioned before (e.g. pollutants, UGR, noise)

All previous changes and extensions could be performed with respect to the Greek national standards in order to classify Greek constructions with greater precision. The platform's implementation allows modifying the embedded methodologies easily in order to convert the classification models according to national standards, for every country.

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Appendix A - Recommended criteria for lighting

Table 19 contains examples of design illumination levels for some buildings and spaces from EN12464. For information purposes the UGR (Unified Glare Rating) and Ra (Colour rendering index) are also presented.

Building's Type	Space	Maintained luminance, $\hat{E}_m$, at working areas, lx	UGR	Ra	Remarks
Office buildings	Single offices	500	19	80	at 0,8m
	Open plan offices	500	19	80	at 0,8m
	Conference rooms	500	19	80	at 0,8m
Educational buildings	Classrooms	300	19	80	at 0,8m
	Classrooms for adult education	500	19	80	at 0,8m
	Lecture hall	500	19	80	at 0,8m
Hospitals	General ward lighting	100	19	80	at 0,8m
	Simple examination	300	19	80	at 0,8m
	Examination and treatment	1000	19	90	at 0,8m
Hotels and restaurants	Restaurant, dining room	-	-	80	at 0,8m
Sport facilities	Sports halls	300	22	80	at 0,1m
Wholesale and retail premises	Sales area	300	22	80	at 0,8m
	Till area	500	19	80	at 0,8m
Circulation areas	Corridor	100	28	40	at 0,1m
	Stairs	150	25	40	at 0,1m

Table 19 - Recommended criteria for lighting

APPENDIX B - Leed Green Building Rating System ("Credits")

This appendix states the basic intent and requirements that are necessary to achieve each "credit". A short description of technologies and strategies is also included. The credits are organized into five categories.

B.1 Sustainable Sites [SS]

Erosion & Sedimentation Control – 2 points

Intent

Control erosion to reduce negative impacts on water and air quality.

Requirements

Design a sediment and erosion control plan, specific to the site. The plan shall meet the following objectives:

- Prevent loss of soil during construction by stormwater runoff and/or wind erosion, including protecting topsoil by stockpiling for reuse.
- Prevent sedimentation of storm sewer or receiving streams.
- Prevent polluting the air with dust and particulate matter.

Potential Technologies & Strategies

Adopt an erosion and sediment control plan for the project site during construction. Consider employing strategies such as temporary and permanent seeding, mulching, earth dikes, silt fencing, sediment traps and sediment basins.

Site Selection – 1 point

Intent

Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site.

Requirements

Do not develop buildings, roads or parking areas on portions of sites that meet any one of the following criteria:

- Land which is specifically identified as habitat for any species threatened or endangered lists.

- Within 30 meters of any water including wetlands and isolated wetlands or areas of special concern

Potential Technologies & Strategies

During the site selection process, give preference to those sites that do not include sensitive site elements and restrictive land types. Select a suitable building location and design the building with the minimal footprint to minimize site disruption. Strategies include stacking the building program, tuckunder parking, and sharing facilities with neighbors.

<u>Development Density – 1 point</u>

Intent

Channel development to urban areas with existing infrastructure, protect greenfields and preserve habitat and natural resources.

Requirements

Increase localized density to conform to existing or desired density goals by utilizing sites that are located within an existing minimum development density of 60,000 square feet per acre.

Potential Technologies & Strategies

During the site selection process, give preference to urban sites.

<u>Reconfiguration of Contaminated Areas – 1 point</u>

Intent

Rehabilitate damaged sites where development is complicated by real or perceived environmental contamination, reducing pressure on undeveloped land.

Requirements

Develop on a site documented as contaminated or on a site classified as a brownfield by a local, agency. Effectively remediate site contamination.

Potential Technologies & Strategies

During the site selection process, give preference to brownfield sites. Identify tax incentives and property cost savings. Develop and implement a site remediation plan using strategies such as pump-and-treat, bioreactors, land farming and in-situ remediation.

Alternative Transport Ways [*Public Transportation Access*] – 1 point

Intent

Reduce pollution and land development impacts from automobile use.

Requirements

Locate project within 800m of a commuter rail, light rail or subway station or 400m of two or more public or campus bus lines usable by building occupants.

Potential Technologies & Strategies

Perform a transportation survey of future building occupants to identify transportation needs. Site the building near mass transit.

Alternative Transport Ways [*Bicycle Storage & Changing Rooms*] – 1 point

Intent

Reduce pollution and land development impacts from automobile use.

Requirements

For commercial or institutional buildings, provide secure bicycle storage with convenient changing/shower facilities (within 200 yards of the building) for 5% or more of regular building occupants. For residential buildings, provide covered storage facilities for securing bicycles for 15% or more of building occupants in lieu of changing/shower facilities.

Potential Technologies & Strategies

Design the building with transportation amenities such as bicycle racks and showering/changing facilities.

Alternative Transport Ways [*Alternative Fuel Vehicles*] – 1 point

Intent

Reduce pollution and land development impacts from automobile use.

Requirements

Provide alternative fuel vehicles for 3% of building occupants and provide preferred parking for these vehicles, or install alternative-fuel refueling stations for 3% of the total vehicle parking capacity of the site. Liquid or gaseous fueling facilities must be separately ventilated or located outdoors.

Potential Technologies & Strategies

Provide transportation amenities such as alternative fuel refueling stations and carpool/vanpool programs. Consider sharing the costs and benefits of refueling stations with neighbors.

Alternative Transport Ways [*Parking Capacity*] - 1 point

Intent

Reduce pollution and land development impacts from single occupancy vehicle use.

Requirements

Size parking capacity to meet, but not exceed, minimum local zoning requirements and provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants; or add no new parking for rehabilitation projects and provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants.

Potential Technologies & Strategies

Minimize parking lot/garage size. Consider sharing parking facilities with adjacent buildings.

Reduced Site Disturbance [*Protect or Restore Open Space*] – 1 point

Intent

Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.

Requirements

On greenfield sites, limit site disturbance including earthwork and clearing of vegetation to 15 meters beyond the building perimeter; or, on previously developed sites, restore a minimum of 50% of the site area (excluding the building footprint) by replacing impervious surfaces with native or adapted vegetation.

Potential Technologies & Strategies

Perform a site survey to identify site elements and adopt a master plan for development of the project site. Select a suitable building location and design the building with a minimal footprint to minimize site disruption. Strategies include stacking the building program, tuck-under parking and sharing facilities with neighbors. Establish clearly marked construction boundaries to minimize disturbance of the existing site and restore previously degraded areas to their natural state.

Stormwater Management [*Rate and Quantity*] – 1 point

Intent

Limit disruption and pollution of natural water flows by managing stormwater runoff.

Requirements

If existing imperviousness is greater than 50%, implement a stormwater management plan that results in a 25% decrease in the rate and quantity of stormwater runoff.

Potential Technologies & Strategies

Design the project site to maintain natural stormwater flows by promoting infiltration. Specify garden roofs and pervious paving to minimize impervious surfaces. Reuse stormwater volumes generated for non-potable uses such as landscape irrigation, toilet and urinal flushing and custodial uses.

Stormwater Management [*Treatment*] – 1 point

Intent

Limit disruption of natural water flows by eliminating stormwater runoff, increasing on-site infiltration and eliminating contaminants.

Requirements

Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP).

Potential Technologies & Strategies

Design mechanical or natural treatment systems such as constructed wetlands, vegetated filter strips and bioswales to treat the site's stormwater.

Heat Island Effect [*Non-Roof*] – 1 point

Intent

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Requirements

Provide shade (within 5 years) and/or use light-colored/high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of the site’s non-roof impervious surfaces, including parking lots, walkways, plazas, etc.

Potential Technologies & Strategies

Shade constructed surfaces on the site with landscape features and minimize the overall building footprint. Consider replacing constructed surfaces (i.e. roof, roads, sidewalks, etc.) with vegetated surfaces such as garden roofs and open grid paving or specify high-albedo materials to reduce the heat absorption.

Heat Island Effect [*Roof*] – 1 point

Intent

Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Requirements

Use highly reflective and high emissivity roofing for a minimum of 75% of the roof surface; or install a “green” (vegetated) roof for at least 50% of the roof area. Combinations of high albedo and vegetated roof can be used providing they collectively cover 75% of the roof area.

Potential Technologies & Strategies

Consider installing high-albedo and vegetated roofs to reduce heat absorption.

Light Pollution Reduction – 1 point

Intent

Eliminate light trespass from the building and site, improve night sky access and reduce development impact on nocturnal environments.

Requirements

Design exterior lighting such that all exterior luminaires with more than 1000 initial lamp lumens are shielded. The maximum candela value of all interior lighting shall fall within the building (not out through windows) and the maximum candela value of all exterior lighting shall fall within the property. Any luminaire within a distance of 2.5 times its mounting height from the property boundary shall have shielding such that no light from that luminaire crosses the property boundary.

Potential Technologies & Strategies

Adopt site lighting criteria to maintain safe light levels while avoiding off-site lighting and night sky pollution. Minimize site lighting where possible and model the site lighting using a computer model. Technologies to reduce light pollution include full cutoff luminaries, low-reflectance surfaces and lowangle spotlights.

B.2 Water Efficiency [WE]

Water Efficient Landscaping [*Reduce by 50%*] – 1 point

Intent

Limit or eliminate the use of potable water for landscape irrigation.

Requirements

Use high-efficiency irrigation technology or use captured rain or recycled site water to reduce potable water consumption for irrigation by 50% over conventional means.

Potential Technologies & Strategies

Perform a soil/climate analysis to determine appropriate landscape types and design the landscape with indigenous plants to reduce or eliminate irrigation requirements. Use high-efficiency irrigation systems and consider using stormwater and/or greywater for irrigation.

Water Efficient Landscaping [*No Potable Use or No Irrigation*] – 1 point

Intent

Limit or eliminate the use of potable water for landscape irrigation.

Requirements

Use only captured rain or recycled site water to eliminate all potable water use for site irrigation (except for initial watering to establish plants), or do not install permanent landscape irrigation systems.

Potential Technologies & Strategies

Perform a soil/climate analysis to determine appropriate landscape types and design the landscape with indigenous plants to reduce or eliminate irrigation requirements. Consider using stormwater and/or greywater for irrigation.

Innovative Wastewater Technologies – 1 point

Intent

Reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge.

Requirements

Reduce the use of municipally provided potable water for building sewage conveyance by a minimum of 50%, or treat 100% of wastewater on site to tertiary standards.

Potential Technologies & Strategies

Specify high-efficiency fixtures and dry fixtures such as composting toilets and waterless urinals to reduce wastewater volumes. Consider reusing stormwater or greywater for sewage conveyance or on-site wastewater treatment systems (mechanical and/or natural).

Water Use Reduction [*20% Reduction*] – 1 point, [*30% Reduction*] – 1 point

Intent

Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.

Requirements

[*20% Reduction*] – 1 point

Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation).

[*30% Reduction*] – 1 point

Employ strategies that in aggregate use 30% less water than the water use baseline calculated for the building (not including irrigation).

Potential Technologies & Strategies

Estimate the potable and non-potable water needs for the building. Use highefficiency fixtures, dry fixtures such as composting toilets and waterless urinals, and occupant sensors to reduce the potable water demand. Consider reuse of stormwater and greywater for non-potable applications such as toilet and urinal flushing, mechanical systems and custodial uses.

B.3 Energy and Atmosphere [EA]

Fundamental Building Systems Commissioning – 2 points

Intent

Verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended.

Requirements

Implement or have a contract in place to implement the following fundamental best practice commissioning procedures.

- Engage a commissioning team that does not include individuals directly responsible for project design or construction management.
- Review the design intent and the basis of design documentation.
- Incorporate commissioning requirements into the construction documents.
- Develop and utilize a commissioning plan.
- Verify installation, functional performance, training and operation and maintenance documentation.
- Complete a commissioning report.

Potential Technologies & Strategies:

Engage a commissioning authority and adopt a commissioning plan. Include commissioning requirements in bid documents and task the commissioning agent to produce a commissioning report once commissioning activities are completed.

Minimum Energy Performance – 2 points

Intent

Establish the minimum level of energy efficiency for the base building and systems.

Requirements

Design the building to comply with the local energy code (e.g. ASHRAE/IESNA Standard 90.1-1999).

Potential Technologies & Strategies:

Design the building envelope and systems to maximize energy performance. Use a computer simulation model to assess the energy performance and identify the most cost effective energy measures. Quantify energy performance compared to the baseline building.

CFC Reduction in HVAC&R Equipment – 2 points

Intent

Reduce ozone depletion.

Requirements

Zero use of CFC-based refrigerants in new base building HVAC&R systems. When reusing existing base building HVAC equipment, complete a comprehensive CFC phase-out conversion.

Potential Technologies & Strategies:

When reusing existing HVAC systems, conduct an inventory to identify equipment that uses CFC refrigerants and adopt a replacement schedule for these refrigerants. For new buildings, specify new HVAC equipment that uses no CFC refrigerants.

Optimization of Energy Performance 1-10 points

Intent

Achieve increasing levels of energy performance above the prerequisite standard to reduce environmental impacts associated with excessive energy use.

Requirements

Reduce design energy cost compared to the energy cost budget for energy systems regulated by Standards (without amendments). Regulated energy systems include HVAC (heating, cooling, fans and pumps), service hot water and interior lighting. Non-regulated systems include plug loads, exterior lighting, garage ventilation and elevators (vertical transportation).

Percentage of energy cost reduction according to reference buildings		Points
New Buildings	Existing buildings	
15%	5%	1
20%	10%	2
25%	15%	3
30%	20%	4
35%	25%	5
40%	30%	6
45%	35%	7
50%	40%	8
55%	45%	9
60%	50%	10

Potential Technologies & Strategies

Design the building envelope and building systems to maximize energy performance. Use a computer simulation model to assess the energy performance and identify the most cost-effective energy efficiency measures. Quantify energy performance as compared to a baseline building.

Renewable Energy Sources [*5%*] – 1 point, [10*%*] – 1 point, [*20%*] – 1 point

Intent

Encourage and recognize increasing levels of on-site renewable energy selfsupply in order to reduce environmental impacts associated with fossil fuel energy use.

Requirements

[*5%*] – 1 point

Supply at least 5% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.

[10*%*] – 1 point

Supply at least 10% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.

[20*%*] – 1 point

Supply at least 20% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.

Potential Technologies & Strategies

Assess the project for non-polluting and renewable energy potential including solar, wind, geothermal, low-impact hydro, biomass and bio-gas strategies. When applying these strategies, take advantage of net metering with the local utility.

Ozone Depletion – 1 point

Intent

Reduce ozone depletion and support early compliance with the Montreal Protocol.

Requirements

Install base building level HVAC and refrigeration equipment and fire suppression systems that do not contain HCFCs or Halons.

Potential Technologies & Strategies

When reusing buildings, inventory existing building systems using refrigerants and fire suppression chemicals and replace those that contain HCFCs or Halons. For new buildings, specify refrigeration and fire suppression systems that use no HCFCs or Halons.

Measurement & Verification – 1 point

Intent

Provide for the ongoing accountability and optimization of building energy and water consumption performance over time.

Requirements

Install continuous metering equipment for the following end-uses:

- Lighting systems and controls
- Constant and variable motor loads
- Variable frequency drive (VFD) operation
- Chiller efficiency at variable loads (kW/ton)
- Cooling load
- Air and water economizer and heat recovery cycles
- Air distribution static pressures and ventilation air volumes
- Boiler efficiencies
- Building-related process energy systems and equipment
- Indoor water risers and outdoor irrigation systems

Potential Technologies & Strategies

Model the energy and water systems to predict savings. Design the building with equipment to measure energy and water performance. Draft a Measurement & Verification Plan to apply during building operation that compares predicted savings to those actually achieved in the field.

Green Power – 1 point

Intent

Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.

Requirements

Provide at least 50% of the building's electricity from renewable sources by engaging in at least a two-year renewable energy contract

Potential Technologies & Strategies

Determine the energy needs of the building and investigate opportunities to engage in a green power contract with the local utility.

B.4 Materials and Resources [MR]

Storage & Collection of Recyclables – 2 points

Intent

Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.

Requirements

Provide an easily accessible area that serves the entire building and is dedicated to the separation, collection and storage of materials for recycling including (at a minimum) paper, corrugated cardboard, glass, plastics and metals.

Potential Technologies & Strategies

Designate an area for recyclable collection and storage that is appropriately sized and located in a convenient area. Identify local waste handlers and buyers for glass, plastic, office paper, newspaper, cardboard and organic wastes. Instruct occupants on building recycling procedures.

Building Reuse [*Maintain 75% of Existing Shell*], [*Maintain 100% of Shell*], [*Maintain 100% Shell & 50% Non-Shell*]

Intent

Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.

Requirements

Maintain 75% of Existing Shell] – 1 point

Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material).

[*Maintain 100% of Shell*] – 1 point

Maintain an additional 25% (100% total) of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material).

[*Maintain 100% Shell & 50% Non-Shell*] – 1 point

Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) and at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems).

Potential Technologies & Strategies

Consider reuse of existing buildings, including structure, shell and non-shell elements. Remove elements that pose contamination risk to building occupants and upgrade outdated components such as windows, mechanical systems and plumbing fixtures. Quantify the extent of building reuse.

Resource Reuse [*Percentage 5%]* – 1 point, [*Percentage 10%]* – 1 point

Intent

Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.

Requirements

[*Percentage 5%]* – 1 point

Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of building materials.

[*Percentage 10%]* – 1 point

Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials.

Potential Technologies & Strategies

Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.

Recycled Content [*Percentage 5%*] – 1 point, [*Percentage 10%*] – 1 point

Intent

Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials.

Requirements

[*Percentage 5%*] – 1 point

Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the post-industrial content constitutes at least 5% of the total value of the materials in the project. Mechanical and electrical components shall not be included in this calculation.

[*Percentage 10%*] – 1 point

Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the post-industrial content constitutes at least 10% of the total value of the materials in the project. Mechanical and electrical components shall not be included in this calculation.

Potential Technologies & Strategies

Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. During construction, ensure that the specified recycled content materials are installed and quantify the total percentage of recycled content materials installed.

Local/Regional Materials [*20% Manufactured Locally*] – 1 point, [*35% Manufactured Locally*] – 1 point

Intent

Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation.

Requirements

[*20% Manufactured Locally*] – 1 point

Use a minimum of 20% of building materials and products that are manufactured regionally within a radius of 350 khm.

[*35% Manufactured Locally*] – 1 point

Use a minimum of 35% of building materials and products that are manufactured regionally within a radius of 350 khm.

Potential Technologies & Strategies

Establish a project goal for locally sourced materials and identify materials and material suppliers that can achieve this goal. During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed.

Rapidly Renewable Materials – 1 point

Intent

Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials.

Requirements

Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 5% of the total value of all building materials and products used in the project.

Potential Technologies & Strategies

Establish a project goal for rapidly renewable materials and identify materials and suppliers that can achieve this goal. Consider materials such as bamboo flooring, wool carpets e.t.c.

B.5 Indoor Environmental Quality [QE]

Minimum IAQ Performance – 2 points

Intent

Establish minimum indoor air quality (IAQ) performance to prevent the development of indoor air quality problems in buildings, thus contributing to the comfort and well-being of the occupants.

Requirements

Meet the minimum requirements of voluntary consensus standards.

Potential Technologies & Strategies

Design the HVAC system to meet the ventilation requirements of the referenced standard. Identify potential IAQ problems on the site and locate air intakes away from contaminant sources.

Environmental Tobacco Smoke (ETS) Control – 2 points

Intent

Prevent exposure of building occupants and systems to Environmental Tobacco Smoke (ETS).

Requirements

Zero exposure of non-smokers to ETS by either:

- prohibiting smoking in the building and locating any exterior designated smoking areas away from entries and operable windows;

or

- providing a designated smoking room designed to effectively contain, capture and remove ETS from the building. At a minimum, the smoking room must be directly exhausted to the outdoors with no recirculation of ETS-containing air to the non-smoking area of the building, enclosed with impermeable deck-to-deck partitions and operated at a negative pressure compared with the surrounding spaces of at least 7 PA (0.03 inches of water gauge).

Potential Technologies & Strategies

Prohibit smoking in the building or provide separate smoking rooms with isolated ventilation systems.

Carbon Dioxide (CO2) Monitoring – 1 point

Intent

Provide capacity for indoor air quality (IAQ) monitoring to help sustain longterm occupant comfort and well-being.

Requirements

Install a permanent carbon dioxide (CO_2) monitoring system that provides feedback on space ventilation performance in a form that affords operational adjustments.

Potential Technologies & Strategies

Design the HVAC system with carbon dioxide monitoring sensors and integrate these sensors with the building automation system (BAS).

Ventilation Effectiveness -1 point

Intent

Provide for the effective delivery and mixing of fresh air to support the safety, comfort and well-being of building occupants.

Requirements

For mechanically ventilated buildings, design ventilation systems that result in an air change effectiveness (Eac) greater than or equal to 0.9. For naturally ventilated spaces demonstrate a distribution and laminar flow pattern that involves not less than 90% of the room or zone area in the direction of air flow for at least 95% of hours of occupancy.

Potential Technologies & Strategies

Design the HVAC system and building envelope to optimize air change effectiveness. Air change effectiveness can be optimized using a variety of ventilation strategies including displacement ventilation, low-velocity ventilation, plug-flow ventilation such as under floor or near floor delivery, and operable windows. Test the air change effectiveness of the building after construction.

Low-Emitting Materials [*Adhesives & Sealants*] – 1 point, [*Paints, Coverings*] – 1 point, [*Carpet, Moquetes*] – 1 point, [*Composite Wood*] – 1 point

Intent

Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of installers and occupants.

Requirements

[*Adhesives & Sealants*] – 1 point

The VOC content of adhesives and sealants used must be less than the current VOC content limits contained in standards.

[*Paints, Coverings*] – 1 point

VOC emissions from paints and coatings must not exceed the VOC and chemical component limits contained in standards.

[*Carpet, Moquetes*] – 1 point

Carpet systems must meet or exceed the requirements of standards.

[*Composite Wood*] – 1 point

Composite wood and agrifiber products must contain no added urea-formaldehyde resins.

Potential Technologies & Strategies

[*Adhesives & Sealants*] – 1 point, [*Carpet, Moquetes*] – 1 point, [*Paints, Coverings*] – 1 point

Specify Low-VOC materials in construction documents. Ensure that VOC limits are clearly stated in each section where adhesives and sealants are addressed.

[*Composite Wood*] – 1 point

Specify wood and agrifiber products that contain no added urea-formaldehyde resins.

Indoor Chemical & Pollutant Source Control – 1 point

Intent

Avoid exposure of building occupants to potentially hazardous chemicals that adversely impact air quality.

Requirements

Design to minimize pollutant cross-contamination of regularly occupied areas:

- Where chemical use occurs (including housekeeping areas and copying/ printing rooms), provide segregated areas with deck to deck partitions with separate outside exhaust at a rate of at least 0.50 cubic feet per minute per square foot, no air re-circulation and maintaining a negative pressure of at least 7 PA (0.03 inches of water gauge).
- Provide drains plumbed for appropriate disposal of liquid waste in spaces where water and chemical concentrate mixing occurs.

Potential Technologies & Strategies

Design separate exhaust and plumbing systems for rooms with contaminants to achieve physical isolation from the rest of the building. Install permanent architectural entryway systems such as grills or grates to prevent occupantborne contaminants from entering the building.

Thermal Comfort, Based on international Standards -1 point

Intent

Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.

Requirements

Comply with Standard's requirements.

Potential Technologies & Strategies

Establish temperature and humidity comfort ranges and design the building envelope and HVAC system to maintain these comfort ranges.

Thermal Comfort, Permanent Monitoring System – 1 point

Intent

Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.

Requirements

Install a permanent temperature and humidity monitoring system configured to provide operators control over thermal comfort performance and the effectiveness of humidification and/or dehumidification systems in the building.

Potential Technologies & Strategies

Establish temperature and humidity comfort ranges and design the building envelope and HVAC system to maintain these comfort ranges. Install and maintain a temperature and humidity monitoring system in the building to automatically adjust building conditions as appropriate.

Daylight & Views, Daylight 75% of Spaces – 1 point

Intent

Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Requirements

Achieve a minimum Daylight Factor of 2% in 75% of all space occupied for critical visual tasks. Spaces excluded from this requirement include copy rooms, storage areas, mechanical plant rooms, laundry and other low occupancy support areas. Other exceptions for spaces where tasks would be hindered by the use of daylight will beconsidered on their merits.

Potential Technologies & Strategies

Design the building to maximize interior daylighting. Strategies to consider include building orientation, shallow floor plates, increased building perimeter, exterior and interior permanent shading devices, high performance glazing and photo-integrated light sensors. Predict daylighting via calculations or model daylighting strategies with a physical or computer model to assess footcandle levels and daylight factors achieved.

Daylight & Views, Views for 90% of Spaces – 1 point

Intent

Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Requirements

Achieve direct line of sight to vision glazing for building occupants in 90% of all regularly occupied spaces. Examples of exceptions include copy rooms, storage areas, mechanical, laundry and other low occupancy support areas. Other exceptions will be considered on their merits.

Potential Technologies & Strategies

Design the building to maximize view opportunities.

Appendix C - Short Application Manual

This appendix presents a short manual for the java application platform. It describes each form and menu and provides a guideline on how anyone can use it for the insertion of buildings' information and classification execution.

C.1 Login Operation

The application may be used only by authenticated users. Each user is characterized by a unique username and password. In order to enter the application, username and password must be inserted into the login form as shown in figure 29.

Figure 29 - Login Form

1. Insert Username
2. Insert Password
3. Press Enter Button

C.2 Main Menu

Main menu appears after a successful login. From this menu, user is able to do the following operations:

- Open the New User Menu: Settings → New User
- Open Database Settings: Settings → Database
- Open Locations Menu: Settings → Locations
- Open Buildings Data Window: Press Buildings Data Button
- Open Buildings Classification Window: Press Buildings Grading Button

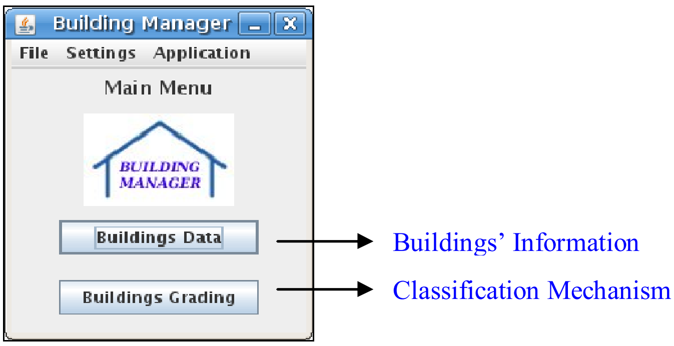


Figure 30 - Main Menu

C.3 New User Menu

An authorized user has the capability of adding new users into the application. In the New User window (Main Menu → Settings→New User), insert a new username, password combination and press the Insert Button.

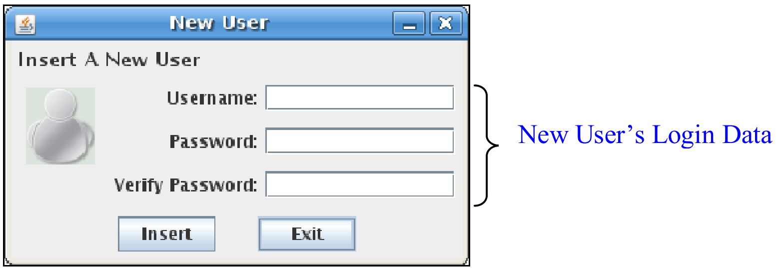


Figure 31 - New User Window

C.4 Database Settings

Application may operate and process data from different databases with the same structure. In order to have access to a different database, database connection settings must be changed. This can be performed from Database Settings Window (Main Menu → Settings→Database Settings).

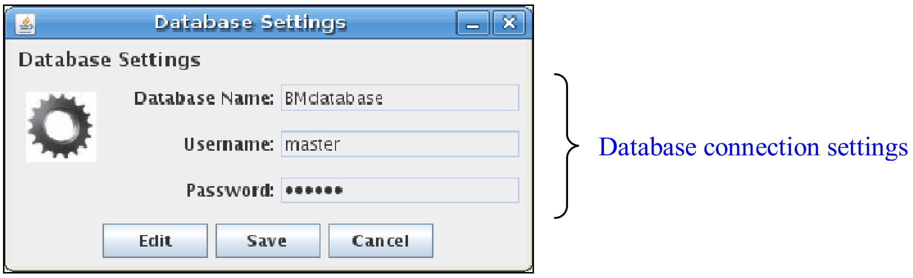


Figure 32 - Database Settings

1. Press Edit Button
2. Change Database Connection Settings
3. Press Save Button

C.5 Locations' Menu

The application can store locations, where buildings may be located. Each location is escorted by geographical and statistical data, which may be used in several classification methods. In order to insert, change or delete a location, move to Locations Menu (Main Menu → Settings→ Locations).

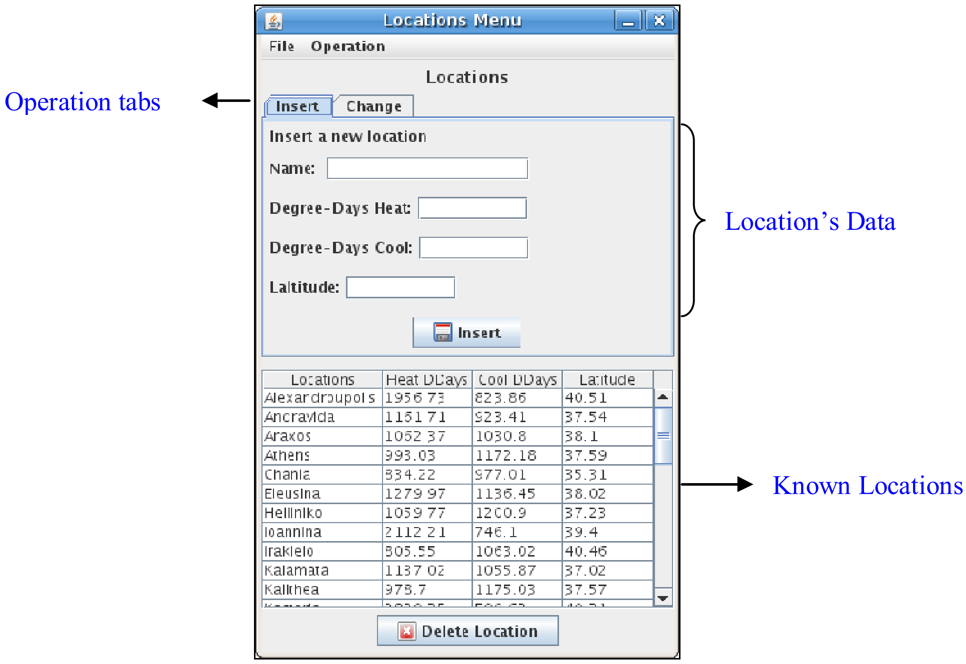


Figure 33 - Locations Menu

- *Insert a new location*: select Insert tab, insert location's data and press the Insert Button.
- *Change an existent location*: select the Change tab, select a known location from location's table, change the preferred data and press the Change Button.
- *Delete an existent location*: select a known location from location's table and press the Delete Button.

C.6 Buildings' Menu

From Building's menu, user is able to do the following operations:

- View, Insert, Change or Delete a building (physical characteristics) from the application.
- Access Zones' Menu: Options → Building's Zones.
- Access LEED Environmental Classification Questionnaires: Options → LEED Questionaires.

Four types of buildings are supported: Offices, Hotel, School and Shop. Stored locations are presented, when user inserts a new building in location combo box.

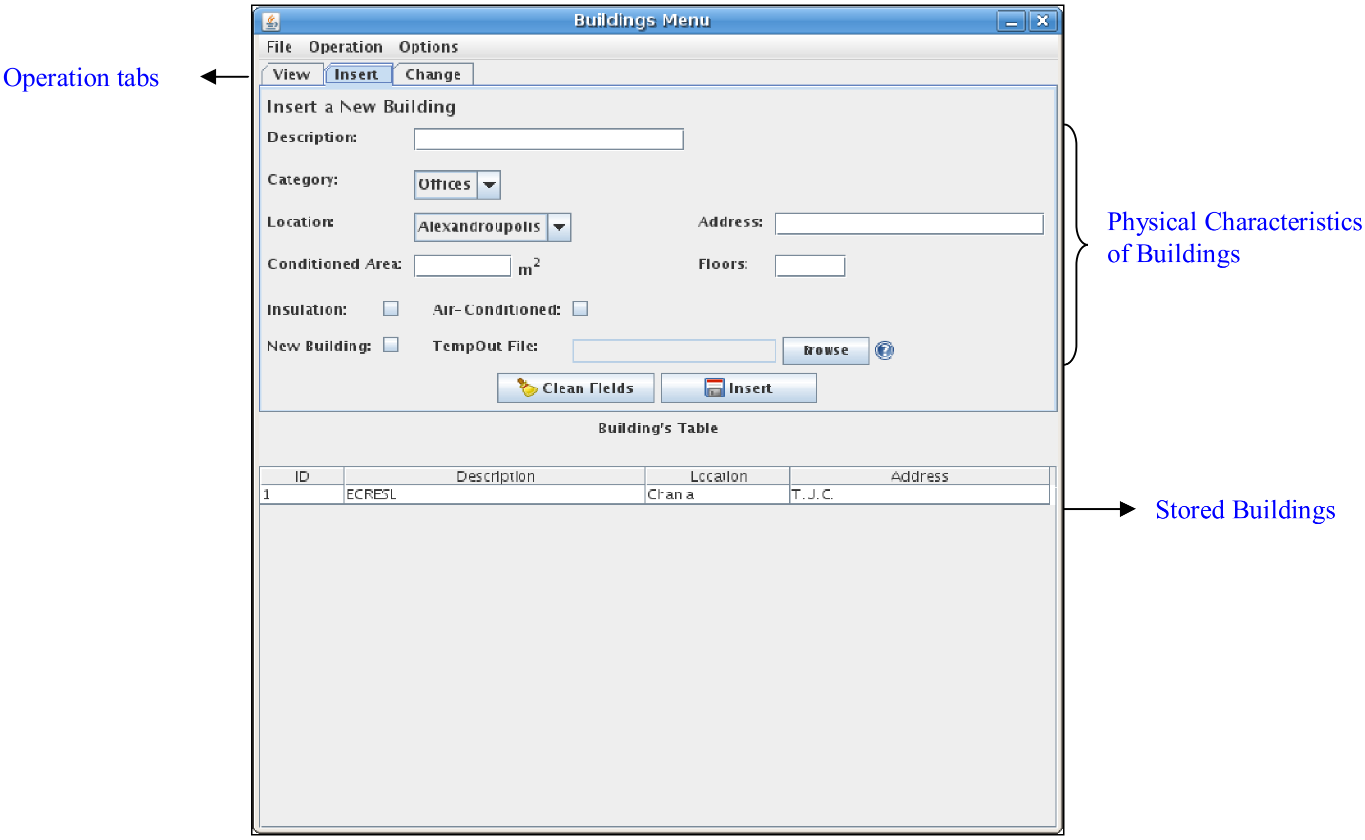


Figure 34 - Buildings' Menu

- *Insert a new building*: select Insert tab, insert building's data and press the Insert Button. All data must be fulfilled for a successful insertion.
- *Change an existent building*: select the Change tab, select a stored building from buildings' table, change the preferred data and press the Change Button.
- *Delete an existent building*: select View tab, select a stored building from buildings' table and press the Delete Button.

C.7 Building's Zones Menu

Each building is divided into zones. To adjust a building's zones move to zones menu (Buildings' Menu →Options →Building's Zones). From this menu, the following operations may be performed:

- View zones' data.
- Insert a new zone for the building.
- Change zone's data.
- Delete an existent zone for a building.

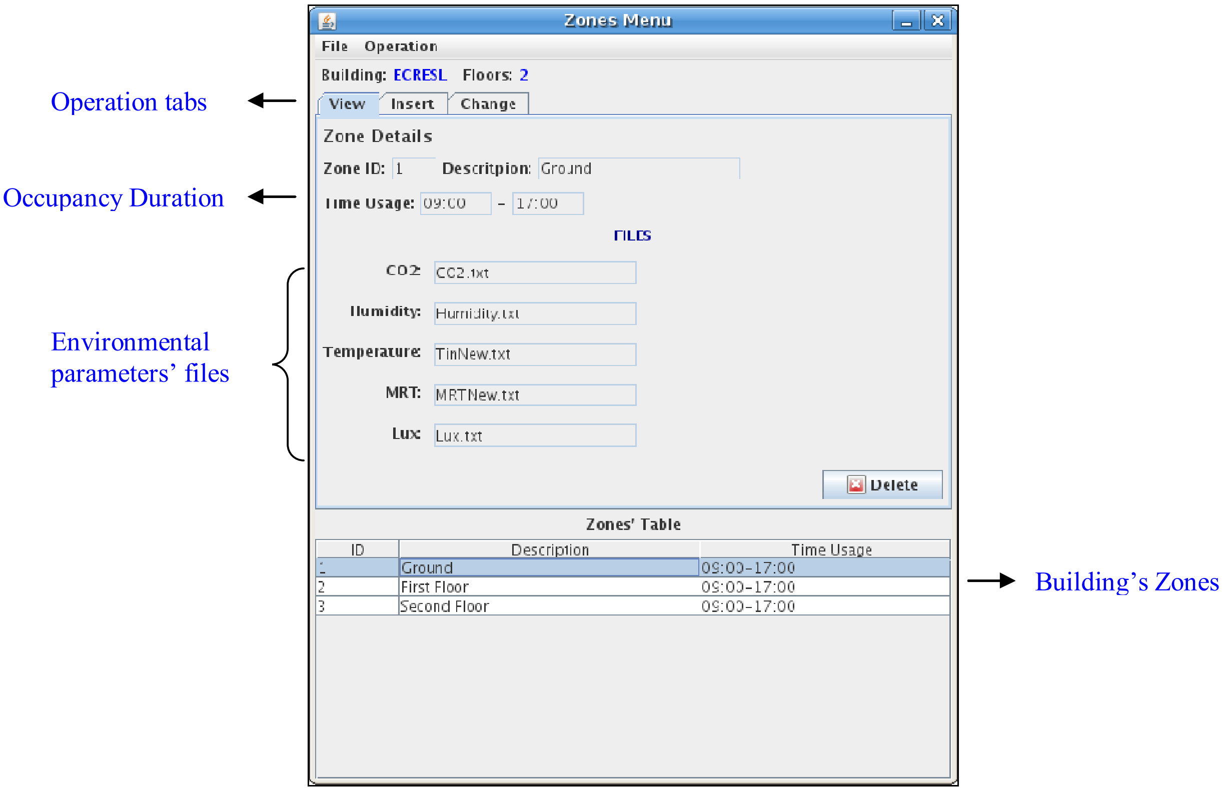


Figure 35 - Zones' Menu

- *Insert a new zone*: select Insert tab, insert zone's data and press the Insert Button.
- *Change an existent zone*: select the Change tab, select a stored zone from zones' table, change the preferred data and press the Change Button.
- *Delete an existent zone*: select View tab, select a stored zone from zones' table and press the Delete Button.

C.8 LEED Environmental Questionnaires Menu

More than one LEED questionnaire can be assigned to each building. LEED Environmental menu is responsible for the management of LEED questionnaires. Move to this menu by selecting Buildings' Menu →Options → LEED Questionaires.

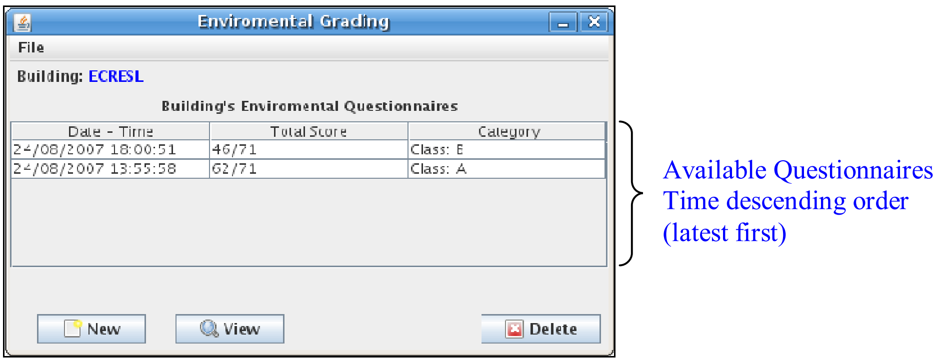


Figure 36 - LEED Environmental Questionnaires

From this menu following operations can be performed:

- *View an old questionnaire*: Select a questionnaire from the questionnaires' list and press the View Button.

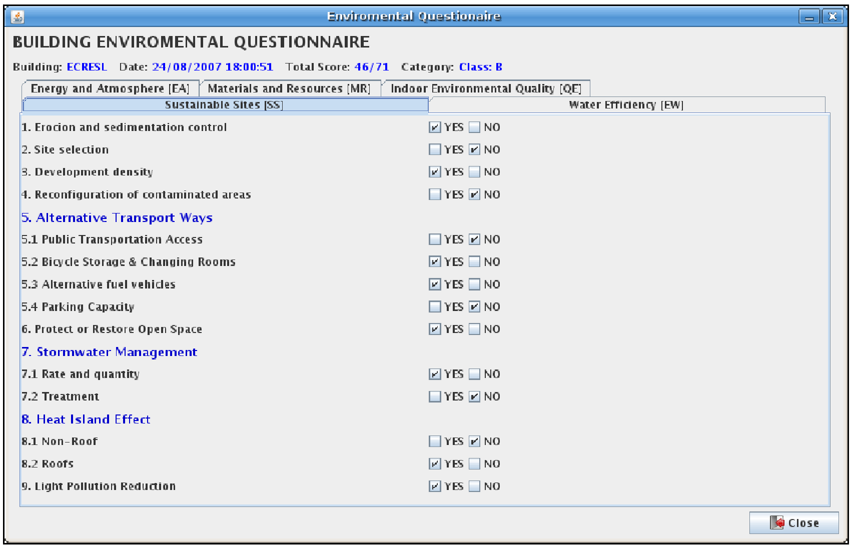


Figure 37 - Existent questionnaire presentation

- *Insert a new questionnaire* for a specific building: Press New Button.

  For the insertion of a new questionnaire, all questions must be answered (in all sections' tabs) and the Save button must be pressed. Before saving, a test of the questionnaire classification may be performed by pressing the Test Button.

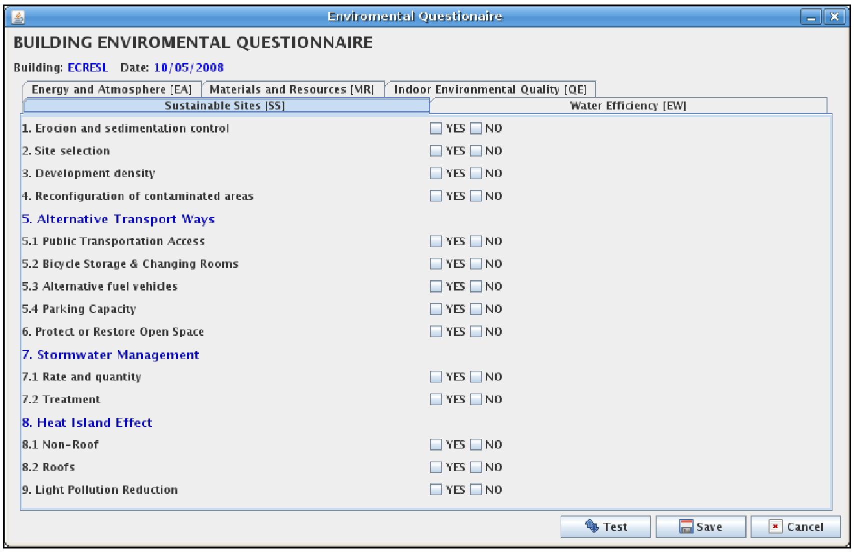


Figure 38 - Insert a new questionnaire

- *Delete an old questionnaire*: Select a questionnaire from the questionnaires' list and press the Delete Button

C.9 Environmental Classification Execution

In order to perform the classification procedure, for a building, move to the Building Grading Menu (Main Menu →Buildings Grading Button). A list of all available buildings for classification appears. Select the preferred building and press the Environmental Button.

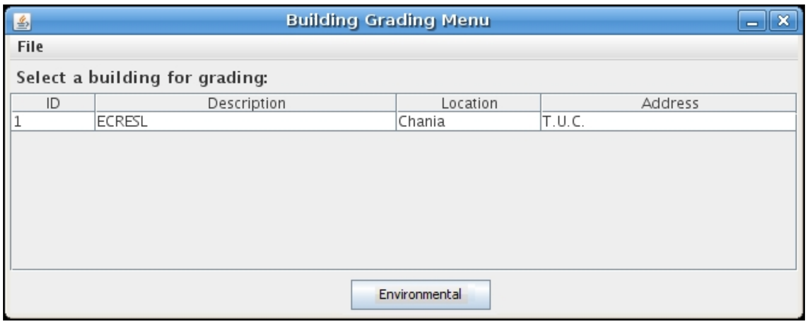


Figure 39 - Select building for Environmental classification

When environmental classification ends, results are presented as shown in figure 40. Each parameter is classified for each zone of the building. If a LEED questionnaire is available, then LEED classification results are also presented.

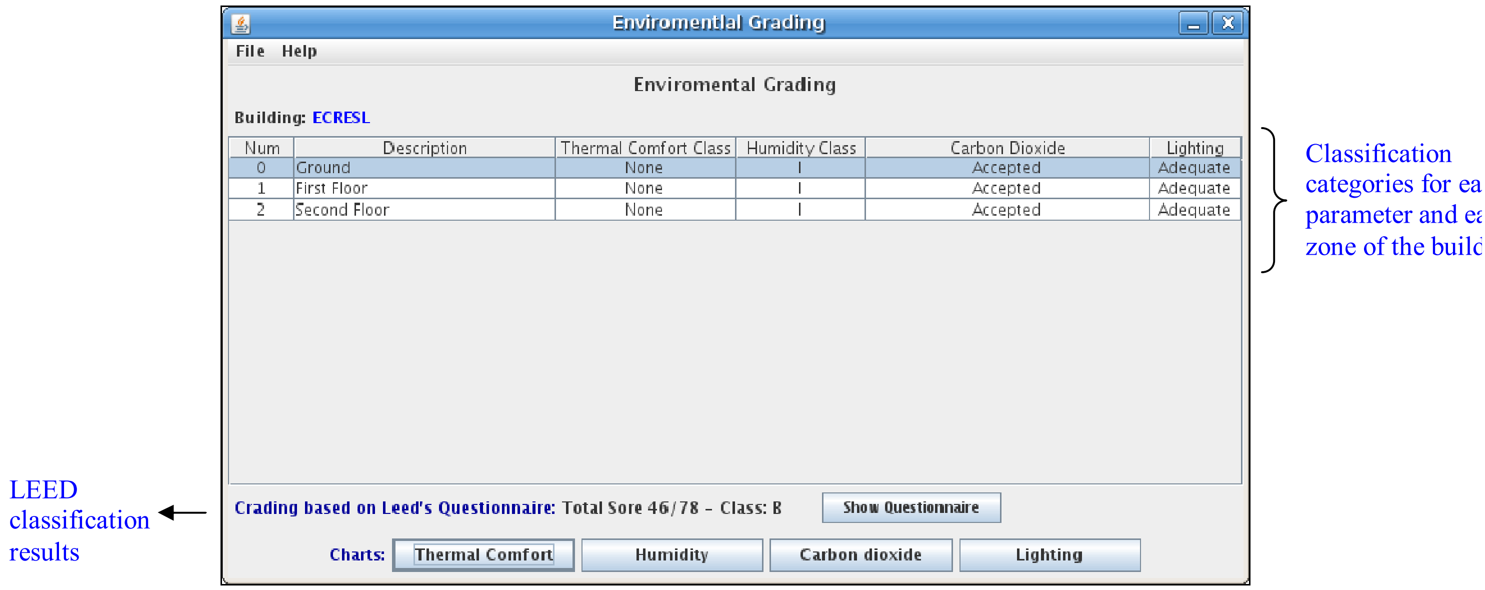


Figure 40 - Environmental Classification Results

- To see the charts of a parameter, for a specific zone, select the zone (row) from the zones' table and press the respective button. Examples of humidity charts are shown in figure 41.

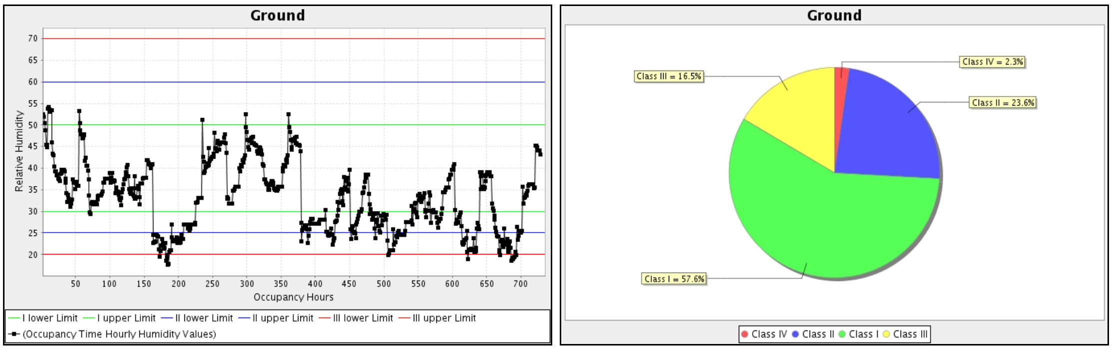


Figure 41 - Charts for the Humidity Classification

- To create the environmental classification report for a building select File → Environmental Report

Appendix D - Significant java classes

This appendix provides a small description of the most significant java classes and their most significant methods.

MyDBConnection Class

This class is responsible for the connection procedure of the java application with the embedded database, implemented in JavaDB. It is used from any other class which requires access to the database system.

Methods:

- *public int initre():* Establishes the connection with the database and prepares the system for the exchange of data. It uses the *apache.derby.jdbc* driver and the database's authentication settings in order to accomplish the connection. It is called at the initiation of the application and returns 1, if connection is established.
- *public Connection getMyConnection():* Returns the connection object wherever a connection is needed. Passes the connection between different classes.
- *public void destroy():* Close the established connection of the application with the database system. It is called only at application's termination (exit of the program).

EnviromentalQuestionaire Class

This class is responsible for the implementation of LEED Green Building Rating methodology. It creates the LEED questionnaire (interface) and contains methods that perform the classification of building according to the specific methodology.

Methods:

- *private void SaveActionPerformed():* It checks if all questionnaire's answers have been answered, and performs the addition of all positive fulfilled requirements' points. The questionnaire's answers and the grading results (total score and classification category) are stored into the database.

- *public String EnvGrading(int grade):* Returns the classification category (A-E) according to the total score (sum of all positive fulfilled requirements' points).

<u>EnviromentalGradingResults Class</u>

This class is responsible for the classification results' extraction and presentation according to CEN standard. It processes the parameter's measurement files for each zone and performs the classification for each parameter. It produces measurements and statistic charts and is able to create an environmental report.

<u>Methods – Thermal Comfort:</u>

- *public ArrayList<Double> ReturnAverageFromFile(String filename):* Returns an array list which contains the daily average values extracted from a measurement file. Daily average values are calculated as the average of the minimum and maximum daily values. It is used for the extraction of the daily average values for Indoor Air Temperature, MRT, and Outdoor Air Temperature files.
- *public double[] Toperative(ArrayList<Double> Tin, ArrayList<Double> MRT)*: Returns a double array which contain the indoor operative temperature for all days.
- *public double[] Tref(ArrayList<Double> Tout, ArrayList<Double> Tin):* Returns a double array which contains the running mean outdoor temperature values.
- *public String Classification_Alpha_Beta(double[] Toper, double[] Tref, int alphabeta):* Returns the classification category for the thermal comfort. It takes into account the type of building, Alpha or Beta.
- *public double[] FindHintsClassifyZoneThermal(double[] Toper, double[] Tref, int alphabeta):* Returns a double array which contains the percentages of days for each subclass of the thermal comfort model.
- *public void PlotThermalControlChart(double[] Toper, double[] Tref, String Zonelabel, int alphabeta, double[] percents):* Creates the thermal comfort classification charts and stores them into EnvironmentalResults class object.

Methods – Relative Humidity:

- *public ArrayList<Double> ReturnAllOccupancyHumidityHours(String filename, String From, String To):* Returns an array list which contains the hourly values from the Humidity measurements' file.
- *public double[] Classification_Humidity(ArrayList<Double> Humidity):* Returns a double array which contains the percentages of hours for each category of humidity classification.
- *public String FindClassHum(double[] percents):* Returns the category (I-IV) according to the percentages of hours.
- *public void PlotHumChart(ArrayList<Double> hum, double[] percents,String Zonelabel,int maxocchours):* Creates the humidity classification charts and stores them into EnvironmentalResults class object.

Methods – Carbon Dioxide Concentration:

- *public ArrayList<Double> ReturnAverageCo2perDay(String filename, String From, String To):* Returns an array list which contains the daily average values extracted from the CO_2 concentration's measurement file.
- *public double[] FindHintsClassifyZoneCo2(ArrayList<Double>co2):* Returns a double array which contains the percentages of days for each category of carbon dioxide classification.
- *public String FindClass(double[] percents):* Returns the category (Accepted – Marginal - Unaccepted) according to the percentages of days.
- *public void PlotCo2Chart(ArrayList<Double> co2, double[] percents,String Zonelabel):* Creates the carbon dioxide classification charts and stores them into EnvironmentalResults class object.

Methods – Lighting:

- *public ArrayList<Double> ReturnLightingOccupancyValues(String filename, String From, String To):* Returns an array list which contains the hourly values from the Illuminance measurements' file.
- *public double[] FindHintsClassifyZoneLight(ArrayList<Double> light, String Category):* Returns a double array which contains the percentages of hours for each category of lighting classification.

- *public String FindClassLight(double[] percents):* Returns the category (Adequate - Inadequate) according to the percentages of days.
- *public void PlotLightingChart(String Zonelabel, ArrayList<Double> light, double[] percents, String Category, int maxocchours):* Creates the lighting classification charts and stores them into EnvironmentalResults class object.

<u>Methods – General:</u>

- *GradeBuilding():* Performs the environmental classification of a building combining methods described above. It is responsible for the presentation of the results.
- *private void EnviromentalReportActionPerformed(): It c*reates the environmental report. It uses the *EnviromentalResults* class object which stores all classification results. The creation of the report is based on an external jrxml file, which describes the template of the report.
- *public void LeedsResults():* Checks if one or more environmental questionnaires are available. If so, the classification results (LEED methodology – implemented on EnviromentalQuestionaire Class) of the latest questionnaire are presented.

<u>**EnviromentalResults Class**</u>

This class is responsible for the storage of the environmental classification results. It creates a structure of array lists and store all classification graphic charts and parameter's categories/classes resulted by the classification mechanism (EnviromentalGradingResults Class).

<u>Methods:</u>

- *public void SetResults(String desc, String TC, String humCat, String Co2Cat, String LightCat):* Store all classification resulted categories/classes into the appropriate array lists.
- *public void SetThermaCharts(JFreeChart ch1, JFreeChart ch2):* Store thermal comfort classification charts into the appropriate array list.
- *public void SetHumCharts(JFreeChart ch1, JFreeChart ch2):* Store relative humidity classification charts into the appropriate array list.

- *public void SetCO2Charts(JFreeChart ch1, JFreeChart ch2):* Store carbon dioxide classification charts into the appropriate array list.
- *public void SetLightCharts(JFreeChart ch1, JFreeChart ch2):* Store lighting classification charts into the appropriate array list.

Table 20 below presents all application's java files and a small description of each one.

Java File	Small Description
About.java	Implements the interface of a window which gives information about the designer of the application.
Buildings.java	Implements the interface and methods for the management of buildings' information related to the physical characteristics.
EnvironmentalGrading.java	Implements the interface and methods of the LEED questionnaires' manager menu.
EnvironmentalGradingResults.java	Implements the interface and methods for the environmental classification based on CEN standard.
EnvironmentalQuestionnaire.java	Implements the interface and methods of LEED Grading methodology – questionnaire form.
EnvironmentalQuestionnaireView.java	Implements the interface of a form which presents filled LEED questionnaires.
EnvironmentalResults.java	Class for the storage of Environmental Classification results
FileChooseroperations.java	Class which implements the browse frame for searching in an operation system.
Locations.java	Implements the interface and methods of the locations' manager menu.
Login.java	Implements the interface and methods of the authentication mechanism.
MainFrame.java	Implements the interface and methods of the main menu.
MyDBConnection.java	Class for the establishment of the connection between the application and the database system.
MyFilterFile.java	Class which implements a filter for file types (e.g.: .txt).
NewUser.java	Implements the interface and methods for the insertion of new users in the application.
Notations.java	Implements the interface of a help window for the environmental classification results.
PFileoperations.java	Class which contains methods for reading and writing java property files.
SelectBuilding.java	Implements the interface for the selection of the building which will be classified.
Zones.java	Implements the interface and methods for the management of building's zones.

Table 20 - Java Application's Files

Appendix E - Database's Tables, Relational Schema

Below all database's tables are given in analytic form.

Table Users		
Field	Type	Null
username	varchar(30)	No
pasword	varchar(30)	No

Table Locations		
Field	Type	Null
lid	int(11)	No
lname	varchar(40)	No
DDheat	Double	No
DDCool	Double	No
latitude	Double	No

Table Environmental Grading		
Field	Type	Null
enbid	int(11)	No
endate	timestamp	No
q1	int(11)	No
…	int(11)	No
q55	int(11)	No
total_score	int(11)	No
grade	varchar(1)	No

Table Buildings		
Field	Type	Null
bid	int(11)	No
bloc_id	int(11)	No
bCategory	varchar(30)	No
bDescription	varchar(60)	No
bSurface	Double	No
bFloors	int(11)	No
bAddress	varchar(40)	No
bInsulation	int(11)	No
bAC	int(11)	No
bNB	int(11)	No
bTout	varchar(50)	No

Table Zones		
Field	Type	Null
zid	int(11)	No
zbid	int(11)	No
zDescription	varchar(40)	No
zFrom	varchar(5)	No
zTo	varchar(5)	No
zCO2	varchar(50)	No
zHum	varchar(50)	No
zTemp	varchar(50)	No
zMRT	varchar(50)	No
zLux	varchar(50)	No

Figure 42 presents the relational Schema of database.

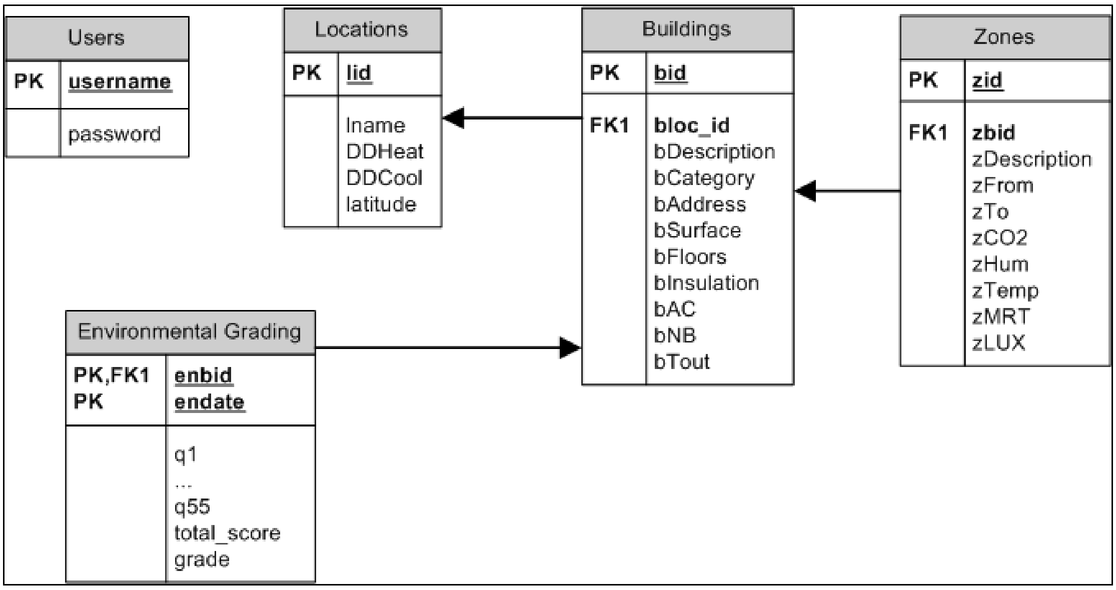


Figure 42 - Relational Schema

Appendix F - Experimental Results, LEED filled questionnaire, Environmental Report

This appendix presents the filled LEED environmental questionnaire for Byte S.A. facilities and the environmental report created by the application.

F.1 LEED Environmental Questionnaire

Sustainable Sites [SS]			
		Answer	Points
1	Erosion & Sedimentation Control	YES	2 points
2	Site Selection	YES	1 point
3	Development Density	YES	1 point
4	Reconfiguration of Contaminated Areas	NO	0 point
5.1	Alternative Transport Ways [*Public Transportation Access*]	YES	1 point
5.2	Alternative Transport Ways [*Bicycle Storage & Changing Rooms*]	NO	0 point
5.3	Alternative Transport Ways [*Alternative Fuel Vehicles*]	NO	1 point
5.4	Alternative Transport Ways [*Parking Capacity*]	YES	1 point
6	Reduced Site Disturbance [*Protect or Restore Open Space*]	NO	0 point
7.1	Stormwater Management [*Rate and Quantity*]	NO	0 point
7.2	Stormwater Management [*Treatment*]	NO	0 point
8.1	Heat Island Effect [*Non-Roof*]	NO	0 point
8.2	Heat Island Effect [*Roof*]	NO	0 point
9	Light Pollution Reduction	YES	1 point
			Total Points: 8

Water Efficiency [WE]			
		Answer	Points
1.1	Water Efficient Landscaping [*Reduce by 50%*]	NO	0 point
1.2	Water Efficient Landscaping [*No Potable Use or No Irrigation*]	NO	0 point
2	Innovative Wastewater Technologies	YES	1 point
3.1	Water Use Reduction [*20% Reduction*]	YES	1 point
3.2	Water Use Reduction [*30% Reduction*]	YES	1 point
			Total Points: 3

Energy and Atmosphere [EA]			
		Answer	Points
1	Fundamental Building Systems Commissioning	YES	2 points
2	Minimum Energy Performance	YES	2 points
3	CFC Reduction in HVAC&R Equipment	YES	2 points
4	Optimization of Energy Performance	25%	5 points
5.1	Renewable Energy Sources [*5%*]	NO	0 point
5.2	Renewable Energy Sources [*10%*]	NO	0 point
5.3	Renewable Energy Sources [20%]	NO	0 point
6	Ozone Depletion	YES	1 point
7	Measurement & Verification	YES	1 point
8	Green Power	YES	1 point
			Total Points: 14

Materials and Resources [MR]			
		Answer	Points
1	Storage & Collection of Recyclables	YES	2 points
2.1	Building Reuse [*Maintain 75% of Existing Shell*]	NO	0 point
2.2	Building Reuse [*Maintain 100% of Shell*]	NO	0 point
2.3	Building Reuse [*Maintain 100% Shell & 50% Non-Shell*]	NO	0 point
3.1	Construction Waste Management [*Divert 50%*]	YES	1 point
3.2	Construction Waste Management [*Divert 75%*]	YES	1 point
4.1	Resource Reuse [*Percentage 5%]*	YES	1 point
4.2	Resource Reuse [*Percentage 10%]*	YES	1 point
5.1	Recycled Content [*Percentage 5%*]	YES	1 point
5.2	Recycled Content [*Percentage 10%*]	YES	1 point
6.1	Local/Regional Materials [*20% Manufactured Locally*]	YES	1 point
6.2	Local/Regional Materials [*35% Manufactured Locally*]	NO	0 point
7	Rapidly Renewable Materials	YES	1 point
			Total Points: 10

Indoor Environmental Quality [QE]			
		Answer	Points
1	Minimum IAQ Performance	YES	2 points
2	Environmental Tobacco Smoke (ETS) Control	YES	2 points
3	Carbon Dioxide (CO2) Monitoring	YES	1 point
4	Ventilation Effectiveness	YES	1 point
5.1	Low-Emitting Materials [*Adhesives & Sealants*]	YES	1 point
5.2	Low-Emitting Materials [*Paints, Coverings*]	YES	1 point
5.3	Low-Emitting Materials [*Carpet, Moquetes*]	YES	1 point
5.4	Low-Emitting Materials [*Composite Wood*]	YES	1 point
6	Indoor Chemical & Pollutant Source Control	YES	1 point
7.1	Thermal Comfort, Based on international Standards	YES	1 point
7.2	Thermal Comfort, Permanent Monitoring System	YES	1 point
8.1	Daylight & Views, Daylight 75% of Spaces	YES	1 point
8.2	Daylight & Views, Views for 90% of Spaces	NO	0 point
			Total Points: 14

F.2 Bytes S.A. Environmental Report

ENVIROMENTAL GRADING REPORT

Date - Time: 17/05/2008 11:57:23

BUILDING MANAGER

Building: BYTE A.E.

Category: Offices Location: Athens

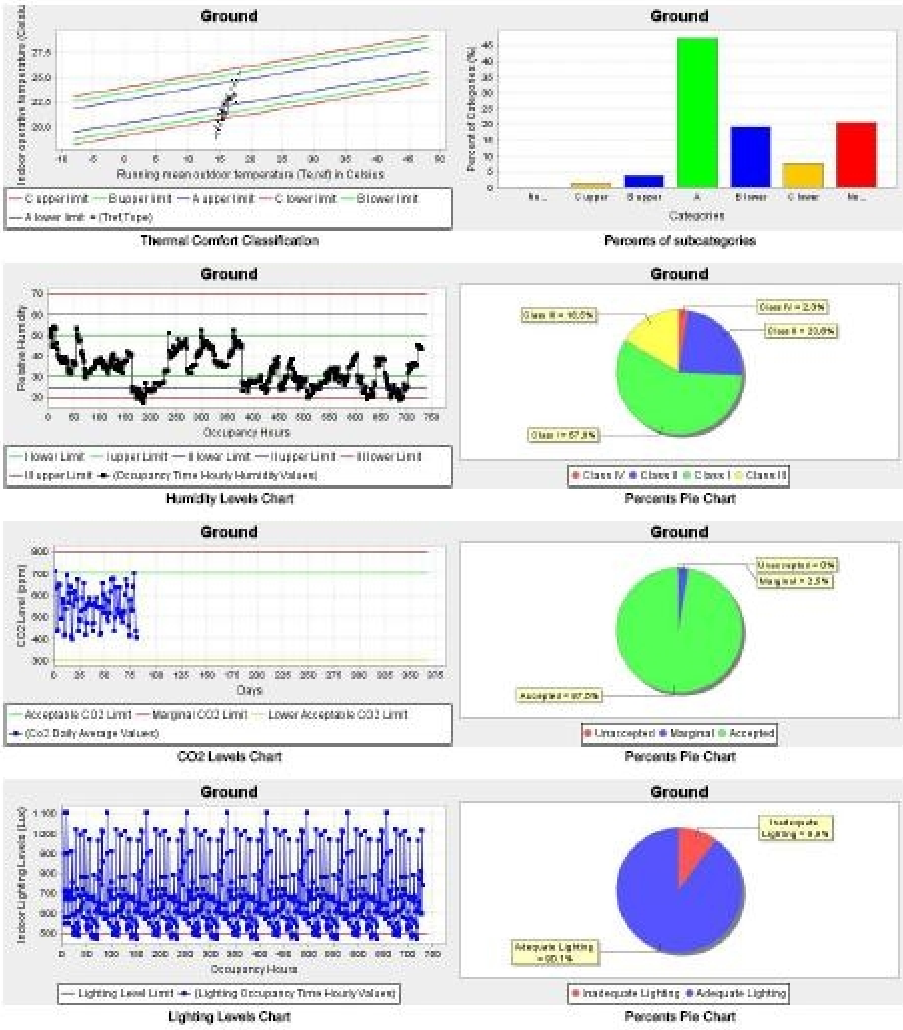
Address: Athens

Air-Condition State: Yes Graded Zones: 3

Zone Description: Ground

Thermal Comfort Class:	None
Humidity Class:	I
Carbon Dioxide Class:	Accepted
Lighting Result:	Adequate

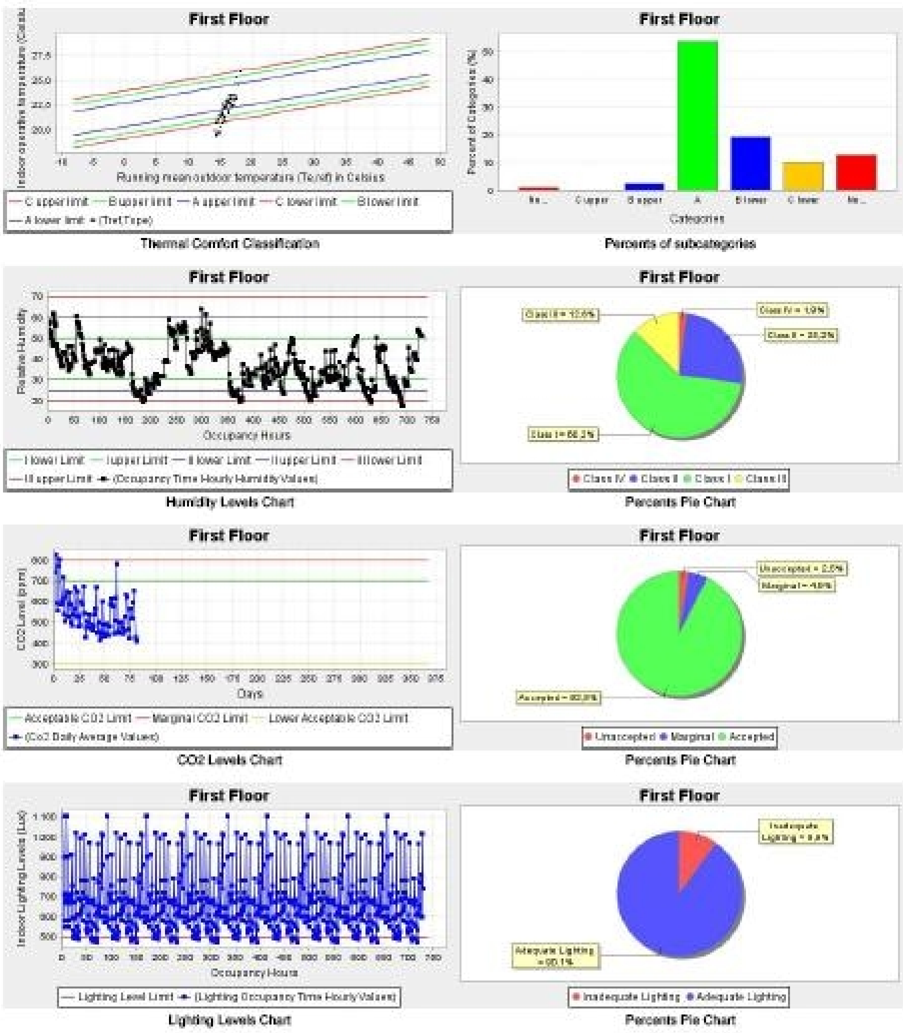
Charts



Zone Description: First Floor

Thermal Comfort Class:	None
Humidity Class:	I
Carbon Dioxide Class:	Accepted
Lighting Result:	Adequate

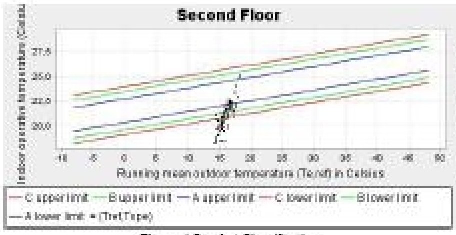
Charts



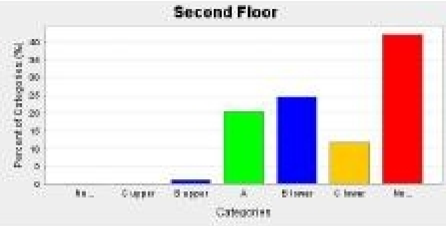
Zone Description: Second Floor

Thermal Comfort Class: None
Humidity Class: I
Carbon Dioxide Class: Accepted
Lighting Result: Adequate

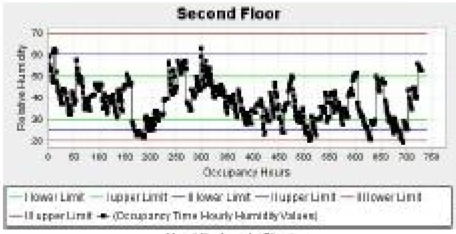
Charts



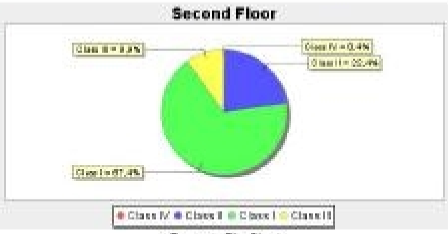
Thermal Comfort Classification



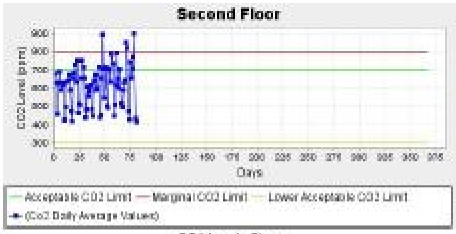
Percents of subcategories



Humidity Levels Chart

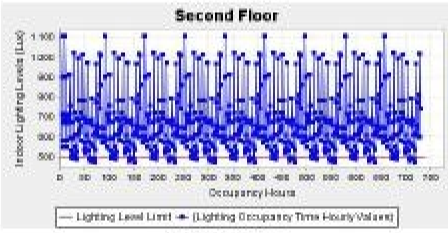


Percents Pie Chart



CO2 Levels Chart

Percents Pie Chart



Lighting Levels Chart

Percents Pie Chart

Appendix G - Java based Building Manager System

This appendix describes the development of a java interface for the PCI-6024E card, manufactured by Native Instruments. This interface implements a simple building management system for monitoring several sensors.

G.1 Java Native Interface (JNI)

G.1.1 Java Platform and Host Environment

The Java platform is a programming environment consisting of the Java virtual machine (VM) and the Java Application Programming Interface (API). Java applications are written in the Java programming language, and compiled into a machine-independent binary class format. A class can be executed on any Java virtual machine implementation. The Java API consists of a set of predefined classes. Any implementation of the Java platform is guaranteed to support the Java programming language, virtual machine, and API.

The term *host environment* represents the host operating system, a set of native libraries, and the CPU instruction set. *Native applications* are written in *native programming languages* such as C and C++, compiled into host-specific binary code, and linked with native libraries. Native applications and native libraries are typically dependent on a particular host environment. A C application built for one operating system, for example, typically does not work on other operating systems.

Java platforms are commonly deployed on top of a host environment. For example, the Java Runtime Environment (JRE) supports the Java platform on existing operating systems such as Solaris, Linux and Windows. The Java platform offers a set of features that applications can rely on independent of the underlying host environment.

G.1.2 The Role of JNI

When the Java platform is deployed on top of host environments, it may become desirable or necessary to allow Java applications to work closely with native code written in other languages. The JNI is a powerful feature that allows us to take advantage of the Java platform, but still utilize code written in other languages. As a part of the Java virtual machine implementation, the JNI is a *two-way* interface that allows Java applications to invoke native code and vice versa.

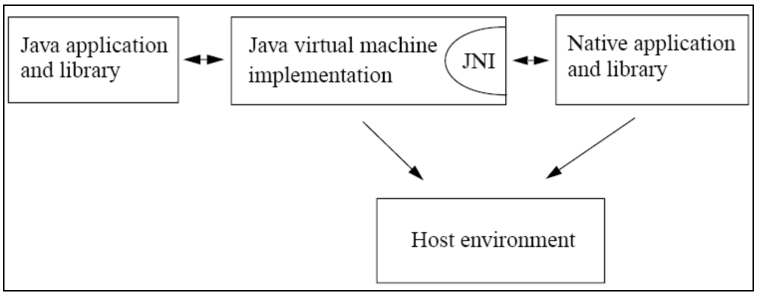


Figure 43 - Role of JNI

The JNI is designed to handle situations where we need to combine Java applications with native code. As a two-way interface, the JNI can support two types of native code: native *libraries(our case)* and native *applications*.

- We can use the JNI to write *native methods* that allow Java applications to call functions implemented in native libraries. Java applications call native methods in the same way that they call methods implemented in the Java programming language. Behind the scenes, however, native methods are implemented in another language and reside in native libraries.
- The JNI supports an *invocation interface* that allows us to embed a Java virtual machine implementation into native applications. Native applications can link with a native library that implements the Java virtual machine, and then use the invocation interface to execute software components written in the Java programming language

G.1.3 Implications of Using the JNI

Once an application uses JNI, it takes the risk of loosing two benefits of the Java platform.

- First, Java applications that depend on the JNI can no longer readily run on multiple host environments.
- Second, while the Java programming language is type-safe and secure, native languages such as C or C++ are not. A misbehaving native method can corrupt the entire application.

G.1.4 Using JNI based on BEMS application interface

Java application interface requires to call the NIDAQ functions, implemented in C, in order to read a value from an analogue PCI card output. The process consists of the following steps:

1. Creation of the class NIDAQConnector.java that declares the native method.
2. Compilation of the NIDAQConnector source file, resulting in the class file NIDAQConnector.class.
3. Generation of the C header file (NidaqAinput.h) containing the function prototype for the native method implementation. For the generation of the header file we use the javah tool provided with JDK releases.
4. Writing the C implementation (nidaqdllAinpt.c) of the native method.
5. Compilation of the C implementation into a native library, creating NIDAQdll.dll.
6. Running the java application using the java runtime interpreter. Both the class file (NIDAQConnector.class) and the native library (NIDAQdll.dll) are loaded at runtime.

Figure 44 illustrates the pre described process.

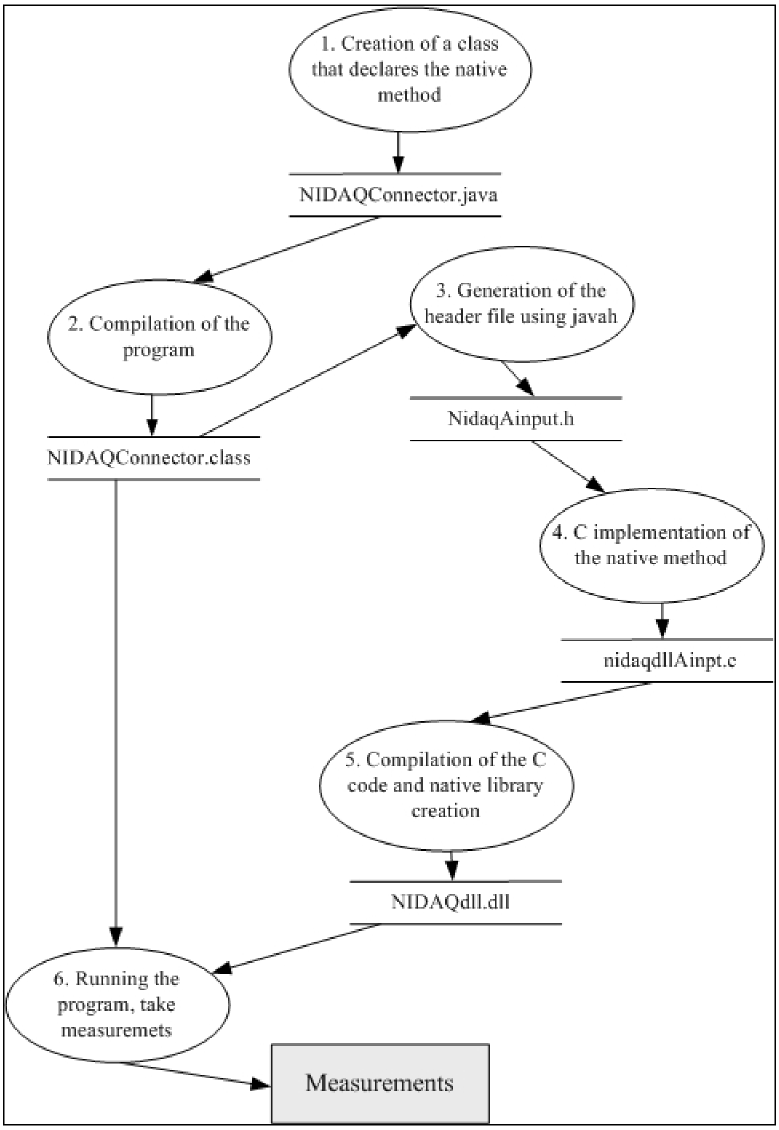


Figure 44 - Steps in writing JNI method

G.1.5 Declare the native method

In the java application the class named NIDAQConector contains the native method NIDAQ_AInput(short ch,short gn).

```
public class NIDAQConnector {
public NIDAQConnector() {}
public double returnvoltage(short channel, short gain){
double voltage;
voltage = NIDAQ_AInput(channel,gain); NATIVE FUNCTION
return voltage;
}
private native double NIDAQ_AInput(short ch,short gn) ;  NATIVE METHOD
static {System.loadNIDAQdll.dll");}}
```

The NIDAQConector class definition begins with the declaration of a function (returnvoltage) that calls the native method in order to return the voltage measurements. This is followed by the declaration of the native method. The last part of the class definition is a static initializer that loads the native library containing the implementation of the NIDAQ_AInput native method. Before the native method can be called, the native library that implements NIDAQ_AInput must be loaded. In this case, we load the native library in the static initializer of the NIDAQConector class. The Java virtual machine automatically runs the static initializer before invoking any methods in the NIDAQConector class, thus ensuring that the native library is loaded before the NIDAQ_AInput native method is called.

G.1.6 Compile the NIDAQConector class

After the definition of the NIDAQConector class, the source code is saved in a file called NIDAQConector.java. Then the source code file is compiled and the result is the generation of NIDAQConector.class file.

G.1.7 Create the native method header file

Afterwards the javah tool is used to generate a JNI-style header file, useful to implement the native method in G. The most important part of the header file is the function prototype for

Java_NDMeasurements_NIDAQConnector_NIDAQ_1AInput, which is the C function that implements the NIDAQConnector.NIDAQ_1AInput method:

*JNIEXPORT jdouble JNICALL Java_NDMeasurements_NIDAQConnector_NIDAQ_1AInput (JNIEnv *, jobject, jshort, jshort);*

The first argument of the native method implementation is a JNIEnv interface pointer. The second argument is a reference to the NIDAQConnector object itself. The two last arguments are the arguments of the native method declared in the java file (function's inputs).

G.1.8 Native Method Implementation and the Native Library Creation

For the C implementation of the native method Microsoft Visual Studio 6 were used. The function follows the prototype specified in the generated header file.

The C file nidaqdllAinpt.c contains the implementation of NIDAQConnector. NIDAQ_1AInput as follows:

```
#include <jni.h>
#include <stdio.h>
#include "NidaqAInput.h"
#include "nidaqex.h"

JNIEXPORT jdouble JNICALL Java_NDMeasurements_NIDAQConnector_NIDAQ_1AInput
  (JNIEnv * env, jobject thisobject, jshort channel, jshort gain){
   i16 iStatus = 0;
   i16 iRetVal = 0;
   i16 iDevice = 1;
   i16 iChan = channel;
   i16 iGain = gain;
   f64 dVoltage = 0.0;
   i16 iIgnoreWarning = 0;

   iStatus = AI_VRead(iDevice, iChan, iGain, &dVoltage);
   iRetVal = NIDAQErrorHandler(iStatus, "AI_VRead", iIgnoreWarning);
   if (iStatus == 0) {
return(dVoltage);
}
}
```

The implementation of this native method uses the NIDAQ **AI_VRead()** function to read the analogue channel iChan and returns the voltage value according to the gain iGain. The C program includes four header files:

- *jni.h* - This header file provides information the native code needs to call JNI functions.
- *NidaqAInput.h* - The header file that we generated using javah. It includes the C/C++ prototype for the NDMeasurements_NIDAQConnector_NIDAQ_1AInput function.
- *nidaqex.h* - This header file provides all information for the NIDAQ functions we use and it comes with the PCI card drivers.
- *stdio.h* - This library provides all the input/output operations for C/C++

Now that all the necessary C code is written, nidaqdllAinpt.c is compiled and the native library is created. We generated a dynamic link library (DLL) NIDAQdll using the Microsoft Visual C++ compiler.

G.2 Presentation of PCI – 6024E

G.2.1 Features of PCI – 6024E Device

The 6024E hardware card is constituted by 16 channels of analog input, two channels of analog output, a 68-pin connector and eight lines of digital I/O. The specific device uses the NI – DAQ STC system including timing controller for time – related functions. The DAQ-STC consists of three timing groups that control analog input, analog output, and general-purpose counter/timer functions. These groups include a total of seven 24-bit and three 16-bit counters and a maximum timing resolution of 50 ns. The block diagram, and the I/O layout of the NIDAQ card is presented in figures 45,46.

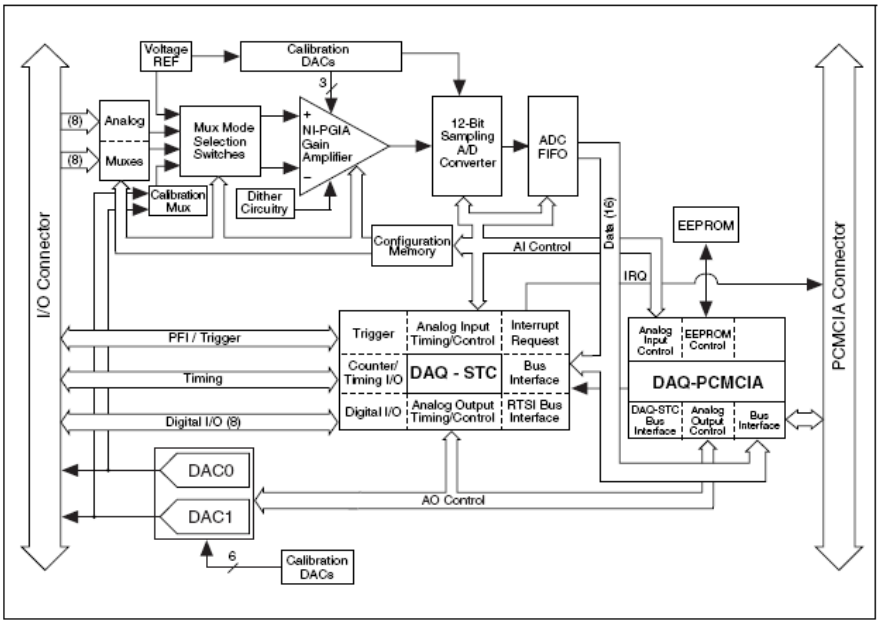


Figure 45 -Block diagram of 6024E

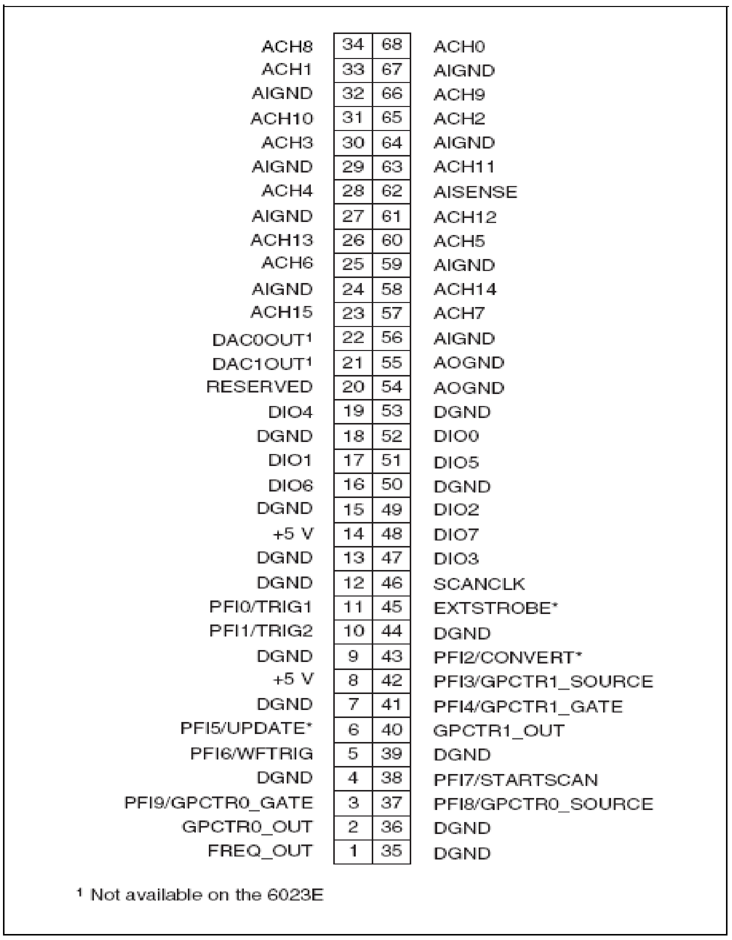


Figure 46 - I/O layout for 6024E device

G.2.2 Measurement Precision

PCI 6024E device has a bipolar range which modifies according to the gain. In this case, each channel of the card can be programmed with gains (see the following table) maximizing the resolution.

Gain	Input Range	Precision
0.5	-10 to +10V	4.88 mV
1.0	-5 to +5V	2.44 mV
10.0	-500 to +500mV	244.14 µV
100.0	-50 to +50mV	24.41 µV

Table 21 - Measurement precisions

G.2.3 Differential Connection

The connection used for the communication between the sensors and the NI – DAQ device 6024E is presented below.

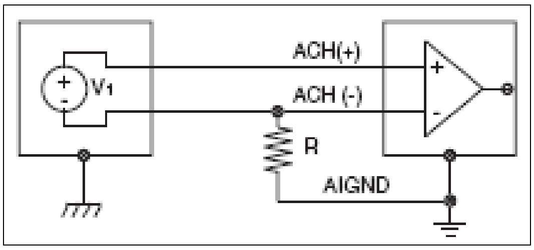


Figure 47 - Differential Connection between sensor and 6024E

From the image above, it is obvious that a Resistor R has been inserted between the sensor and the device. This resistor is equal to 100KΩ. But it is essential to point out that this was not the first connection which had been used. Another connection similar to this had been used but without a resistor. In this case, the system (programming code and device) did not behave very well. Although the programming code read the inputs of the sensor, these values were not accurate and compatible with the real measurements of the temperature that prevailed in that day. Moreover, the values of the inputs varied and were not constant.

This phenomenon led to the conclusion that a resistor should have been used. The role of the resistor was essential since after using it, the measurements approached the real ones without any variance and they were constant.

G.2.4 NI – DAQ Driver Software

The software driver makes the NI – DAQ device compatible to any Personal Computer. It contains libraries and functions which can be used in a programming environment. All necessary functions, for reading an analogue voltage value from a PCI card output, are contained in an existing native library, nidaq32.lib. This library comes with the drivers of the PCI card and is implemented in C language. Furthermore, the software is quite consistent among the different versions in order minimal modifications of the programming code to be achieved.

G.3 BEMS Java Platform Presentation

G.3.1 Platform Interface

The interface of the platform consists of two parts, the PCI card's measurements settings and the measurement procedure settings.

The first part is responsible for the selection of the analogue channels' pairs, the gain of measurements for each pair of channels, the mathematical expression which converts the measured volts to the desirable unit (e.g. Celsius degrees), and the names of the txt files where measurements will be saved. It consists of eight similar rows, one for each pair of channels. Each row includes the following objects:

- A checkbox (Use), responsible for the selection of the channels' pair.
- A label (Channel Pair), which describes the pair of channels.
- A Gain combo box which contains all possible gains of the PCI card.
- A Range field which describes the range of measurement and depends on the selected gain.
- A Description field which holds the description of measurements (e.g. CO_2).
- A Conversion field which holds the mathematical expression used for the conversion of voltage value to the desired unit (e.g. Celsius Degrees).
- A Name field which holds the name of the txt file where measurements will be saved.

Finally, this part of the interface includes two buttons: a) the save settings button which is responsible to save card's measurement setting into a property file, b) the clear settings button which clears all platform's fields.

The second part of the interface is responsible for the measurements procedure. It consists of the following objects:

- The Sample Rate field which holds the measurements sample rate, in seconds.
- The start button which starts the measurements procedure.
- The stop button which stops the measurements procedure.

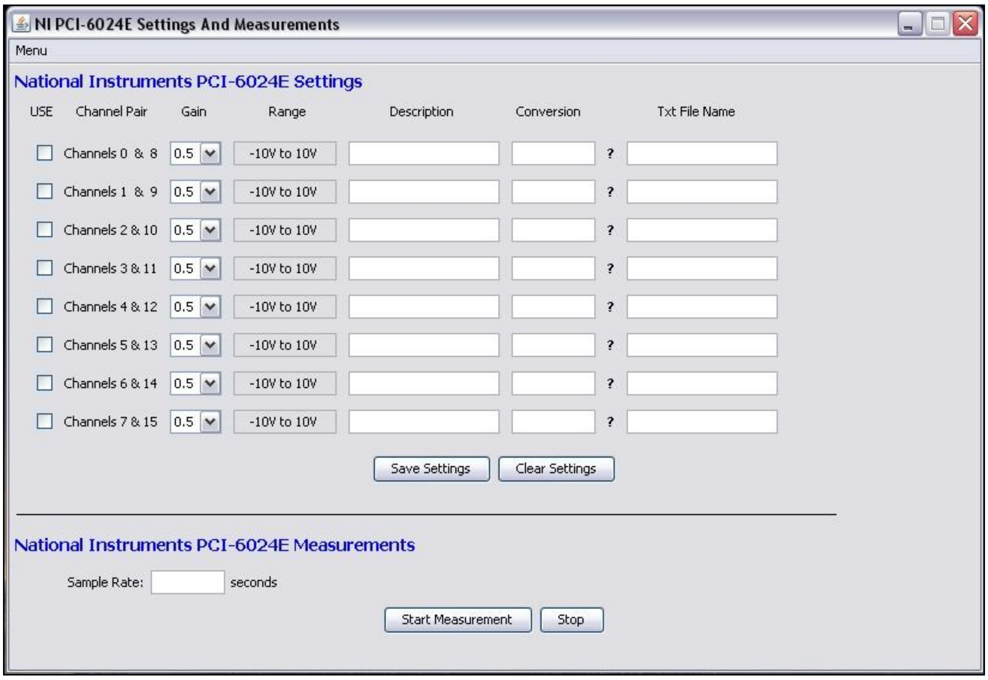


Figure 48- Application Interface

G.3.2 Platform Operation

This section describes the platform operation and gives a little explanation of the java files which implement this application.

The user has to select which channels are connected to sensors in order to take measurements with this platform. Also, he has to select the measurement gain for each pair of channels, give the descriptions of the channels' measurements and give the mathematical expressions for each channels' pair. Furthermore, he has to give the names of the files, where measurements will be saved, for each pair of channels. Finally, he has to give the sample rate (T) of measurements, in seconds, and press the start button in order to start the measurements procedure. The program measures all selected channels' outputs (volts) every T seconds, converts them into the desirable units, and saves these values in the txt files respectively. The format of each line in the txt files is as follows: DATE TIME MEASUREMENT (e.g.: 25/02/2004 12:35 25.4). In order to stop measurements, he has to do is to press Stop button. In order to start the measurement procedure, all fields for the selected channels must have been filled. Also sample rate field must contains a number (seconds).

C.3.3 Presentation of application's java files

NIDAQConnector.java

As mentioned before, this java file is responsible for the declaration of the native method that measures the analogue card's outputs. It contains the class NIDAQConnector which declares the native method and the function *returnvoltage(channel, gain)*. This function calls the native method and returns the measured voltage value for channel "*channel*" with gain "*gain*".

RangeGainCon.java

This java file declares the class RangeGainCon which is responsible for two operations:

- First, to change the value of the range field, according to the gain combo box selection. *RangeChange(combobox,textfield)* function is responsible for this operation.
- Second, to return the short value of the gain according to the gain combo box selection. *ReturnShort(combobox)* function is responsible for this operation. The returned short value is inserted as the second argument of the *returnvoltage()* function, described before.

Gain Selection	Short value
0.5	-1
1	1
10	10
100	100

Table 22 - Gain to short values

Pfileoperations.java

This java file declares the class Pfileoperations which is responsible for the write and read operations of the property file PCI6034E.properties. This property file stores the platform's settings when save settings button is pressed. The structure of the file is as follows: property = value. *SetProperties()* function is responsible for writing into the property file. It takes as input an array of properties and is called when the save settings button is pressed. *Returnproperty()* function is responsible to read and return the stored information from the property file. This function is called, each time the application starts.

GlobalTimer.java

This java file declares the class GlobalTimer. This class sets a timer (class Timer) and contains two timer functions:

- *Settimer(Timetask, delay, period)*: this function initializes the timer and starts a periodical procedure after a *delay* of time. It repeats the task (*Timetask*) every *period* (seconds).
- *Stoptimer()*: this function stops the timer.

Filewriter.java

This java file declares the class Filewriter which is responsible for the write operation of the txt files that hold the measurements. It contains the function *FileWriter(name, value)* which appends the *value* to the txt file with name, *name*.

Conversion.java

This java file is responsible for the conversion of data. The sensor's output varies between 0 to 10 volts. The technical manual of this sensor reports that when the output is equal to 0 volts then the temperature is -10 and when it is equal to 10 volts then the temperature is $40\,^{0}C$. So, this java file reads the output of the sensor and converts it to the corresponding temperature value.

MeasureSettings.java

This java file is the main file of our application. It contains the main function and implements the interface of the platform. Also, it contains the measurement operation.

The measurement operation starts when the start measurement button is pressed. A new GlobalTimer is declared and a number of checks are performed. These checks examine if all fields for the selected channels have been filled. Also a check, if sample rate field contains a number, is performed. If all checks are passed, the Timetask for the GloobalTimer is declared. This contains a block of operations for each pair of channels, as shown below:

```
if(usebox.isSelected()==true){  //if channel is selected
        String conversion = conversionfeild.getText().toString(); //conversion expression
        String txt = filepathfield.getText().toString(); //name of the output txt file
```

```
short gain = RGConn.Returnshort(gaincombobox); //The short value for the selected gain
 short channel = #;  //number of channel
 double voltage = NIDAQAI.returnvoltage(channel,gain); //voltage measured value
voltage = conver.ReturnConversion(conversion,voltage); //Conversion voltages → desired unit
fw.Filewriter(txt,voltage); //write the converted value to the txt file
}
```

After the declaration of the Timetask, the *settimer()* function is perfomed, and the measurement procedure starts.

gt.settimer(nt,delay,period);

where *nt* is the Timetask, *delay* is 3 seconds and *period* is the sample rate field's value(sample rate in seconds).