Energy Assessment Methodologies and Climatic Measurements - A Field Monitoring Project in Maputo City

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Key words

Energy efficiency, measurement, equipment, modelling and simulation tools, outdoor and indoor thermal environment, tropical and sub-tropical zones, field measurements.

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Preface

This thesis is based upon studies conducted at the Department of Construction Sciences in both Lund and Eduardo Mondlane University, Maputo, Mozambique and it deals with the study of methodologies for assessment of energy used in buildings and climatic measurements in Maputo City, Mozambique.

The research presented here has received a financial support from sida/SAREC through Eduardo Mondlane University.

I would like to express my sincere gratitude to my leading supervisors Professor Bertil Fredlund and Dr. Kurt Källblad, without their advice this thesis would never have a success.

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I would also like to thank the staff at the Department of Construction Sciences, especially the Division of Construction Management. My special thanks go to Engineer Thord Lundgren for his help in the field of measurement equipment installation in the test house and treatment of data for this work.

Finally, I wish to express my greatest thanks to my family, friends and colleagues at Eduardo Mondlane University.

Dedication

I dedicate this work to my beloved late father, Auziane Auze, who showed me the way to school.

Gabriel Auziane
Lund, December, 2010.

Abstract

Initial results of the research have shown that a great deal of energy in buildings is used in a highly inefficient manner. The existing instruments for measuring, evaluating and calculating the quantity of energy used in buildings have not yet been implemented in Mozambique. This fact leads, in most cases, to a failure in achieving best comfort levels for households. In fact, energy evaluation in houses can provide information about energy used in buildings, accredited professionals and energy buyers can have exact information on what they have to pay. This information is important for buyers once it helps them to control and reduce energy used in buildings.

The use of instruments, protocols, experiments and simulations tools to evaluate energy use in buildings is not common in Mozambique. This thesis presents both a review of modeling and simulation tools for energy efficiency in buildings. It also explains the process of equipment installation in the test house for measuring microclimatic and indoor parameters which influence the indoor comfort.

A wide range of tools are now available to help architects and engineers in designing energy-efficient buildings. The main aim of this work is to find suitable tools for energy buildings management in Mozambique and to create database from the measurement equipment.

To test and validate modeling and simulation tools, literature review of energy assessment methodologies, energy use theory in buildings and experimental techniques was conducted. The focus was on tropical and subtropical countries. From this work; three tools were chosen for closer studies of climatic conditions in Mozambique, namely the University project, the Energy Barometer and the DEROB-LTH Program.

A case study was taken into consideration to measure building climatic parameters by installing measurement equipment in “3 de Fevereiro Building” in Maputo City. The building measurement data during winter (from June to September, 2009) was compared with the one from Maputo Meteorological Station and the conclusions showed a great similarity between the two data sets, which means that the equipment is reliable for measuring building data. It also means that it can be used to test and to validate simulation tools in Maputo City, Mozambique. There is a need for

further data collection, short and long term monitoring building climatic parameters, and the use of data results in simulation tools for its validation.

Keywords: Energy efficiency, measurement equipment, modeling and simulation tools, outdoor and indoor thermal environment, tropical and sub-tropical zones, field measurements.

Acronyms and abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BRE	Building Research Establishment
BREDEM	Building Research Establishment Domestic Energy Model
DEROB	Dynamic Energy Response of Buildings
DIN	Deutsches Institut für Normung in English, The German Institute for Standardization
DOE	United States Department of Energy
EB	Energy Barometer
EN	European Standards in English EN Standards
Enerdata	Energy Data (Independent Consulting and Information Services Company)
EU	European Union
HERS	Home Energy Rating System
HVAC	Heating, Ventilating, and Air Conditioning
INE	Instituto Nacional de Energia
LTH	Lunds Tekniska Högskola
NICER	National Irish Centre for Energy Rating
MAMS	Maputo Airport Meteorological Station
PMV	Predicted Mean Vote index
PPD	Predicted Percentage of Dissatisfied index

RCCTE	Regulamento das Características de Comportamento Térmico dos Edifícios
RSIUEE	Regulamento de Segurança de Instalações de Utilização de Energia Eléctrica
SAE	Statistical Adjusted Engineering
SAP	Standard Assessment Procedure
SAREC	Swedish Agency for Research Cooperation
Sida	Swedish International Development Cooperation Agency
STEM & PSTAR	Short-Term Energy Monitoring, and Primary and Secondary Term Analysis and Renormalization
UK	United Kingdom
USA	United States of America

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Part A

Introduction and Overview

1. Introduction

1.1 Background

Traditional buildings are seen to consume much more energy than modern and green buildings. The advent of green buildings has even put emphasis to the need of energy efficiency measures being strongly considered. In fact, a high performance building is perceived as using less energy and being more economical to operate and to maintain.

The quantity of energy waste in buildings through inefficient use is, indeed, significant. This has adverse technical, economical, environmental and social impacts. Despite that fact, little work has been done to improve energy performance of buildings, particularly within the construction industry community. And this corroborates the recent study by Tavares and Lambert (2005) in which they urge researchers to address building energy use with emphasis on the embodied energy in materials and construction techniques. Furthermore, the fact is no exception since most countries in the world do not have standards for energy efficiency in buildings (Westphal and Lambert, 2002). The authors mentioned that in 1994, only 27 countries had mandatory standards and 11 had voluntary ones in that regard.

The standards have now been developed to measure the environmental performance of buildings and energy efficiency; one of the fundamental criteria in order to address sustainable construction. Sustainable construction provides standards for energy efficiency of completed buildings. This helps to ensure that during the operational stage; only the minimum amount of additional energy is required. For example, Standard Assessment Procedure (SAP) has been used in UK to evaluate energy efficiency of existing buildings (Wilkinson, 2001). Generally, the results shows that a great deal of existing buildings have bad energy performance.

Based on research, Westphal and R. Lambert (2003) concluded that through a retrofit process in lighting and air conditioning systems, significant amount of energy saving can be achieved with a considerable payback. And the potential of savings can reach about 40%.

Energy assessments in both USA and UK have been used in buildings since the 1980s. The HERS program was implemented in five pilot states, Alaska, Arkansas, California, Vermont and Virginia. Today many states in USA have adopted the HERS version or its equivalent. However, only 2% of new houses in USA receive energy rating recently and the rest use programs with tax payer subsidies (M. Santamouris, 2005).

The BRE performed hundreds of multi-year energy audits in residential buildings of UK. From these audits, BRE was able to develop the Domestic Energy Model (BREDEM), (M. Santamouris, 2005).
In Denmark, studies about energy efficiency have been developed in commercial buildings since 1992 and they extended to residential buildings in around 1993 (M. Santamouris, 2005).

In 1992, NICER created ERBM in order to deal with energy consumption in the existing buildings (M. Santamouris, 2001).

Energy assessment system has been developed to classify new residential buildings in Spain and Netherlands and a rating of energy efficiency was developed in the 1990s (M. Santamouris, 2005).

The Swedish government has introduced a financial support and subsidies for saving energy use in buildings. The main goals behind this initiative are among the others to stimulate efficient energy use, to reduce the heating energy, and most importantly, to decrease the gross heating energy use within residential buildings (Westergren K-E, 2000).

In virtue of this initiative, the research first started at Universities in Sweden, and models as well as simulation tools, like the Energy Barometer (EB), developed in Stockholm (Westergren K-E, 2000), the simplified BKL METHOD, developed at Lund University (K. Källblad, B. Adamsson, 1979), the University projects 1 and 2 methods, developed in Stockholm (M. Santamouris, 2005) were developed for assessment of buildings energy use.

The DEROB program from University of Texas, USA, developed by Arumi-Noa (1979) has been used in several sites and presented in many versions in various countries. One of them, DEROB-LTH, was adopted by Department of Building Science at Lund University (Manual of Derob-lth, version 2.0, ebd.lth.se).

1.2 Problem statement and significance of research

Buildings account for nearly a third of the world's energy use today, and this share is expected to rise along with population growth and with levels of prosperity. The building sector is constantly expanding with consequences of energy expenditure, being it either in the residential sector or in the service sector (Pellegrino et al 2010).

The energy use shared with buildings in EU is about 40% of the total average energy consumed (Tavares et al 2006). In the United States, residential and commercial buildings consume about 40 % of primary energy use. In Brazil during 2006, residential and commercial buildings were responsible for 58% and 42%, respectively (Pellegrino et al 2010).

In Mozambique it is estimated that from the total average of the energy produced, 0.39% is consumed in commercial buildings and 72% in residential buildings. For more details, see Table 1.

Table 1: Energy use by sector in Mozambique

Energy use by Sector in Mozambique (thousand metric tons of oil equivalent)	
Industry	1,628
Transportation	304
Agriculture	5
Commercial & Public Services	27
Residential	4,979
Non-energy uses and other consumption	12
	6,955

Source: Energy and Resources – Mozambique (Earth trends country profile,1999)

Energy demand has been on the increase in Mozambique and measures are now being taken to cater for the problem with the planning of new power generation, concrete dams, and transportation infrastructure (INE, 2005). However, these measures will not by themselves be able to ensure enough energy if efficiency strategies are not properly implemented.

The government of Mozambique has defined energy efficiency in its strategy for science and technology as one of the key areas to be addressed; the strategy includes energy efficiency research and the production of construction materials with reduced energy requirement as two pillars. Furthermore, energy efficient buildings are of paramount importance in economic, environmental and social terms.

This research attempts to fill the gap in the field of building energy performance through energy analysis, auditing, modeling, and simulations of energy use in buildings. This is important as it generates knowledge, data and information for Architects, engineers, building designers, constructors and maintenance operators.

1.3 Research Questions, Aim and Objectives

1.3.1 Research question

The questions that outlined this research are presented as following:

- How efficient is the management of residential building energy system in Mozambique?

- Why is the use of energy in residential buildings high?

- What influence has tropical and subtropical climate on buildings energy use?

- How can the contributing parameters and variables of the buildings be managed in order to improve energy use systems?

In the field of buildings energy efficiency which leads this research, questions were considered better than hypotheses because testing of hypotheses would be difficult to accomplish without previous data that are needed for comparison.

1.3.2 Aim and objectives

The aim of this research is to study theoretical techniques and models of modeling and simulation tools for evaluating buildings energy use intending to identify the suitable one for carrying out energy rating of buildings and for establishing a framework of outdoor climatic and indoor parameter database which can be used by engineers, building designers, constructors and professionals at simulation energy efficiently for climatic conditions such as the ones of Mozambique.

The specific objectives of the research include the following:

1. Review of the current practices on energy in buildings in Mozambique and worldwide.

2. Identify and analyze the impact of climatic elements and internal gains of energy use in residential buildings.

3. Identify, analyse and evaluate the suitable models, modeling and simulation tools for assessment of energy used in buildings in tropical and subtropical countries.

4. Develop a framework for models and tools that can be used by researchers, designers and constructors in field of energy efficiency use in buildings.

1.4 Delimitation

The target of this research is the modeling and simulation of energy efficiency in buildings with focus on active systems and it was presented as doctoral research project proposal. This thesis is a part of that project and presents the work done as preliminary investigation. The work deals with literature review study in field of modeling and simulation residential energy performance with a focal target at energy efficiency related to indoor comfort based on active systems such as HVAC and measurement equipment for collecting data for creation of database of the outdoor climatic and indoor parameters.

A lot of modeling and simulation software can be used to estimate energy in buildings and to perform energy efficiency in buildings during the design phase, construction, retrofits of the buildings or for research purposes.

In this thesis, the literature review was based on software tools for colder, tropical and subtropical countries in order to create general background in this field. Later it was necessary to select among models, modeling and simulations tools suitable in compliance with national and international energy codes for building energy assessment in tropical and subtropical countries as Mozambique.

Case study was conducted in “3 de Fevereiro Building” located in Maputo City, Mozambique.

2. Previous research in energy assessment methodologies and climatic measurements

2.1 Introduction

The objective of this chapter is to summarize the theory related to methodologies, models and simulations tools for assessing energy in buildings. The matter inherent to the testing and validation of models and simulations tools is presented below.

2.2 Energy efficiency indicators

According to "Enerdata" energy efficiency indicators can be used to make several types of analysis for building energy assessment. Below are mentioned some of the functions of energy efficiency indicators:

- Monitor the targets set at the national and international levels of energy efficiency and CO_2 abatement programs.

- Evaluate energy efficiency policy and programs.

- Plan future actions related to energy efficiency programs.

- Feed the energy demand by forecasting models and improving the quality of forecasts and technical-economic models that are characterized by a high level of desegregation (end-uses) and by making use of energy efficiency indicators to account for future changes in energy efficiency.

- Make cross-country comparisons in a harmonized way.

2.3 Energy assessment methodologies

The matter for literature review was selected for topics inherent to models, modeling and simulation tools, and experimental techniques for assessing buildings energy use (including methodologies which can be applied in this field). The general theory of such methodologies is presented in paper II and report I, at the end of this work. In this chapter, is presented standard theories related to methodologies for observing energy performance of buildings. So, for better energy classification and certification of buildings performance an assessment that can be applied without distinction to new and existing buildings methodology is required.

To this end, the EN 1503 standard can be applied for improving energy performance of buildings; for enabling the overall energy use in buildings; for reducing CO_2 emission; and finally, for defining energy ratings. This last one (defining energy ratings) presents several assessment methodologies, some of which are illustrated below:

- Obtain the same results for different data sets.

- Estimate the missing data and calculate standard energy consumption for air conditioning (heating, cooling and ventilation), production of domestic hot water and lighting.

- Assess the effectiveness of possible energy efficiency improvements.

2.4 End-Use consumption estimation methodology

The use of energy data provided by energy companies suppliers are for total use within the residential buildings. Estimates for major end-users can be calculated by disaggregating the total energy consumption into end-use consumption by using the following several approaches: Engineering simulations, statistical modeling or a hybrid approach known as statistical adjusted engineering (SAE). The aim behind this project was to use these approaches for energy end-use by the employment of engineering simulation systems considering buildings characteristics and weather data for the sampled buildings. Within the EN 15603 standard, it is considered that energy performance evaluation is based on the weighted sum of the calculated or measured energy use by primary energy source (natural gas, oil, electric energy, etc.).

Depending on the circumstances, we can determine energy performance of a building through a calculation model based on the building characteristics (direct approach), or assess the energy use through the present consumption measurement (inverse approach), **(**Stefano Paolo Corgnati and Vincenzo Corrado, 2008).

Asset rating represents the intrinsic potential of a building under standardized conditions of its use, and it can also be applied for energy certification. On the other hand, operational rating is a measure of the in-use performance of the building, and it can be useful in certifying the present performance of the building energy use system. Obviously, in order to obtain an operational rating, it is essential to implement monitoring strategies that will enable one to measure the present energy use of the building (Corgnati et al., 2008).

To conduct the study of energy in overall sense, it is necessary to have the knowledge about the classification of energy evaluation. For this purpose, the following classification of energy assessment is proposed by EN 15603 Standards:

- Operational rating is obtained by measuring and summing up (after appropriate weighting) all amounts of delivered energy by each energy source (electricity, oil, natural gas, etc.).

- Calculated rating is obtained by measuring and summing up (after appropriate weighting) all amounts of delivered energy by each energy source. This assessment can be further differentiated from the method adopted to collect the climate data.

- Design rating is based on calculations using the data derived from design results and design values estimated for a building under construction.

- Asset rating is the value based on calculations using the existing building data (the data is obtained from field surveys and deductive rules) and input standard values that have to do with indoor/outdoor environment and occupancy.

Tailored rating is based on calculations using the present data of a building as well as the climatic and occupancy data. The data about the building may be rectified after a comparison between the calculated and the measured consumptions (validated rating).

The consideration of the set of the methodologies presented above were important base for all activities related to case study.

2.5 Model analysis methods

The report I is about literature review and presents some principal models applied for assessment of energy in buildings. There are two methods, namely Dynamic analysis methods (which are techniques to analyze dynamic processes) and static analysis method (consists in identifying the typical parameters of physical processes like energy flows in buildings). Dynamic methods focus the time aspect whereas static analysis method does not.

Dynamic evaluation techniques (parameter identification) and dynamic effects, due to accumulation of heat in the equipment and test room envelope and test specimen, are strongly taken into account. In general, the idea behind the identification of climatic parameter of buildings is, actually, to enable the steady state properties from a short test with dynamic conditions (e.g. fluctuating outdoor) to derive.

The traditional method for simulating energy demand in buildings is based on implementations of building characteristic in more or less ideal physical sub-processes. Other common modeling techniques based on measured performance data are, for instance, time-series analysis and statistical methods (Jan Akander, 2000).

2.6 Modeling of Building Energy Performance

Energy modeling or simulation is a method for predicting energy use of a building. The analysis considers the building´s numerous thermal characteristics including wall materials and the rest of the building envelope, the size and orientation of the building; it also considers the local climate and how the building is occupied and operated. Energy modeling can be used as a tool to test the building performance with regards to an established standard; and it can be used to compare different building systems, to provide innovative solutions to reduce the energy consumption and environmental impact of building designs.

Modeling and simulation has become a very important technology for assisting engineers with nontrivial task in designing and analyzing buildings and associate environmental systems with which the result will enable a low energy consumption, good indoor conditions, and minimal impact on the environment (Clarke et al. 1994).

The goal of energy modeling of buildings is to theoretically study the energy use. Energy modeling can be used as a tool to test the building performance with regards to an established standard and to compare different building systems.

Utilizing a full suite of powerful modeling tools, it is possible to accurately predict the energy flows, power requirements, temperature, humidity, and thermal comfort of buildings systems as well as its energy-consuming components.

2.7 Procedures for evaluation of energy

The research work was carried out following both national (RCCTE-6/7, RSIUEE) and international (DIN, EN, DOE, ASHRAE 90.2) norms for air conditioning (heating, cooling and ventilation), heat pumps, water heating, electrical heating and energy performance in buildings.

According to (Servando, et al.), in the measurement equipment it was important to consider the rating procedures, once the rating procedure is a comparison of schemes that makes it possible to give a score to a certain building. It is based on three issues:

- The variable of performance or the set of variables that are going to be compared.

- The comparison of the scenario that are going to provide the distribution of variables of performance, creating the framework of comparison.

- The rating score, which includes the criteria and the limits that give the score when the variable of performance is compared in the comparison of the scenario.

2.8 Validation and calibration of simulation tools

The matter presented in paper III and report II is related to measurement equipment installed in the test house “3 de Fevereiro building” with objective to collect data of the microclimate and indoor parameter. The main objective of this field measurement is to create a database which can be used by modeling and simulation tools.

Within this project, the data from measurement equipment will have the same use and, first of all, they will be used for testing, validation and calibration of the simulation tool selected during the literature review.

Calibration involves estimating the values of various constants and parameters in the model structure. The objective is that of getting the simulation tool which can provide simulation outputs close to field data. This is a difficult task in many applications, and evidently for energy assessment. Our challenge is to verify the functionality of the DEROB-LTH program, once it has shown good performance when used in tropical and subtropical countries like Mozambique by Wang Zhiwu (1992) and Hans Rosenlund (1993).

The validation of a tool is the process which establishes the credibility of the model by demonstrating its ability to replicate current outdoor and indoor climatic elements patterns.

The objective of the calibration is always to have simulation outputs close to field data. It is necessary to propose different ways of measuring deviations from the field data.

Verification is extremely important and involves debugging the model to ensure its functionality, whereas validation ensures that you have built the right model (Sargent, 2000 and Galán et al., 2009).

As a way to end this chapter we can say that energy efficiency and conservation can lower energy use in buildings and still providing the same level of service. Influenced by the need for utility bill savings and environmental protection, energy efficiency measures permanently reduce peak load by reducing overall use. In buildings, this is typically done by installing energy efficient equipment and operating buildings efficiently (Kiliccote 2006).

3. Case study

3.1 Introduction

Historically, it is believed that the case study method was first introduced into social science by Frederic Le Play in 1829 as a handmaiden of statistics in his studies of family budgets (Sister Mary Edward Healy, C. S. J. 1947).

Since that time many studies have been conducted to define and apply the case study method in other areas. And it was in the succession of these studies that Yin and other researchers formulated the definitions below:

- Case study is a research method that investigates a contemporary phenomenon of energy use in buildings within of the real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used (Robert K. Yin, 1984).

- Case study can be descriptive or explanatory. The former type is used to explore causation in order to find underlying principles, Sharpard John, Robert W. Greene (2003) and Robert K. Yin, (2009).

According to Yin, there are three types of case study research, namely exploratory, descriptive and explanatory. Researchers in business related subjects they sometimes limit case studies to the exploratory use. Descriptive case study is an attempt to describe, for instance, what happens to a product when it is launched. Explanatory research can be useful for example to study processes of effective production in companies.

According to the explanation above, descriptive case study is appropriate to our investigation and it can be conducted as longitudinal research method that provides systematic data collection, data analysis and reports of the data results from field measurements periodically.

3.2 Design case study

The case study presented in this thesis is about a building which presents similar building characteristics to many houses in Maputo City. The data results from the measurement equipment installed in the building will be used as the main base to test and validate the simulation tools in Mozambique.

The case study methodologies for this work are presented as follows:

- Selection of the case for study.
- Definition of the research questions.
- Designing the layout of the measurement equipment and its installation.
- Determination of data gathering and technical analysis.
- Preparation of the data collected at the field measurement.
- Evaluation and analysis of the data.
- Preparation of the report.

Buildings are intensive energy users; when poorly oriented and operated they can waste high quantities of energy, and consequently increase energy use. The evaluation of the energy performance of a building requires knowledge about two important issues, namely the building design details and the energy use characteristics within the occupied spaces. The latter is essential for predicting energy use for active control of indoor environment, especially for air conditioning systems (heating, cooling and ventilation) which are a vital process for optimization of buildings performance. With building information, it was possible to organize building characteristics and energy end-use surveys. The survey was targeted to obtain data about construction and energy characteristics of residential building, such as:

- Design features of building facades.
- Types of energy (purpose and intensities of their uses).
- Type and quantity of domestic appliances.
- Type and quantity of lighting.
- Household composition and characteristics.
- Outdoor and indoor environmental conditions.

The details of findings in this survey can be seen in paper III and report II, at the end of this thesis.

4. Papers and reports overview

This chapter is the base of all the work that is being carried out since 2008 up to present year 2010.

4.1 Paper I: Ten years of sustainable construction – perspectives from a north construction manager and a south architect point of view

4.1.1 Introduction

The first paper sums up the themes related to sustainable construction from North and South perspective; it also discusses how international views of sustainable construction have changed over the past ten years. The north part focuses on a review from four different international and regional sustainable building conferences based on the notes taken by an author during the conferences between 1998 and 2007. These notes were specially taken from plenary sessions, such as GBC98 (Vancouver, Canada, 1998), SB02 (Oslo, Norway, 2002), SB05 (Tokyo, Japan, 2005), and the regional conference SB07 (Malmö, Sweden, 2007). The south part presented in this paper focuses on the contribution of Mozambique and Tanzania towards the sustainability issues based on literature reviews, research findings and reference buildings.

4.1.2 Findings

The findings presented in this paper show that the views of sustainable construction have changed from solely environmental aspects to a more broad and transparent complexity of sustainability which involves ecological, economic, social, esthetical and cultural aspects. It also reflects regional and national differences and some shifting views about sustainability in the construction sector during the past ten years.

4.1.3 Conclusion

Sustainable construction is based on best practices which emphasize long term affordability, quality and efficiency. At each stage of the building life cycle, it increases its comfort and quality of its life. While the negative environmental impacts decrease, the economic sustainability of the project increases. A building designed and constructed in a sustainable manner, minimizes the use of energy over its whole life cycle.

4.2 Paper II and Report I: Energy assessment methodologies and energy use in buildings – a review of selected theoretical and experimental techniques

4.2.1 Paper II

The paper II is presented at the end of this thesis and deals with the theory related to energy efficiency in buildings. The matter related to paper II is basically the abstract presented to the SB11 conference, which will take place in Helinsiki, Finland, 2011.

4.2.2 Report I

Report I, is a review of energy efficiency, theoretical, experimental and measurement techniques and energy use in buildings.

It is worth stressing that the use of protocols, experiments and simulation techniques to evaluate energy use in buildings are rarely applied in Mozambique. This thesis presents a literature review of different methods and techniques for data collection, analysis, and interpretation of the data collected from measurement equipment used in research. At the initial stage the review of relevant literature was conducted in the area of energy use systems and energy efficient strategies. This work was carried out within informal discussions by the construction professionals and building owners/users and the views about it were elicited on the design approaches, energy use and energy management.

4.2.3 Conclusion

From the Table 5 (Chapter 4.8 of Report I), it was concluded that, for the type of buildings under investigation in Mozambique, The University Projects is suitable to study building retrofitting and the Energy Barometer is useful to get solutions to the problem of energy use in buildings. Finally, the DEROB-LTH program is a suitable tool for modeling, simulating and assessing of energy use in buildings.

4.3 Paper III and Report II: Experimental Design of Weather Station and Field Measurement of Climatic Factors in the Building

4.3.1 Paper III

The third paper "Design of weather station and measurement equipment for assessment of buildings energy use in Mozambique" and second report present the measurement equipment installed in "3 de Fevereiro Building" in Maputo City, Mozambique. It is titled "Experimental design of weather station and field measurement of climatic factors in "3 de Fevereiro Building"; these appendices can be seen at the end of this thesis.

The matter relating to paper III is basically the one presented to AET2011 Conference which will take place in Kampala, Uganda, 2011.

4.3.2 Report II

Report II is titled "experimental design of weather station and field measurement of climatic factors in the building", presents the results from measurement equipment installed in “3 de Fvereiro Building”, in Maputo City.

4.3.3 Conclusions

The measurement equipment installed in the apartments can be considered effective and reliable inasmuch as it provides the building parameter data and the weather elements which can be used for assessment of energy use in buildings. Analyzing data from the measurement equipment can be concluded that it provides fair results since the comparison of these data with the one from other weather stations, such as Maputo Airport Meteorological Station presents similar trends. For more details about this comparision, see Table 3.7(a) and Figure E.1, Appendix E of the report II.

5 Final conclusions

5.1 Introduction

This thesis is part of the project currently in study; and its main objective is to give the overall conclusion of the whole work carried out during the period of the study with observation of the research questions and specific objectives presented in previous chapter 1.3 of this thesis.

5.2 Literature review

The literature review accounted for in this work brought in useful methodologies to the rating processes of energy use in buildings. The thesis presents a resume of appropriate methodologies for survey, study of the model, modeling and simulation of energy use in buildings, and particularly in residential buildings. In this study, it was concluded that the energy in buildings is used in a highly inefficient manner in Mozambique. The existing instruments for measuring, evaluating and calculating the quantity of energy used in buildings have not yet been employed in Mozambique. That fact leads, in many cases, to a failure in achieving best comfort levels for households. It is worth stressing that the use of protocols, experiments and simulation techniques to evaluate energy use in buildings is still a big problem in Mozambique, and there is need to apply these methodologies in order to help building designers, constructors, architects and engineers in their activities related to evaluation of energy efficiency during design, construction and retrofit phase of the buildings.

It was realized that there is a wide variety of tools and models for energy assessment in buildings; and only the most suitable for the climatic condition typical of Mozambique were analyzed and selected. Among the others Energy Barometer method, University Projects and DEROB-LTH Program are the ones which appeared to be more suitable for Mozambique climatic conditions. For more details about the functionality of these tools, see report I. To test, validate and calibrate these tools was concluded that it is important to have data from the test house where the outdoor and indoor climatic condition can be collected.

5.3 Experimental Design of Weather Station and Field Measurement of Climatic Factors in the Building

According to the conclusions presented in 5.2 of this thesis, paper III and report II present the matter related to measurement equipment installed in "3 de Fevereiro Building". This building was analyzed and selected for installation of the measurement equipment. Chapter 3.2 related to design case study presented in this thesis, describes the methodologies applied for this work and report II (Table B.2, Figures B.1 (a) and B.1 (b), Appendix B), presents the general elements of the building.

From the analyzed data and the measurement equipment, it was concluded that the equipment is effective and reliable as it provides the building parameter data and weather climatic elements and it also presents fair results as mentioned in point 4.3.3 above.

6 Further research

Further research is required in order to verify the functionality of the DEROB-LTH Program utilizing the data from field measurement which was collected in measurement equipment installed in "3 de Fevreiro Building".

After conducting the analyses inherent to functionality of the DEROB-LTH Program using the data from test house, further work will consist of measuring and monitoring variables for validation and calibration of this modeling and simulation tool for mozambican climatic conditions. In addition, there is need to use the measured data for assessment of building energy use and to create the framework for building energy performance.

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Part B

Appended Papers and Reports

Paper I

Ten Years of Sustainable Construction – Perspectives from a North

Construction Management and a South Architect Point of View

TEN YEARS OF SUSTAINABLE CONSTRUCTION – PERSPECTIVES FROM A NORTH

CONSTRUCTION MANAGER AND A SOUTH ARCHITECT POINT OF VIEW

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Keywords: sustainable construction, conferences, differences, North and South perspectives

Summary

This paper is about, from a North and South different perspective, how the international focus of sustainable construction issues has changed over the past ten years. The north part is a review from four different international and regional sustainable building conferences between 1998 and 2007, mostly based of the first author's notes from the conferences, especially from the plenary sessions and discussions. The reviewed conferences are GBC98 in Vancouver, Canada 1998, SB02 in Oslo, Norway 2002, SB05 in Tokyo, Japan 2005 and the regional conference SB07 in Malmö, Sweden 2007. The south part is based on literature reviews, research findings and reference buildings from Mozambique and Tanzania reflecting sustainability.

The perspectives presented in the paper are those of construction project and environmental manager from northern Europe and from architects in southern Africa with an interest in sustainable construction. The findings of the paper shows that focus of sustainable construction matters has changed from almost solely environmental aspects to a more broad and transparent complexity of sustainability, including ecological-, economic- social- esthetical- and cultural aspects. It also

reflects regional and national differences and some shifting views of focus about sustainability in the construction sector during the past ten years.

1. Introduction

Sustainable development is a subject that has been of increasing interest by the global community the last two decades. The construction sector has adapted this by introducing the concept of sustainable construction. However, the adaptation depends of the level of the sustainability view, global, national, regional or individual level. It also depends of the cultural and social context of the actual society. For example many of the modern buildings and settlements in developing countries reflect an uncritical reception of modern European buildings form without taking into consideration the special climatic and social conditions of the home country. The aim is to make some reflexions of these differences from a North and South perspective through engineers and architects eyes respectively.

The first section, the North perspective, is about how the international (read North) focus of sustainable construction issues has changed over the last ten years by a review from four different international and regional sustainable building conferences between 1998 and 2007. This section is mostly based of the first author's notes from the conferences, especially from the plenary sessions and discussions, but some contributions are also considered and selected from breakout sessions and from the proceedings. The reviewed conferences are GBC98 in Vancouver, Canada 1998, SB02 in Oslo, Norway 2002, SB05 in Tokyo, Japan 2005 and the regional conference SB07 in Malmö, Sweden 2007. The reviewing perspective is a engineer by a project and environmental manager.

The architecture in Mozambique and Tanzania, like in many other developing countries, shows little concern for the local environment and climate. The South perspective exams the contribution architects have made towards sustainable architectural practice for the last ten years in Mozambique and Tanzania. Key information is derived from literature review, existing documents, observation, interviews and experience. The section focuses mainly on the analysis of traditional and modern/contemporary architecture in Mozambique and Tanzania with the aim of understanding the attempts that architects have made in the search for sustainable architecture in the tropical countries. This perspective is by architects with southern Africa matter of sustainable construction

2. The North Perspective

2.1 GBC98, Vancouver, Canada

The aim of the Green Building Challenge Conference in Vancouver, Canada, 1998, was to benchmark Green Buildings with different design and assessment tools of current and next generation. Many design and assessment methods were presented by the participated designers and researchers, e.g. among others: GBC98 Tool (international), Athena (Canada), BEES (USA), HK-BEAM (Hong Kong), C2000 (Canada), BREEAM (UK), EcoQuantuum (The Nederlands), Home Scheme (New Zeeland), Ekoprofil (Norway), LEED (USA), Green Building Adviser (USA), CAAD (Germany), Building Stock Model (Germany) etc. The keys of most of these tools were to minimize energy demand during construction and operation, to optimize energy use integrated with renewable energy and to maximize living and working quality for occupants. To ensure the data quality of the inputs was the most frequent issue about to use these tools. Other comments of the tools regarding usefulness was too much information, too much criteria, too many choices and too little time to assess. Two examples of contributions were:

- A test of different assessment tools (Boonstra et al 1998) on the same building showing the output data was too differentiated to be comparable between the methods and an optimization of data not a goal for most tools. Most of the tested tools were developed for specialized consultants and not for actors in the market

- The introducing of the international GBC98 Tool (Cole and Larsson 1998) developed to assess different buildings in different countries with the same tool.

The general conclusions of the assessment methods were about to recognize differences between the tools and the sites of assessments and differences between local and global conditions. But it was important on the other hand to maintain the big picture by the methods

The conference was mainly a presentation of pros and cons of "second generation" tools where the design methods were looking forward and the assessment methods were looking backwards. The main opinion of the future was to develop more LCA-based methods or applications. Absence of methods or tools that covered the construction process was obvious. Most of the methods and the contributions were about Green Buildings and environmental issues, only a very few regarded the whole triple bottom line of sustainability, balancing economy and social development with ecological considerations.

2.2 SB02, Oslo, Norway

The introducing theme of SB02 in Oslo, Norway, was about the -02 World Summit and issues of economic growth, natural resources, environmental impacts, social and cultural development. It was about the challenge of sustainability with prioritized key issues as:

1. Objectives of sustainable development – find reordering of global priorities
2. Sustainability – realize the closed system of earth, the spaceship view
3. Eco-efficiency – Factor 4 is a minimum, Factor 10 is a vision
4. Ratification of the Kyoto Protocol

The knowledge has to shift from a deductive view to a holistic view. The technologic knowledge is dominated over the socio-related. It has to be an integrated design process. The Building Industry is rather proactive than active and the feedback from the performance stage is very low. The solution has to be in small steps with ISO 14001 significant environmental aspects. It is important with affordable living in a market driven environment.

Presentations were made of assessment and design tools that were developed by Europe and North America countries. Some of them were already evaluated and commercial available as national applications as LEED in USA and BREAM in UK. The methods were environmental oriented with most focus on energy savings. It occurred frequently a lot of confusing interpretation of the terms sustainable construction, sustainable building, environmental sustainable building and green building. One effort of explaining the differences between these terms was by CIB´s Agenda 21 of Sustainable Construction. New parts of the world were introduced by the Developing Countries Agenda 21 (du Plessis 2002) with South Africa and Brazil in the frontline. There was also a couple of construction process oriented contributions from Australia, Finland and South Africa. Discussions of indicators of sustainable construction was made e.g. by the CRISP project (Häkkinen et al 2002)

This conference focused mainly on environmental issues as material productivity, CO_2 emissions and assessment tools and methods. But some awareness of the rest of the triple bottom line of sustainability was addressed. Two agendas of sustainability in the constructions sector were presented, one general by CIB and one concerning the developing countries. The latter stated a definition of sustainable construction including the triple bottom line and the necessity of a holistic view. New countries as Brazil and South Africa contributed with thoughts about more socio-economics and management focus. Still, the mainstream research community was focused on solely environmental issues.

2.3 SB05, Tokyo, Japan

The latest world conference about sustainable buildings, SB05, was held in Tokyo, Japan, 2005. The introducing theme was about the importance of reducing CO_2 emissions, to reduce environmental loads, about eco-efficiency through Factor 4 and Factor 10. Some new approaches were made as Life Cycle Value and Management of Environmental Ethics i.e. sharing common vision and ideas. New issues about ethics, the global aspect and city development were discussed. The conclusion was that sustainability in construction in general was initiated and has become to gain acceptance but it is still a very long way to go. Concerning the broad spectra of sustainability in different economies and regions of the world follows a few examples of contributed presentations and papers:

- Procurement procedures were discussed by Brophy and Lewis (2005) as barriers to sustainable development and sustainable construction. They found the building projects within their study were procured, the scope of sustainability was lacking. The design teams in the study indicated that client commitment, design team commitment, motivation and expertise as the features that most contributed to the achievement of the project targets
- Sustainable – affordable habitat for the rural poor in developing economies by Nair et al, 2005, is depending on socio-cultural, economic, technologic and environmental factors including strategies and policies
- Sustainable construction contains environmental, economic and social values (Yin and Cheng 2005) where local dimensions are significant. Sustainable construction is a long term objective. It should be in account of an early stage of a facility development. This with a management approach and with a focus on procurement methods.

This conference contained more practical issues as procurement procedures, valuating of assessment methods and social housing issues regarding all triple bottom line values. More of management approach was assigned. Again, the mainstream contributions were focused on environmental issues as energy savings and material productivity.

2.4 SB07, Malmö, Sweden

Before the next world conference in Melbourne, Australia, SB08, there were some regional conferences during 2007. One was held in Malmö Sweden as SB07 Malmö or Sustainable City Development -07. The key issue was to demonstrate good examples of sustainable buildings and sustainable development of a city. The concept of Passive Houses and the importance of local sustainable development were highlighted plus the UK housing agenda – the Green Paper. Some lessons were learned, as S-house in Austria – a factor 10 example, but sustainability in the real mainstream project is still invisible. An ethical commitment is essential. From a plenary discussion of how to make sustainability more attractive there were some summarized keywords as liveability, make it easy, initiative, motivate, transparent, local context, lifecycle value and participation.
Following conclusions was made:
- Sustainability not enough – it is necessary to regenerate.
- Reduce consumption – changes in values and lifestyle is also necessary
- A holistic triple bottom view.

Some good practice of green buildings in Scandinavia was demonstrated as progress in sustainability, but the arguments of sustainability contained only environmental issues. Mainstream project is still in the very beginning to adapt a sustainability view.

3 The South Perspective

The history shows that even the greatest monuments and largest civil and religious buildings, the ancient builders designed in harmony with nature (Barr-Kumar 2003). Buildings were designed and oriented to take advantages of prevailing winds, to block excessive solar radiation for the case of tropics and in other climates to face the warming rays of the sun. Tanzania and Mozambique, like many other developing countries, has abundant natural resources like water, sun, and natural building materials. However, the development of Dar es Salaam and Maputo, the major urban centers in these two countries, does not utilize these abundant resources. The emerging architectural development of these countries has to consider more appropriate architecture techniques in order to contribute to the sustainable use of the available natural resources. This can be achieved by considering micro climate, culture, and the economy of the country and the specific geographical area within the country which the building will be located (Yimprayoon 2005). However, the level of environmental sustainability awareness in the construction industry in Tanzania and Mozambique is very low and government environmental policies are yet to be implemented. Awareness about the use of climatic principles of architecture (Tombazis 2005) and their utility in achieving sustainable architecture has to be increased.

3.1 The Colonial Heritage: a Paradigm of Environmentally Sustainable Architecture

Before the German colonial period in Tanzania most buildings were of typical Swahili–Islamic style that featured simple regular plans utilizing mangrove poles for construction. Swahili–Islamic architecture was characterized by the use of an interior courtyard and a deep covered front veranda. Materials used were wooden sticks, mangrove poles, coral hardcore, and clay soil. The German regime adapted

traditional construction techniques in an innovative and sophisticated way giving the colonial architecture of Tanzania a unique character and quality.
The “old Boma” built during the German colonial period is an example of architectural environmental sustainability. The Germans used thick coral hardcore, poles and limestone walls of about 600mm to protect interiors from heat gain and also act as noise barrier. The materials and construction technology used were locally available. Windows were mainly placed on the north and south side to allow cross ventilation since air conditioning was not available. The courtyard design was also adopted from traditional Swahili architecture of Dar es Salaam. The use of a courtyard was important to facilitate air flow through a chimney effect. White colour was an essential part of colonial buildings and was used mainly to reflect solar heat. The German colonialists learned and adopted local building techniques to suit their own purposes. From the pre-colonial and colonial architecture there are clearly lessons to be learned in order to achieve sustainable architecture for Tanzania. The optimal cross ventilation of spaces, shading against sunshine by walls and other shading devices are things that can still be employed in today’s architecture (La Roche 2005). Precolonial and early colonial architecture is highly instructive.

3.2 Last Ten Years Development

Since the colonial era Tanzania has invested funds to improve its infrastructure, particularly in the area of transportation, urban planning and public buildings (Lauber, 2005). However, most buildings in Dar es Salaam and Maputo in Mozambique show a minimum concern for the micro–climate, economy, and social cultural conditions of the country. In general, in these last ten years we have seen a gradual disappearance of traditional architectural forms as a result of importing the European, American and Asian technology without taking into consideration the special climatic and social condition of the home country. Some cities of these countries such as; Maputo, Beira, Nampula and Nacala in Mozambique; Dar es Salaam, Mwanza, Arusha in Tanzania, did start to construct some buildings using glass materials. These buildings have many air-conditioners which expend a lot of energy for cooling. The extra energy so used would be better used somewhere else.
Some examples:
- The Kilimanjaro (Kempinski) Hotel, facing Dar es Salaam’s harbor, was renovated in 2005. The hotel has a perfect orientation for sun protection; east–west, with the long façade facing north–south. During renovation operable windows on the south and north façade were replaced by fixed glass panels, which necessitates the use of an air conditioning system all the time. This increases energy expenditure for maintaining a comfortable temperature in the building, and prevents any use of the cool breezes from the ocean and the south–east monsoon winds.
- A few blocks southwest from the Kilimanjaro Hotel is the PPF (Parastatal Pension Fund) tower in downtown Dar es Salaam. It was designed in 1996 and features glass facades that are completely exposed towards to the east and west ensuring the PPF tower heats up all day because it must absorb the maximum daily dose of the intense equatorial sun. This leads to a high level of energy consumption for cooling the building.

During the same period, a number of recently built houses, residential and institutional, present different design solutions corresponding to specific local conditions. This is evidence of climatically appropriate architecture. These buildings are well-oriented with optimal natural cross-ventilation of spaces and protection

against direct sunshine offered by walls; benefits easy to achieve using local material. Some of these buildings can be seen in Maputo and Dar es Salaam, e.g.:
- A new Central Library at Eduardo Mondlane University, Maputo. The building incorporates the most important aspects of sustainability. The design has been conducted in a very participative way and focus was placed on the need to find innovative architectural and engineering solutions. Local conditions were regarded important and such effort was made to take them into account.

- The offices of The World Bank and Swedish Embassy are other examples of sustainable architecture in Maputo.

- The American Embassy in Dar es Salaam where it is good relationship between natural and artificial situation. It is possible to see the application of Sustainable Construction knowledge.

Both countries have other public and private buildings where this knowledge has been applied.

3.3 Influence from the North

Instead of applying and modifying proven design and construction techniques developed in Southern Africa to meet Southern African conditions, the building industry has become fixated on importing the latest technological developments and new construction techniques from the North with little reflection on their suitability for local conditions. This new phase of building design completely ignores traditional and early colonial architecture. In many ways the building industry reflects larger patterns of economic, political, and social interaction between Southern Africa and the North, where Northern ideas and practices serve as the benchmark to be adopted. In the building industry this has meant the disappearance of efforts to achieve sustainable architecture and its replacement with buildings that use high rates of energy in their daily operation and imported materials for their construction.

3.4 Awareness of Sustainable Architecture

The construction industry by large should be responsible for converting the natural environment into a built environment without destroying its natural state. However, in Tanzania and Mozambique, awareness of environmentally sustainable architecture is very low. In order to make an impact, the basic principles of sustainable architecture will have to be known to all members of the building team - including the client, architect, consultants, contractors, building product manufacturers, and building users. There is a need to change the way in Southern Africa to build and use the buildings from an architecture based on low quality replication of Northern designs to more innovative use of traditional low technology. It is a matter of low energy use designs to achieve greater long term sustainability of the region’s natural resources, the economic viability of the client’s building and to ensure greater comfort to the buildings users.

3.5 Lack of Architectural Research and Communication

Research in the field of architecture provides an opportunity to link new knowledge with design. It is therefore a fundamental aspect of the architectural profession (Emmitt 1996). It provides scientific knowledge, useful for resolving architectural problems. However, the research element in Tanzanian and Mozambican architecture is not given the importance it deserves in order to promote a positive development of the profession towards sustainable development.

4 Conclusions

Many developing countries in the Southern hemisphere do not apply the knowledge of Sustainable Construction due to many reasons. As a result of this situation, many of the modern buildings and settlements in these countries, in the last ten years, reflect an uncritical reception of modern European buildings forms without taking into consideration the special climatic and social conditions of the home country. The examples from the pre-colonial and early colonial era when mechanical air conditioning did not exist and the use of local materials showing the structures that made use of materials, cross ventilation, colours, and orientation toward/away from the sun that kept occupants comfortable with minimal energy inputs, even under the intense equatorial sun. In comparing this earlier period to modern day architecture in Southern Africa we can see that the principals that underpinned the early sustainable architecture have been forgotten. However, this knowledge has gradually started to be applied and it is making it possible to see some buildings on the basis of this knowledge. The principal of making buildings to fit their environment, climate and culture, rather than aping the architectural styles of developed countries is the key for making sustainable architecture to be achieved in Tanzania and Mozambique.

The economic development that occurs in the North and the South perspective, especially in non-developed countries, in the last decade, is made up of great utilization of the production of energy from the fossil resources. The finite nature of this natural resource, and the environmental impact of its production and consumption, makes these countries to rethink their development plans. New strategies must be found to maintain the current standards of life in developed societies and to help aspiring new developed countries to reach higher standard of life. This has to be developed without compromising the new technology, not only for the benefit of the environment, but also in level of economic and social development.

With a look backwards from the Rio summit in the beginning of the nineties, there has been a long time for the construction sector in the industrial countries to adapt the whole concept of sustainability including the triple bottom line. The research community of sustainable building has moved its focus slowly from solely environmental issues and assessment methods through questions as energy savings and material productivity to a holistic view of sustainable buildings including the triple bottoms. What about the mainstream project and its involved stakeholders as clients, project management team and end users?
Where are the process thinking and management aspects of sustainability? The objective is to reach a resource productive factor of Factor 10 or Factor 20 in one generation but the first generation is soon at halftime and we have barely just started. It is time to prioritize the objectives to make it easy to get information how to do and make rules or opportunities to promote the mainstream construction project towards sustainability. It is obvious that a general global agenda of sustainable construction has to be complemented with specific conditions of the actual site, of the specific project or facility, of the ability or knowledge of the design and management team and of course regional and local conditions of the triple bottom

lines of sustainability. It is a matter of fact a question of knowledge transfers from bottom-up and top-down perspectives locally adapted, despite if the site is located in a Northern Artic mountain area or in a Southern tropical urban area.

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Paper II

ENERGY ASSESSMENT METHODOLOGIES AND ENERGY USE IN BUILDINGS – A REVIEW OF SELECTED THEORETICAL AND EXPERIMENTAL TECHNIQUES

Energy Assessment Methodologies and Energy Use in Buildings – A Review of Selected Theoretical and Experimental Techniques

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ABSTRACT

A great deal of energy is used in a highly inefficient manner in buildings in Mozambique. The existing instruments for measuring, evaluating and calculating the quantity of energy used in buildings have not been implemented which lead, in many cases, to failure in achieving best comfort levels for households. Indeed, energy evaluation of houses can provide information about energy used in buildings and accredited professionals and energy buyers can have exact information on what they have to pay. This information is important for the buyers once it helps them to control and to reduce the energy used in buildings. This paper reviews energy efficiency, theoretical, experimental and measurement techniques of energy use in buildings in order to find acceptable tools for energy audit in Mozambique. It is worth stressing that use of protocols, experiments and simulation techniques to evaluate energy use in buildings are rarely applied in Mozambique. There is a wide variety of tools and models for energy assessment in buildings and this study selected and analyzed some of the most suitable such as the University Project, Energy Barometer, and DEROB-LTH Program. The University Project is the retrofitting method developed in order to assess the characteristics of the existing buildings and to estimate energy savings on the data collection basis of the building energy bills. Energy Barometer method provides estimates of actual and predicts energy use in buildings for house owners with a means of monitoring their energy cost budgets. Finally, DEROB-LTH Program is a tool for estimation of indoor thermal climate, energy for heating and cooling, comforts indices PMV and PPD in buildings. It has been concluded that, for the type of buildings under investigation in Mozambique, The University Projects is suitable in studying building retrofitting and the Energy Barometer is useful to get solutions to the problem of energy use in buildings. Finally, the DEROB-LTH program is a suitable tool for modeling, simulating and assessment of energy use in buildings.

Key Words: Buildings, efficiency, energy, simulations, tools

Paper III

Design of Weather Station and Measurement Equipment for Assessment of Buildings Energy Use in Mozambique

Design of Weather Station and Measurement Equipment for Assessment of Buildings Energy Use in Mozambique

ABSTRACT

The use of modeling and simulation tools for assessment of buildings energy in Mozambique is under investigation. Thus, measurement equipment was installed in “3 de Fevereiro Building” in Maputo City, Mozambique. The measurement equipment comprises of Data Logger System, Weather Station, temperature and humidity sensors. This aims at measuring climatic factors around the building and indoor parameters which influence the internal environment of the buildings. This paper describes the plan design and the layout of the measurement equipment. It also presents and discusses the results of the climate parameters and the building factors for the winter season such as global and diffuse solar radiation, outdoor temperature and humidity, indoor temperature and humidity, wind speed, wind direction and rainfall. The measured results relate to a period of four months from June to September, 2009. With this field measured results it was possible to analyze a greater part of the winter climate factors. Maputo City has a subtropical climate with two seasons, a wet season from October to March (summer) and a dry season from April to September (winter). The measured results show that the equipment provides fair data which can be used for evaluating energy of the building and for testing and validating the simulation tools of building energy.

Keywords: Design experiment, Energy efficiency, Outdoor and indoor thermal environment, Field measurements, Subtropical climate.

1 INTRODUCTION

Maputo City, the capital of Mozambique, is situated at 25º57´S and 32º35´E with a subtropical climate which means that it is submitted to vast solar energy with potential to increase the thermal heat inside the buildings especially in summer. On the other hand, the solar energy can be used to reduce the electrical energy used in buildings if active systems using solar energy are implemented in the buildings.

The main aim for installing the measurement equipment in “3 de Fevereiro Building” is to collect data and create database from field measurements for testing and validation modeling and simulation tools of energy use in buildings for Mozambican climatic conditions. DEROB-LTH Program, an acronym for Dynamic Energy Response of Buildings, was selected by the author in the work related to Energy assessment Methodologies and Energy use in Buildings. This Program was tested in other tropical and subtropical countries. Espriella (1993), verified the conditions of comfort in offices in Bocota, Colombia, Fernandes (2004), analyzed the indoor temperatures in Porto Alegre, Brazil with good results and Zhiwu (1992) showed that simulations with DEROB-LTH program indicate that the results agree well with full-scale tests of the Nanning dwellings, China. The results of the field measurement from June to September, 2009 are presented in this paper.

1.1 Characterization of the building and the measurement system

The measurement equipment was installed in “3 de Fevereiro Building” as presented in Figure 1 and Figure 2.

The building was built in the 1990s. The materials used were plastered hollow concrete block walls, concrete columns, wood framed windows with single glass, wood frame external and internal doors, concrete cement ceiling, and gypsum ceiling roof and has a floor area of 378 m^2 spread over the floors, 3 apartments on each floor. The long axis of the building is NE-SW and the main facade is south oriented. This orientation is typical in Maputo Municipality.

1.1.1 Measurement Equipment

Figure 1 and Figure 2 show the measurement equipment installed on the first floor. The ground floor has the same layout of the measurement equipment as in Figure 2 but without the solar meter sensor. The equipment allows measuring the outdoor climatic data such as the global and diffuse solar radiation, wind, rainfall, temperature and humidity and indoor parameters such as temperature and humidity.

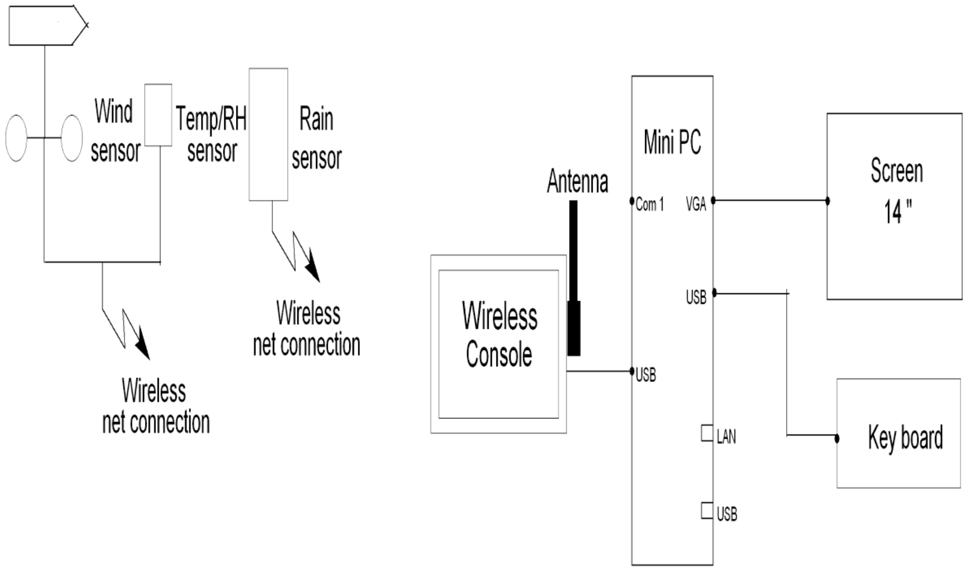

Figure 1: Weather Station system installed on the first floor.

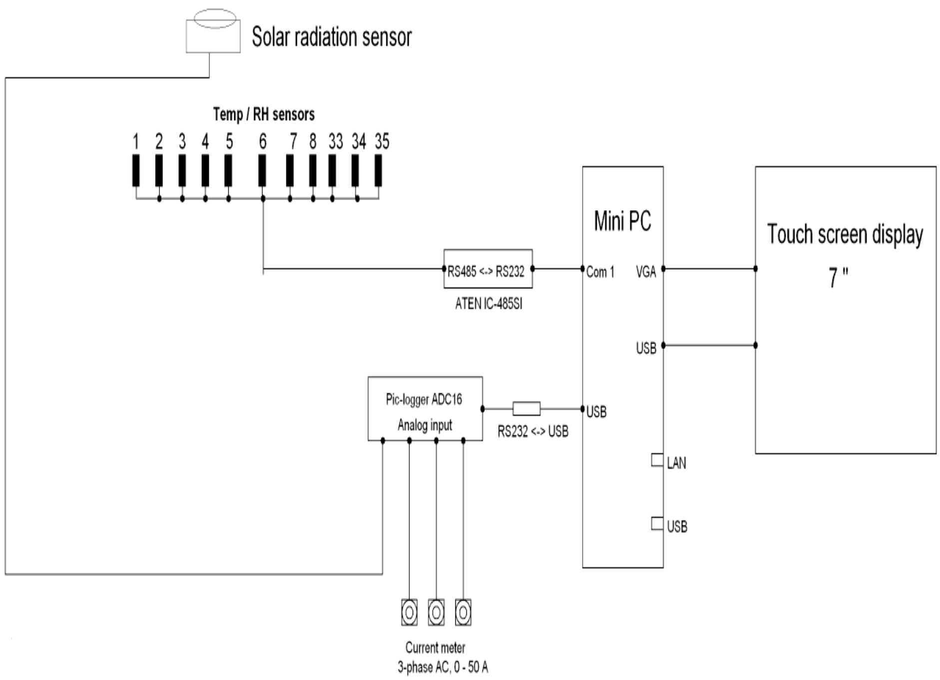

Figure 2: Measurement equipment installed on the first floor.

The East and West sides of the building are the best for analyzing the thermal loads because there are directly radiated by the sun during the morning and noon periods of the days respectively. But, the owner of the building (Faculty of Engineering) allowed installing the equipment in the East side. The equipment was installed at the beginning of May, 2009.

Table 1: Measured factors and measurement equipment

Item	Measured factors	Quant. Ground floor	First floor	Sensor	Range	Accuracy
01	Global and diffuse solar radiation in horizontal surface	-	1	BF3	0 – 1250 W/m^2	Global: ±5W/m^{-2} ±12% Diffuse: ±20W/m^{-2} ±15%
02	Wind speed	-	1	WMR200	2m/s ~ 10m/s 10m/s~56 m/s	(+/- 3m/s), (+/- 10%)
03	Wind direction	-	1	WMR200	0-360º	16 positions, approx. every 14 seconds
04	Outdoor temperature	-	1	WMR200	-30ºC to 60ºC (-4ºC to140ºC	+/- 1% (+/- 2%)
	Outdoor Humidity	-	1	WMR200	25% to 90%	+/- 7%
05	Rainfall	-	1	WMR200	0 to 999mm	+/- 7%
06	Temperature in shaded volumes	-	1	SHT75	-30ºC to 60ºC (-4ºC to140ºC	+/- 1% (+/- 2%)
	Humidity in shaded volumes	-	1	SHT75	25% to 90%	+/- 7%
07	Inside temperature	9	11	SHT75	-30ºC to 60ºC (-4ºC to 140ºC	+/- 1% (+/- 2%)
08	Inside humidity		11	SHT75	25% to 90%	+/- 7%
09	Electrical current	1	1	Onset CTV-B	0 to 50 A	+/- 4.5%

1.2 Measurement results and discussion

The field measurement results present data (outdoor climatic elements and indoor parameters) which are important for analysis of indoor thermal loads, heating and cooling and ventilation systems for providing indoor comfort. July, 2009 measurements are used as the reference month as it is the coldest one.

1.2.1 Solar Radiation

Figure 3 shows the variation of the global and diffuse solar radiation in July, 2009 and Figure 4 shows the monthly maximum, mean and minimum global and diffuse solar radiation from June to September, 2009.
Mozambique has two main seasons, namely hot, normally wet season from October to March and a cooler, mostly dry season from April to September. So, from April to September it is winter with June and July presenting the low rates of the solar radiation and July the lowest month as indicated in Figure 4.

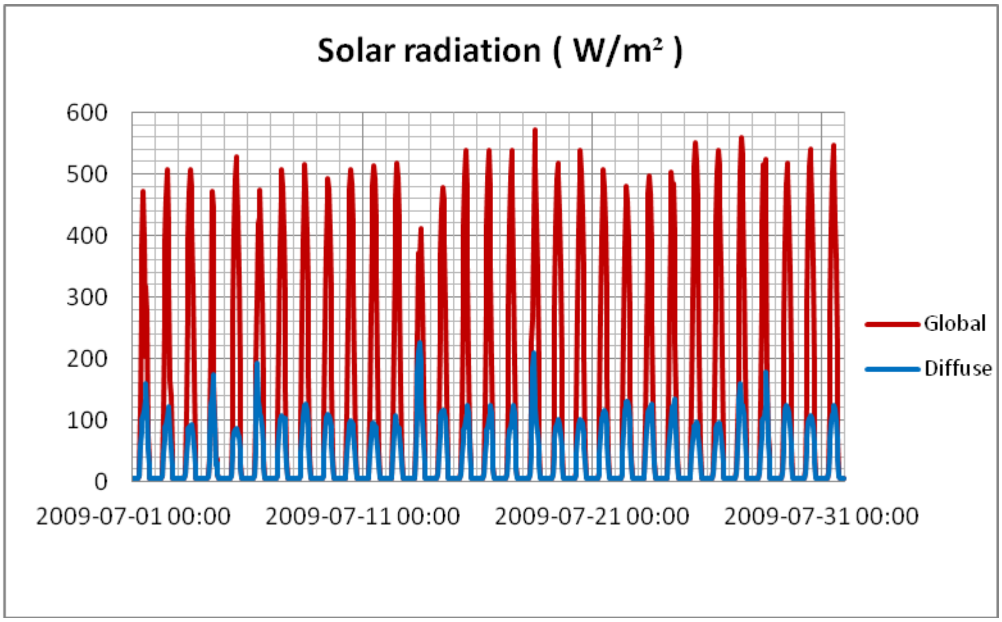

Figure 3: Global and diffuse sol. Rad., July, 2009

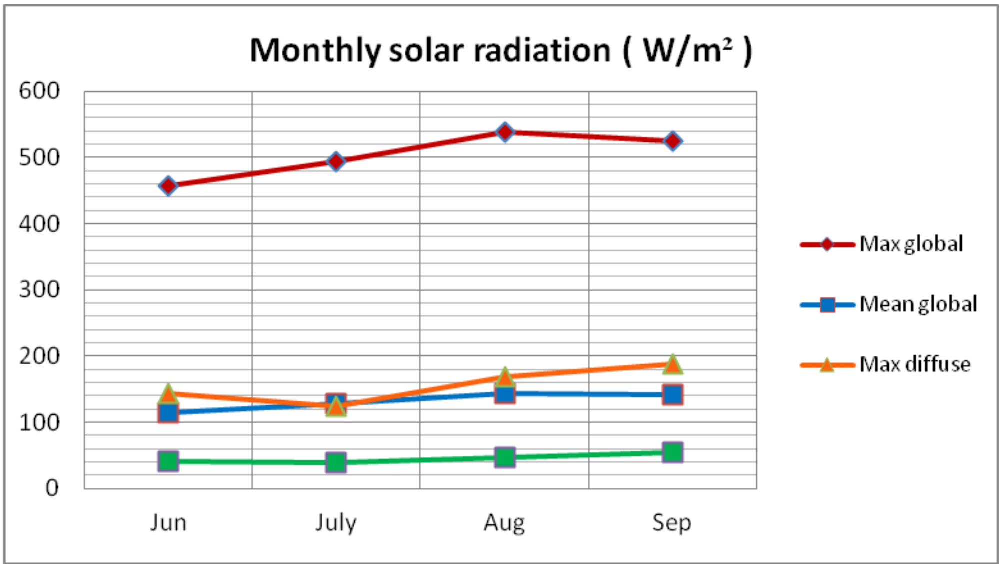

Figure 4: Monthly maximum and mean global and diffuse solar radiation, June to September, 2009.

The maximum and mean solar radiation energy from June to September are presented in Table 2. The rates show that Maputo City has enough solar energy to cover the needs for hot water and heating or cooling in buildings.

Table 2: Solar radiation energy.

	Solar radiation energy (KWh/m^2/Period)		Daily solar radiation energy (KWh/m^2/day)	
	Global	Diffuse	Global	Diffuse
Max.	1,475	457	12	4
Mean	*386*	*132*	*3*	*1*

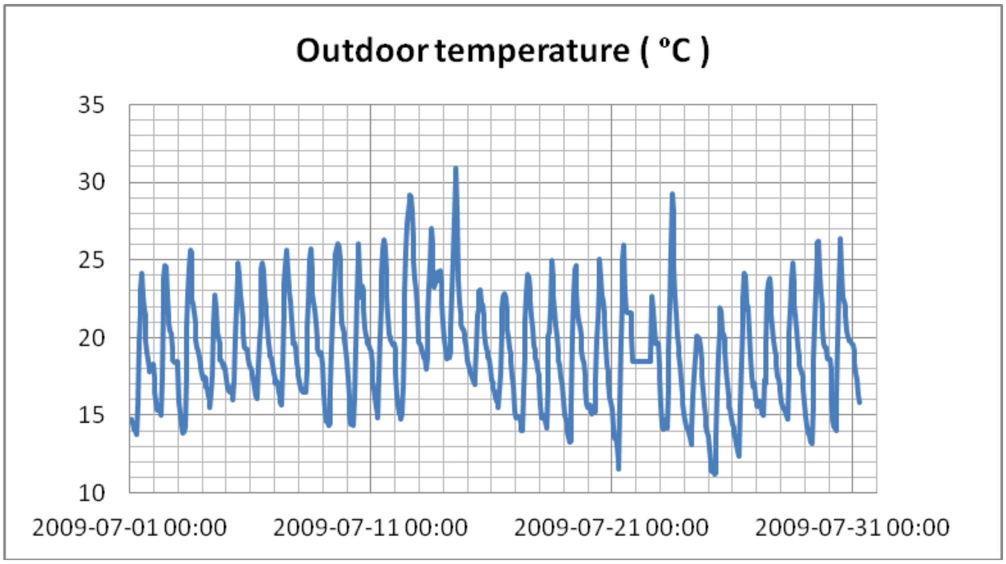

Figure 5: Outdoor temperatures of July, 2009

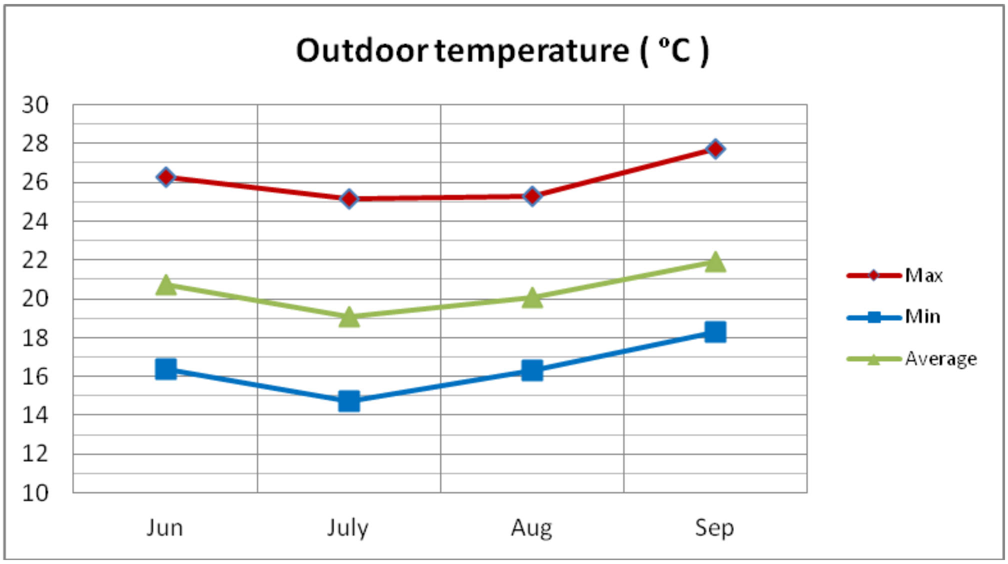

Figure 6: Max., Mean and min. outdoor temperature, July , 2009

1.2.2 Outdoor Temperature and Solar Radiation of the Coldest Day

Figure 5 present the measured outdoor temperature in July, the coldest month in winter, 2009, with low outdoor temperature and 25th July 2009 was the day with a minimum of 11.2ºC at 6:00 a.m., the lowest temperature from June to September, 2009, see Table 3.

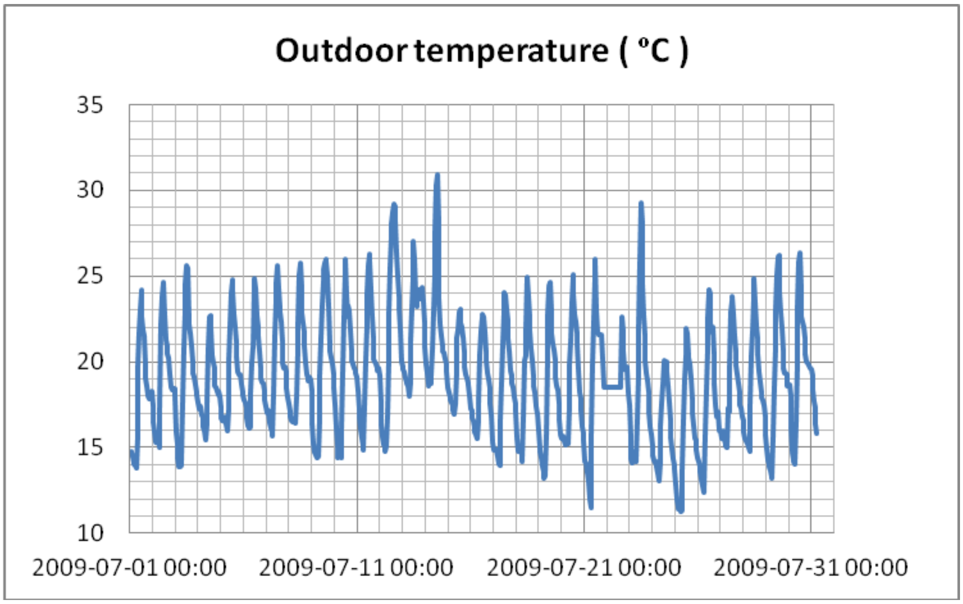

Figure 7: Outdoor temperatures in July, 2009

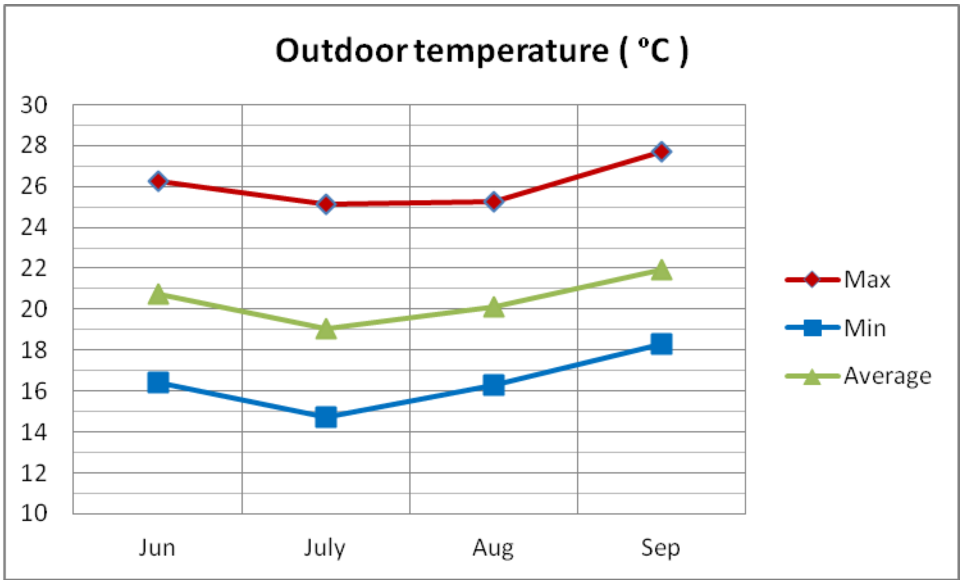

Figure 8: Max., Mean and min. outdoor temperature

Table 3: Maximum and minimum temperatures (monthly peak outdoor temperature)

Month	Day	Time (h)	Out. Temp. (^0C)		Month	Day	Time (h)	Out. Temp. (^0C)	
June	23-06-09	13:00	Max.	30.3	Aug.	09-08-09	14:00	Max.	30.4
	27-06-09	07:00	Min.	11.3		09-08-09	06:00	Min.	12.9
July	14-06-09	12:00	Max.	30.3	Sep.	08-09-09	14:00	Max.	35.8
	25-07-09	06:00	Min.	11.2		13-09-09	04:00	Min.	16.1

Figure 9 shows the graph of the outdoor temperature on 25th July 2009, the coldest day in winter and Figure 10 shows the global and diffuse solar radiation on the same day. The maximum value of the global solar radiation was 527.8 W/m^2 occurred at 12:00 and the diffuse was 87.2 W/m^2 at 13:00.

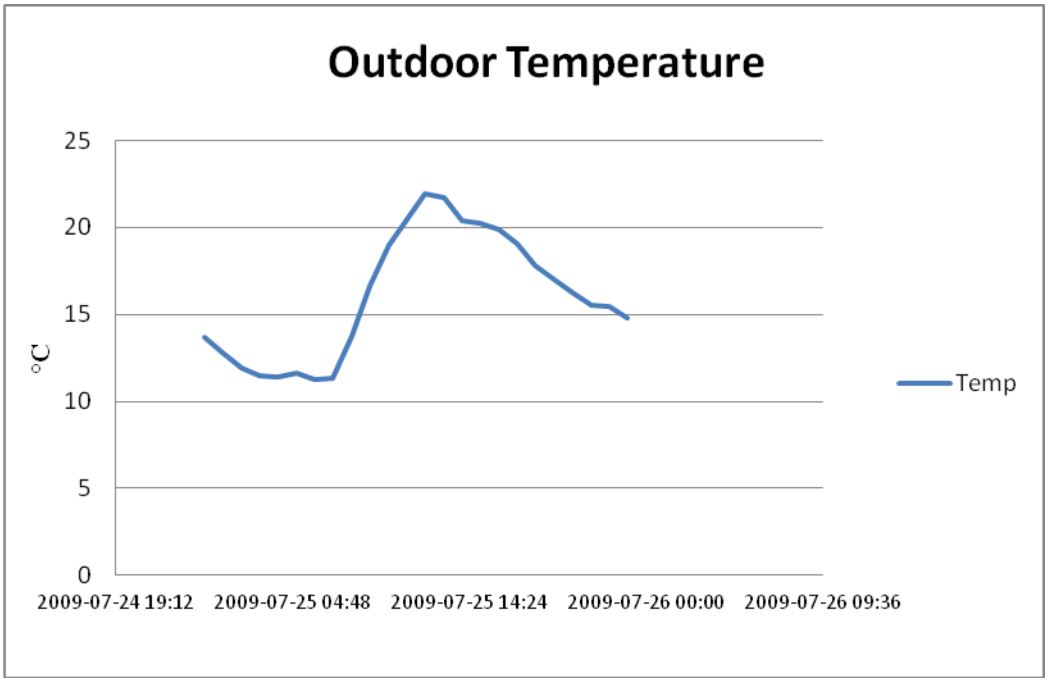

Figure 9: Outdoor temperature of the coldest day in winter, 2009.

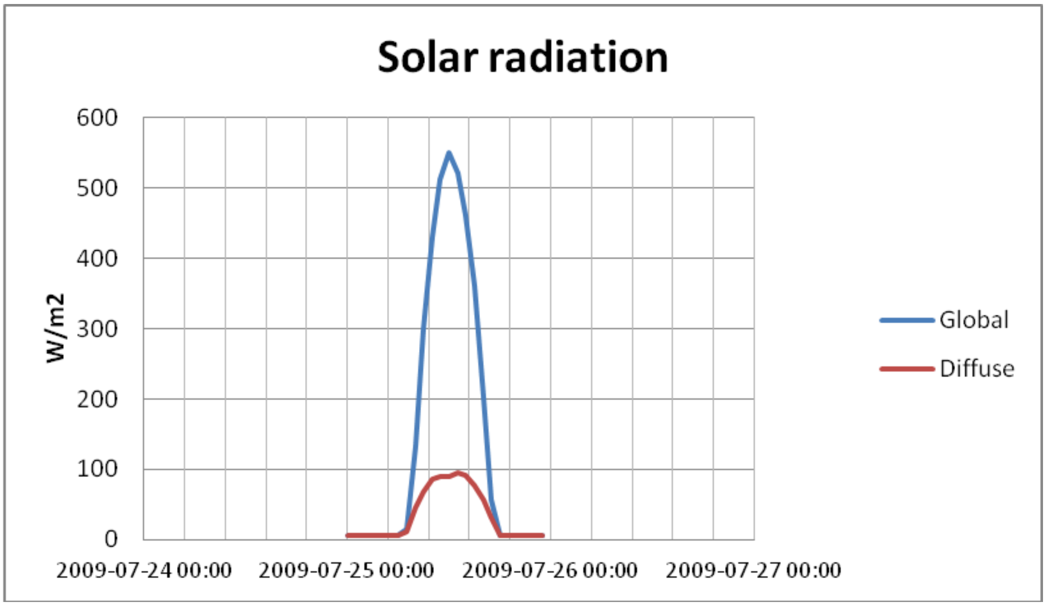

Figure 10: Global and diffuse solar radiation coldest day in winter, 2009.

1.2.3 Temperature Inside of the Building

Figure 11 shows the indoor temperature of the ground floor and Figure 12 shows the indoor temperature of the first floor. The kitchens of the apartments are located in the north side, the hottest position in terms of solar gains. The temperatures in these rooms are higher than the rooms placed in the south side of the building. In both flats, the temperatures of the living room and bed room are very similar due to the fact that two volumes having the same location (south side), the same characteristics, the same solar radiation and the same casual gains.

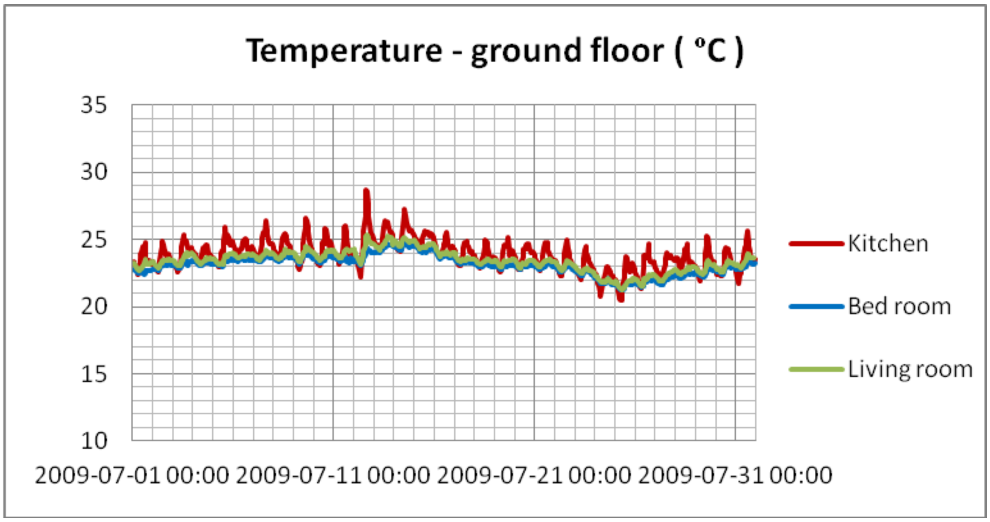

Figure11: Indoor temperatures on the ground floor, July, 2009.

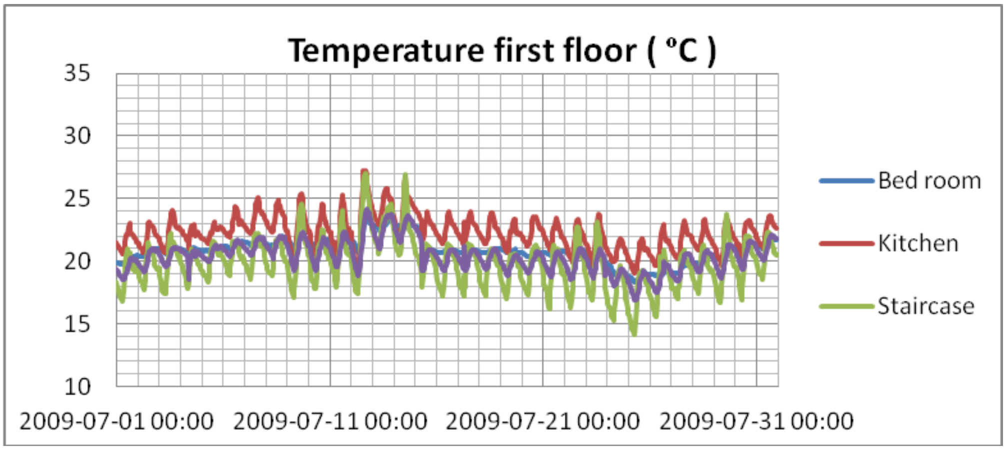

Figure 12: Indoor temperatures on the first floor July, 2009.

Table 4 Maximum, mean and minimum indoor temperatures in the apartments.

	Indoor temperatures (ºC) Ground Floor				Indoor temperatures (ºC) First Floor			
	June	July	Aug	Sep	June	July	Aug	Sep
Max	24.8	23.8	24.0	25.3	23.2	20.4	22.3	24.4
Mean	24.5	23.4	23.7	24.9	22.3	20.4	21.4	22.9
Min	24.2	23.0	23.3	24.4	20.4	19.2	20.4	20.4

From June to September the maximum indoor temperature on the ground floor was 25.3ºC in September and the minimum on the first floor was 19.2ºC in July.

1.2.4 Meteorological Instrument

WM200/WM200A anemometer was used to measure the wind speed and its direction around the building. This instrument was installed outside of the building in the south side. Analyzing the Figure 13 related to the wind, it can be concluded that the wind is southerly.

Table 5: Maximum, mean and min. wind speed, for the months from June to September.

Wind speed (m/s)				
	June	July	Aug	Sep
Max	6.4	7.1	7.5	9.7
Mea	3.5	3.9	4.2	5.8
Min	1.0	1.2	1.6	1.5

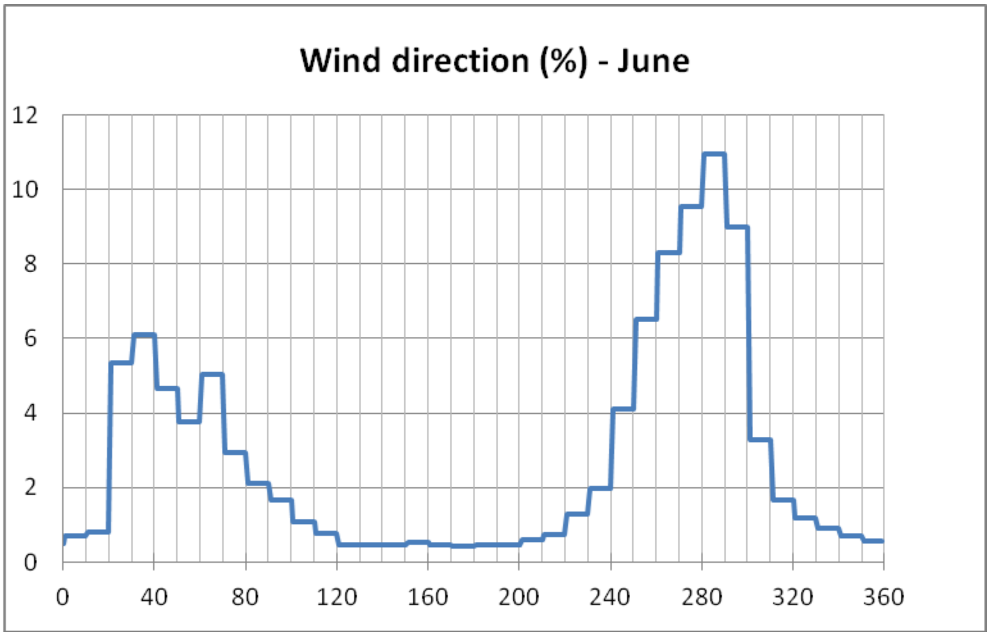

Figure 13: Wind direction in June, 2009

1.2.5 Rainfall

The objective of measuring the rainfall is to provide a database of the rainfall on the site of the building. This information is useful for preventing the harmful phenomena caused by the moisture in the structure of the buildings. If the quantity of rain is known; it is possible to take certain precautions for eliminating the harmful effects of the moisture caused by the rain. The rates of the rainfall from June to September are presented in Table 6.

1.2.6 Outdoor Relative Humidity

Figure 14 illustrates the outdoor relative humidity during July and Figure 15 represents maximum, mean and minimum outdoor humidity from June to September, 2009.

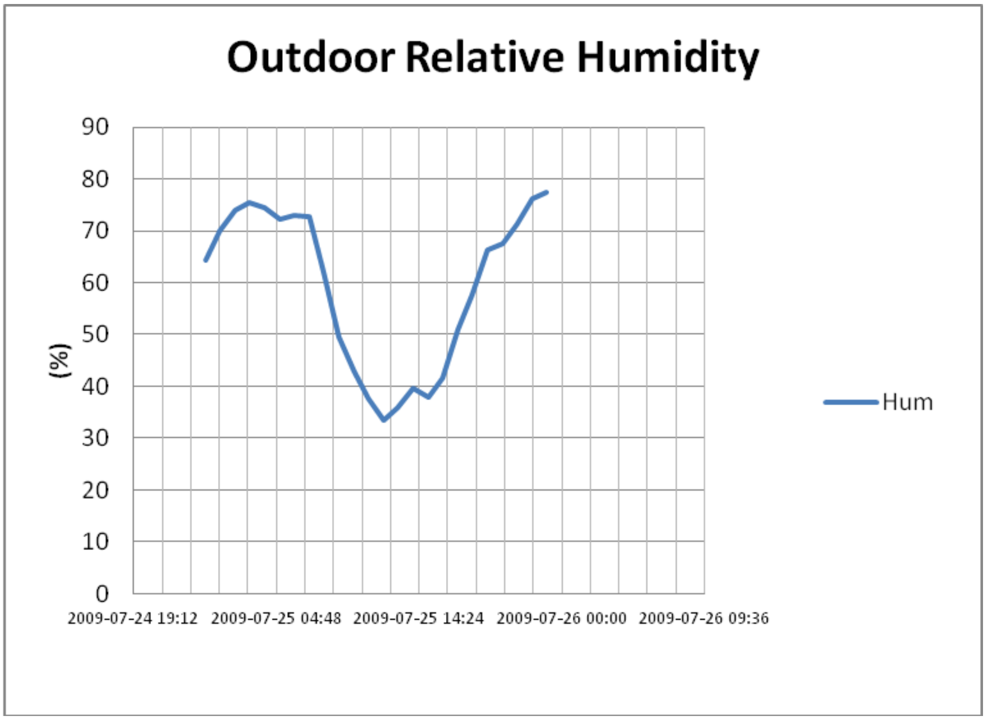

Figure 14: Relative humidity of the coldest day in winter.

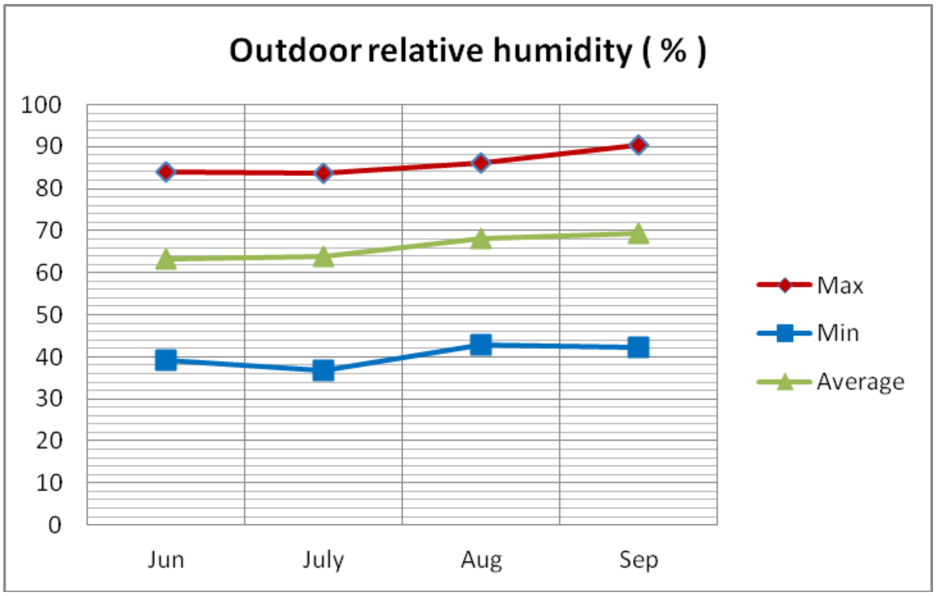

Figure 15: Maximum, mean and minimum outdoor relative humidity.

1.2.7 Comparison of the site measurements and Maputo Airport Meteorological Station Data.

The Table 6 presents the data from field measurement and the outdoor data from Maputo Airport Meteorological Station for comparison.

Table 6: Data of the outdoor temperature, rainfall and relative humidity

		Outdoor temperature (%)			Rainfall (mm)	Relative Humidity (%)		
		Max.	Mean	Min.	-	Max.	Mean	Min.
June	Meas.	26.3	20.7	16.4	9.5	83.9	63.4	39.2
	MAMS	25	18.5	14.2	26	-	66	-
July	Meas.	25.1	19.1	14.7	2	83.8	64.0	36.8
	MAMS	25	18.2	13.9	12	-	66	-
Aug.	Meas.	25.3	20.1	16.3	-	86.2	68.1	42.8
	MAMS	25.7	19.1	15.0	12	-	65	-
Sep.	Meas.	27.7	21.9	18.3	-	90.3	69.5	42.4
	MAMS	28.4	20.6	16.0	35	-	65	-

Meas. = Measured and MAMS = Maputo Airport Meteorological Station.

1.3 CONCLUSIONS

The measurement equipment installed in the apartments can be considered effective and reliable as it can provide data on building parameters and the climatic weather elements which can be used for assessment of energy use in buildings as well as for testing, validation and calibration, modeling and simulation tools of building energy use.

Analyzing data from the measurement equipment can be concluded that, it provides fair results since the comparison of these data with the one from other weather stations, such as Maputo Airport Meteorological Station presents similar trends.

Further work will consist of measuring several variables for testing the functionality of the DEROB-LTH.

1.4 ACKNOWLEDGEMENTS

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Report I

Energy Assessment Methodologies and Energy Use in Buildings – A Review of Selected Theoretical and Experimental Techniques

Energy Assessment Methodologies and Energy Use in Buildings – A Review of Selected Theoritical and experimental Techniques

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Keywords: Energy efficiency, theoretical and experimental techniques, energy characterization, measurement techniques, simulation, energy conservation, retrofitting, tropic and sub-tropic zones, Mozambique.

Summary

This paper is a review of energy efficiency, theoretical, experimental and measurement techniques of energy use in buildings, since the use of instruments, protocols and experiments to evaluate the energy used in buildings using simulations tools is not common in Mozambique. So, this paper presents important methods and techniques for energy characterization in buildings.

After analyzing such methods, it was concluded that for the type of buildings under investigation in Mozambique, it is convenient to select University Projects, Energy Barometer and DEROB-LTH Program to simulate and assess the energy used in buildings. The University Project method is suitable to study the retrofit of buildings. Energy Barometer is a method which allows us to deal with many parameters of energy use in buildings by supplying climatic data, building and energy elements in the computer system. With this method, it is also possible to get solutions to the combined problem of energy use in buildings. And finally, DEROB-LTH Program is a more appropriate method for estimation of energy, indoors thermal climate and visual comfort in buildings.

1 Introduction

The energy resources management is one of the principal challenges that both developed and undeveloped countries confront nowadays. The economical development that occurred last decades in the world is made up of a great utilization of energy production from the fossil resources. The finite nature of

this natural resource, and the environmental impact of its production and consumption, makes all countries to develop plans towards energy use in buildings. Allied with this problem is the global interdependence on energy resources for development, poverty eradication and environmental concerns.
Energy efficiency is a critical issue for high quality use of energy in buildings, energy does not represent only a high percentage of the running cost of buildings but it also has a major effect on the visual and thermal comfort to the occupants of the household (M. Santamouris, 2005). Normally the energy used for heating and cooling is a great part of the energy used in a country.

Studies in development of energy technology make it possible to significantly decrease energy consumption in buildings, to create housing that is more comfortable and to implement a major decrease in carbon emissions to the environment (Randall Mcmullan, 2002).

Performing energy rating through standard measurements and carrying out specific experimental protocols by specialized and accredited professionals can provide information on energy use in the buildings. It is possible for potential buyers and energy users to have good information of the energy bills they have to pay. Thus, the owners of the buildings may have to identify specific costs of effective improvement of energy efficiency (M. Santamouris, 2001).

Energy rating started just after energy crisis in 1974. With regard to energy, the interest of industrialized countries lay in energy efficiency in the building sector, especially in residential buildings and finally, initiated actions and programs aiming to rationalize energy use in the dwellings. The main aim of this interest was to stimulate efficient energy use and to reduce energy for house heating.

Energy demand has been increasing in Mozambique; therefore measures are now being taken to cope with the problem through planning new power generation, transportation infrastructures and efficient energy use in buildings (INE, 2005).

In order to calculate energy efficiency and to analyze the energy used in buildings, different calculation methods were developed in various countries, for instance: The Save HELP Method in Belgian Research Institute, Brussels, Short-Term Energy Monitoring, Primary and Secondary Term Analysis and Renormalization (STEM & PSTAR), in Golden, CO, USA, Neural Networks, in Stockholm, Sweden, University Projects and Energy Barometer methods, in Stockholm, Sweden, The BKL METHOD and DEROB-LTH Program in Lund University, Sweden, etc.

2 Aims

The principal aim of this paper is to analyze and select suitable methods that are applicable to analyze and assess energy use in Mozambique. This includes methods to monitor buildings and analyze the results as well as the methods to predict results of building retrofitting. Predicting energy use is also important for a buyer or a user of the building because it enables them to have specific information on the cost effectiveness and energy efficiency of the buildings.

3 Background

Many countries in the world have carried out a research on building technology activities and building energy programs where architects and engineers work for the development of methods and software tools to improve the energy efficiency in buildings. The principal goal in involving architects and engineers is to optimize building performance, comfort, and savings of energy efficiency in buildings. Nowadays there are many methods available such as instruments and programs which are grouped into the following broad categories: appliances, building envelope, indoor air quality, lighting, water heating and whole building design for improvement of energy efficiency in buildings.

3. 1 Some Available Methods

The energy assessment in houses has attained a high level in many European and American countries and low level in non-cooling countries. It is expected that the new view in energy efficiency in the buildings will enforce the studies on national methodologies of energy efficiency in the Southern European countries and in non-cooling countries, particularly in both subtropical and tropical countries such as Mozambique.

The Swedish government has introduced a financial support and subsidies for saving energy use in the buildings. The main goals are among the others: to stimulate the efficient energy use, to reduce the heating energy, and most importantly, it is to decrease the gross heating use of energy within the residential buildings (Westergren K-E, 2000).

To evaluate the energy used in buildings, the Energy Barometer (EB) method was developed in Stockholm, Sweden. It consists of monitoring the development of the building energy use by measuring the energy and climatic conditions in houses. The information provided with the measurements consisted of two parts: first aimed for providing wider public information on the actual and the predicted energy use in the dwellings together with analyses of trends and effects of energy-related measures on a large scale, the second part aimed mainly at providing individual house owners with means of monitoring their energy bills (Westergren K-E, (2000).

In USA and UK, energy assessments have been used in buildings since the 80s. The Home Energy Rating System (HERS) program was implemented in five pilot states, Alaska, Arkansas, California, Vermont and Virginia. Today many states in USA have adopted the (HERS) version or its equivalent. However, only 2% of new houses receive energy rating in USA recently, and most are useful programs with tax payer subsidies (M. Santamouris, 2005).

In UK the Building Research Establishment (BRE) performed hundreds of multi-year energy audits in residential buildings. From these audits, BRE was able to develop the Domestic Energy Model (BREDEM), (M. Santamouris, 2005).

In Denmark, studies about energy efficiency have been developed in commercial buildings since 1992 and they were extended to residential buildings in 1993 (M. Santamouris, 2005).

The National Irish Centre for Energy Rating (NICER), created the Energy Rating Bench Mark (ERBM) in 1992 to deal with energy use in existing buildings (M. Santamouris, 2001).

In Sweden, the simplified BKL METHOD to predict energy use in buildings was developed by Kurt Källblad and Bo Adamson during the 70s. Further studies of this method and comparisons with other methods were presented at the CIB-symposium in Copenhagen (Källblad-Adamsson, 1979).

The DEROB program from University of Texas, USA, developed by Arumi-Noa (1979) has been used on several sites and presented in many versions in various countries. One of them, DEROB-LTH, was adopted by Department of Building Science at Lund University (Manual of DEROB-LTH, version 2.0, ebd.lth.se).

Energy assessment system has been developed to classify new residential buildings, in Spain. Finally, in Netherlands, a rating of energy efficiency was developed in the 90s (M. Santamouris, 2005).

3.2 Problems and Requirements in Mozambique

Energy demand has been increasing in Mozambique; therefore, measures are now being taken to cope with the problem through planning a new power generation, infrastructures, transportation and studies in efficient energy use in buildings (INE, 2005). However, these activities are not by themselves going to ensure that enough energy is conserved if efficient strategies are not put in place and properly implemented. Thus, the government has defined energy efficiency in its strategy for science and technology as one of the key areas to be addressed. The strategy includes energy efficiency and conservation research in buildings and the production of construction materials with reduced energy requirements.

Recent development in energy efficiency studies and its technology in the world, made it possible to decrease significantly energy use in buildings, to create housing that is more comfortable and to decrease the carbon emissions to the environment, Godfrey Boyle (2000).

Energy evaluation of a house can provide particular information about energy use. The standard measurements and experiments carried out by accredited professionals and energy buyers can provide exact information on what they have to pay. This information is very important because it helps them to control and to reduce energy use.

A huge quantity of energy is used in a highly inefficient manner in buildings and the country has not habit to adopt instruments to measure energy use, evaluate and calculate the quantity of energy used in buildings, and consequently, it does not provide best comfort for people in the houses.

The obstacles on the use of home rating systems are mentioned below

- Lack of the users ´awareness of energy efficiency benefits;
- Insufficient awareness and training of the managers, builders and engineers;
- Lack of sufficient funding to assist the penetration of home rating systems on the market;
- The relatively high cost of home energy systems;

- Lack of data of energy use in dwellings;
- Lack of specialized professionals to perform energy audits and ratings in residential buildings;
- Lack of builders' incentives from the government;
- Lack of financial interest and gains of the house owners, the builders and the real-estate managers.

Years ago, other types of energy assessment methods in buildings such as environmental issues, ecological parameters, shortage of raw materials, water consumption, indoor air quality, noise and pollution, health aspects and waste treatment have been considered. It is believed that environmental rating systems, involving energy issues and life-cycle analysis, will have a very fast development in the near future (Randall Mcmullan, 2002).

Over the last years, other types of energy assessment methods in buildings such as environmental issues have been considered. Ecological parameters, such as: shortage of raw materials, water consumption, indoor air quality, noise and pollution, health aspects and waste treatment are the main considerations. It is believed that environmental rating systems involving energy issues and life-cycle analysis will have a very fast development in the near future (Randall Mcmullan, 2002).

4 Examined Methods of Energy Assessment Methodologies in Buildings

There are a lot of theories, methodologies, techniques and instruments in the world that deal with estimations and predictions of the energy used in buildings. Some are based on calculation methods and others on usage of software tools. In this work were only selected those which could be used to assess the energy used in buildings. The selection was focused towards the methods and software tools which could be usable to assess energy efficiency in residential buildings of the sub-tropical and tropical countries.

The methods considered are: The Save HELP Method, Short-Term Energy Monitoring, Primary and Secondary Term Analysis and Renormalization STEM & PSTAR), Neural Networks, University Projects, Energy Barometer methods, the BKL Method and DEROB-LTH Program.

4.1 The Save HELP Method

This method was developed in Belgian Research Institute, Brussels in 1996, in the framework of the EU-financed Save HELP project with the objective to characterize energy performance in non-occupied buildings.

The experimental activities basically were done on measurements of the examined non-occupied houses in order to collect data set for identification of a single-zone thermal model. Appendix A, Figure A.1, presents the example of simplified single zone-model of the dwelling which can be used in determination of thermal characteristics of the buildings such as UA and gA.

Some important climatic factors, such as: Solar radiation, outdoor temperature, air change, indoor temperature and energy for heating and appliances are considered in the field of measurements.

Simulations were carried out considering defined climatic conditions and internal gains data set to determine energy use in buildings, once obtained the single-zone model. The heated space is handled as a single-zone and internal doors are considered opened during the simulation works.

Energy simulations with a set of climatic factors and gains can be carried out from internal loads throughout a model with the objective of determining a standardized energy use level which can be used in the determination of energy performance index of the examined building.

According to Martin S. et al. (1996), to achieve good results and constant indoor temperature, it is used as homogeneous indoor conditions within the buildings and that, can be applicable in all types of houses where it is easy to measure the energy. However, the answers of this method are not suitable to the occupied houses and to buildings heated by fuel because of the larger uncertainties towards the functioning of the method.

This method presents the significance of continuous measurements of temperature and solar radiation and it is an appropriate method in the determination of a normalized solar radiation.

The energy measured is performed on a daily basis and only the average of air change rate for heated space is possible to obtain using this method.

To improve the performance of this method more studies about the measurements have to be carried out in the occupied houses where this method failed. For more details about this method, see Appendix A.

Table 4.1: Summary of the HELP Method.

Name	The Save HELP Method	
Factors Measured	Factors	Recording Methods/instruments
	Solar radiation in horizontal surface	Recording
	Air change	Perfluorocarbon tracer (PFT)
	Outdoor temperature	Tynytag sensor
	Indoor temperature	Wireless Tinytag sensor (in each room)
	Electrical energy	Reading by occupants
Advantages	• It is easy to obtain the homogenous of indoor conditions. • It is applicable to all types of dwellings where energy use is easily measurable	
Disadvantages	• Determination of the internal capacity is almost impossible. • The accuracy of the heating power measurement is reduced, as it has no continuous measurement of energy used in the buildings. • Occupied houses give larger uncertainties than unoccupied ones. • Large errors were obtained from houses where large solar gains can be assumed. • The method cannot be applied to houses heated with fuel (unless special techniques are used to measure the fuel consumption. • It is not applicable in tropical and subtropical climates.	

4.2 Short-Term Energy Monitoring, Primary and Secondary Term Analysis and Renormalization (STEM & PSTAR)

The STEM and PSTAR is a method which can be used in monitoring the energy in buildings. This method basically consists of three consecutive days of monitoring energy used in buildings and it is classified as macrostatic and macrodynamic methods. This method was developed in University of California, USA in the 1980s.

According to the procedure developed by Subbarao, (1984), the STEM protocol was programmed in the computer and three days and nights are considered for analysis. The steady state conditions were obtained in the first night, the second night was for cooling down and the last night for calibration of the heating system. The test during the last two days started at midnight after a stead state period. The effect of the solar gains is determined using daytime data.

Subbarao K. and Burch J. (1985), developed and presented detailed background of the method as well as the explanation of macro-static and macrodynamic procedures. Macro-static procedure can be considered as based on time integration of energy balance of the building with the input data such as building performance and outdoor temperature, while macro-dynamic methods directly employ the dynamic energy balance equation of the building.

Subbarao K. (1988), described the procedures for renormalization factors for analysis within the PSTAR, and mathematical equations are considered for separating building energy flows in order to identify the following thermal characteristics: the building loss coefficient, the effective building mass and the effective solar gains.

Data logger or energy management is required to extract some subset of energy balance parameters. So, the measurement equipment is installed in building, see Table 4.2.

For predicting future building performance, the heat that flows into the room is treated mathematically in order to separate some terms which influence the factors of energy balance and increase the heat flow in the building. The primary terms to be normalized and others not normalized can be seen in Burch J. D. et al. (1989).

Burch and et al. (1986), concluded that considering some adaptations of the STEM and PSTAR methods, it was possible to apply them to analyze the energy in commercial buildings and for assessment of the efficiency of passive cooling strategies in residential buildings and the application of this method produced fair accurate results.

Table 4.2: Summary of the STEM & PSTAR.

<table>
<tr><td>Name</td><td colspan="2">STEM & PSTAR</td></tr>
<tr><td rowspan="9">Factors Measured</td><td>Factors</td><td>Recording methods/instruments</td></tr>
<tr><td>Global solar rad. in horizontal surf.</td><td>Recording</td></tr>
<tr><td>Global solar rad. in vertical surf.</td><td>Pyrameter sensor</td></tr>
<tr><td>Wind speed</td><td>Hot wire Anemometer</td></tr>
<tr><td>Outdoor temperature</td><td>Wireless recording sensor (PFT) and samplers</td></tr>
<tr><td>Indoor temperature</td><td>Tinytag temperature logger</td></tr>
<tr><td>Relative humidity</td><td>Perfluorocarbon tracer (PFT)</td></tr>
<tr><td>Electricity Power</td><td>Reading by occupants</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Advantages</td><td colspan="2">• Simple and have been used for a wide variety of applications.
• The procedure developed in the STEM and PSTAR methods are very detailed.
• The results obtained are probably the most accurate of the different methods presented in this work.</td></tr>
<tr><td>Disadvantages</td><td colspan="2">• Require “three days” and low information content can make it difficult or impossible to reach reliable specific conclusions.
• The protocol is very strict and the houses have to be unoccupied in order to make measurement convenient.</td></tr>
</table>

4.3 Neural Networks (NN)

Neural Networks is a significant tool for predicting the future thermal behavior of a building when the data from the past are known. It is made by interconnection of the node in order to get input, hidden and output layers or nodes.

The input nodes receive the equal number of the measured data, such as: solar radiation, wind, relative humidity and air pressure, which can be obtained from the nearest weather station. The number of the input data or nodes correspond the same number of the output data. So, one of the neuron acts as a connection associated with each connection and adjustable value called weight. According to Olofsson T., (1998), this process is basically managed with a node that calculates the weighted sum of its input, and then passes the sum through a function to produce results.

Neural Networks is a very wide technique developed in Stockholm, Sweden and it can be considered as the networks that function as a model of mapping input patterns to output patterns.

Kreider J. (1991), presented the applications of the neural networks to produce a utility consumption and prediction indicator for commercial buildings and the results can be used to realize diagnostics for heating, ventilation and air conditioning systems.

Olofsson T, and Andersson S., (2000), presented the results of case studies and showed that these techniques could assess only measured data of supplied space heating demand and climatic data in terms of indoor and outdoor temperatures, the supplied space heating demand can be predicted within 5-10% on an annual basis.

More studies of this method were performed by S.L. Wong et al (2008), when he developed the Artificial Neural Networks for energy analysis of office buildings in broad daylight. The method was addressed for subtropical and tropical countries. Using a total of nine variables of input parameters (four variables related to weather conditions; four for building envelope and one for day type), modeled cooling, heating, electric lighting and total building electricity use was obtained with results indicating excellent predictive power. And the error analysis of three independent design cases was: lighting electricity 0.2% under-estimation to 3.6% over-estimation.

Comparisons between the annual and seasonal error analysis of cooling and heating electricity consumption showed that the method has more accurate predictions of electricity use during summer and winter.

Table 4.3: Summary of the Neural Networks Method.

Name	NEURAL NETWORKS	
Factors supplied	weather data	Solar radiation
		Wind speed
		Air Pressure
		Outdoor air temperature
		Indoor air temperature
		Relative humidity
	Electricity	Energy used
Results	Predicted energy use in buildings	
Advantages	• Very wide application of techniques and good ability to map non-linear dependencies between input and output data and also, this can be done without any conceptions of intrinsic relations in the presented data. • Good ability to map non-linear dependencies between input and output data	
Disadvantages	• Difficulty to interpret the model in practical terms, as well as the limitations in the accuracy of the predictions for events outside the data sets. • The model needs first to be trained with the available data before it is used with the meteorological conditions of the reference year. This method could be difficult to apply for certification purposes which are necessary and important for many countries. • Depending on the type of the networks and data used, this protocol can influence the results. In many cases it is difficult to interpret the results in terms of physical sense. • It could be difficult to apply for certification purposes	

4.4 The University Projects

University projects 1 and 2 are methods developed in Stockholm, Sweden in 1980. These methods were introduced together with the Swedish government decision on financial support for energy-saving measurement programs in existing buildings. The objective was to stimulate the efficient methods of energy use in heating systems of the buildings.

The retrofitting methods were adopted within these programs in order to assess the characteristics of the existing buildings and to estimate energy savings on data collection basis of energy bills and inspections in the buildings elements and installations.

The principal steps followed in these two University Projects were: collection of the energy used bills before and after retrofitting was carried out, normalization of the energy used bill according to the temperature variations over the years. The energy saved was matched in order to correspond to oil during a reference year.

The calculation methods are based on degree-hours, and due to seasonal variations of the outdoor temperature among the climatic factors, such as: temperature, solar radiation, wind, snow, long wave radiation and moisture, which influence the heat balance of the buildings, the outdoor temperature data from weather stations existent in Swedish territory was considered the most important factor.

Basically, these methods use measurement and theoretical models where parameters describing the energy performance of the building, climate parameters of the normalized year and the indoor temperature data are required for calculation models based on an energy balance for the building which was split up into summer and winter.

The University Project 2 (UP2) was applied as a continuation of University Project 1 (UP1) with the objective to introduce some improvements related to the accuracy of the results where the UP1 was considered weak.

The most important results obtained from this method show that the energy conservation measures gave statistical established savings in many cases and the measured savings agree with the theoretically predicted savings (M. Santamouris, 2005). For more details about the method, see Appendix B.

Table 4.4: Summary of the University Project Methods.

Name	The University Projects	
Factors for calculation methods	Outdoor temperature	Weather station
	Indoor temperature	Assumed 21ºC
	Internal gains	Assumed values
	Electricity Power	Assumed values
Advantages	• In most cases, the measured savings agreed with the theoretically predicted economics.	
Disadvantages	• It was not possible to evaluate the values of energy use by appliances and hot water. So, it was necessary to assume some values for these equipments.	

4.5 The Energy Barometer

Like the University Project 1 and 2, the Energy Barometer method was developed in Stockholm, Sweden, with the aim to measure energy use in different types of single-family houses during winter and summer. It is projected to provide foundation for analysis and assessment of energy use for heating, hot water and indoor environment.

The system information in the Energy Barometer can be divided into two parts: The first part aimed at the population level, supplying estimates of actual and predicted energy use; these estimates were based on a representative statistical sample from a selected population.

The second part was aimed at providing available individual house owners with means for monitoring their energy cost. So, buildings connected with system can analyze their own energy cost and they can observe what happens in relation to other people conjoint in the same system.

Westergren K-E, (1998), described the static and dynamic energy balances and presented the background and calculation methods considering a whole year consisting of a certain number of hours when the building is heated and other hours when it is not heated.

Norlén U. (1985), concluded that the Energy Barometer system gives a solution to the combined problem of obtaining (a) timely estimates and (b) reliable estimates of energy use in buildings.

M.Santamouris (2005), described the details and specifications of the measurement equipment used in this subproject, see table 4.5. For more details about the method, see Appendix B

Table 4.5 (a): Summary of Energy Barometer.

Name	Energy Barometer	
Factors Measured	Run time-oil	Sensor/electromagnetic sound
	output of pulses for oil burn	Flow meter
	Outdoor temperature	Temperature sensor
	Indoor temperature	Temperature Sensor
	District heating	Integration meter
	Electricity energy	Kilowatt meter
Advantages	• The use of technology of the Energy Barometer project seems to be the most appropriate method among many recently developed. The use of the Internet and the modem to collect the data is the most promising technology available for developing an accurate method with reasonable exploitation costs. • Provide estimates of actual and predicted energy use in buildings. • Provide individual house owners with a means of monitoring their energy cost budgets. • Supply possibility to measure electrical energy use by household appliances and heating systems including heating from tap water.	
Disadvantages	• The accuracy of results depends of the quality of the sensors used in the installation for measuring of various types of energy in buildings. • The sensitive of the sensors can influence the results.	

The sub-project of the Energy Barometer, called the "Virtual Housing Laboratory" (VHL) was the first application of this method; this was a system for simulating total energy use in the examined houses. It was based on a sample with very detailed data from the buildings and actual climatic data from nearest weather station.

This system can be considered presenting a lot of advantages because apart from offering facilities in the houses, it also allows the collection of data using the NET of communications. This system also allows operations and maintenance to be done remotely, thus saving on transport costs.

Table 4.5 (b): Summary of Energy Barometer (VHL).

Name	The Energy Barometer	
Inputs	Building description and environment data	Walls, roof, floor, openings
		Orientation, shading screen
		Ventilation, infiltration
	Weather data	Direct solar radiation on horizontal surface
		Diffuse solar radiation on horizontal surface
		Sky temperature
		Air temperature
Results	Total energy use	

4.6 The BKL Method

The BKL is a simplified method developed at the Department of Building Science, Lund Institute of Technology, Sweden, by Kurt Källblad and Bo Adamson to predict energy use in buildings. Further studies of this method and its comparisons with other methods and details about the computer calculations gave the method some improvements towards the applicability of the tools for assessing the energy use in buildings (Kurt Källblad, 1984).

The objective of the BKL is to provide the engineers, architects and other building technicians with a hand calculation tool for evaluation of energy use in houses. The calculations were designed in order to assess energy demands in low energy houses.

Calculations in this method are made considering that heating loads were thermostatically controlled, for instance the indoor temperature was maintained within certain interval of time. So, heat from people, pets, apparatus and appliances, hot water and direct solar are considered controlled. In this way, the heating system will operate in order to maintain the desired indoor environment.

This method was used by Arne Elmroth and Bertil Fredlund in their study of The Optima- House in 1996. The results attained in this study were proximal of the measured results which show that the BKL is a good tool for evaluation of energy use in buildings. However, this method should not be applied in tropical countries because it was especially designed for normal Swedish climate and problems can arise if it is applied in warmer climates (Kurt Källblad, 1984).

Källblad, (1984), shows that to calculate the solar gain with an acceptable accuracy, the solar radiation must be divided into direct solar radiation and diffuse sky radiation.

The method needs the input data such as presented in Table 4.6 below. The results from validation work done by Källblad, 1984, and based on comparison with JULOTTA Program, DD, JAENV, SMELL and others, shows that the BKL method presents acceptable results.

Table 4.6: Summary of the BKL Method.

Name	The BKL Method	
Inputs	Building description and environment data	Global solar rad. in horizontal Surface
		Global solar rad. in vertical surface
		Wind speed
	weather data	Outdoor temperature
		Indoor temperature
		Relative humidity
		Electricity Power
Results	Acceptable results	

Advantages	• Personal computer gives the possibility to be used as a very quick design tool. • Gives good results in field of measurements in both occupied and unoccupied houses where information about the fabric and ventilation losses, useful free heat, useful solar heat and Space heating with reasonable accuracy can be found.
Disadvantages	• It is not useful in tropical and subtropical countries.

4.7 DEROB-LTH Program

DEROB-LTH is an acronym for Dynamic Energy Response of Buildings and detailed energy simulation program tool, originally developed at Austin School of Architecture, University of Texas, in USA and later developed at the Department of Construction and Architecture, in Lund University. The improvement made in Department of Construction and Architecture in Lund turned DEROB-LTH v1.0 into DEROB-LTH v2.0 and it is performed annually.

The users consider this program as simple because it does not need detailed knowledge in mathematical field and thermal physics. Although, requires some understanding of the thermal model and dependencies between building design and performance parameters.

It has an accurate model to calculate the influence of solar insulation and shading devices on energy balance in the buildings. The buildings are modeled in 3-D, a necessary condition for accurate calculations of the distribution of solar insulation and temperatures in the rooms and its surfaces (Källblad, K. 1993).

For simulation, two general types of input data are needed: first the building description data and the environment data. The building description data includes the geometry of the spaces which define the thermal and active building elements such as: wall, roof, floor and openings (doors and windows) and the thermal inactive exterior shading screens, orientation of the building, schedules for forced ventilation, infiltration, heating, cooling and free heating. The second type has to do with the weather data of hourly values and results from simulations, see the Table 4.7.

Hans Rosenlund (1993), in his study of Desert Buildings, a parametric study on passive acclimatization, presented some limitations of this program and showed that the program could not handle the issue of excavation into the ground and does not treat the effect of long-wave radiation.

A lot of research programs have been performed using DEROB-LTH program and it seemed to be a good tool for analysis of the indoor thermal environment of buildings. Wang Zhiwu (1992), in his study about the "Indoor Thermal Environment of Residential Buildings in Subtropical Climates in China", demonstrated that the simulations results are in good agreement with field measurements and the deviation of mean indoor air temperature is less than 1ºC, maximum temperatures 2ºC and the deviation of surface temperature is 1ºC. For more details of the method and some results done by author using DEROB-LTH program, see Appendix D.

Table 4.7: Summary of the DEROB-LTH Program.

<table>
<tr><td>Name</td><td colspan="2">DEROB-LTH Program</td></tr>
<tr><td rowspan="7">Inputs</td><td rowspan="3">Building description and environment data</td><td>Walls, roof, floor, Openings</td></tr>
<tr><td>Orientation, shading Screen</td></tr>
<tr><td>Ventilation, infiltration, heating, cooling and free heating</td></tr>
<tr><td rowspan="4">weather data</td><td>direct solar radiation on horizontal surface</td></tr>
<tr><td>diffuse solar radiation on horizontal surface</td></tr>
<tr><td>sky temperature</td></tr>
<tr><td>ambient air temperature</td></tr>
<tr><td rowspan="4">Results</td><td colspan="2">drawings of the building geometry</td></tr>
<tr><td colspan="2">diagrams for space temperatures</td></tr>
<tr><td colspan="2">space heating and cooling demand and solar parameters</td></tr>
<tr><td colspan="2">Diagrams for comfort indices PMV and PPD for each space.</td></tr>
<tr><td>Advantages</td><td colspan="2">• This tool can manage rooms with specific geometries, buildings with 8 volumes and several zones and can be used to calculate peak loads, energy demand, temperatures and thermal comfort in the buildings.</td></tr>
<tr><td>Disadvantages</td><td colspan="2">• Humidity is not simulated</td></tr>
</table>

4.8 Comparison of the selected methods

Table 5 shows the summary of the overall selected methods and the comparisons made to show which method presents good results for retrofitting, assessment and simulations and a number of climatic factors which can be measured.

Table 5: Summary of the selected methods.

		Methods						
Item	Methods	The Save HELP Method	STEM & PSTAR	Neural Network	The University Projects	The Energy Barometer	The BKL Method	DEROB--LTH Program
	Retrofitting	F	F	F	G	F	F	F
	Assessment	F	F	F	F	G	F	G
	Simulation	_	_	_	_	F	G	G
Item	Factors	Results						
01	Global Solar radiation in horizontal surface	M	M	M	M	M	S	S
02	Diffuse solar radiation	NM	NM	NM	NM	NM	S	S
03	Solar radiation in vertical surface	NM	M	NM	NM	NM	S	S
04	Outdoor temperature	M	M	M	M	M	S	S
05	Wind speed	NM	M	M	M	NM	NS	S
06	Relative humidity	NM	M	M	NM	NM	NS	NS
07	Surface heat Flux	NM	M	NM	NM	NM	S	S
08	Air change	M	NM	NM	NM	M	S	S
09	Indoor temperature	M	M	NM	M	M	S	S
10	Internal gains	NM	M	NM	NM	M	S	S
11	Electrical energy	M	M	NM	M	M	S	S
12	Air	NM	NM	M	M	M	S	S

	pressure							
13	Long wave radiation	NM	NM	NM	M	NM	NS	S
14	Moisture	NM	NM	NM	M	S	S	NS

Note: F= Fair, G = Good, M = Factors measured, NM = Factors not measured, S = Factors simulated, NS = Factors not simulated.

5 Conclusions

To assess energy use in buildings, it was necessary to find a suitable methodology for evaluation, analysis and simulation of the energy used in residential buildings; since the buildings of Maputo City have rather a poor thermal performance. People in Mozambique complain about the temperature in summertime because it tends to be higher inside the buildings than outside. This is the period at which electrical energy use occurs on a large scale because the mechanical equipments are used to provide indoors comfort conditions.

After having analyzed all these studied methods, we came to a conclusion that (Table 5) is best and suitable to select the University Project either before or after retrofitting buildings based on calculation models following the energy balance of the buildings. Energy Barometer is a method for assessing parameters of energy use in buildings by supplying climatic data and building elements in the computer, and DEROB-LTH is a program for simulating energy for heating and cooling, and it also simulates the thermal peak loads, indoors temperature and visual comfort.

From experimental techniques methods and energy characterization of buildings presented in section four, we concluded that following the conditions of Maputo City buildings, the selected experimental methods of energy rating can bring the basis for calculation methods for different types of energy use in building stocks following the specific conditions for evaluation of energy use. So, analyzing the advantages and disadvantages presented in this chapter, University Projects and Energy Barometer methods (EB) can be chosen for energy assessment in buildings, but the most appropriate methods between these two, is the Energy Barometer Project, since it presents the advantages for evaluation of energy use in buildings by using internet and modem to collect data and take it to a variables of energy parameters that influence the use of energy in the existing buildings which are not possible in UP and other methods presented in this report.

Energy Barometer (EB) method is the most promising technology in the future because it can provide results with high accuracy and reasonable exploration costs in assessment of energy in the buildings, especially the ones in Mozambique.

The EB project can be used in certain moments when it is necessary to have information about energy use of the buildings and it can also give the potential buyer's exact data of the energy bills they have to pay. Thus, the owners of the buildings may have to identify specific cost of effective improvements of the energy efficiency.

The best method to calculate and analyze the energy, thermal and visual environment in buildings is through simulation. Thus, analyzing the results presented in Table 5, it is concluded that DEROB-LTH Program is useful for the analysis of energy use, heating and cooling, peak loads for heating and cooling, thermal comfort and visual comfort. So, our future studies aimed at evaluation of indoor thermal comfort, electrical appliances and comparison between field measurements and computer simulations, DEROB-LTH Program will be used in order to show how to improve the indoor climate of buildings in Maputo City.

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Appendices

The appendix A, B, and C are parts of methodologies used in this paper for analysis of energy efficiency in buildings basically, from reference, M. Santamouris, 2005.

Appendix A

The Save HELP Method

The main aim of this method is to develop a reliable monitoring procedure which can provide the necessary input for an analysis tool within the Save HELP Method. This analysis tool provides the information that makes it possible to reach a normalized annual heating consumption for the dwelling based on restricted data from the heating season. In the applied model, the overall UA-value of the dwelling and the gA-value are determined by means of multiple regressions.

For a determination of these values, daily measurements such as: The ambient temperature, the mean inside temperature, the amount of heating inside the dwelling, the solar radiation and the mean ventilation rate are necessary. A multiple regression calculation is used to determine the unknown parameters (UA_{global} and gA) from the model below, Figure A.1.

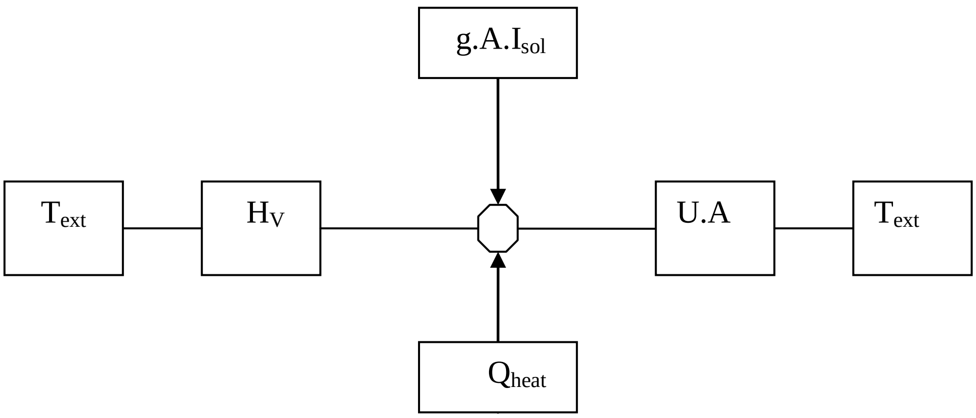

Figure A.1 The simplified single zone-model of a dwelling.

UA - is equivalent global UA-value, and U-value is a measure of air to heat transmission (loss or gain) due to the thermal conductance and difference in indoor and outdoor temperatures.

gA - is the pseudo-solar gain factor, and g-value is a measure of the total solar energy transmittance, is physically measurable parameter corresponding to the total fraction of the incident solar energy that is transferred through a building component g-value consists of two parts: First, the solar transmittance and second internal heat transfer factor.

I_{sol} - is the solar radiation – the radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy.

Q_{heat} – Heat flow through building from solar radiation through windows, objects in the building envelope other than windows, leakage, ventilation, generation of heat from pets or human bodies or through their activities such as washing clothes or cooking, etc.

H_V – Hybrid ventilation is two-mode systems which are controlled to minimize energy use while maintaining an acceptable indoor air quality and thermal comfort. In general, the two modes refer to natural and mechanical driving forces. The purpose of the control system is to establish the desired air flow rate and air flow pattern at the lowest energy use in buildings.
T_{ext} - is the external temperature

$$E_{day} = UA_{global} . \int_{day} \Delta T_{i,e} - gA . \int_{day} I_{sol} \qquad \text{(A1.1)}$$

with

$$E_{day} = Q_{heat} - C.\Delta T_{day,day-1} - n.V.\rho.\, C_p \int_{day} \Delta T_{i,e} \qquad \text{(A1.2)}$$

This model can only be used if it is possible to define a unique T_{int}. This is possible only when the dwelling is assumed to be one heated zone. In this case T_{int} is simply the only temperature of the heated zone.

The experimental method applied does not require detailed information on the building, but a relatively long monitoring period (at least two weeks) is required and energy readings can cause problems too, as well as disturbances from the occupancy.

However, the experimental method can be seen as the most reliable way to determine normalized annual heating energy use since its output is relatively independent of the observed conditions and since a very limited number of assumptions regarding the building have to be made. It is clear that such method could hardly be applied on a large scale in the framework of energy certification because of the amount of work that is required.

Appendix B

University Projects UP1 and UP2

Here are presented some methodology used for some calculation procedures following the net energy balance structures as: illustrated in Figure B.1 and B.2. The calculation model is based on an energy balance for the building, which is split up into summertime (Figure B.1) and wintertime (Figure B.2). So, the degree-hours and U-values are considered in the calculation model.

Degree-hours – Among the climatic factors, such as: temperature, solar irradiation, wind, snow, long-wave irradiation and moisture, which influence the heat balance of the buildings the outdoor temperature is considered to be the most important factor because of the seasonal variations over the years. The number of degree hours is calculated from,

$$Q = T\,(\theta_i - \theta_e)\ (^0C.h) \qquad \text{(B.1)}$$

For calculations in the heating season were considered months with low outdoor temperature. In figure B.1 and B.2 the shaded parts depict the energy supplied for an electrical heated building.

U-values – U-values are calculated in accordance to CIBS norms. For double and triple-glazed windows, the values are 3.0 and 2.0 $W/m^2.^0C$), respectively. The glazed part is normally assumed to be 70% of the gross window area (G. J. Levermore, 2000).

		Net energy supplied	Net energy loss
Summer		SG_s	TL_s+ VL_s+ SL_s+
	Energy Content of Fuel	PG_s	
		EG_s	
	HW_s/h_s	HW_s	

Figure B.1 Net energy balances for a building.

where: SG = solar gains
PG = heat from people
DL = heat loss due to via drainage
EG = heat from household

	Net energy supplied		Net energy loss
Winter	HW_w/h_w	HW_w	TL_w
	HS_w/h_w	HS_w	
		EG_w	
		PG_w	VL_w
		DG_w	DL_w

Figure B.2 Net energy balances for building.

where: HW = net heat supplied for hot water
HS = net heat supplied by the heating system.
TL = heat loss due to transmission
VL = heat loss due to ventilation appliances (Electrical gains)

The energy calculation methods using University Project (UP) is presented below.
For electrical heated buildings, the energy use is

$$W = TL_w + VL_w + DL_w - PG_w - SG_w + HW_s + EG_s \quad \text{(B1.1)}$$

For oil, gas or district heated buildings, the energy use is

$$W = (TL_w + VL_w + DL_w - PG_w - SG_w - EG_w)/h_w + HW_s/h_s \quad \text{(B1.2)}$$

If it is assumed that the losses due to transmission and ventilation are proportional to the amount of degree-days and that drainage loss, the heat gains from people and solar irradiation and household appliances are proportional to the number of hours in the heating season (winter) and that the household appliance gains during the non-heating season are proportional then the two equations can be rewritten as:

$$WH = bQ + cT + dP \quad \text{(B1.3)}$$

In the equation (B1.3), the first two terms on the right hand side describe the energy use during winter and the second terms are for the summer. The heat-loss factor "b" is a measure of the insulation and the amount of ventilation of the building.

The summer factor "d" describes the energy use during the non-heating season (summer), whereas the winter factor "c" is more difficult to interpret. All the three factors depend on the efficiency of the heating system. The factors are determined by means of linear regression on data from buildings with extensive information on energy use before and after retrofitting.

With the assumption that winter factor "c" and summer factor "d" are known and remain unchanged during the period before and after retrofitting, the heat-loss factors before retrofitting**,** b_b, and after retrofitting, b_a, are

$$b_b = \frac{1}{Q_b}(W_bH - cT_b - dT_b) \qquad \text{(B1.4)}$$

$$b_a = \frac{1}{Q_a}(W_aH - cT_a - dT_a) \qquad \text{(B1.5)}$$

Now all these values can be determined and can be used to calculate energy use that would have been measured during a year with normal climate:

$$(WH)_{b,r} = b_bQ_r + cT_r + dP_r \qquad \text{(B1.6)}$$

and

$$(WH)_{a,r} = b_aQ_r + cT_r + dP_r \qquad \text{(B1.7)}$$

$$S = (b_b - b_a)Q_r\frac{\eta_w}{\eta_{woil}} \qquad \text{(B1.8)}$$

Index "r" denotes the reference year.

The difference between $(WH)_{b,r}$ and $(WH)_{a,r}$. is due to the energy saving process during the retrofitting.

So, the net energy has to be calculated with the efficiency of the actual heating system, then, divided by the efficiency of an oil-based boiler, the saving expressed in liters of oil per year (equation B1.8).

Appendix C

C.1 The Energy Barometer

The Energy Barometer (EB) is a method used to monitor the development of energy use in single–family houses through continuous energy and climatic measurements in houses reporting changes of energy in short time span. It has been developed to measure energy use in relation to internal and external climates in different types of single-family houses during periods with or without heating. It also provides a basis for analysis and evaluation of energy efficiency measures. The electrical energy used by household appliances and the energy use for heating, including heating of tap water and indoor temperature, are measured in each selected building.

In the Energy Barometer, the information system can be divided into two parts: The first part aims at the population level providing estimates of actual and predicted energy use, together with analyses of trends and the effects of energy and measures on a large scale. The estimates are based on a representative statistical sample of a certain population.

The second part aims at providing individual house owners with means of monitoring their energy cost budgets. Buildings connected to the EB will be able to analyze their own energy situation and to see it in relation to the population as a whole.

C.2 The calculation principles

In Energy Barometer (EB), two kinds of models can be used based on either a static or a dynamic energy balance. The annual energy use can be calculated as: considering a whole year consisting of "T" hours when the house is heated (winter hours) and "P" hours when the house is not heated (summer hours), $\Delta\theta$ is the average indoor-outdoor temperature difference in (^{0}C) during this period and "I" is the global solar radiation on a horizontal surface during the heating period (KW/m^2).

The annual energy use for heating house "i" can be calculated as,

$$E_i = ciTi + b_i D\theta + f_i I_i + d_i P_i \quad \text{(KWh)} \qquad \text{(C1.1)}$$

The energy parameters c, b, f and d have specific values for each house. The climatic variables T, P and I depend on the climatic conditions of the house location.

The number of degree-hours between houses, $Q = T\Delta\theta$, differs depending on the temperature conditions and the length of the heating season. In a first approximation, the variables P, I and T for all houses may be given the same values, especially in certain zones.

For the purpose of estimating total energy for heating, it is sufficient to include in the model solar irradiation on a horizontal surface. When the end points of the heating season are known, the heating season of a normal year can be estimated using a sinusoidal approximation, for more details, see reference, M. Santamouries, 2005.

C.3 Statistic Energy Balance

The energy used in buildings is determined on the basis of a static energy balance. The purpose is to estimate the normal annual energy use for heating (space and tap water).

Under stationary conditions, heat will be stored in or released from the house over a specific period of time. This assumption enables the formulation of a linear static heat balance equation for the house; these are called energy signature models.

Dividing the equation (C1.1) by T, we obtain the average energy use per unit time W (KWh/h) during the heating season. The constant "c" is the average energy use per unit time when there is no temperature difference and no solar irradiation, e is the error term:

$$w = c + d\Delta Q + fs + e \qquad \text{(C1.2)}$$

The model assumptions are valid provided that the period chosen is long enough for the heat stored in or released from the building to be very small compared to the total energy supplied during this period.

C.4 Dynamic Energy Balance

We can get two reasons for using a dynamic energy balance model instead of a static model the one discussed above. The two reasons are: (a) energy use in a building is a dynamic process, e.g. the thermal inertia delays the response of the building to changes in the outdoor climate and (b) data from building is lost in the aggregation from the hourly data to the daily or weekly data needed for the static model.

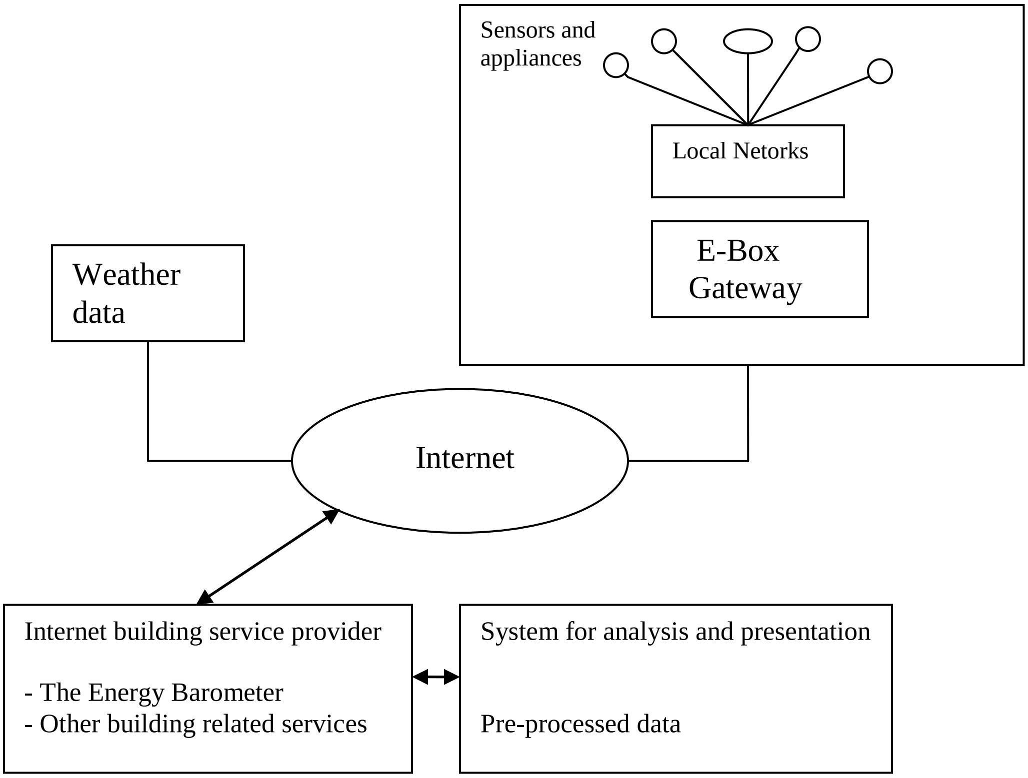

Figure C.1 The structure of the Energy Barometer system

The data handling system in a communication device, a residential gateway (E-box) is basically a computer and consist of standard PC-components. Practical information and specifications of the E-box can be found on the Ericsson´s website.

In each house it is necessary to install the following sensors:

- Energy: Electricity (electric heating, water-borne heating, heat pump)
- District heating.
- Oil burner.
- Run time: oil.
- Temperature: indoor, outdoor.

They are connected via a network to the E-Box-Gateway and are used to connect with local network since it enables physical-layer communication. The socket with 220 volt and cables already existing in the houses are used for supplying energy to the equipment. The sensors are then simply plugged into the wall and no extra wiring is necessary. Raw energy and temperature data are collected continuously and stored in each local E-box and transferred to a central server on a diurnal basis via internet. The weather data is sent from the nearest official climate station existent in each country.

From each house the following data has to be collected:

- The hourly energy use for heating (space and tap water).
- The hourly energy use of energy for household appliances.
- The hourly average indoor temperature.
- Technical data (occupancy, heated area and year of construction).

(Westergreen K-E, Högberg H and Norlén U,1996, gives a sample inspection protocol for this system).

Appendix D

D.1 Objective of the simulation

The objectives of the simulation presented in this report is to verify the functionality of the DEROB-LTH Program in residential buildings of Maputo City, once this Program was selected in previous chapter and shown that it has more advantages for calculations and analyses of peak loads, energy demand, temperatures, thermal and visual comfort of the buildings than others. Whereas, the motivation of this study is to create the improvement of comfort in residential buildings, it means, improvement of living conditions of people in buildings with efficient energy use.

D.2 Climatic Conditions of Maputo City

Maputo City, the capital of Mozambique, is situated at 25^0 57´ S and 32^0 35´ E, with a typical subtropical climate. Meteorological statistics for Maputo city are available and were used for this simulation. For more details, see Figure 5.1.

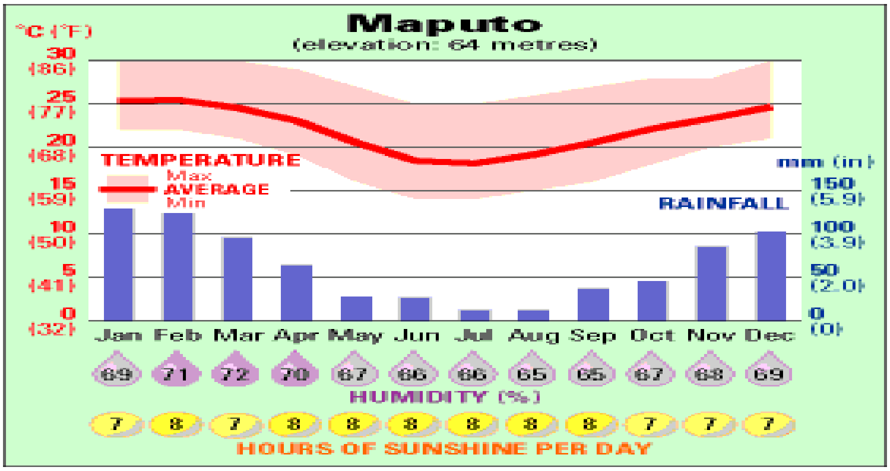

Figure D.1- Climatic conditions in Maputo City (Resource www.unicef.org/mozambique)

D.3 General Description of the Residential Building

The residential building “3 de Fevereiro” was built in the ninety decade. The building has about 378 m^2 with 2 floors and 6 apartments: the ground floor has got 20 compartments, namely, 3 living rooms, 5 bedrooms, 3 bathrooms, 3 kitchens, 3 laundries, 1 principal store 2 stairs and 1 balcony and First floor with 3 living rooms, 3 bedrooms, 3 bathrooms, 3 kitchens, 3 laundries, 3 stores and 4 balconies. See figure D.2 for the picture of the building.

The figure D.2 shows the picture of the building.

Figure D.2 Picture of the building (picture by the author)

D.3.1 Orientation and description of the building

The long axis of this building is oriented towards NE-SW and the main facade of the building is south oriented. This kind of orientation follows the rules of orientation from Maputo City Council for getting the best indoor environment.

For description of the building general volumes and areas, see Table D.1

Table D.1- The compartments areas of the apartments

		Ground floor		First floor	
Items	Designation	Numbers	(m^2)	Numbers	(m^2)
01	Living rooms	3	89.21	3	98.68
02	Bed rooms	5	58.23	3	40.43
03	Kitchens	3	36.10	3	26.59
04	Bath rooms	3	17.16	3	21.40
05	Stores	1	07.03	3	14.68
06	Corridors	2	28.53	1	29.81
07	Stairs	2	38.00	0	33.73
08	Laundry	3	13.34	3	22.88
09	Balcony	1	06.08	4	13.28

D.4: Selecting side for simulation

To simulate the building, we decide to reduce the number of volumes, once the DEROB-LTH Program does not permit to simulate buildings with more than 8 volumes. So, the right side (illustrated in the picture, Figure D.2) was selected for this simulation.

The wall which separates both the left and right parts of the building was considered with infinite resistance in order to provide both sides of the wall with the same temperature.

The Tables D.2 show the volumes in each selected flats.

Table D.2 (a) – Selected volumes for simulation on ground floor.

	Ground Floor				
Items					Volume
01	Kitchen	-	-	-	V1
01	Bed room	Store house	-	-	V2
02	Living room	Bath room	Corridor	-	V3
03	Stairs	-	-	-	V4

Table D.1 (b) – Selected volumes for simulation in First floor.

	First Floor				
Items	Compartments				Volume
01	Bed rooms	Bath room	-	-	V5
02	Kitchens	-	-	-	V6
03	Living room	Corridor	Store house		V7

D.5 Results from simulation

The Figures below show the results of the annual outdoor temperature, indoor temperature per volume, outdoor and absorbed solar radiation in volumes from simulation using dynamic program for simulation DEROB-LTH.

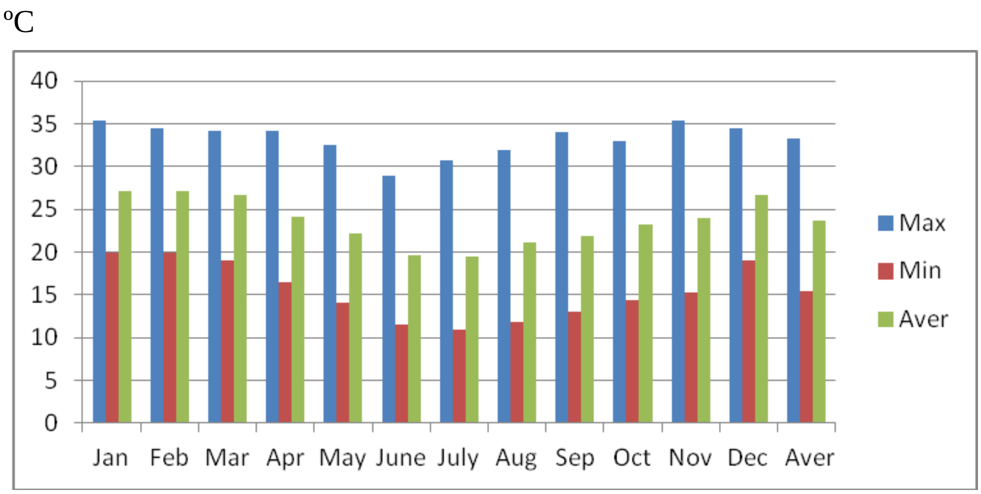

Figure D.3 Annual outdoor temperatures

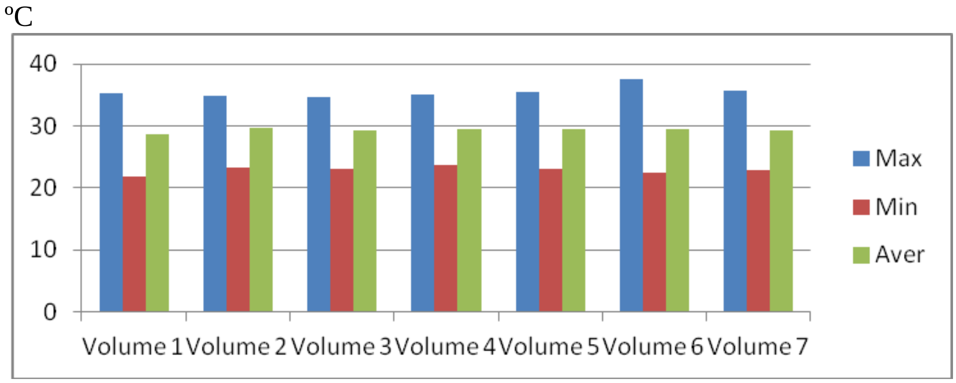

Figure D.4 Indoor temperatures per volume in January (the hottest month)

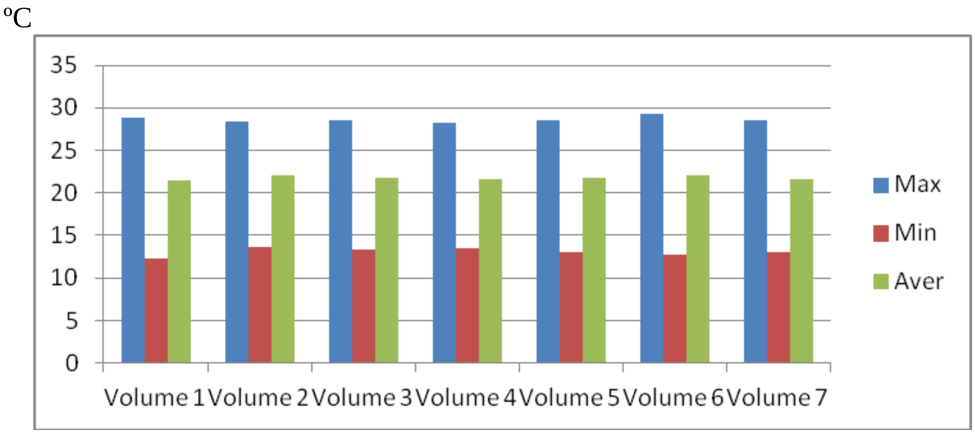

Figure D.5 Indoor temperatures per volume in June (the coldest month)

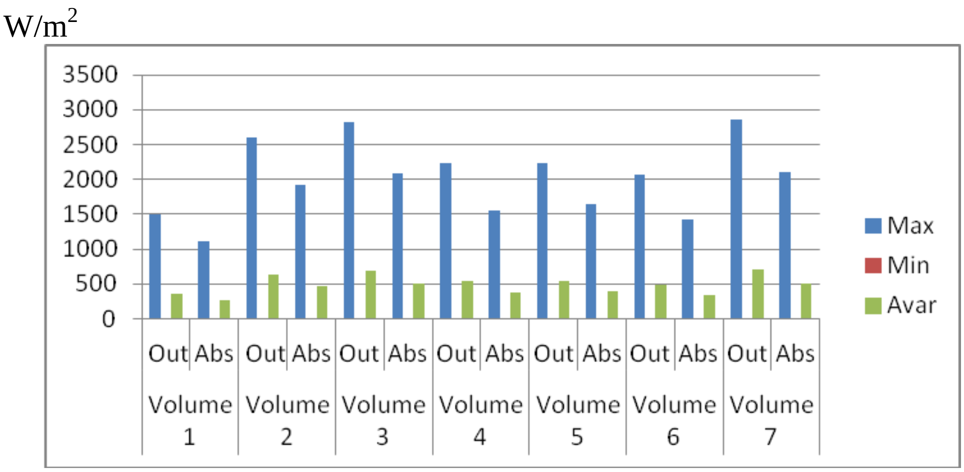

Figure D.6 Outdoor and absorbed solar radiation, January (the hottest month).

Appendix E

Nomenclature

The most commonly used symbols are given here, other symbols are defined in the chapters they were used.

Roman symbols

E Annual energy (kWh)
E_i The annual energy use can be calculated, for heating house i (kWh)
H Conversion factor
I Mean solar irradiation during the heating season ($kWh/m^2/h/year$)
I_i Mean solar irradiation during the heating season, for heating house i ($kWh/m^2/h/year$)
$I(t)$ The solar irradiation at hour t ($kWh/m^2/h/year$)
P Number of hours during the non-heating season (h/year)
Q Number of degree hours during the heating season ($^0C.h/year$)
Q_r Number of degree-hours during a reference year T ($^0C.h/year$)
T Number of hours during the heating season (h/year)
Ti Number of hours during the heating season, for heating house i (h/year)
W Energy use (kWh/apartment/year)
W_{gross} Gross energy use (kWh/apartment/year)
b Building heat-loss factor, liters of oil per hour per degree
b_a Building heat-loss factors after retrofitting (liters/degree per hour)
b_b Building heat-loss factors before retrofitting (liters/degree per hour)
b_i Building heat-loss factors before retrofitting for heating House i (liters/degree per hour)
c Winter factor, during the heating season liters of oil per hour
c_i Winter factor, during the heating season for house i (liters of oil per hour)
d Summer factor (liters of oil per hour)
d_i Summer factor for house i (liters of oil per hour)
f Solar area, which is a fictitious window that transmits all insolation (m^2/apartment)
f_i Solar area, which is a fictitious window that transmits all

	insolation for house i (m^2/apartment)
S	Energy saving if the buildings were heated using oil (liters/year)
t	Time (s) or (h)
w	Energy use (kWh)
w(t)	Energy use during hour number t (kWh)

Greek symbols

θ_i	Mean indoor temperature
θ_e	Mean outdoor temperature based on mean monthly values.
η_w	Efficiency of the actual heating system during winter
$\eta_{w\,oil}$	Efficiency of oil-based heating system
θ^{in}	Indoor temperature
θ^{out}	Outdoor temperature
$e(t)$	Error term
η_{winter}	Efficiency in the winter season
η_{summer}	Efficiency in the summer season

Subscripts

in	Inner, Indoor
out	Outer, Outdoor
r	Reference
sum	Sum

Report II

Experimental Design of Weather Station and Field Measurement of Climatic Factors in the Building

Experimental Design of Weather Station and Field Measurement of Climatic Factors in the Building

Case study of "3 de Fevereiro building" in Maputo City

Gabriel Auziane

This report relates to research grant No: 2006-001251, agreement of year 2008 between Sida/SAREC and Government of Mozambique/Eduardo Mondlane University and it is developed at the Department of Construction Sciences at Lund University; Lund, Sweden.

Preface

Within the research co-operation between Sida/SAREC and the Government of Mozambique/Eduardo Mondlane University, the Republic of Mozambique, a project TecPro-Advancing Sustainable Construction in Mozambique for energy efficiency in residential buildings in tropical and subtropical climates has been agreed on. This project is carried out at the Department of Construction Science – Faculty of Engineering LTH, Lund University, Sweden.

The use of modeling and simulation program tools for assessment of the energy used in buildings in Mozambique is under investigation. Thus, measurement equipment was installed in “3 de Fevereiro Building” in Maputo City, Mozambique. The measurement equipment is composed of Data Logger System, Weather Station, temperature and humidity sensors for measuring the climatic factors around the building and indoor parameters which influence the internal environment of the buildings. In this report the results of the collected data of outdoor and indoor climatic elements are presented, analyzed and discussed.

Lund, November, 2010

Acknowledgements

I would like to express my sincere thanks to Professor Bertil Fredlund and Dr. Kurt Källblad, my supervisors at the Department of Construction Science, Lund University for their guidance and criticisms that have led to the compilation on this Report. I would like to thank Professor Göran Sanberg, Professor Anne Landin and Dr. Daniel Baloi for their guidance.

I thank Sida/SAREC as it was their support through Eduardo Mondlane University and Lund University that has made this research project possible.

I thank all the lectures at the Division of Construction Management, Lund University. I also acknowledge Christina Glans for her timely help whenever it was necessary and Engineer Thord Lundgren for the work done by measurement equipment installation, treatment of data and providing information on which fieldwork are based.

Finally, a special thanks to my family for enduring my absence from home during the time I am in Lund University, Sweden

Lund, November, 2010

Gabriel Auziane

Abstract

The use of modeling and simulation program tools for assessment of the energy used in buildings in Mozambique is under investigation. Thus, measurement equipment was installed in “3 de Fevereiro Building” in Maputo City, Mozambique. The measurement equipment is composed of Data Logger System, Weather Station, temperature and humidity sensors for measuring the climatic factors around the building and indoor parameters which influence the internal environment of the buildings. This paper describes the plan design and the layout of the measurement equipment and it also presents and discusses the results of the outdoor and indoor climatic parameters in winter, such as: global and diffuse solar radiation, outdoor temperature and humidity, indoor temperature and humidity, wind speed, wind direction and rainfall. The measured results are for a period of four months from June to September, 2009. With this field measured results it was possible to analyze a greater part of the winter climatic factors in winter once Maputo City has a subtropical climate with two seasons, a wet season from October to March (summer) and a dry season from April to September (winter). The measured results show that the equipment provides fair data which can be used for evaluating the energy of the building and for testing and validating the simulation program tools of the energy used in buildings.

Keywords

Energy efficiency, energy use, design experiment, outdoor and indoor thermal environment, field measurements, tropical climate, Maputo, Mozambique.

1 Introduction

Maputo City, the capital of Mozambique, is situated at 25º57´S and 32º35´E (see appendix A) with a subtropical climate which means that it is submitted to a predominant solar energy which can increase the thermal heat inside the buildings especially in summer. On the other hand, the solar energy can be used to reduce the electrical energy used in buildings if active systems using solar energy are implemented in the buildings. The need to estimate the energy used in the buildings by using short and long term methods and the need to test the energy simulation program tools was the main aim to install the measurement equipment in the building.
The measurement equipment was installed in May, 2009. So, the measurement results are from June to September, 2009. With these results it was possible to analyze a greater part of the winter in this year. This report presents the measurement system of the climatic factors around and inside the building and most of all; it shows the results of the collected data.

2 Characterizations of the building and the measurement system

The measurement equipment was installed in the “3 de Fevereiro Building” as presented in the description below.

2.1 Examined building

The building was built in the 1990s. The materials used were: plastered hollowed concrete, block walls, concrete column, and wood frame with single glass, concrete cement ceiling, and gypsum ceiling roof, see Table B.1 in appendix B.

The long axis of the building is NE-SW and the main facade is south oriented as presented in Figure 2.1(a-b). This kind of orientation is typical of Maputo Town Council Buildings.

Figure 2.1(a) Photo of the building (photo by the author)

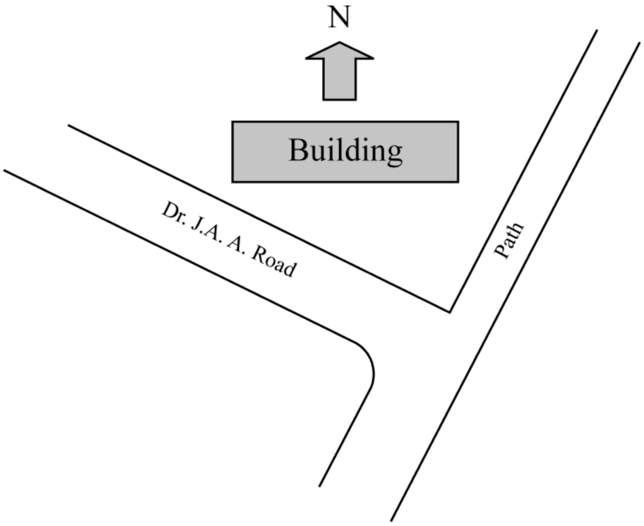

Figure 2.1(b) Location plan

2.2 Data of the building

The examined building has about 378 m^2 with 2 floors, 3 apartments on each floor as presented in Figure 2.2 (a-b). For more details, see appendix B.

The East and West side of the building are the best for analyzing the thermal loads because there are directly radiated by the sun during the morning and noon periods of the days respectively. The owner of the building (Faculty of Engineering) allowed installing the equipment in the East side. So, that fact made the author and Engineer from Lund University to install the measurement equipment in that side in the beginning of May, 2009.

2.2.1 Sensors placement

The Figures 2.2(a-b) present the sensors installed on the ground and first floors. The respective layout of the equipment can be seen in Figures 2.3(a-b).

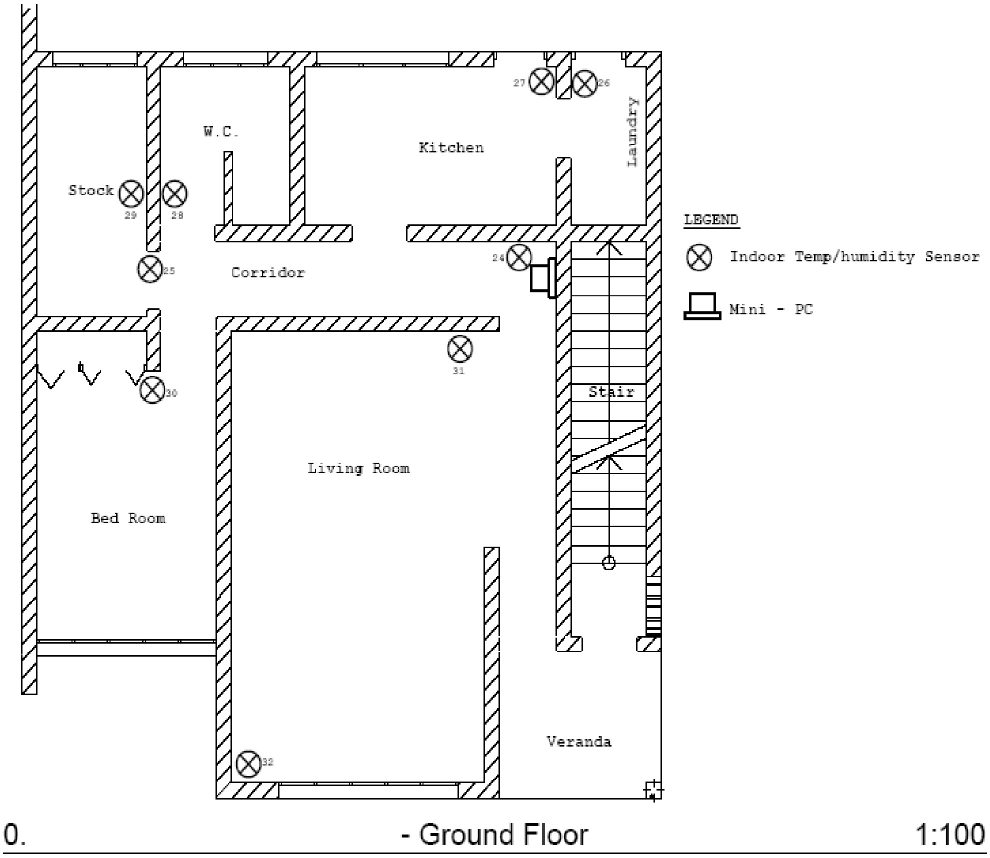

Figure 2.2 (a) Temperature and humidity sensors installed on the ground floor

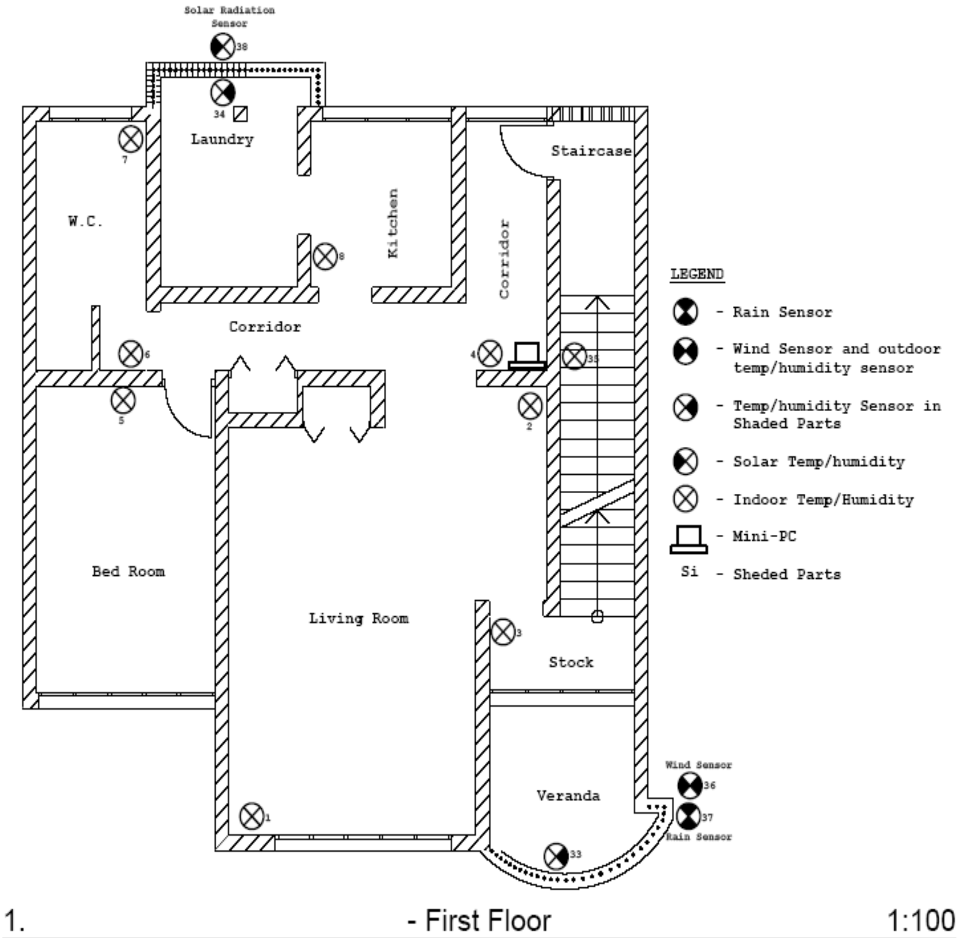

Figure 2.2 (b) Temperature and humidity sensors installed on the first floor

2.2.2 Measurement equipment layout

The Figures 2.2(a-b) are schemes which illustrate the measurement equipment layout installed in the building. Scheme (a) presents the electronic circuit of the equipment installed on the ground floor which allows measuring the indoor climatic data and the electrical current and scheme (b) presents the same equipment as in (a) together with the equipment for measuring the outdoor climatic data, such as the global and diffuse solar radiation, temperature, humidity, wind and rainfall.
The full list of the equipment is presented in Table 2.1. For more details, see appendix C.

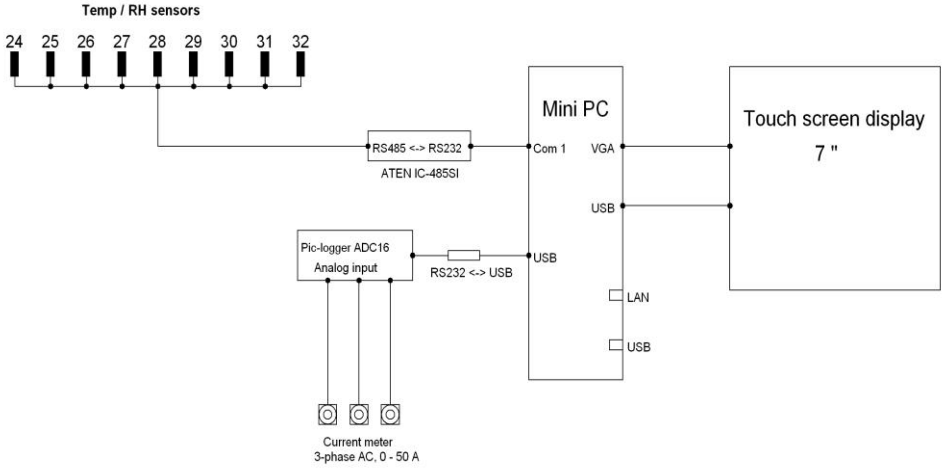

Figure 2.3 (a) - Scheme of the measurement equipment installed on the ground floor (by the author and the Engineer Thord Lundgren Division of Structural Mechanics, Lund University, Sweden)

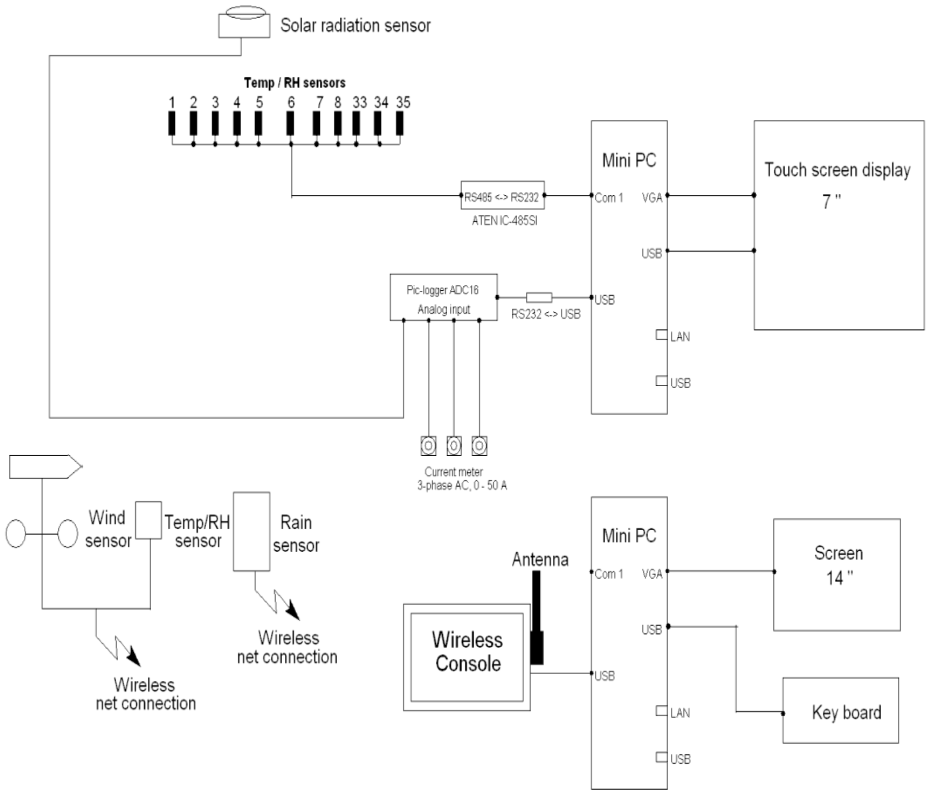

Figure 2.3 (b) Scheme of the measurement equipment installed on the first floor (by author and Thord Lundgren Division of Structural Mechanics, Lund University)

Table 2.1 Measured factors and measurement equipment

Item	Measured factors	Quantity Ground floor	First floor	Sensor	Range	Accuracy
01	Global and diffuse solar radiation in horizontal surface	-	1	BF3	0 – 1250 W/m^2	Global: ±5W/m^{-2} ±12% Diffuse: ±20W/m^{-2} ±15%
02	Wind speed	-	1	WMR200	2m/s ~ 10m/s, 10m/s~56 m/s	(+/- 3m/s), (+/- 10%)
03	Wind direction	-	1	WMR200	0-360º	16 positions,approx. every 14 seconds
04	Outdoor temperature	-	1	WMR200	-30ºC to 60ºC (-4ºC to 140ºC)	+/- 1% (+/- 2%)
	Outdoor Humidity	-	1	WMR200	25% - 90%	+/- 7%
05	Rainfall	-	1	WMR200	0 to 9999 mm	+/- 7%
06	Temperature in shaded volumes	-	1	SHT75	-30ºC to 60ºC (-4ºC to 140ºC)	+/- 1% (+/- 2%)
	Humidity in shaded volumes	-	1	SHT75	25% - 90%	+/- 7%
07	Inside temperature	9	11	SHT75	-30ºC to 60ºC (-4ºC to 140ºC)	+/- 1% (+/- 2%)
08	Inside humidity		11	SHT75	25% - 90%	+/- 7%
09	Electrical current	1	1	Onset CTV-B	0 - 50 A	+/- 4.5%

2.2.3 Data logger system

The indoor temperature, humidity and electrical current are processed and stored in Mini-PC Data Logger System, eBOX-4851. The data can be collected from Mini-PC using USB flash for storing data to the database or displayed in the touch screen display 7" for local analyses. For more details about the description and characteristics of the equipment, see Figures 2.3(a-b).

2.2.4 Weather station

Figure 2.4(a) shows a weather station equiped with sensors for measuring the outdoor temperature, outdoor humidity, wind speed, wind direction and rainfall. The system is wireless and send data to the Wireless Console and stores it in a Mini-PC Data Logger System. The data can be collected from Mini-PC using USB flash for storing in a database or displayed on the touch screen display 14" for local analyses.

Figure 2.4(b) presents the solar radiation sensor installed in the north side of the building which measures the global and diffuse solar radiation.

Figure 2.4 (a) Wind, temperature, humidity and rainfall sensors in the side of the building

Figure 2.4 (b) Solar radiation sensor in the North south side of the building

2.2.5. The SHT75 sensors

SHT75 are the types of sensors installed in “3 de Fevereiro Building” for measuring the indoor as well as the outdoor temperature and humidity. Figure 2.5(a) shows the sensors installed indoor and Figure 2.5(b) shows the temperature and humidity sensor installed in the shaded parts represented by numbers 33 and 34 in the Figure 2.2(b).

4x2.5x5.1 mm, modular wire and fixed on the walls, are the types of cables used for connecting the sensors in the Pic-logger ADC16, see Figure 2.5(a) and (b) below.

The installation was carried out according to the RSIUEE (Regulamento de Segurança de Instalações de Utilização de Energia Eléctrica, Decreto-Lei nº. 740/74, Portugal), Portuguese regulation, applied in Mozambique with some items excluded.

Figure 2.5(a) SHT75 temp. and RH sensor inside the flat

Figure 2.5(b) SHT75 temp. and RH sensor in shaded parts

3 Measurement results and discussion

In this chapter the measurement results are presented and discussed. A period of four month, from June to September, 2009 are presented and analyzed with respect to proper function of the measurement equipment.

3.1 Solar radiation

Figure 3.1 (a) shows the variation of the global and diffuse solar radiation in June and July, 2009. From August to September, see appendix D.

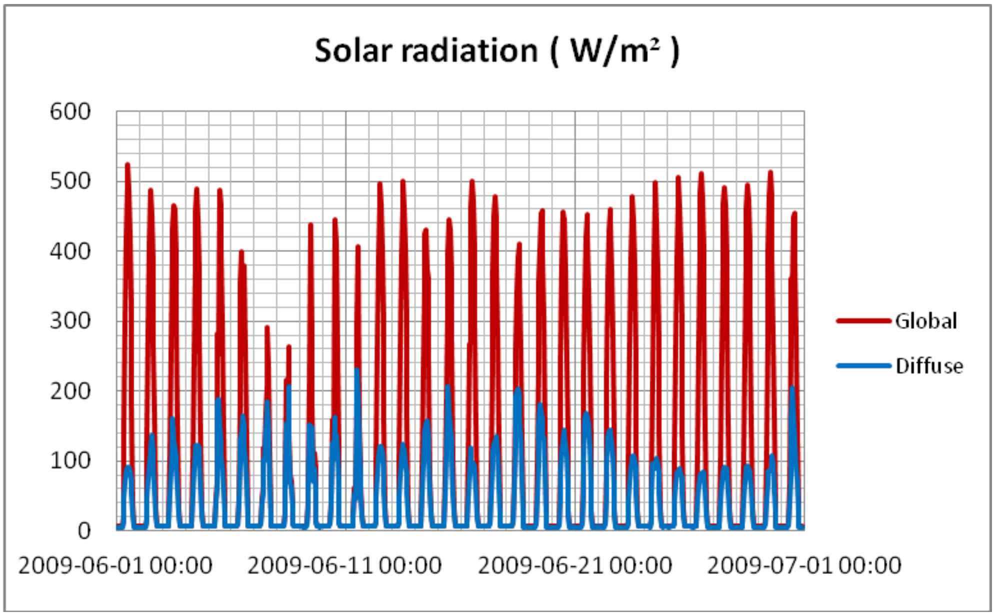

Figure 3.1 (a) Global and diffuse solar radiations in June, 2009

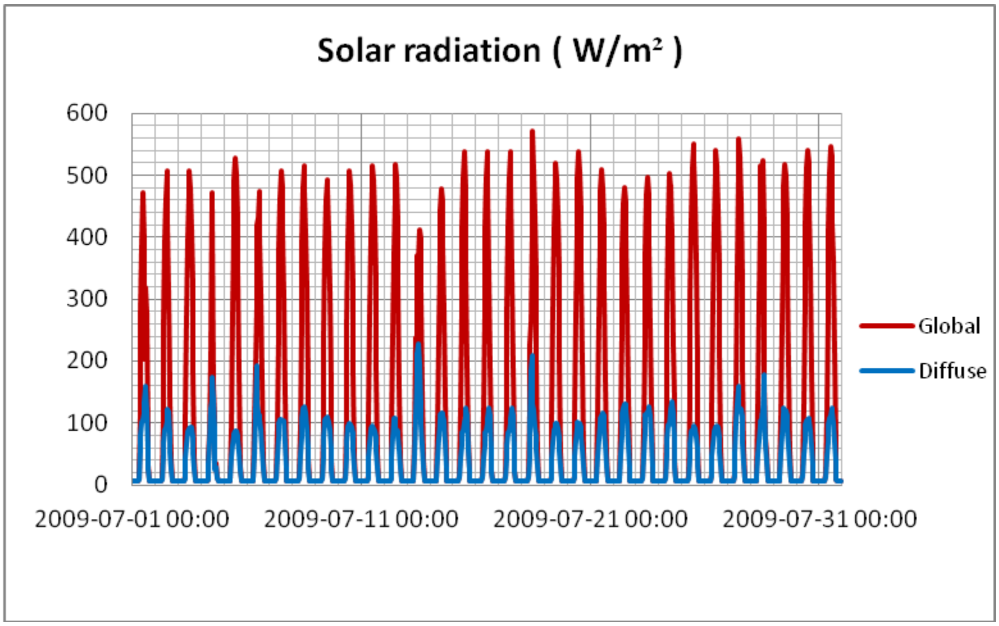

Figure 3.1 (b) Global and diffuse solar radiations in July, 2009

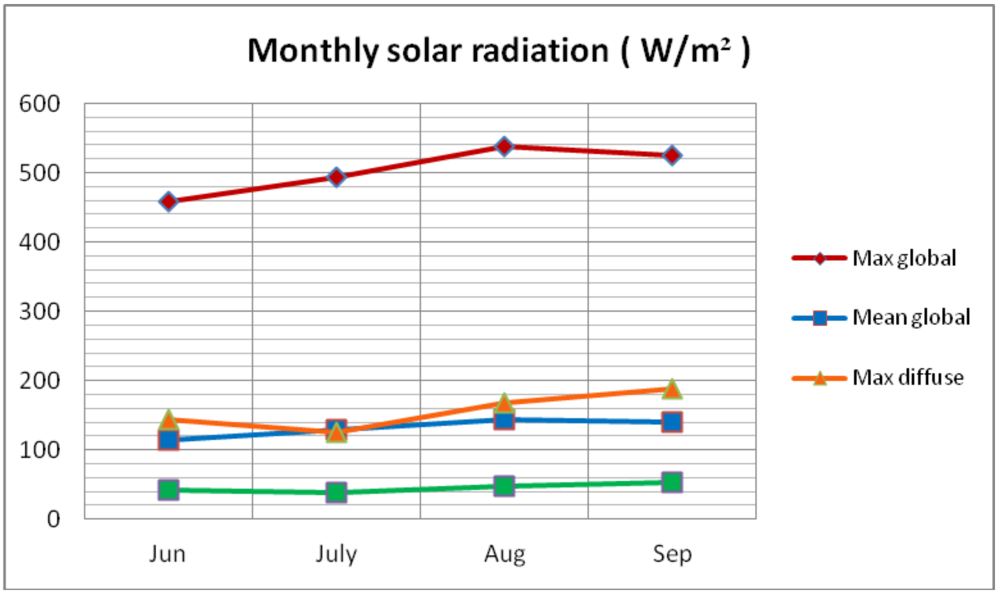

Figure 3.1(c) Monthly global and diffuse solar radiation

Figure 3.1(c) illustrates the maximum and mean values of solar radiation from June to September. The monthly maximum solar radiation values in the figure are the mean value of all the maximum daily solar radiation observations during the month. The monthly mean values are the mean value of all observations during the month. Similar Figures are presented in above chapters, for other outdoor and indoor climatic observations. This presentation is close to that one used by Maputo Airport Meteorological Station which was used for comparison in chapter 3.7.2.

If we analyze the data in Figure 3.1(c) we can come to a conclusion that June and July are months with low rate of solar radiation compared with August and September. As known, Mozambique has two main seasons: a hot, normally wet season from October to March and a cooler, mostly dry season from April to September (htt://www.worldinformation.com). So, from April to September is winter and June and July are the coldest months of the winter. See appendix E.

Table 3.1 (a) shows the date and time when low rates of the global and diffuse solar radiation occurred, during the winter in 2009. The daily variations of the global and diffuse solar radiation are presented in Figures 3.1(d-f).

Table 3.1(a) Days with less global and diffuse solar radiation from June and July (peak rates).

	Solar radiation (W/m^2)					
	Global			Diffuse		
Month	Date	Time	Value	Date	Time	Value
June	2009-06-08	12:00	262.8	2009-06-08	10:00	206.00
July	2009-07-13	13:00	412.5	2009-07-05	13:00	87.2

Figure 3.1(d) shows the global and diffuse solar radiation of 2009-06-08 in winter with low solar radiation. The variation that appears from 10 a.m. up to 11 a.m, is due to clouded sky, see Table 3.1 (b).

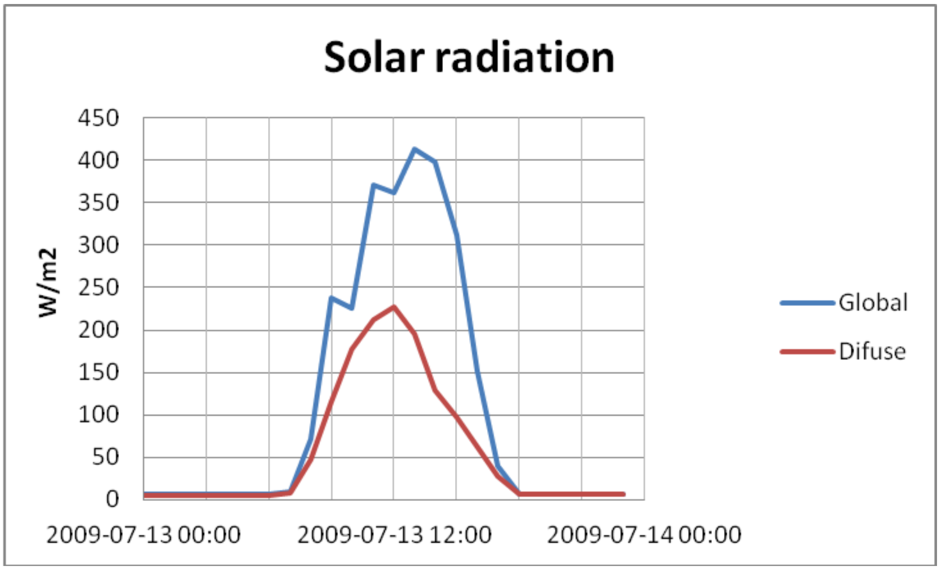

Figure 3.1(d) Global and diffuse solar radiation, 2009-06-08

Figure 3.1(d) Shows winter day (2009-07-13) with low global solar radiation in July. The variation occurred from 9:00 a.m. up to 13 p.m. it is due to clouded sky, see Table 3.1 (b). As indicated in Table 3.1(a) the low global solar radiation in July apears on the 13th inasmuch as the diffuse solar radiation apears on the 5th, Figure 3.1(f). For more data details, see appendix F.

Table 3.1(b) Values during the period of ascent and descent of solar radiation due to clouded sky, see Figures 3.1(c-e).

	Ascent and descent of solar radiation due to clouded sky (W/m^2)								
	2009-06-08			2009-07-13					2009-07-05
	high	low	high	high	low	high	low	high	high
Global	215.8	88.0	262.8	238.4	226.1	370.00	362.4	412.5	-
Diffuse	152.6	71.5	206.00	-	-	-	-	-	87.2
Time	10:00	11:00	12:00	9:00	10:00	11:00	12:00	13:00	13:00

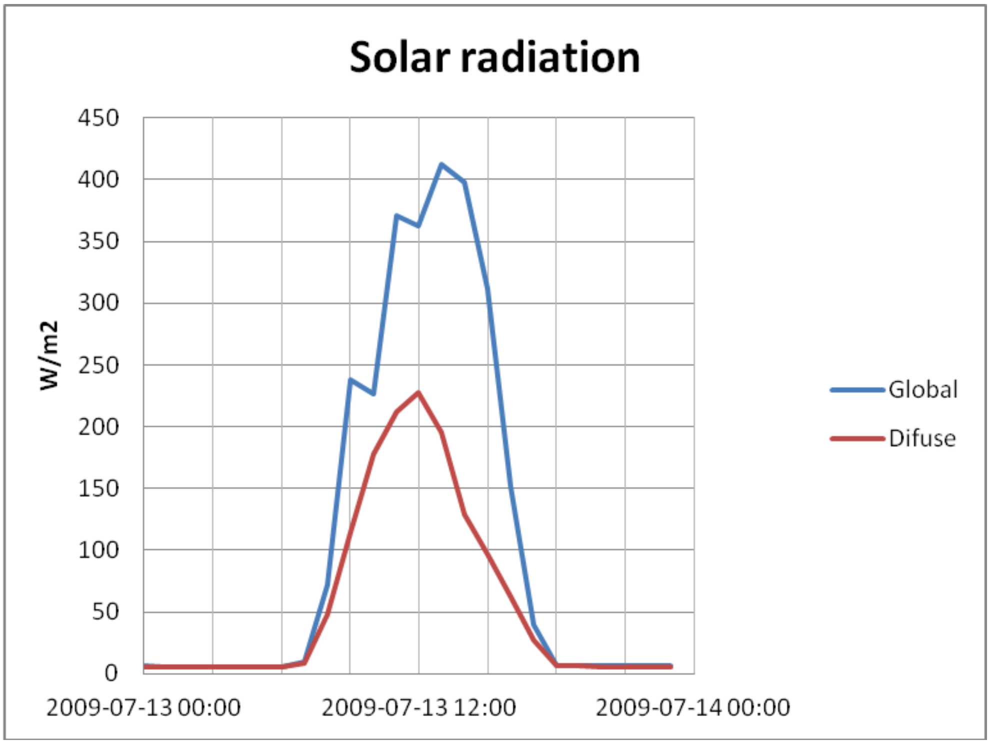

Figure 3.1(e) Global and diffuse solar radiation of 2009-07-13

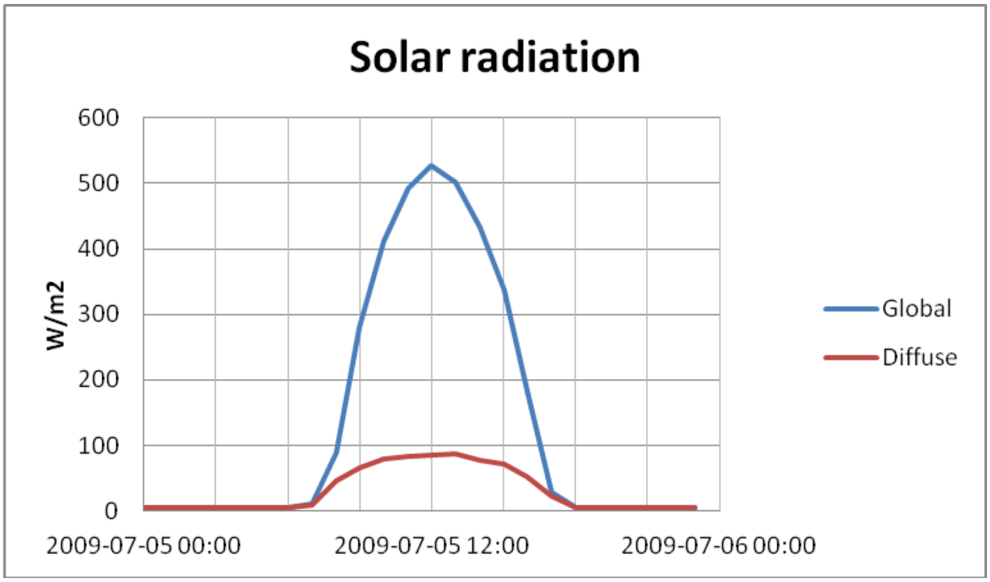

Figure 3.1(f) Global and diffuse solar radiation in June, 2009-07-05

Figure 3.1(g) shows the global and diffuse solar radiation of the 2009-07-25, the coldest day in winter, as mentioned in Chaper 3.2 related to outdoor temperature. The maximum value of the global solar radiation was 527.8 W/m^2 occurred at 12:00 and the diffuse was 87.2 W/m^2 at 13:00.

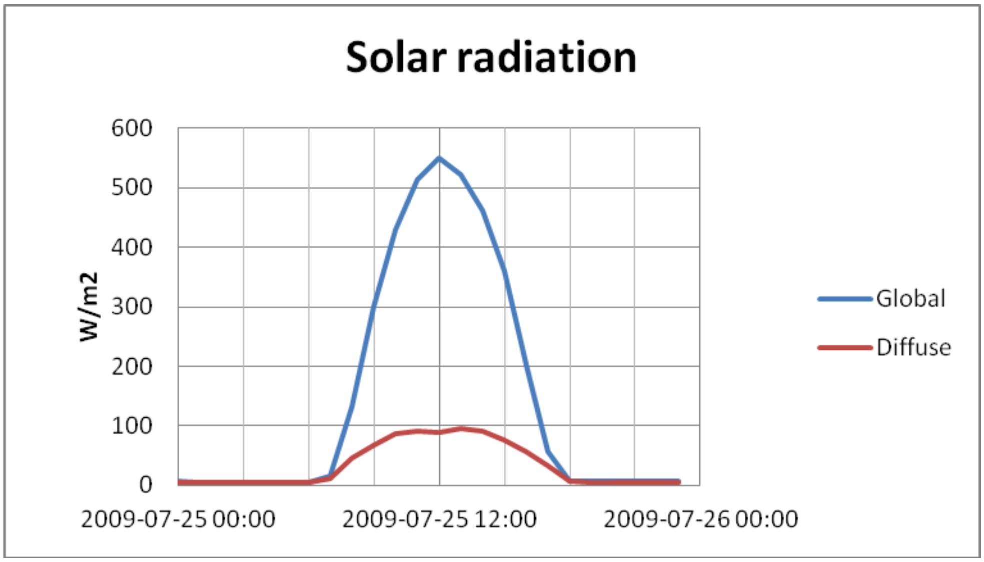

Figure 3.2 (g) Global and diffuse solar radiation of the coldest day in winter, 2009-07-25

The maximum and mean solar radiation energy from June to September are presented in Table 3.2. The rates show that Maputo City has enough solar energy to cover the need for hot water and heating or cooling in the buildings. Further work is required for determination of the needs mentioned for hot water, heating and cooling systems.

Table 3.2 Solar radiation energy

	Solar radiation energy (KWh/m^2/Period)		Daily solar radiation energy (KWh/m^2/day)	
	Global	Diffuse	Global	Diffuse
Maximum	1,475	457	12	4
Mean	386	132	3	1

3.2 Outdoor temperature

Figure 3.2(a-b) present the measured outdoor temperature. The outdoor temperature sensor is placed in the south side of the building, see Figure 2.4(a). June and July are months with low outdoor temperature and 2009-07-25 was the day with a minimum of 11.2ºC at 6:00 a.m., the lowest temperature from June to September, see Table 3.3. For more details about outdoor temperature of August and September, see appendix D.

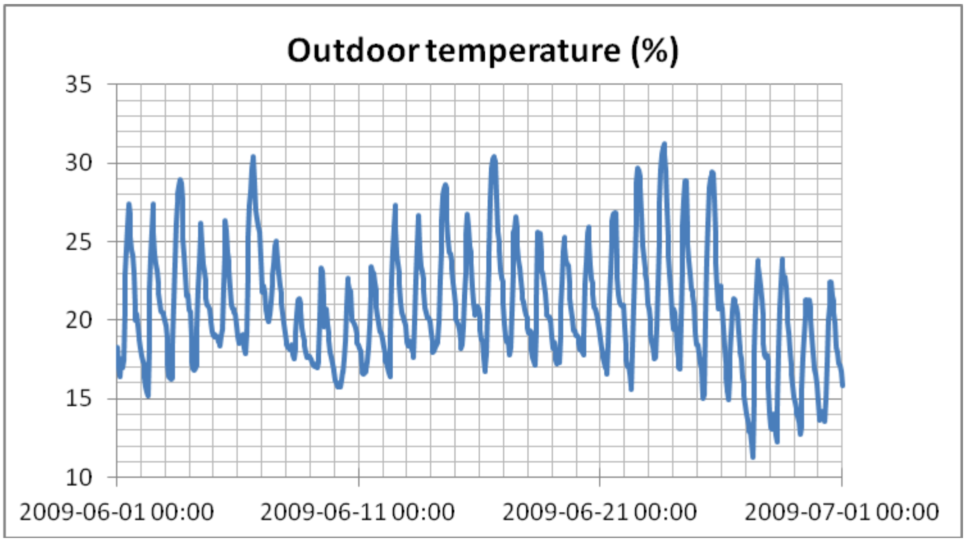

Figure 3.2 (a) Outdoor temperatures in June, 2009

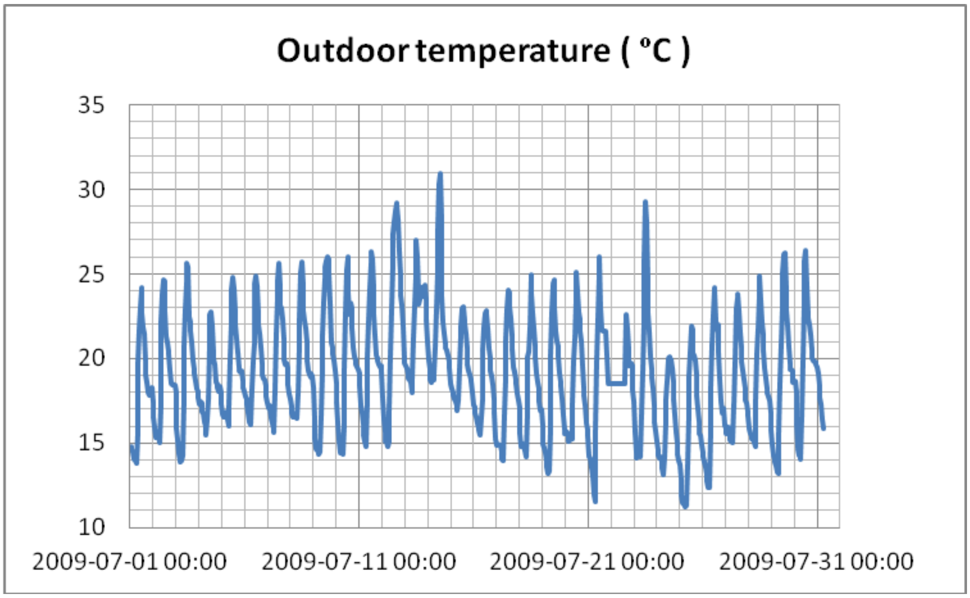

Figure 3.2 (b) Outdoor temperatures in July, 2009

Figure 3.2 (c) presents the calculated maximum, mean and minimum outdoor temperature from June to September, 2009.

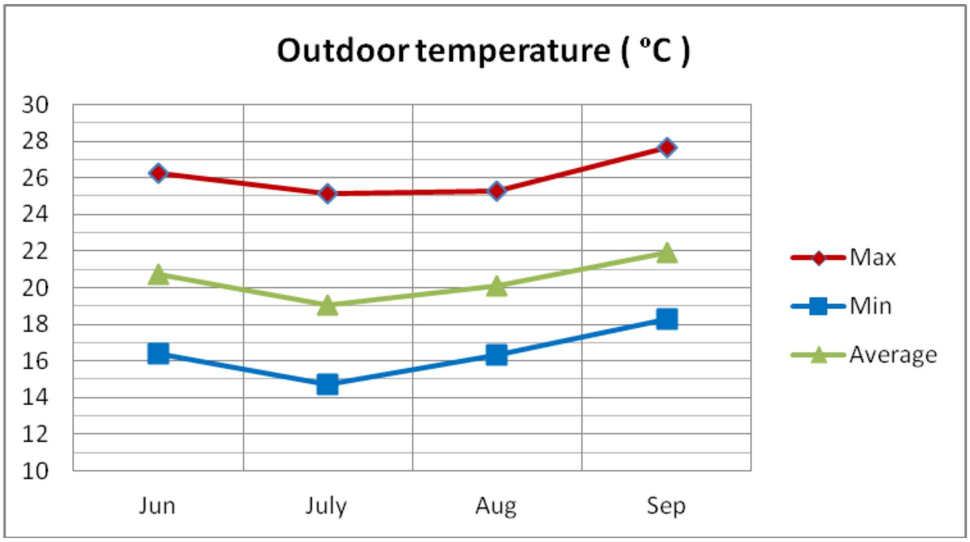

Figure 3.2 (c) Maximum, Mean and minimum outdoor temperature

Table 3.3 Maximum and minimum temperatures (monthly peak outdoor temperature)

Month	Day Time (h)	Outdoor temperature(°C)	
June	23-06-09 13:00	Max	30.3
	27-06-09 07:00	Min	11.3
July	14-07-09 12:00	Max	30.3
	25-07-05 06:00	Min	11.2
August	09-08-09 14:00	Max	30.4
	09-08-09 06:00	Min	12.9
September	08-09-09 14:00	Max	35.8
	13-09-09 04:00	Min	16.1

The Figure 3.2 (d) shows the variation of the outdoor temperature in July 2009-07-25, the coldest day in winter.

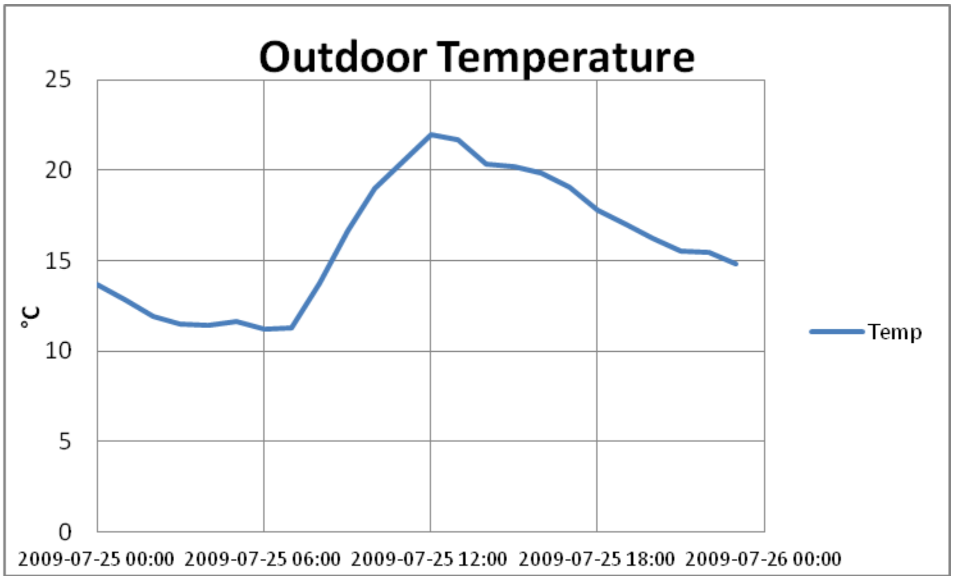

Figure 3.2(d) Outdoor temperature of the coldest day in winter

3.3 Temperature in the shaded parts of the building

Figure 3.3 shows the temperature in the shaded parts of the building. The difference of the temperature results between the graphs of the north and south, lies on the position of the sun relatively to the site of the building (25º57´S and 32º35´E). So, the influence of the solar radiation is more intensive in the north side than in the south side, because during the course of the sun from sunrise to sunset the south side of the building is less irradiated by sunlight and consequently less temperature occurs compared with the opposite side. For more information about outdoor temperature in the shaded parts from July to September, see appendix D.

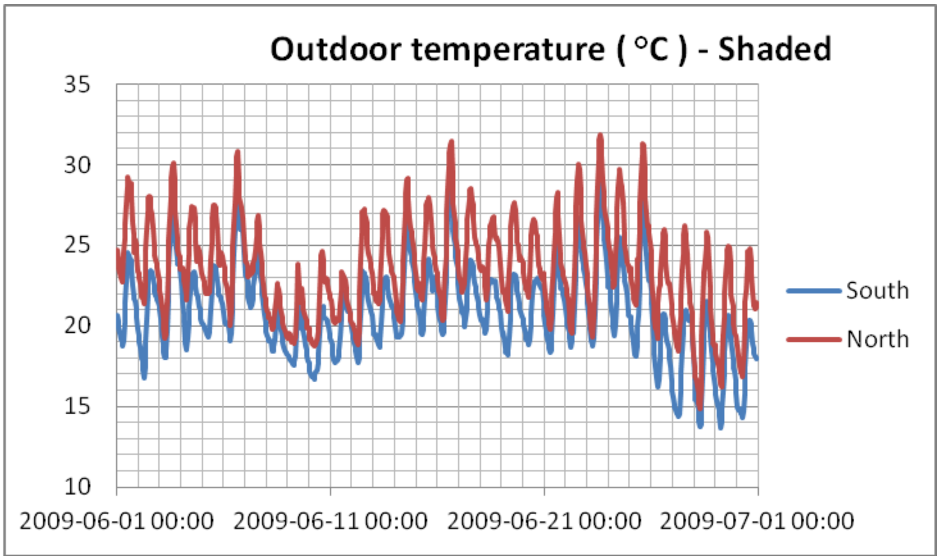

Figure 3.3 Temperatures in the shaded parts of the building in June, 2009

3.4 Temperature inside the building

Figure 3.4(a) shows the indoor temperature of the ground floor and Figure 3.4(b) shows the indoor temperature of the first floor. From Figure 3.4(b) it can be seen that the staircase is the volume with lower temperature than other volumes of the building except in days indicated in Table 3.4(b). The reason of high temperature in the staircase in those days is due to lack of natural ventilation. This means that were days without gale.

According to the orientation of the building, the east wall of the staircase is directly irradiated by the solar radiation in the mornings and warms the air existent in this volume. So, with very little natural ventilation the air temperature of this volume becomes high in afternoons and consequently warms the west wall which increases the air temperature in the living room of the first floor, see Figure 2.2(b) and Figure 3.4 (b).

The kitchens of the apartments are located in the north side, the hottest position in terms of solar gains. So, the temperature in these rooms is higher than the rooms situated in the south side of the building.

On the ground floor, Figure 3.4(a), the graphs present a great agreement between the temperature of the living room and bed room. This is due to the fact that the two volumes having the same location (south side), the same characteristics, the same solar radiation and the same casual gains.

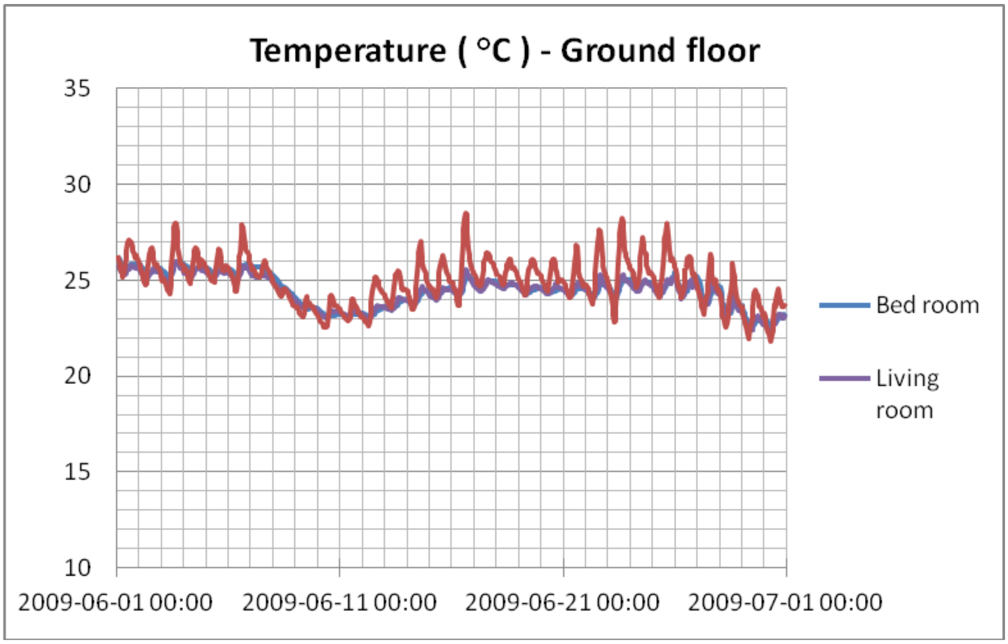

Figure 3.4(a) Indoor temperature on the ground floor, June, 2009

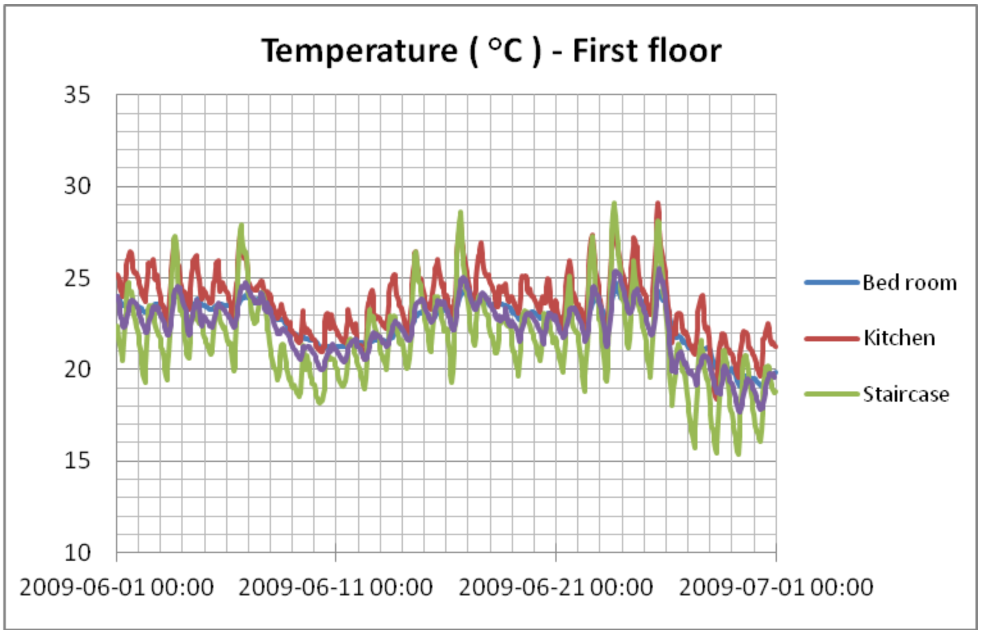

Figure 3.4(b) Indoor temperature on the first floor, June, 2009.

Figure 3.4(c-d) presents the maximum, mean and minimum degrees of the indoor temperatures in the ground and first floors

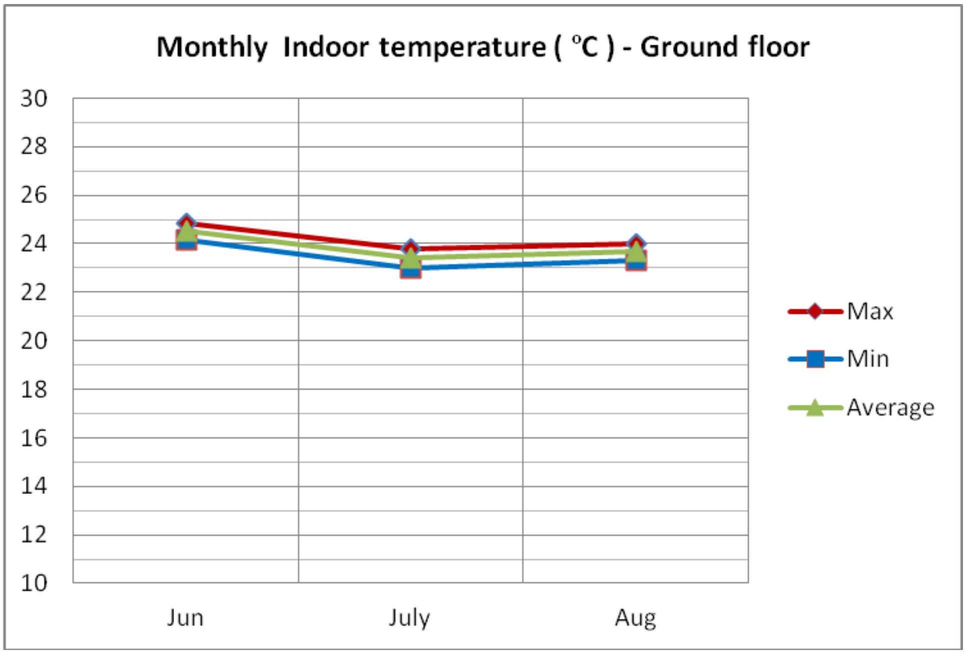

Figure 3.4(c) Max., mean and min. monthly rates of the indoor temperature.

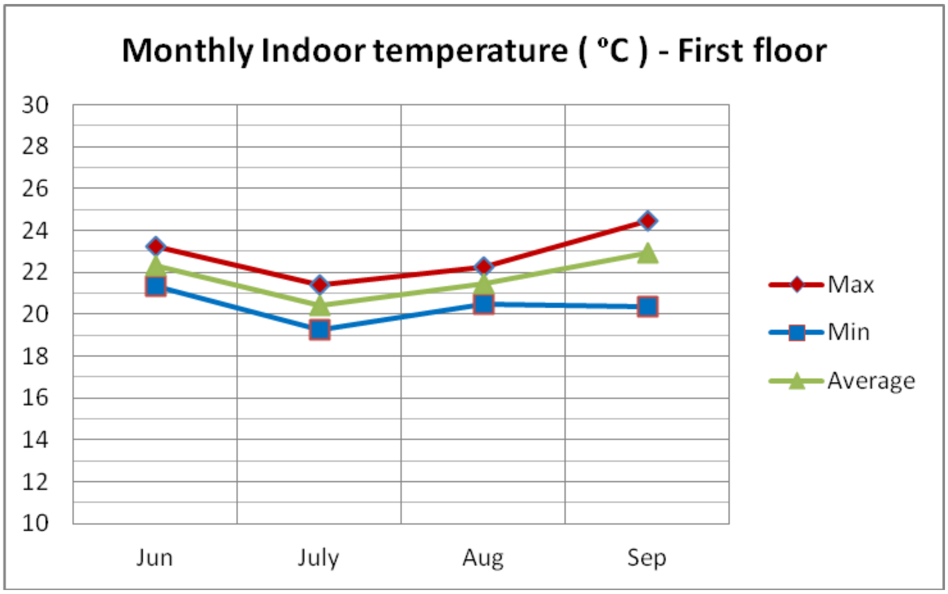

Figure 3.4(d) Max., mean and min. monthly rates of the indoor temperature.

Table 3.4(a) shows the calculated rates of the indoor temperature of the apartments and extracted from Figures above.

Table 3.4(a) Maximum, mean and minimum rates of the indoor temperature in the apartments.

	Indoor temperatures (°C)							
	Ground Floor				First Floor			
	June	July	August	September	June	July	August	September
Max	24.8	23.8	24.0	25.3	23.2	20.4	22.3	24.4
Mean	24.5	23.4	23.7	24.9	22.3	20.4	21.4	22.9
Min	24.2	23.0	23.3	24.4	20.4	19.2	20.4	20.4

Table 3.4(b) shows the days with high temperature in the staircase.

Days with high temperature in the staircase		
Date	Hour	Temp.(^{0}C)
2009-06-03	15:00	27.1
2009-06-06	15:00	27.6
2009-06-14	14:00	26.2
2009-06-16	16:00	28.4
2009-06-22	14:00	26.7
2009-06-23	14:00	23.5

From June to September the maximum indoor temperature on the ground floor was 25.3ºC in September and the minimum on the first floor was 19.2ºC in July.

The need of heating an area independent of a building require useful energy to maintain the temperature within 18ºC, temperature threshold of comfort during a season of heating, RCCTE-7 (Regulamento das Características de Comportamento Térmico dos Edifícios, Decreto-Lei nº. 40/90 e Decreto-lei nº. 118/98, Portugal, 1998), Portuguese regulation, applied in Mozambique but, with adaptation in some items.

During the heating season the minimum temperature is 11.2ºC as indicated in Table 3.3 and Figure 3.2 (d). Thus, during winter space heating is necessary to maintain the building with temperature within 18ºC (Godfrey Boyle (2000). This will be the next work related to the characterization of thermal performance of the building and energy assessment of artificial devices for heating and cooling rooms.

Comparing the temperature between the two floors can be concluded that the ground floor presents higher temperatures than the first floor. That fact can be interpreted as increased by internal gains dependent of occupant behavior such as the closing and opening the windows, the crowding of the apartment, the use of electric devices, etc., see chapter 3.8.1, first paragraph.

The reason for high temperature in the kitchen is the same as explained above for the first floor.

Analysing the graphs of July, August and September it is seen that the indoor temperature presents the same behaviour as the temperature of June. For more details, see appendix D.

3.5 Wind

3.5 1 Meteorological instrument

WM200/WM200A anemometer was used to measure the wind speed and its direction around the building. This instrument was installed outside of the building in the south side as indicated in Figure 2.4 (a).
Wind is often described by two characteristics: wind speed and wind direction. Wind speed is the velocity attained by a mass of air travelling horizontally through the atmosphere and it is measured by meters per seconds (m/s) while wind direction is measured by a wind vane. There are sixteen principal wind direction bearings which are used to report wind direction.

Thus, wind direction is measured from the direction where the wind comes from. For example: southerly wind blows to the north and a northerly wind blows towards the south.

3.5.2 Wind speed

Figure 3.5(a) shows the measurement equipment results of the wind in June. According to the building position of the building it is seen that there is wind speed around the building which will be considered in the future study related to ventilation, cooling and wind frequency survey in the building. For more information about wind speed from July to September, see a appendix D.

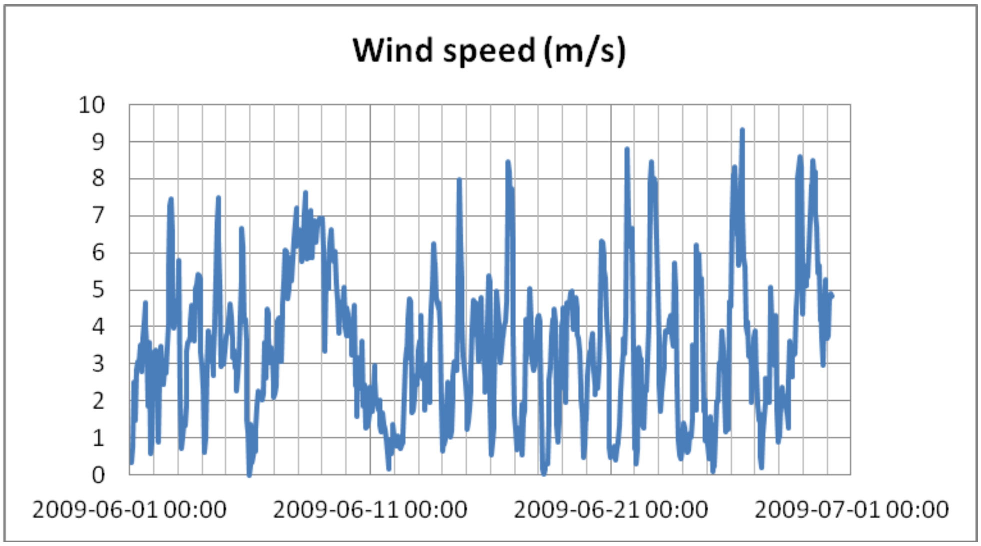

Figure 3.5 (a) Wind speed in June, 2009

The Figure 3.5(b) shows the maximum, mean and minimum rates of the wind speed around the building. Analyzing the results of the wind speed measurement it is concluded that the rates increase from June to subsequent months. The Figure 3.5(b) and Table 3.5 clearly show this increasing wind speed trend from June to September.

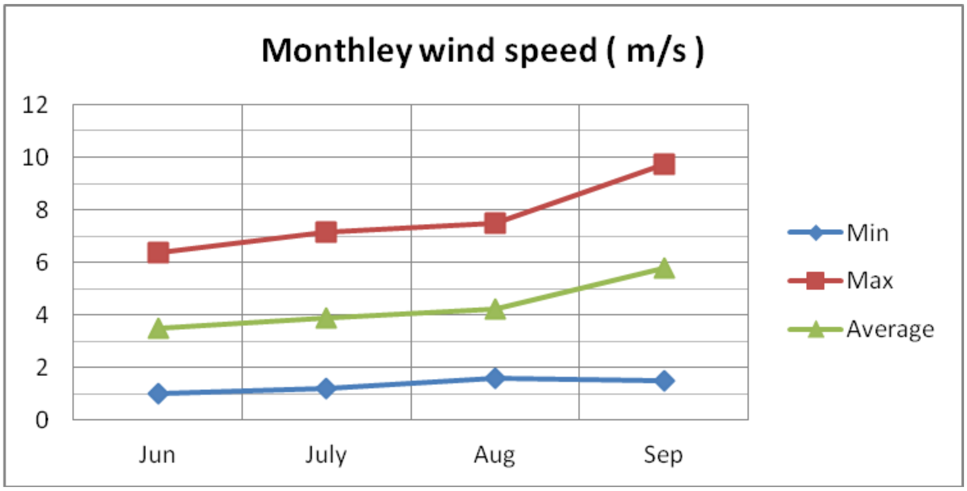

Figure 3.5(b) Monthly maximum, mean and minimum wind speed

Table 3.5 Maximum, mean and minimum wind speed, extracted from the figures above.

		Wind speed (m/s)			
		June	July	August	September
windspeed	Max	6.4	7.1	7.5	9.7
	Mean	3.5	3.9	4.2	5.8
	Min	1.0	1.2	1.6	1.5

3.5.4 Wind direction

Figure 3.5(c) shows the wind direction trend in Maputo City. Theoretically, where the building is located the wind should be southerly, that is: from southeast (SE) to northwest (NW). But due to the influence of the wall (see Figure 2.4(a)), the Figure 3.5(c) shows the wind blowing from Southwest to Northeast in certain periods of the month and in other from East-Northeast to West-Southwest.

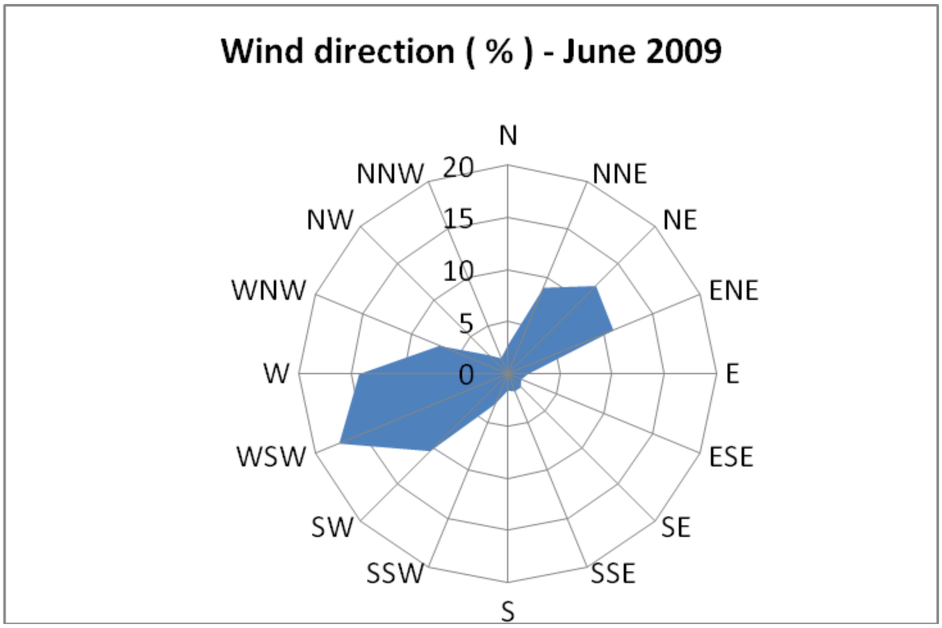

Figure 3.5(c) Wind direction in June, 2009.

3.6 Rainfall

The objective of measuring rainfall is to provide a database of Maputo city rainfall. This information is useful for preventing the harmful phenomena caused by the moisture in the structure of the buildings. If the quantity of rain is known, it is possible to take certain precautions for eliminating the harmful effects of the moisture caused by the rain.

This work presents the results of the data collected in only two months (June and July) because the sensor had initially been installed far away from the Wireless Console and the signal was blocked by internal walls.

During the period of installation of the rainfall sensor, the system worked perfectly but after two months it started to present problems. These problems were solved after October, 2009.

The Figures 3.6 (a-b), show that during June and July there was a little precipitation. Thus, in June the precipitation was about 9.5 mm and about 2 mm in July.

The measured result in July shows that the rainfall measurement equipment ceased to function on 2009-07-05. This is presented by a horizontal line from that day in Figure 3.6(b). The problem was the transmission between the equipment and the Wireless Console failed.

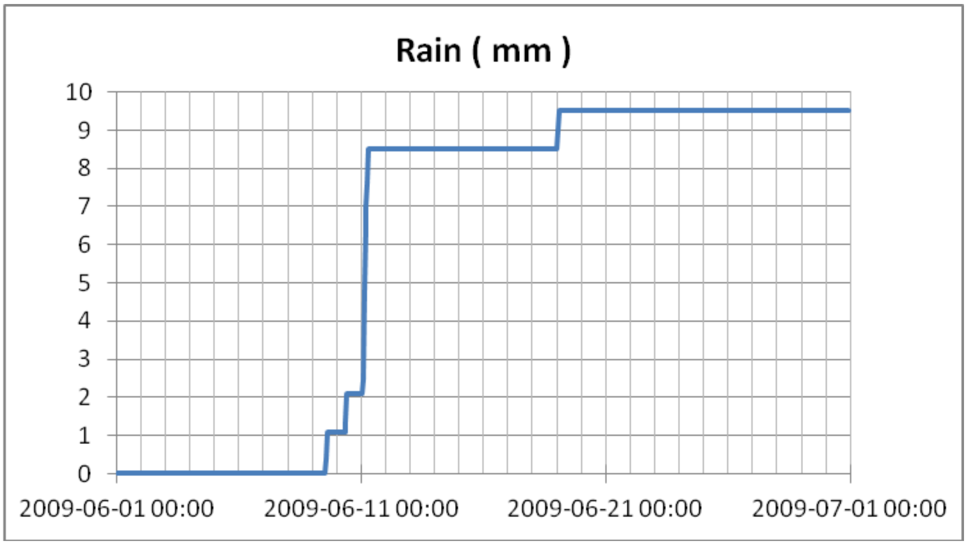

Figure 3.6(a) Rainfall in June, 2009

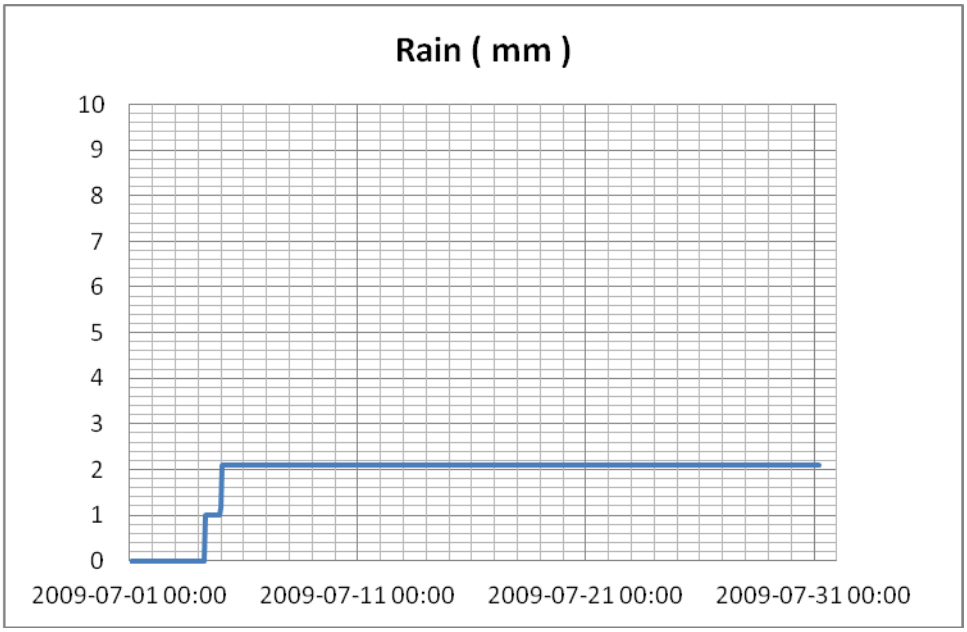

Figure 3.6(b) Rainfall in July, 2009

3.7 Relative humidity

3.7.1 Outdoor relative humidity

Figure 3.7(a-b) illustrate the outdoor relative humidity which represents the ratio of the partial pressure of water vapor in the mixture to the saturated vapor pressure of water at certain temperatures around the building. For more information about outdoor temperature from July to September, see appendix D.

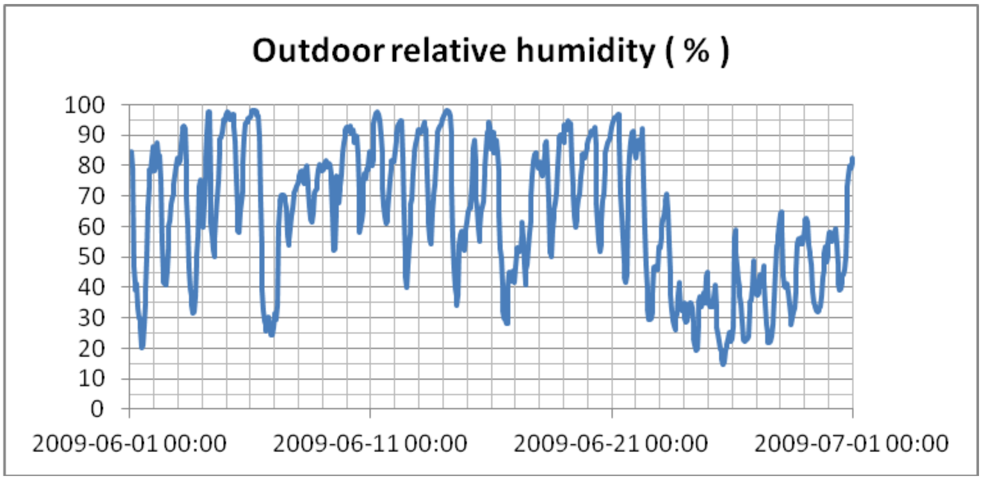

Figure 3.7(a) Outdoor relative humidity in June, 2009

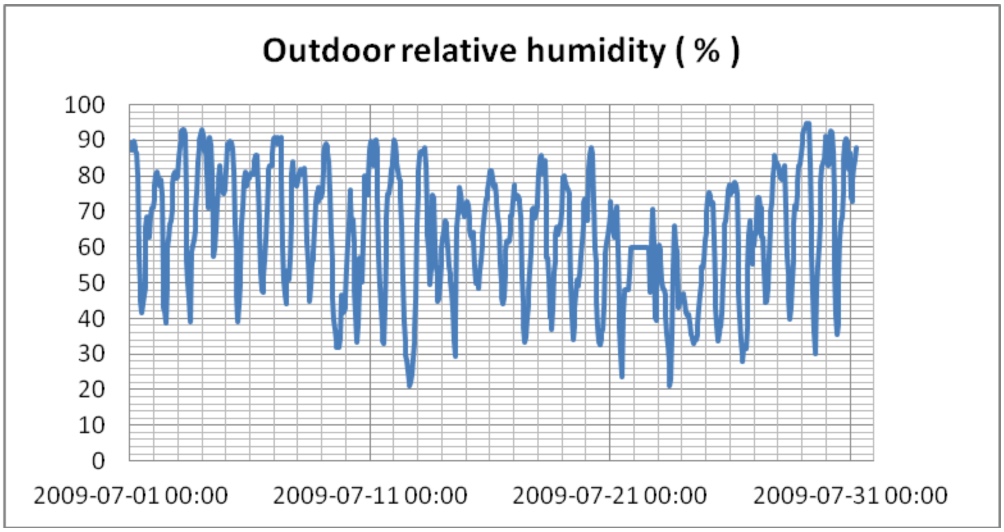

Figure 3.7(b) Outdoor relative humidity in July, 2009

The Figure 3.7(c) presents maximum, mean and minimum outdoor relative humidity calculated from the figures above.

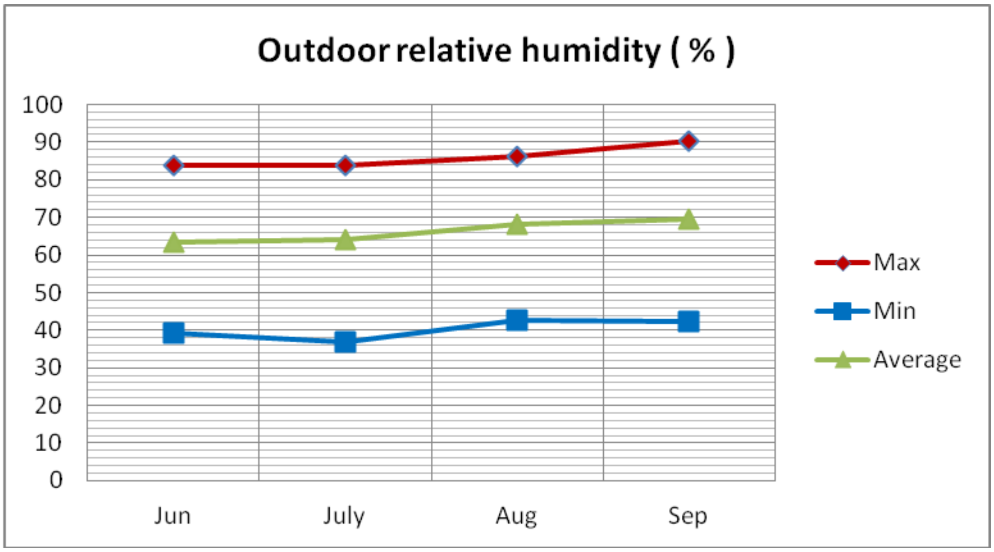

Figure 3.7(c), Maximum, mean and minimum outdoor relative humidity

The Figure 3.7(d) shows the variation of the outdoor relative humidity of 2009-07-25, the coldest day in winter, 2009.

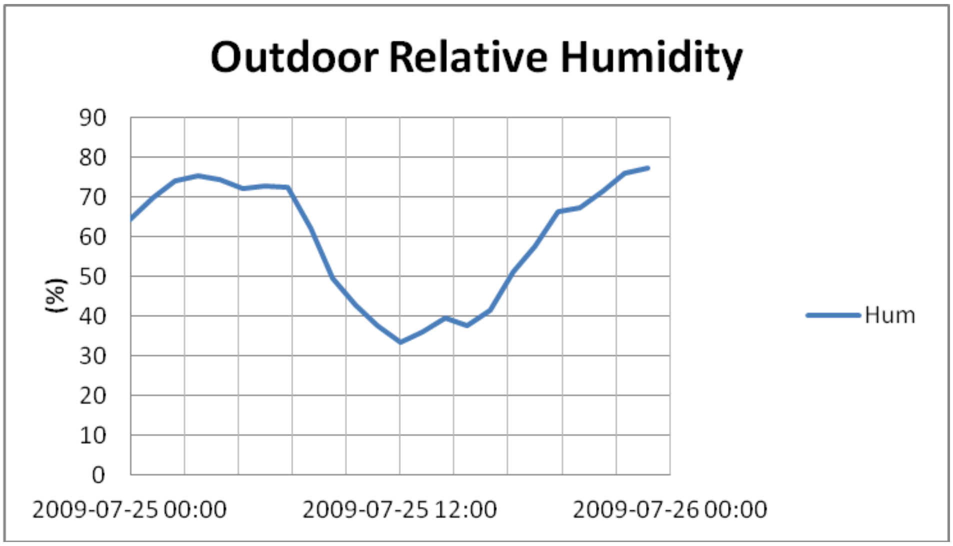

Figure 3.7 (d) Outdoor relative humidity of the coldest day in winter, 2009

3.7.2 Comparison of the field measurement with data from Maputo Airport Meteorological Station.

Table 3.7(a) Data of the outdoor temperature, rainfall and relative humidity from field measurement and Maputo Airport Meteorological Station.

		Outdoor temperature (%)			Rainfall (mm)	Relative Humidity (%)		
		Max.	Mean	Min.	-	Max.	Mean	Min.
June	Meas.	26.3	20.7	16.4	9.5	83.9	63.4	39.2
	MAMS	25.0	18.5	14.2	26	-	66	-
July	Meas.	25.1	19.1	14.7	2.0	83.8	64.0	36.8
	MAMS	25.0	18.2	13.9	12	-	66.0	-
August	Meas.	25.3	20.1	16.3	-	86.2	68.1	42.8
	MAMS	25.7	19.1	15.0	12	-	65.0	-
Sep.	Meas.	27.7	21.9	18.3	-	90.3	69.5	42.4
	MAMS	28.4	20.6	16.0	35	-	65	-

- Meas. – Measured
- MAMS - Maputo Airport Meteorological Station

For verifying, the measurement results were compared with data from Maputo Airport Meteorological Station (MAMS), see Table 3.7(a) and appendix E. The difference of the outdoor temperature measured and those from MAMS it is between -0.7ºC to +2.3ºC and -2% to 4.5% for relative humidity. So, it can be concluded that there is no great difference in results between measured and those from MAMS. The only difference is that of the place where the measurement took place. So, the measurement equipment analyzed in this report is close to the building inasmuch as the MAMS measurement equipment is placed in the open space and far away from the building.

Rainfall – As mentioned above, during the period of installation of the rainfall sensor, the system worked perfectly but after two months it started to present problems and these problems were solved after October, 2009. So, for comparison of the measured data and those from MAMS, first of all is considered the following: Mozambique has a total average rainfall of 769 mm, equivalent to an average monthly rainfall of 64.1 mm. January is the month with the highest quantity of precipitation with 130 mm of rain falls over a period of 9 days while in July and August only 13 mm of rain falls and the average in June is 27 mm (htt://www.climatetemp.info). Coming to the data presented in Table 3.7(a), it can be concluded that June was the driest month.

3.7.3 The coldest day

The Table 3.7 (b) presents the summary of the outdoor data on 25th July 2009 the coldest day in the year.

Table 3.7 (b) the outdoor data on 25th July, the coldest day in winter, 2009.

		Max.	Mean	Min.
Solar radiation (W/m^2)	Global	527.8	96	0
	Diffuse	87.2	36	0
Dry bulb temperature (^{o}C)		23.8	17.5	11.2
Wind speed (m/s)		5.1	2.5	0.2
Relative humidity (%)		60.9	38.1	21.8

3.7.2 Indoor relative humidity of the ground and the first floors

Figure 3.7(e-f) show the graphs of the indoor relative humidity of the ground and first floor of the month of June and the Figure 3.7(g-h) present the calculated maximum, mean and minimum rates of the indoor relative humidity of the same floors. For more information about indoor relative humidity of the months from July to September, see appendix D.

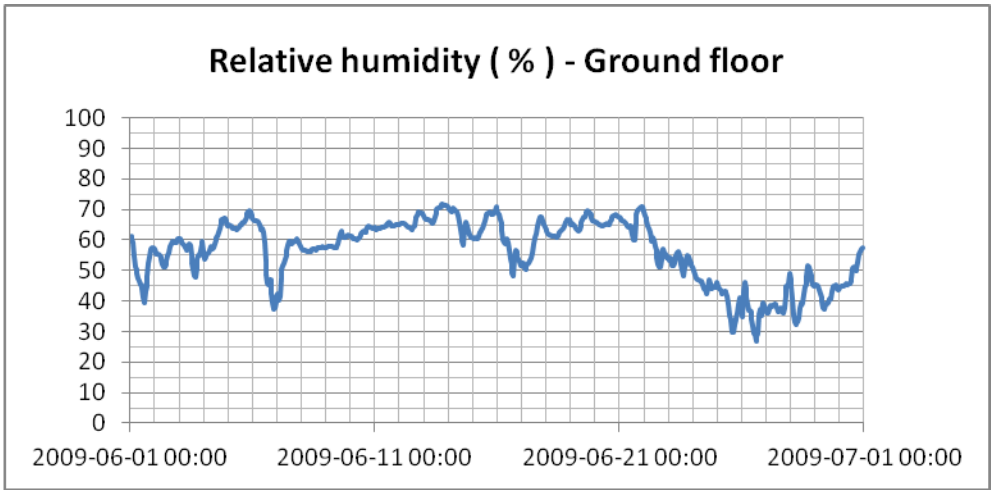

Figure 3.7(e) Indoor relative humidity, June, 2009

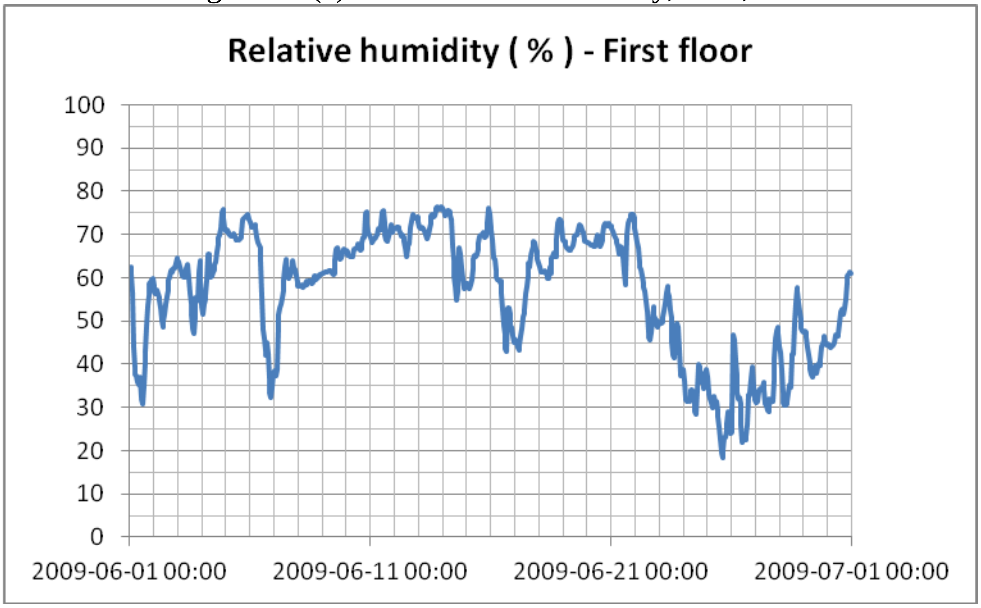

Figure 3.7(f) Indoor relative humidity. June, 2009

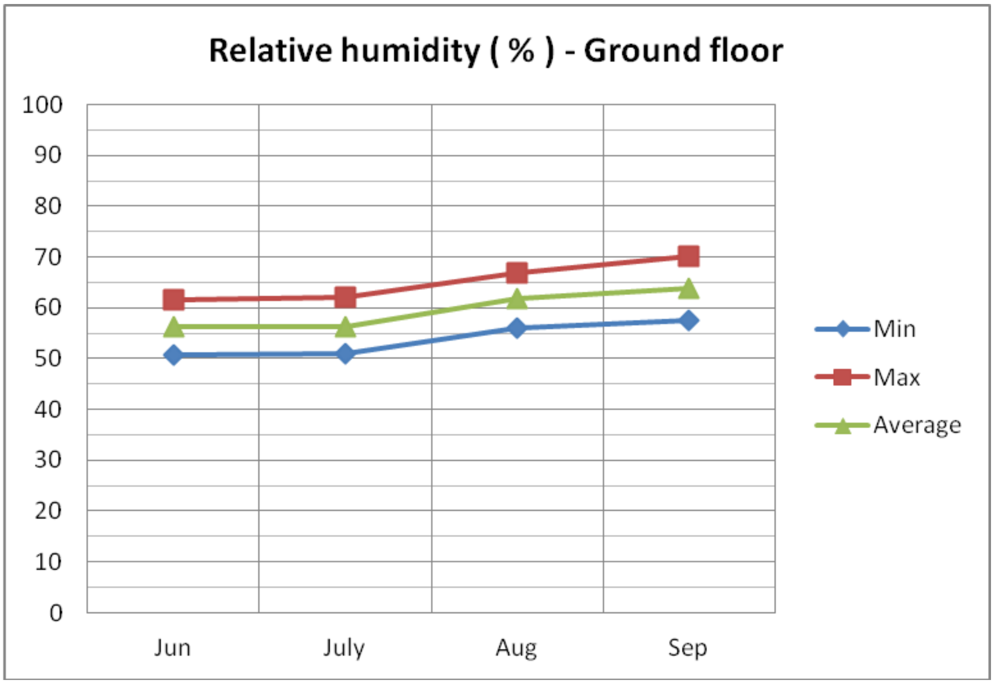

Figure 3.7(g) Max., mean and min. rates of the indoor relative humidity of the ground floor

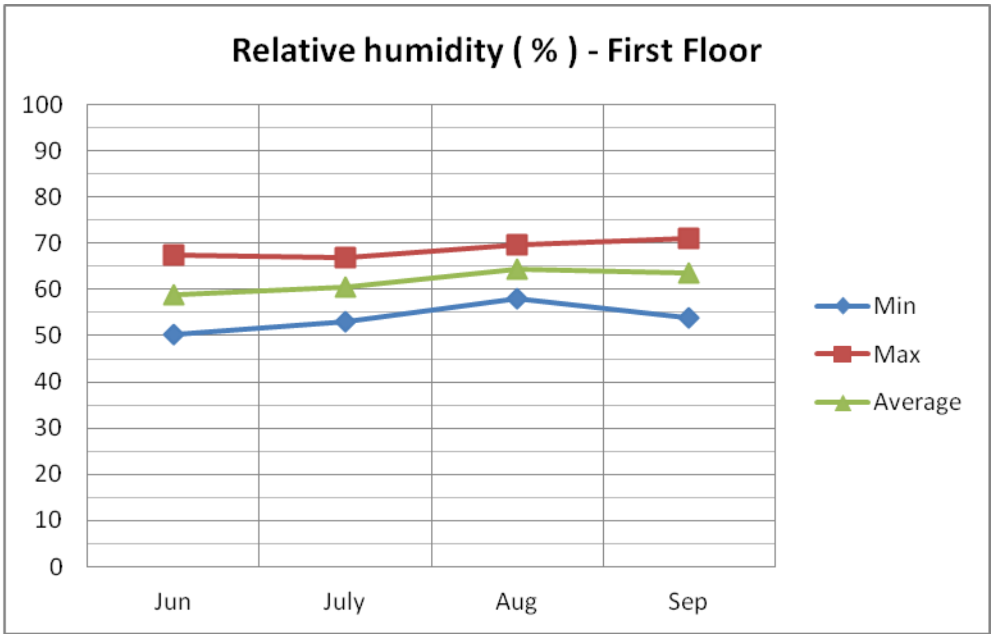

Figure 3.7(h) Max., mean and min. rates of the indoor relative humidity of the first floor

Table 3.7(c) shows the maximum, mean, and minimum indoor relative humidity on the ground and first floors

	Indoor Relative Humidity (%)							
	Ground Floor				First Floor			
	June	July	August	September	June	July	August	September
Max	61.5	61.9	66.8	70.2	67.4	66.8	69.8	71.2
Mean	56.3	56.4	61.7	63.9	58.9	60.5	64.5	63.5
Min	50.7	50.9	55.9	57.4	52.3	52.9	57.9	53.8

The comfortable conditions during the winter are from 40 to 60% relative humidity, and maximum relative humidity (RH) is 65% for people with moderate activities in residential buildings, (Raul Pedragallo Torreira, 1976) and (Hélio Creder, 1997).

Analyzing the above measured data results in the apartments, it is concluded that during winter, it is necessary to take measures in order to improve indoor relative humidity conditions. See Figures 3.7(g-h) indicated above. Normal household activities, for instance, cooking, bathing, cleaning, washing cloves or dishes, drying clothes, breathing and perspiring can raise the humidity level in the houses. To avoid these problems of excess moisture, it is necessary to limit or control the amount of water vapor in the houses. So, modifying lifestyle habits of the households and using mechanical means such as exhaust fans, dehumidifiers, air-to-air heat exchangers and some plants which need high humidity; it is possible to reduce the high humidity levels to comfortable rates.

3.8 Electrical energy

In order to reduce the energy used in buildings, it is necessary to gain access to the energy used in buildings.

The methodology used was to measure the current from the distributing panel of the electrical system in each flat. Thus, there were installed current transformers for measuring current passing through the main electrical wires in each circuit of the apartments. The data of electrical current collected by the current transformers was sent and stored in a Mini-PC Data Logger as shown in Figure 2.3(a-b). From Mini-PC it is possible to collect data stored using USB flash for storing in other computers or the data can be displayed on the touch screen display 7” of the system.

3.8.1 Electrical power on the ground and first floors

Figures 3.8 (a-b) shows the electrical power measured on the ground and the first floors. The ground floor which is occupied by two people has electrical light bulbs, stove, washing machine, iron, wardrobe, air conditioning, fan and other appliances (players, TV, etc.). The first floor which is occupied by one person has the same electrical apparatus but without air conditioning and fan.

The couple on the ground floor was out on vacation in June, and the use of electrical energy was only for security devices basically consisting of electrical light bulbs.

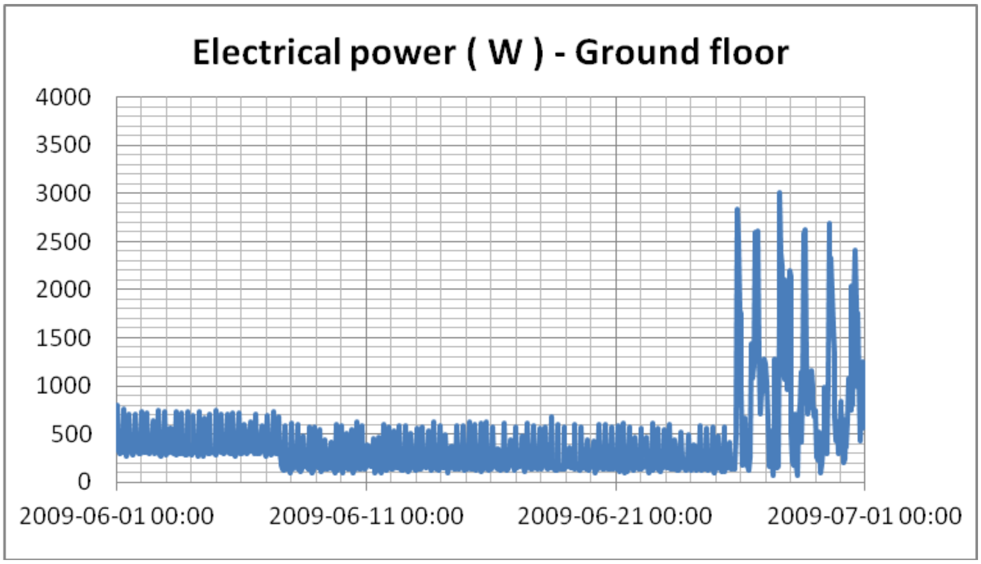

Figure 3.8(a) Ground floor electrical power in June, 2009

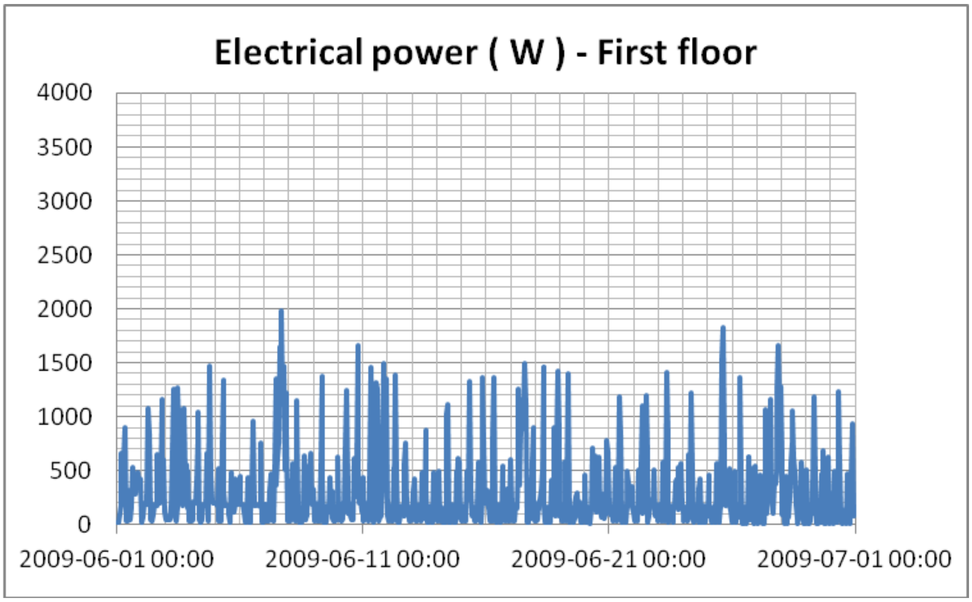

Figure 3.8(b) First floor electrical power in June, 2009

The Figure 3.8(c-d) show the maximum and the minimum values of the electrical power calculated and based on data extracted from the graphs presented above.

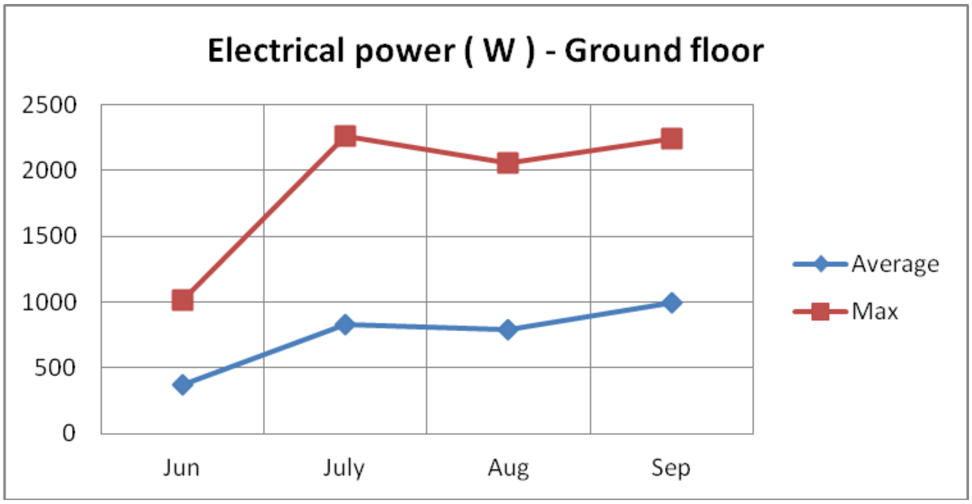

Figure 3.8(c) Maximum and mean rates of electrical power on the ground floor

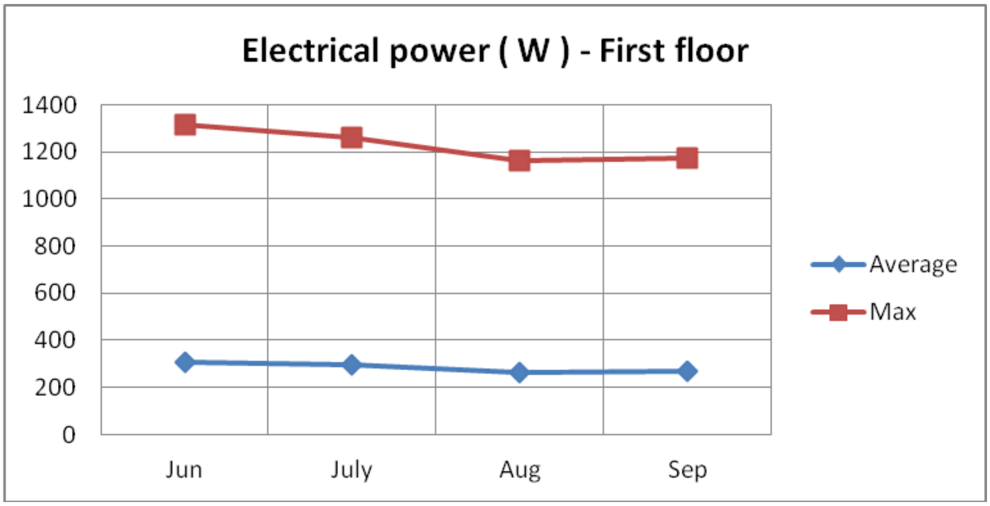

Figure 3.8(c) Maximum and mean rates of electrical power on the first floor

4. Conclusions

The measurement equipment installed in the apartments can be considered as a good equipment for collecting the building parameter data and the weather climatic variables. The equipment offer the possibility to compare thermal loads of the buildings with the ones from simulation program tools for its callibration and validation. The data from this field measurement can provide a lot of information which is necessary for evaluation and improvement of energy use in buildings.

Analyzing data from the measurement equipment, we can conclude that it provides fair results; since the comparison of this data with the one from other weather stations, such as Maputo Airport Meteorological Station presents good agreement.

The data presented in this report only correspond to a period of four months in winter, 2009 inasmuch as the measurement equipment was glitchy during the summer, and consequently, making it unable to analyse the data.

The results from the measurement equipment can be used to check the functionality of the simulation program tools. And that will be the next work using DEROB-LTH program.

5. Reference

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Appendix A

A.1 Mozambique on the World and Africa Continent Map and Maputo on the mozambican map

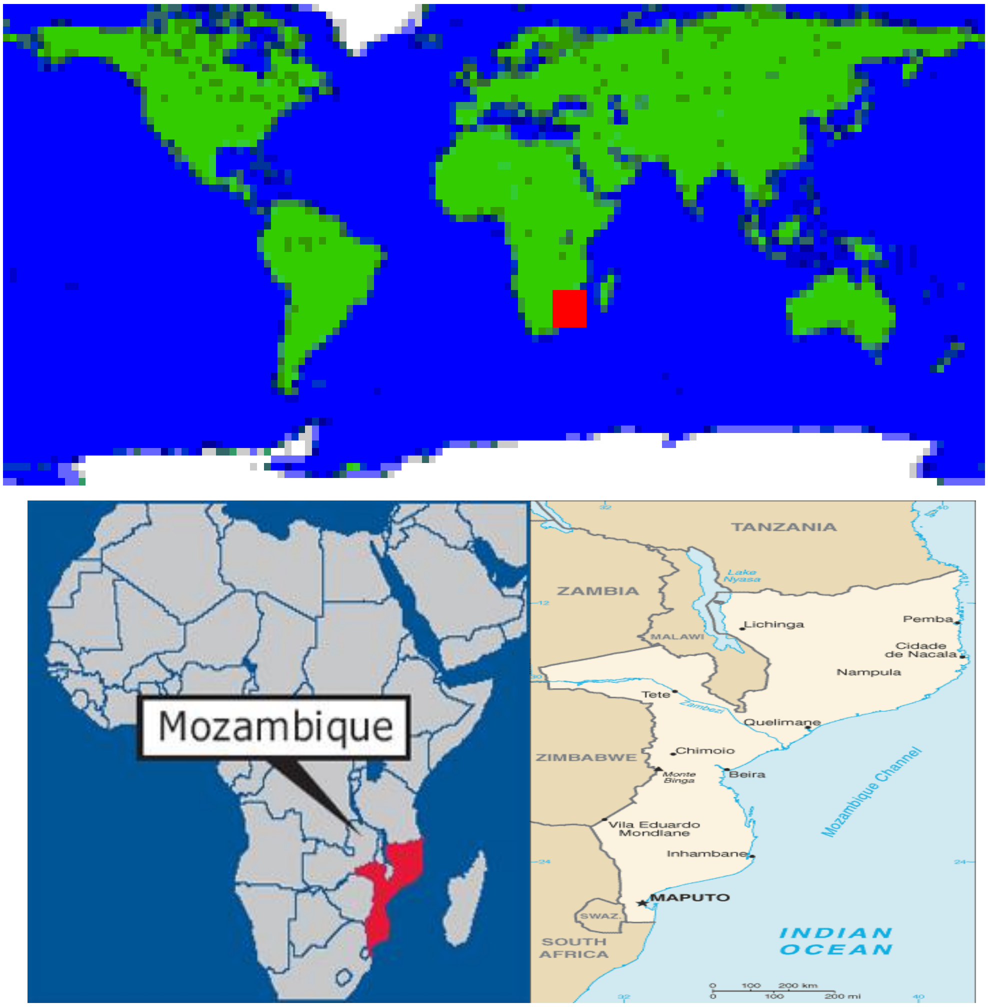

Figure A.1 Localization of Mozambique on the World and Africa Continent Maps and Maputo on Mozambican Map.

Source: OR Tambo International Airport, South Africa

Coordinates:

- Latitude 25º 35´ South
- Longitude: 32º 35´ East

Appendix B

Table B.1 Construction components and elements of the building.

	Elements							
Components	Floors	Ext. walls	Int. walls	Ext doors	Int. doors	Windows	Ceiling	Roof
Parquet								
Cement mortar concrete								
Concrete								
Compacted stone								
Compacted sand								
External plaster								
Brick								
Internal plaster								
Exterior wood frame door								
20 mm of thickness panel door								
Interior frame door								
5 mm of thickness of interior panel doors								
20 mm of air insulation								
5 mm of thickness of interior panel doors								
Wood frame window								
Wood mosquito net frame panel								
Wood simple glass frame panel								
4 mm single glass								
Mosquito net								
Plaster								
Concrete								
Plaster								
Roof-tile								
Wood beams								
Concrete ceiling								
Plaster								

B.2 - The areas of the compartments on the ground and first floors

Table B.2 - The compartments areas of the apartments.

Items	Designation	Ground Floor Numbers	Ground Floor (m^2)	First Floor Numbers	First Floor (m^2)
01	Livingrooms	3	89.2	3	98.7
02	Bedrooms	5	58.2	3	40.4
03	Kitchens	3	36.1	3	26.6
04	Bathrooms	3	17.2	3	21.4
05	stores	1	07.0	3	14.7
06	Corridors	3	28.5	3	29.8
07	Stairs	1	38.0	1	33.7
08	Laundry	3	13.3	3	22.9
09	Balcony	1	06.1	4	13.3

B.3 – Plans of the ground and the first floors of the building considered in this report

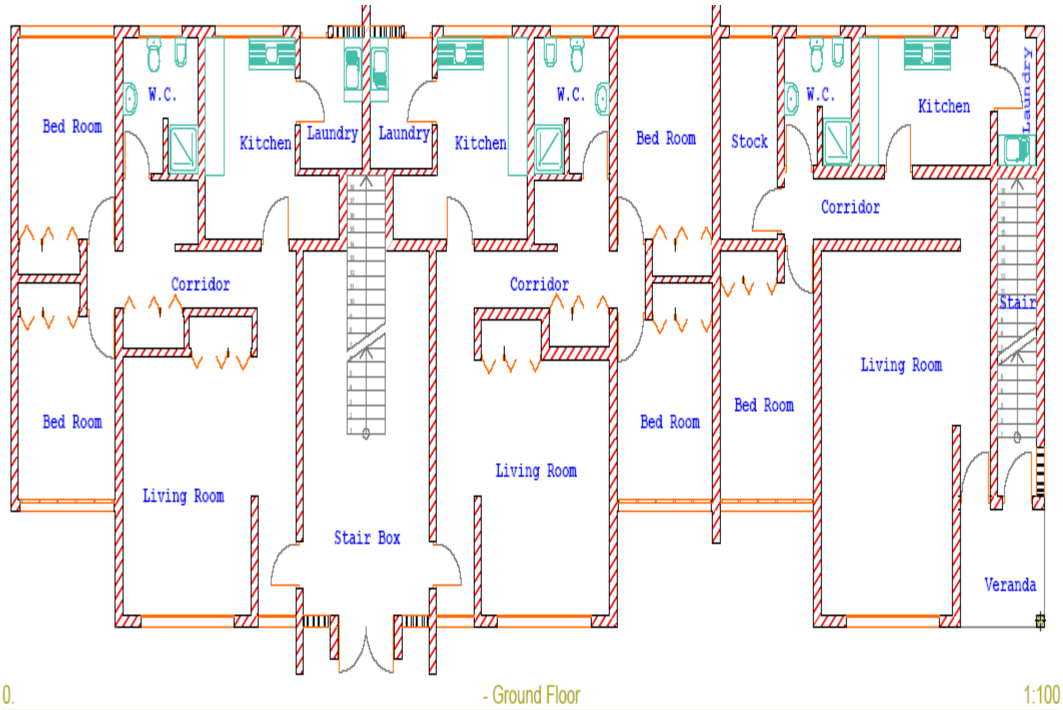

Figure B.1 (a) Ground Floor

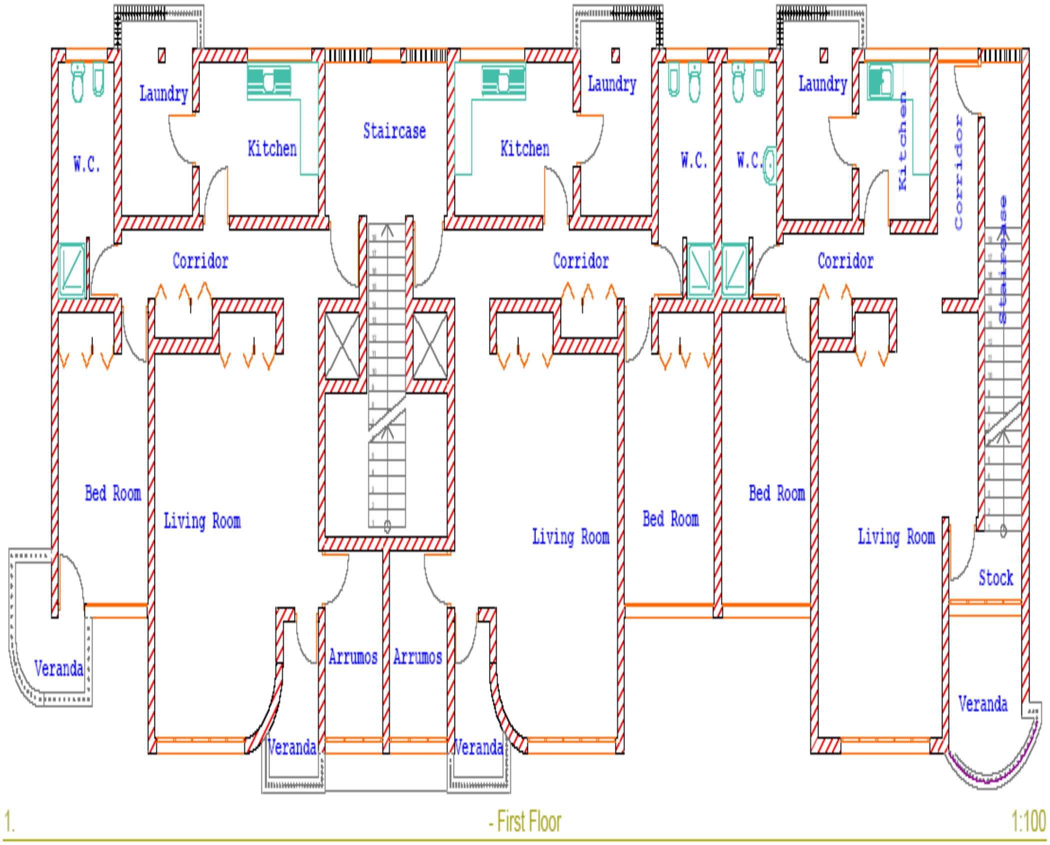

Figure B.1 (b) First Floor

Appendix C

Table C.1 – Technical data of the measurement equipment of the ground floor

Item	Designation	Qty.	Reference	Description / components	Accuracy	Remarks
01	Mini PC	01	EBOX - 4851	1 – Max. 20 Watts External Power Adapter, Vin:100-240VAC, 60/50Hz, 10A/Vout: +5.0..5.25VDC@4A max. LPS		
02	Touch Screen Display	01	TFT LCD 7"	≤100 W		
03	IC - 485SI	01	ATEN	1 Ic-485SI – Interface convertor 1 Power Adapter (DC 9V, 300mA		
04	Pic – Logger ADC16 Analog Input	01		1 Current meter, 3-phase AC, 0-50A 1 R232 <- USB		
05	Energy meter, 3-phase 400 VAC, 32 A	01				Optional
06	Energy meter, 1-phase 230 VAC, 10 A	01				

07	Puls counter	02				
08	Inside temp/RH Sensors	09	SHT75	Power consumption: • Sleep typ= 2 μW,max= 5 μW • Measuring = 3 μW	ΔRH (%RH) ±2	

Table C.2 - Technical data of the measurement equipment of the first floor

Item	Designation	Qty.	Reference /Type	Description / components	Accuracy	
01	Mini PC	01	EBOX - 4851	1 – Max. 20 Watts External Power Adapter, Vin:100-240VAC, 60/50Hz, 10A/Vout: +5.0~5.25VDC@4A max. LPS		
02	Touch Screen Display	01	TFT LCD 7"	≤100 W		
03	IC - 485SI	01	ATEN	1 Ic-485SI – Interface convertor 1 Power Adapter, DC 9V, 300mA		
04	Pic – Logger ADC16 Analog Input	01		1 Current meter, 3-phase AC, 0-50A 1 R232 <- USB		
05	Energy meter, 3-phase 400 VAC, 32 A	01				Optional
06	Energy meter, 1-phase 230 VAC, 10 A	01				
07	Puls counter	02				
08	Inside temp/RH Sensors	08	SHT75	Power consumption: • Sleep typ= 2 μW,max= 5 μW • Measuring = 3 μW	ΔRH (%RH) ±2	
09	Inside temp/RH Sensors	08	SHT75	Power consumption: • Sleep type = 2 μW,max= 5 μW • Measuring = 3 μW	ΔRH (%RH) ±2	
10	Outside temp/RH Sensors	03	SHT75	Power consumption: • Sleep type = 2 μW,max= 5 μW • Measuring = 3 μW	ΔRH (%RH) ±2	
	Outdoor Measurements					
O1	Mini PC	01	eBOX - 4851	1 – Max. 20 Watts External Power Adapter, Vin: 100-240VAC, 60/50Hz, 10A/Vout: +5.0~5.25VDC@4A max. LPS		
02	Screen display 14"	01	TFT LCD 7"	≤100 W		
03	Key board	01				
04	Wireless Console	01	OS – WMR200			
05	Wind sensor	01				
06	Temp/RH sensor wireless connection	01				
07	Rainfall wireless connection	01				
08	Solar radiation	01	BF3	1. Heater output below 5ºC – 18W 2. Heater output from 5-50ºC – 1.8W 3. Heater output above 50ºC – 0W (heater off) 4. Lowest snow & ice-free temp - -20ºC At 2 m/s wind speed • Heater: max power – 18 W at 12 V~ • Heater: max current – 1.5 A at 12V • Fuse: max voltage, current – 24V, 2A 8not self resetting)*		

- For more details see the Manual (sunshine Sensor, type BF3)

Appendix D

D.1 - Solar radiation

Figures D.1(a) and (b) show the variation of the global and diffuse solar radiation rates during a period of two months, August to September, 2009.

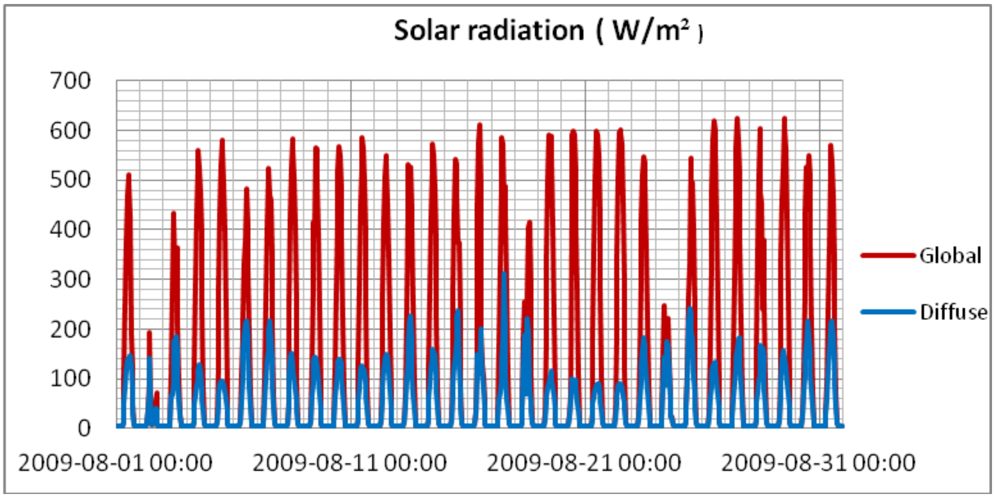

Figure D.1 (a) Solar radiations in August, 2009

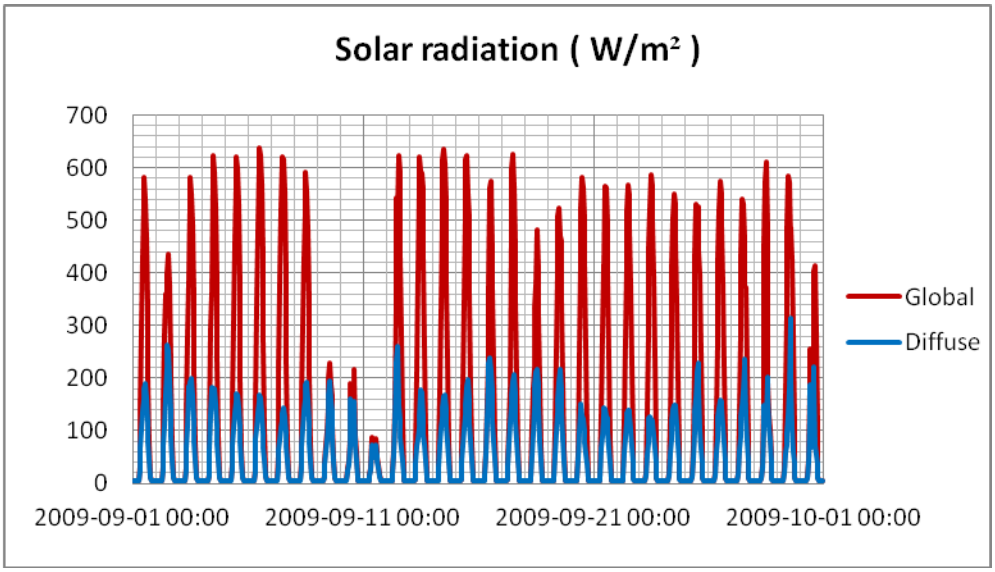

Figure D.1 (b) Solar radiations in September, 2009

D.2 - Outdoor temperature

Figures D.2 (a-b), show the variation of the outdoor temperature rates during a period of four months, July to September, 2009.

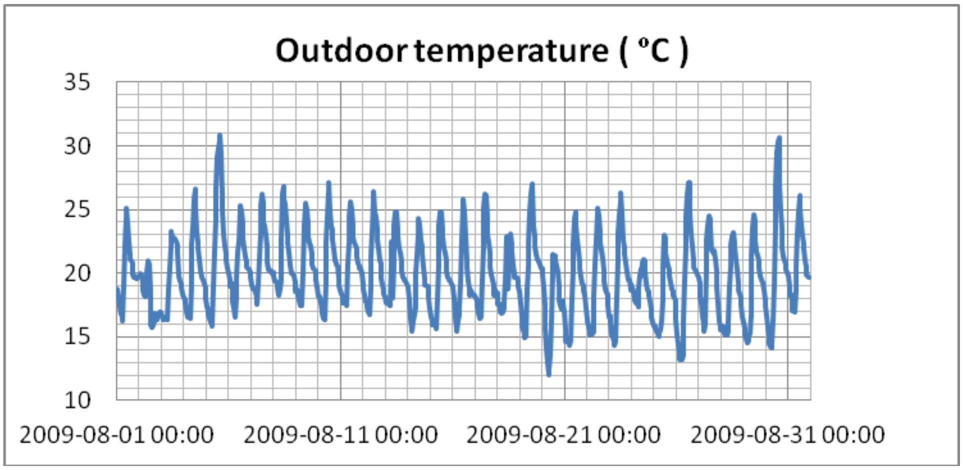

Figure D.2 (a) Outdoor temperatures in August, 2009

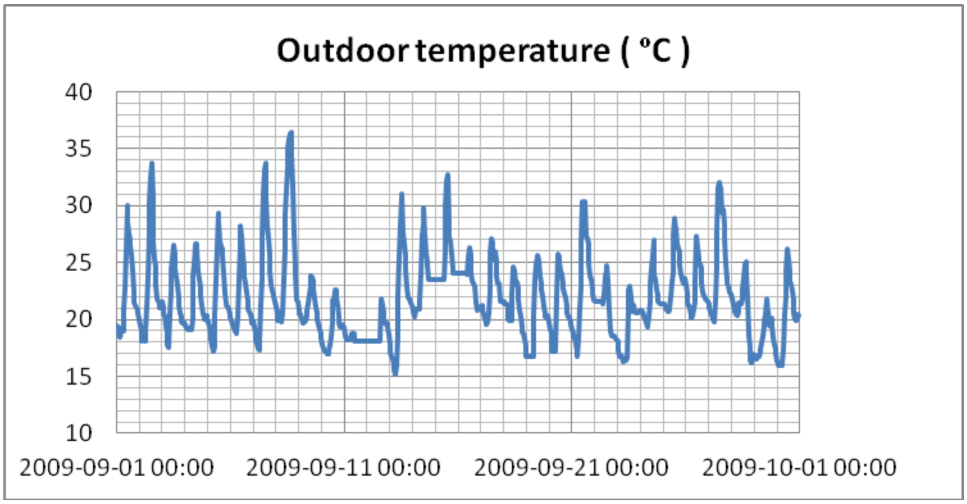

Figure D.2 (b) Outdoor temperatures in September, 2009

These graphs have the same aspects as presented in chapter 3.2 about outdoor temperature. In July, August and September the outdoor sensor had some interruption on sending the data to Data Logger Mini-PC and these interruptions are presented by constant rates of the temperature during certain period of time in some days. The Table D.1 presents the days and times when these interruptions occurred. The interruptions were due to the lack of electrical energy caused by interruptions in the main electrical power grid.

Table D.1 shows the days and times when the system did not work.

			From	At	Outdoor temperature
Month	Year	Days	Hours		ºC
July	2009	13	10:00	11:00	23.9
		21-22	21:00	05:00	18.5
August		02	13:00	20:00	15.7-16.7
September		11	01:00	23:00	18.2-18.1
		14	9:00	20:00	23.5
		15	6:00	20:00	24.4

D.3 - Outdoor temperature in the shaded parts of the building

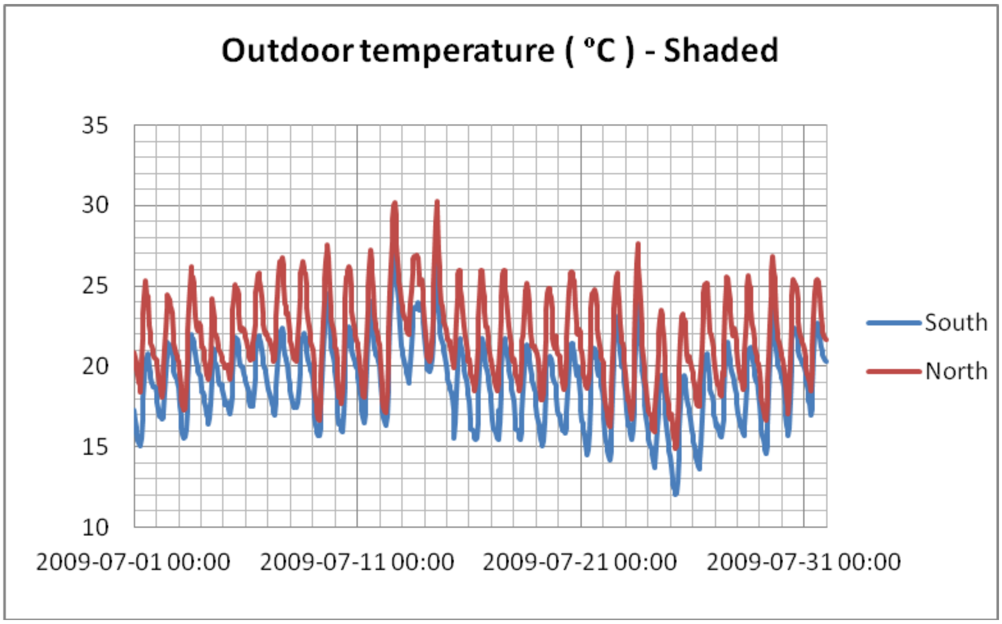

Figure D.3 (a) Temperatures in shaded parts of the parts of the building in July, 2009

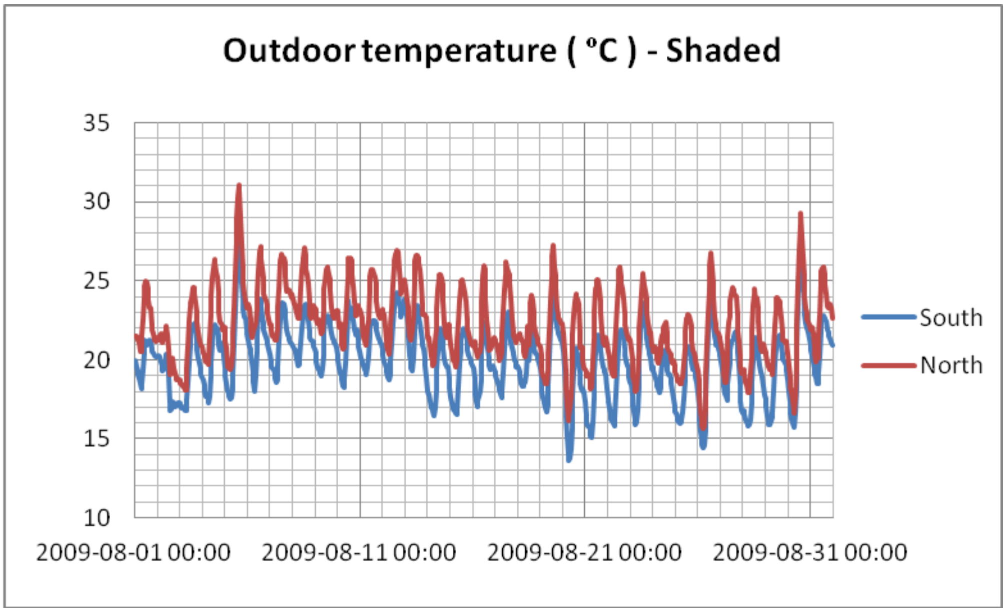

Figure D.3 (b) Temperatures in shaded parts of the building in August, 2009

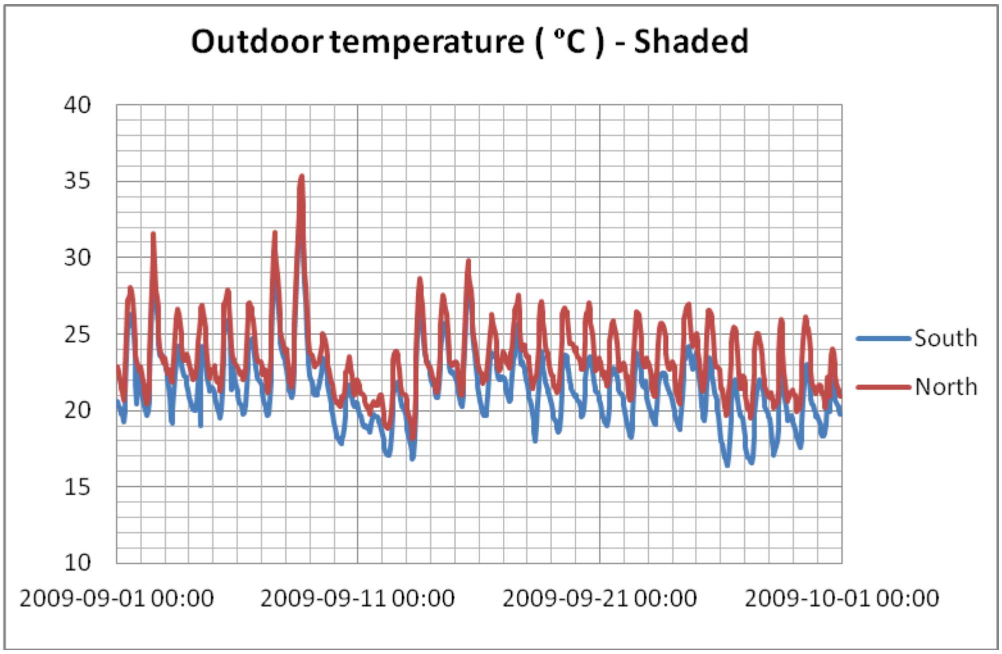

Figure D.3 (c) Temperatures in the shaded parts of the building in September, 2009

D.4 - Indoor temperature of the building

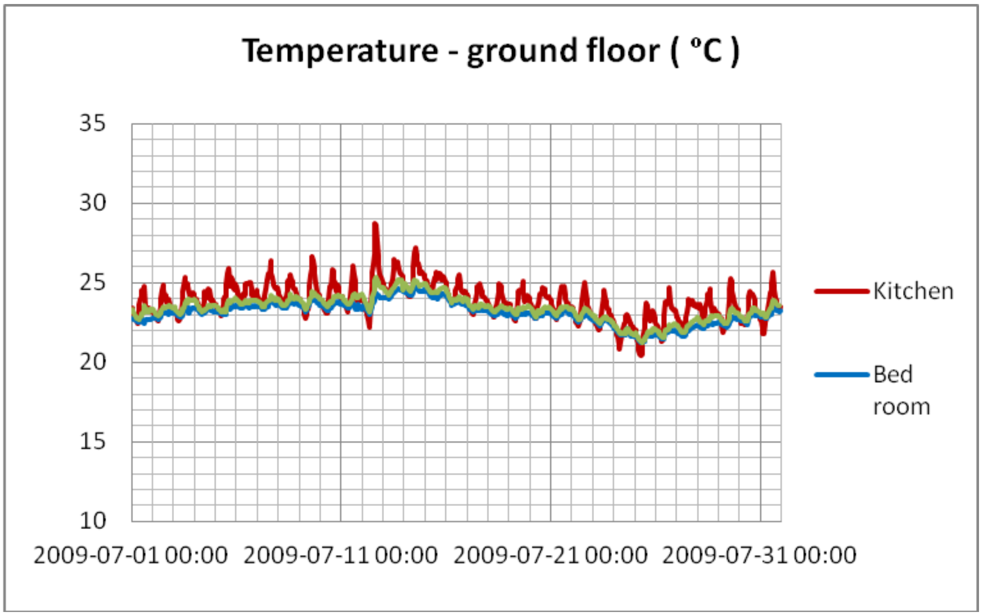

Figure D.4 (a) Temperature on the ground floor in July, 2009

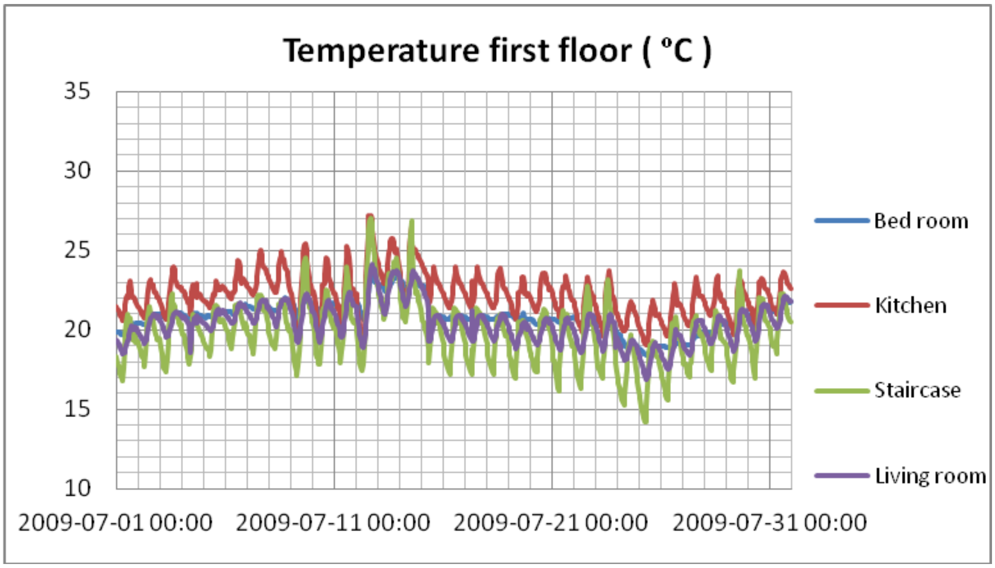

Figure D.4 (b) Temperature on the first floor in July, 2009

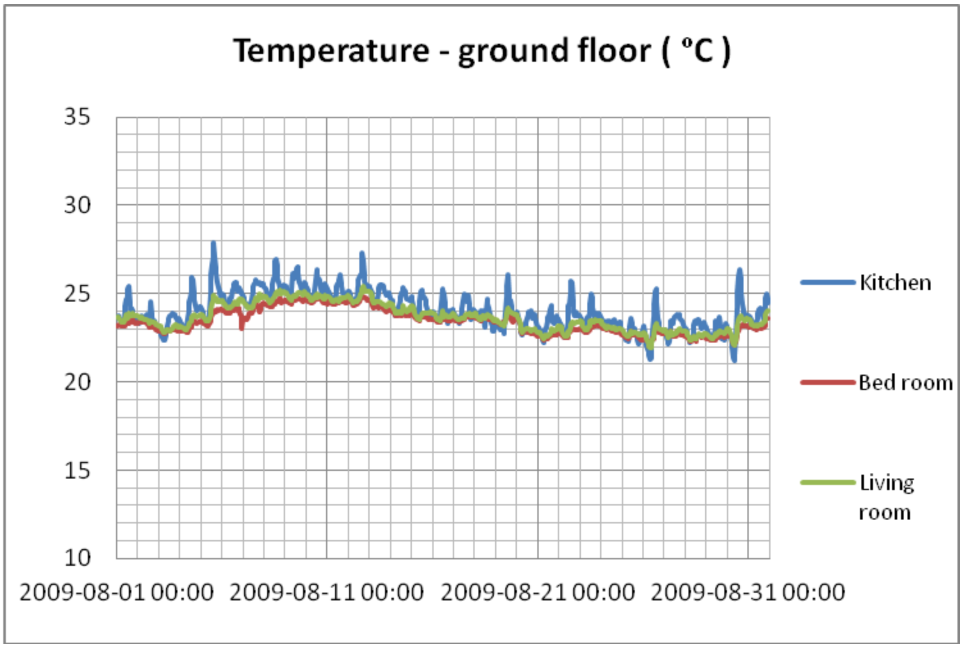

Figure D.4 (c) Temperature on the ground floor in August, 2009

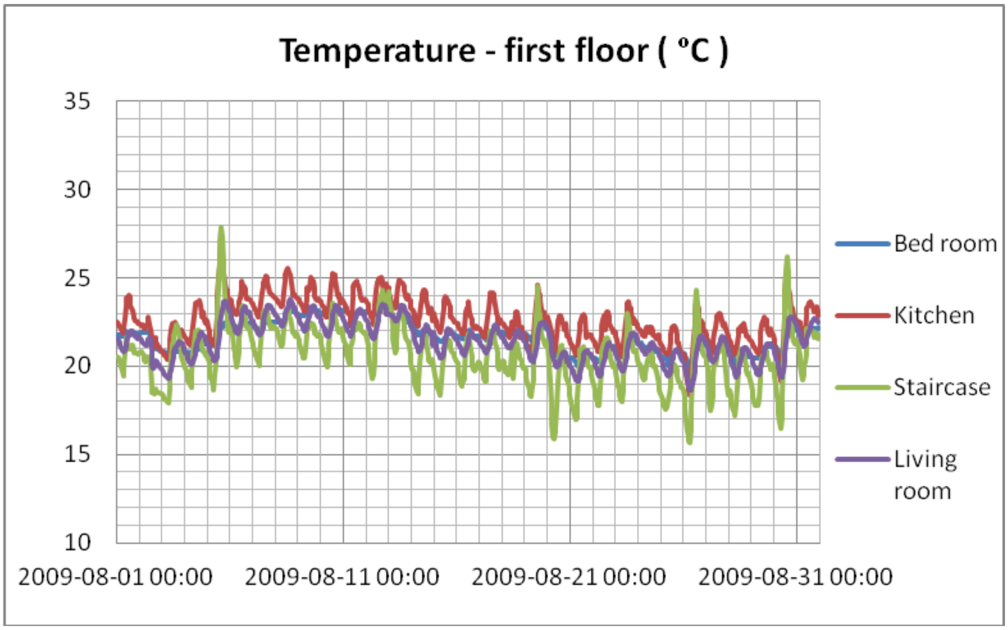

Figure D.4 (d) Temperature on the first floor, August, 2009

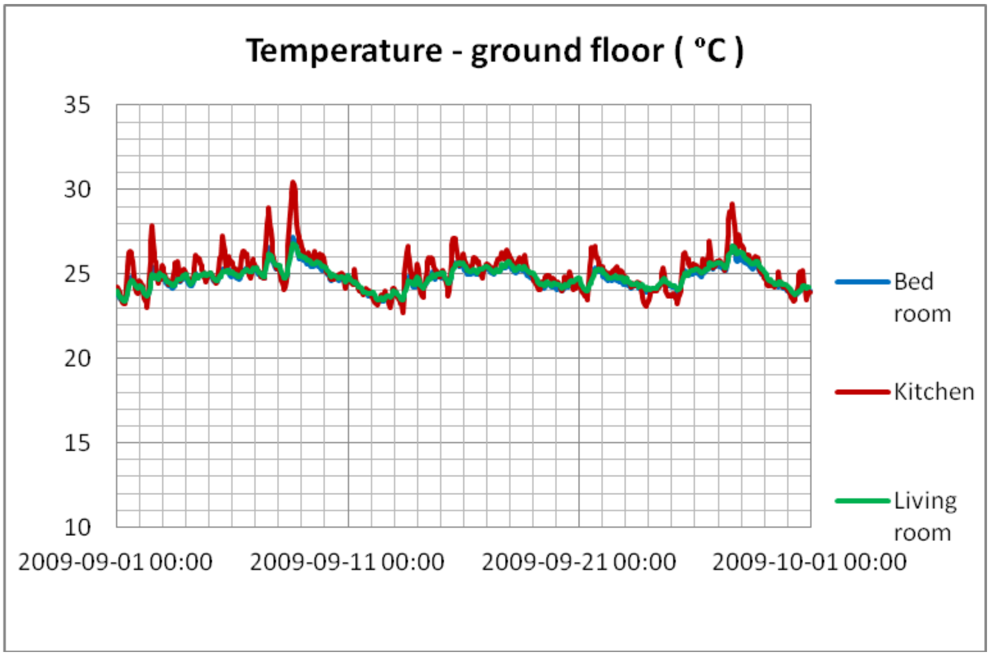

Figure D.4 (e) Temp. on the ground floor in September, 2009

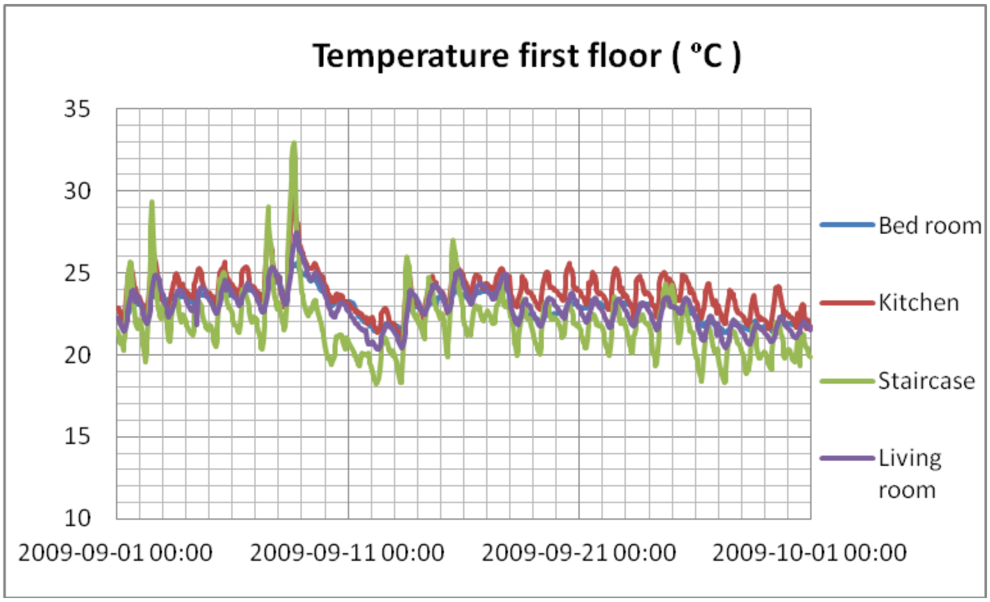

Figure D.4 (f) Temp on the first floor in September, 2009

D.5 – Wind speed

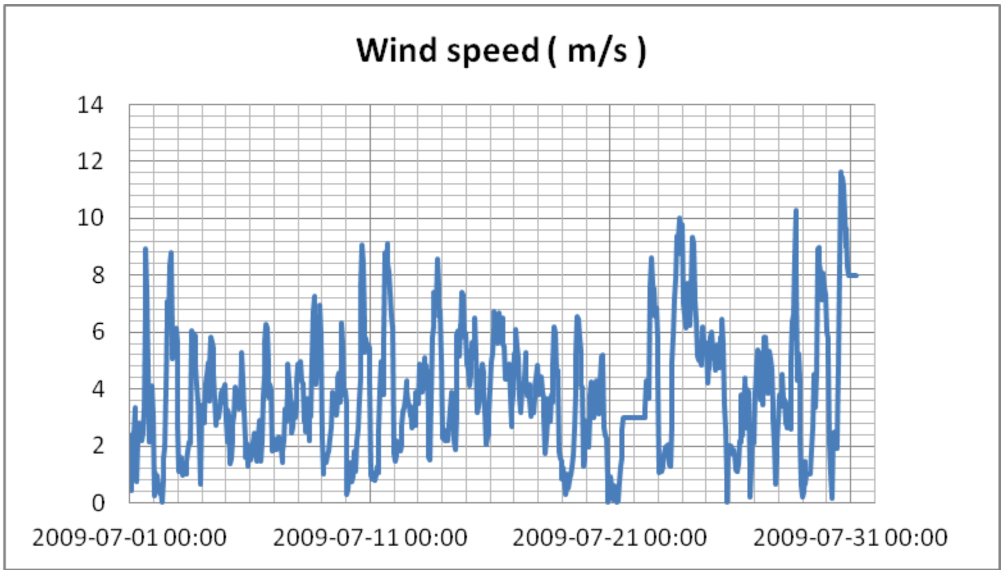

Figure D.5 (a) Wind speed in July, 2009

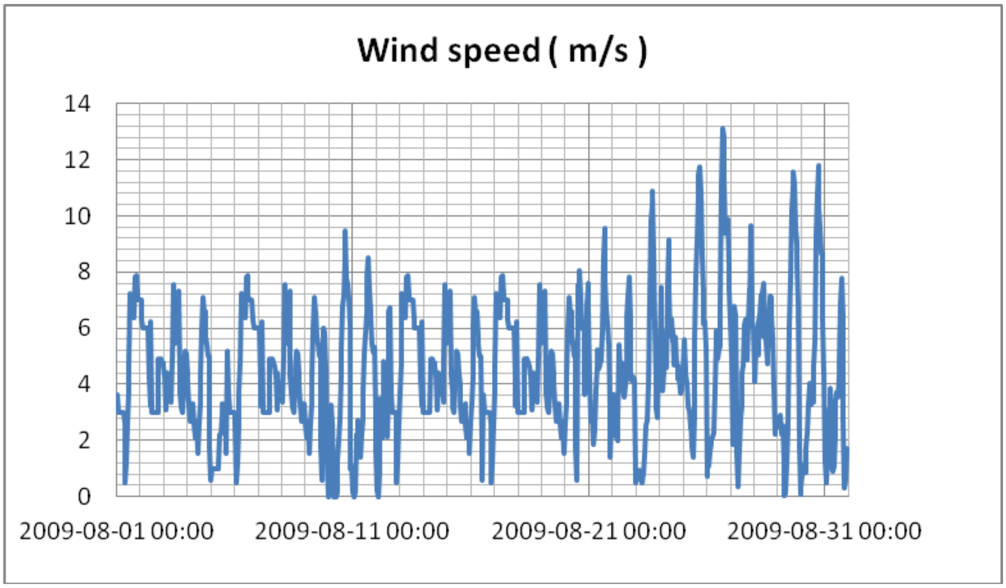

Figure D.5 (b) Wind speed in August, 2009

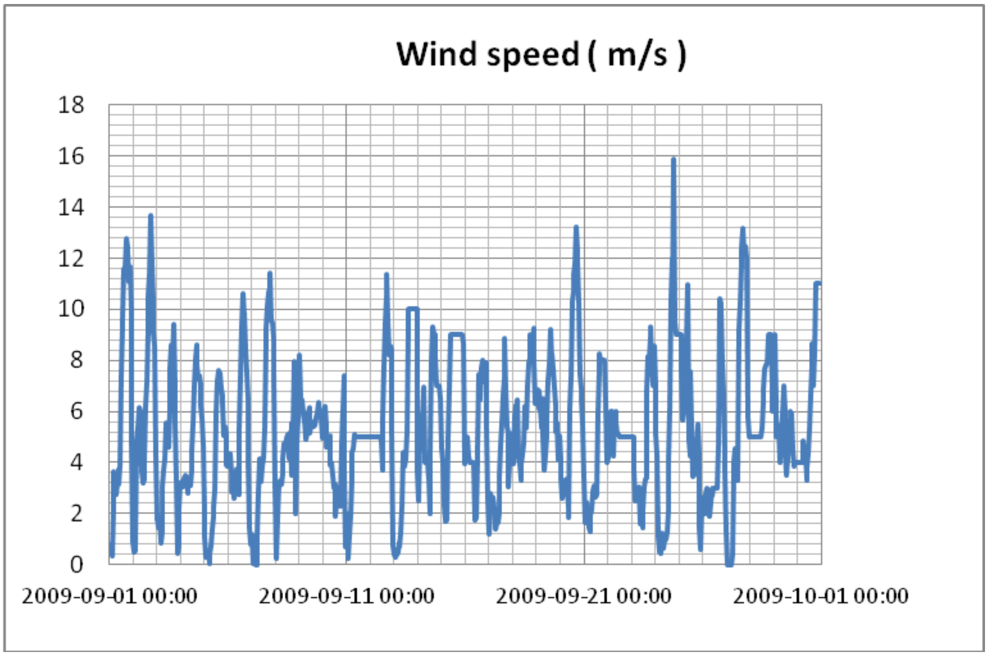

Figure D.5 (c) Wind speed in September, 2009

These graphs have the same aspects as the ones presented in chapter 3.5 about wind speed. In July, August and September the wind speed sensor had some interruption on sending data to the Data Logger Mini-PC and these interruptions are presented by constant rates of wind speed during certain periods of time in some days. Table D.2 presents the days and times when these interruptions occurred. The interruptions were due to the lack of electrical energy caused by interruptions in the main electrical power grid.

Table D.2 shows the days and times when the system did not work.

			From	At	Wind speed
Month	Year	Days	Hours		m/s
July	2009	21	13:00	22:00	3.0
September		11	07:00	20:00	5.0
		15	09:00	11:00	9.0
		22	10:00	13:00	5.0

D.6 – Outdoor relative humidity

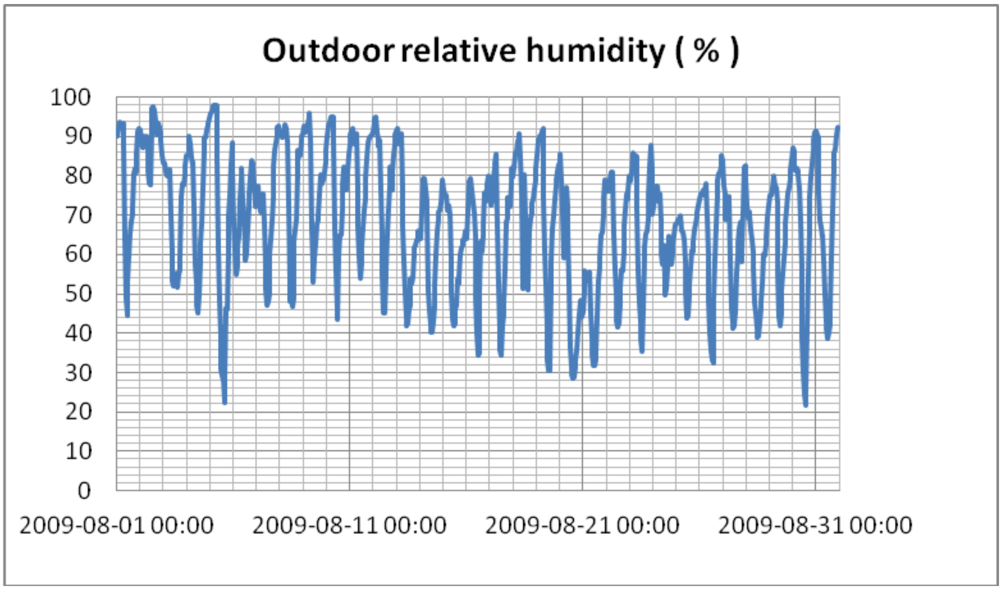

Figure D.6 (a) Outdoor relative humidity in August, 2009

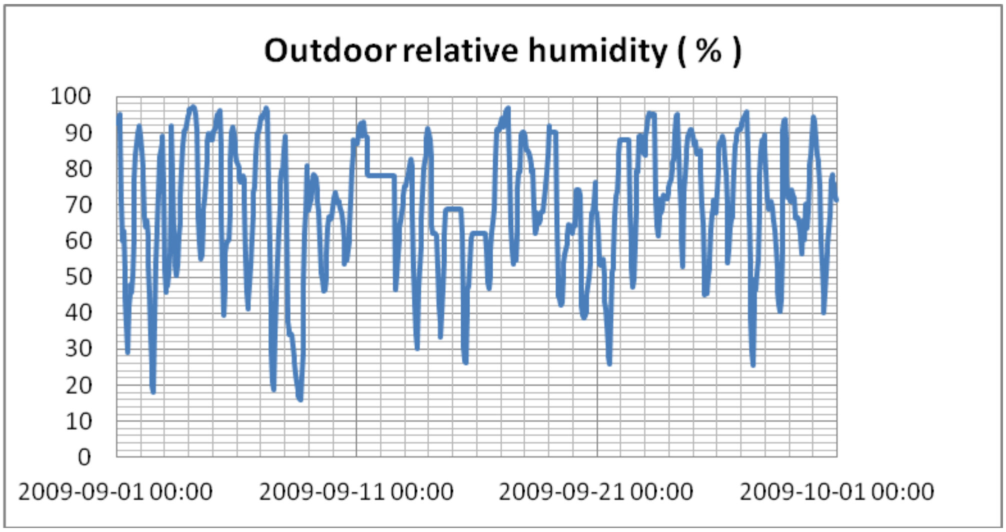

Figure D.6 (b) Outdoor relative humidity in September, 2009

These Figures have the same aspects as the ones presented in chapter 3.7 about outdoor relative humidity. In July, August and September the outdoor relative humidity sensor had some interruptions on sending the data to Data Logger Mini-PC and these interruptions are presented by constant rates of the outdoor relative humidity during certain period of time in some days. The

Table D.3 presents the days and times where these interruptions occurred. The interruptions were due to the lack of electrical energy caused by interruptions in the main electrical power grid.

Table D.3 shows the days and times when the system did not work.

			From	At	Outdoor relat. humidity
Month	Year	Days	Hours		%
July	2009	21-22	21:00	00:00	60
September		11	11:00	20:00	78.6
		14	17:00	18:00	68.4-69
		15	18:00	19:	60.6-62.0

The information presented in Tables D.1, D.2 and D.3 is important because it shows when the main electrical grid does not supply electrical power, the weather station does not work and some data are lost. Thus, it is necessary to introduce additional sources in order to supply electrical power in the system when the main electrical grid does not supply electrical power to the building.

D.7 – Indoor relative humidity

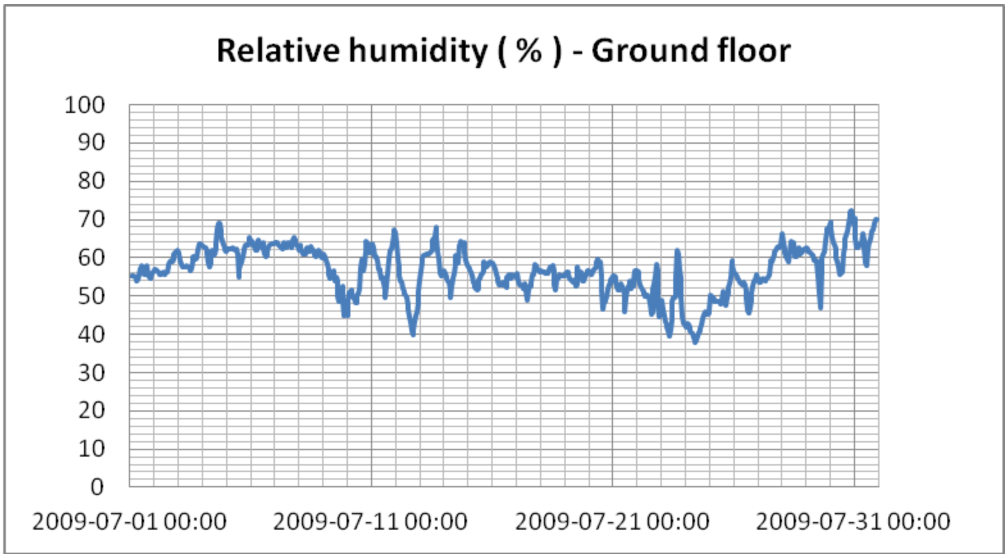

Figure D.7 (a) Indoor relative humidity, July, 2009

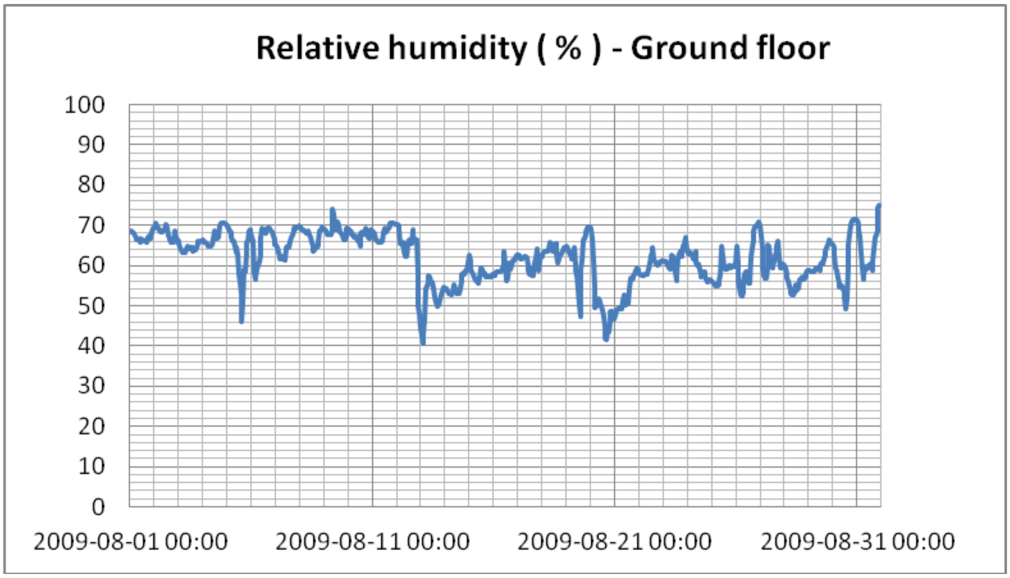

Figure D.7 (b) Indoor relative humidity, August, 2009

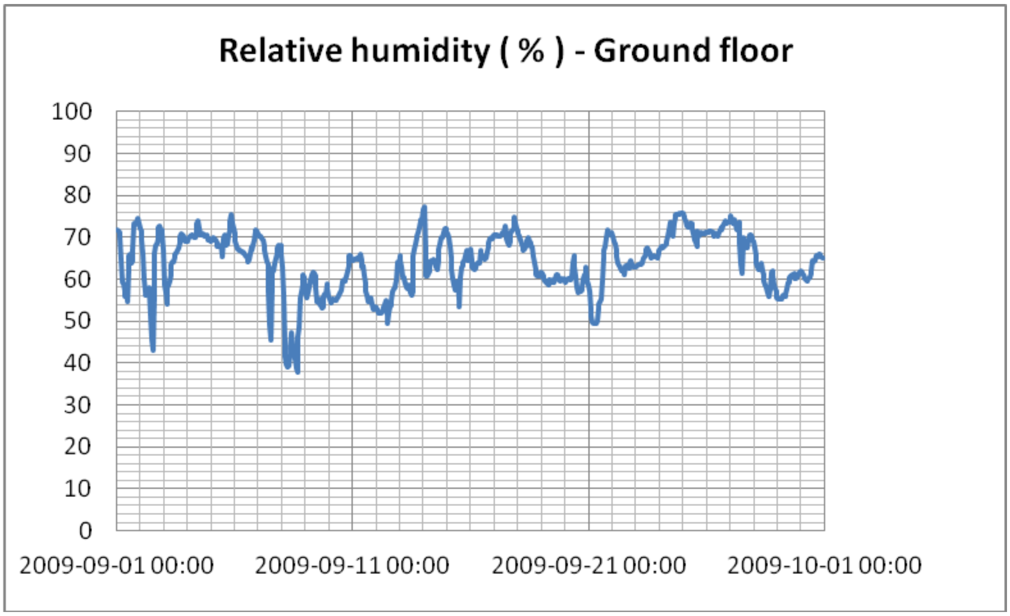

Figure D.7 (c) Indoor relative humidity, September, 2009

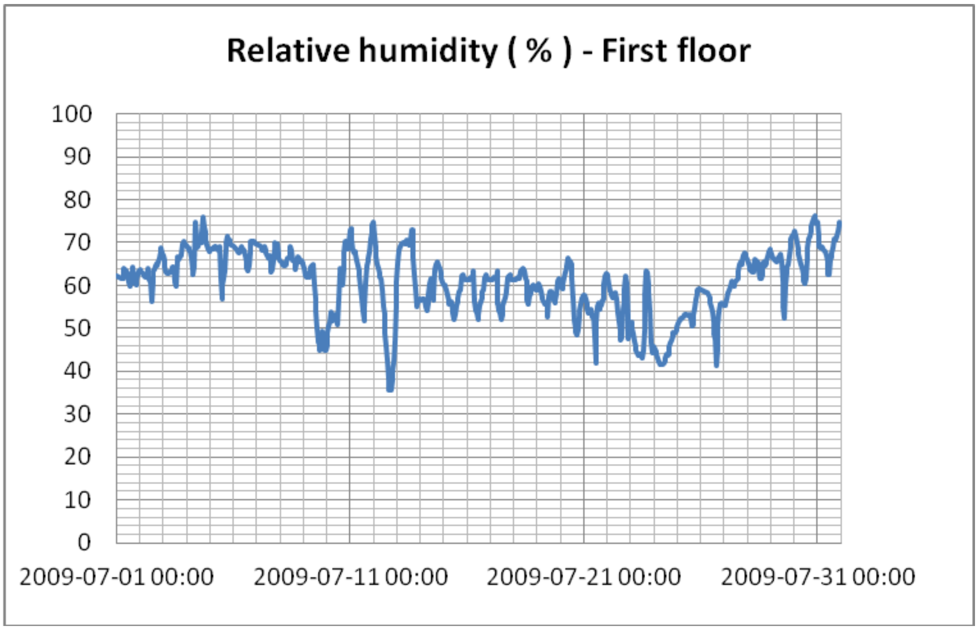

Figure D.7(d) Indoor relative humidity, July, 2009

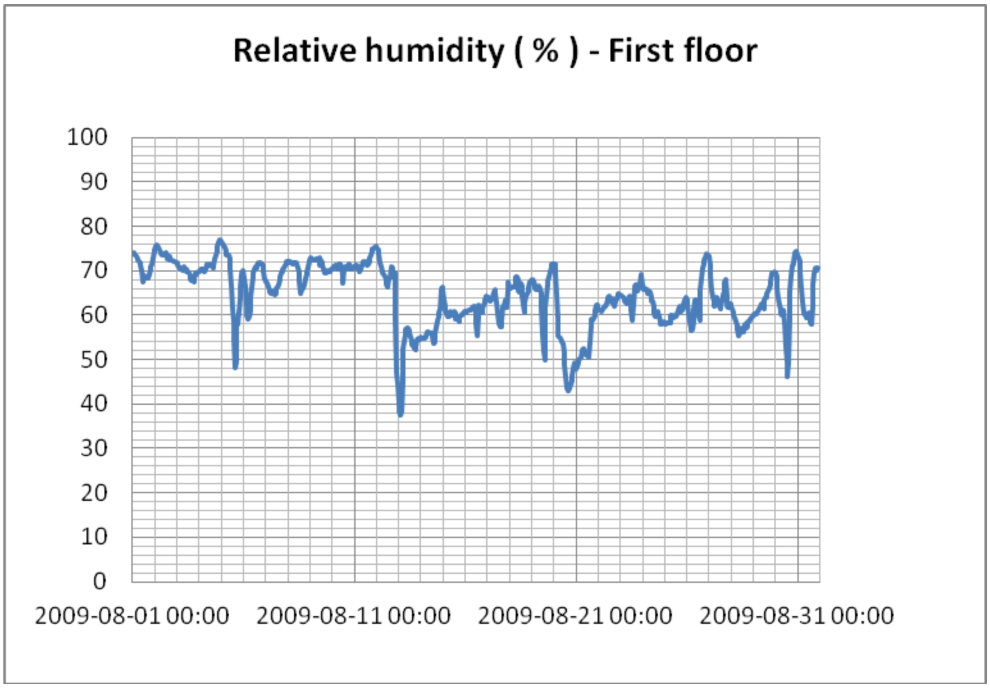

Figure D.7(e) Indoor relative humidity, August, 2009

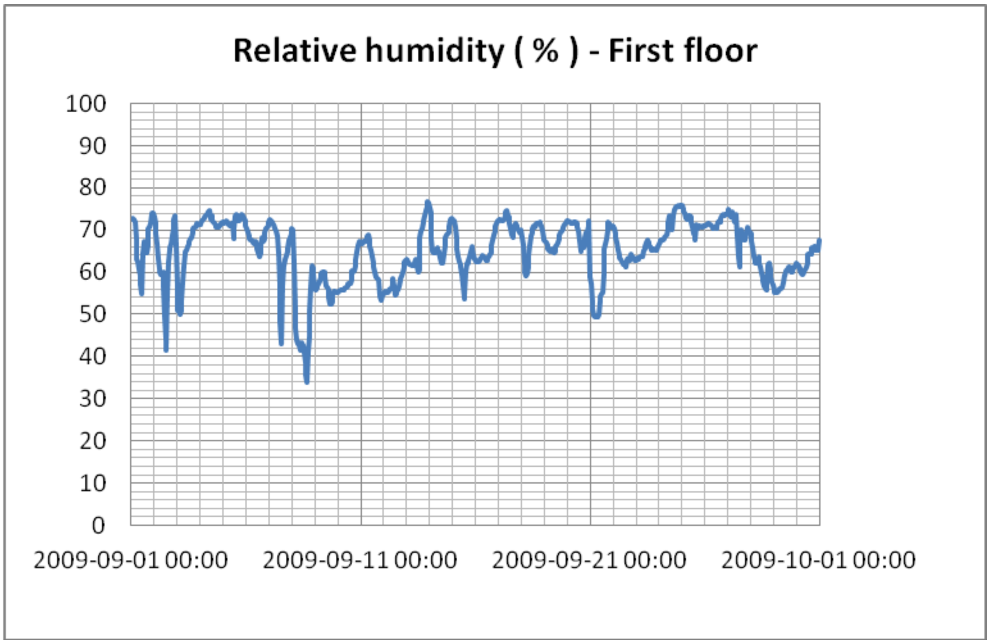

Figure D.7 (f) Indoor relative humidity, September, 2009

D.8 - Indoor temperature of the building

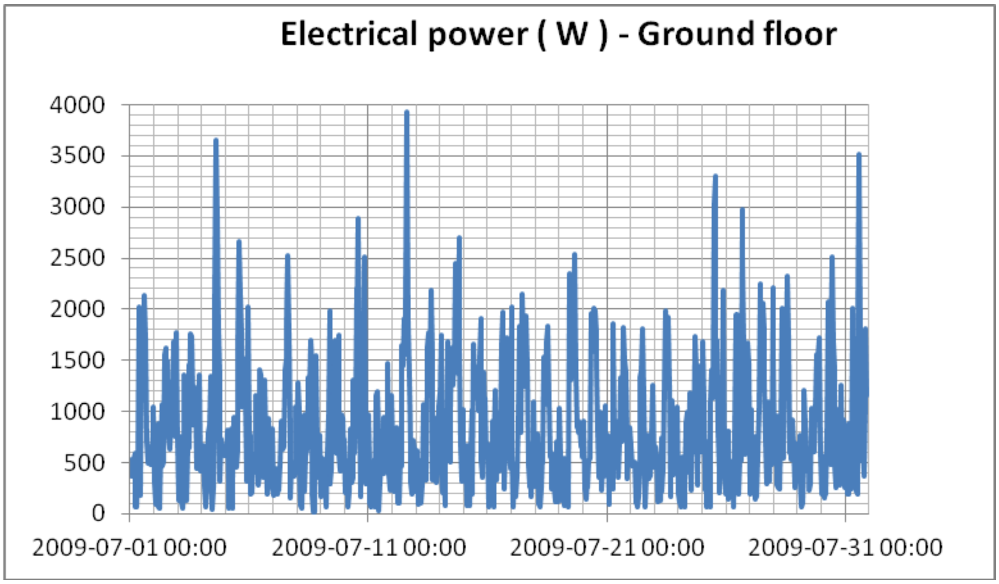

Figure D.8 (a) Elect. power on the first floor in July, 2009

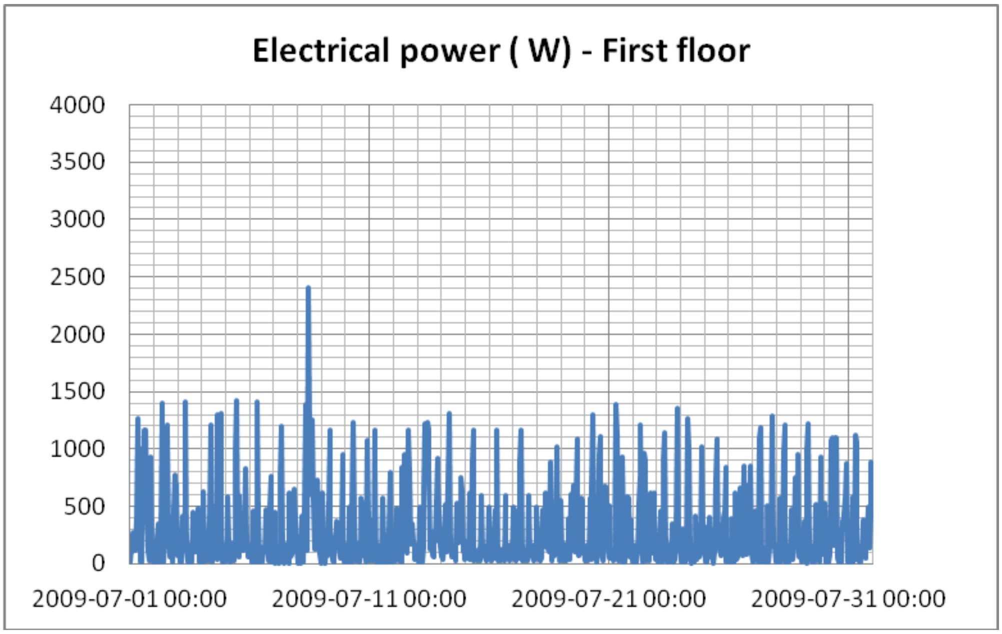

Figure D.8 (b) Elect. power on the first floor in July, 2009

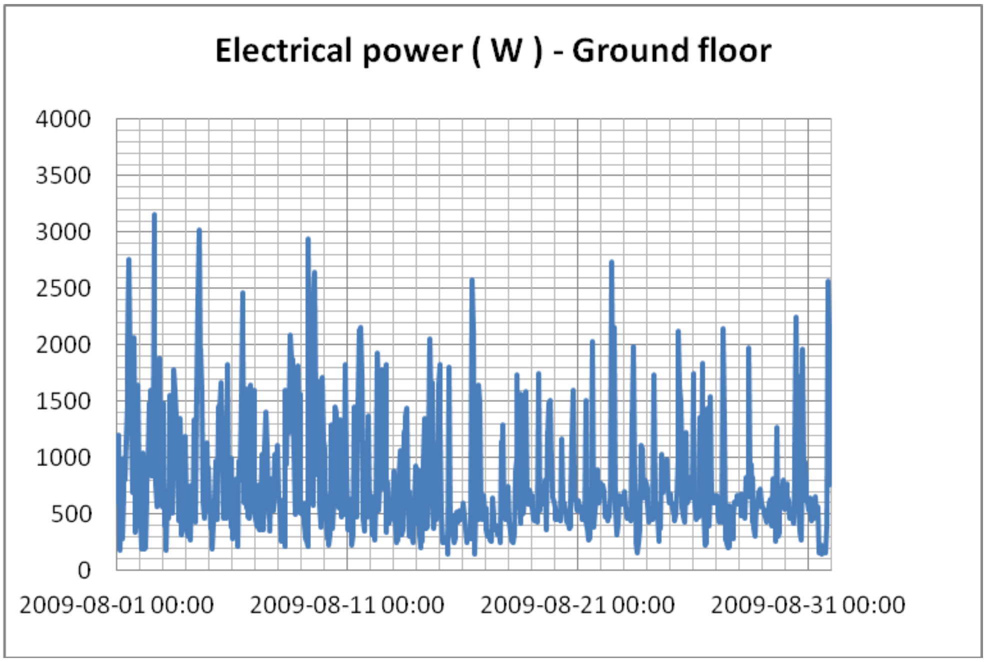

Figure D.8 (c) Elect. power on the ground floor in July, 2009

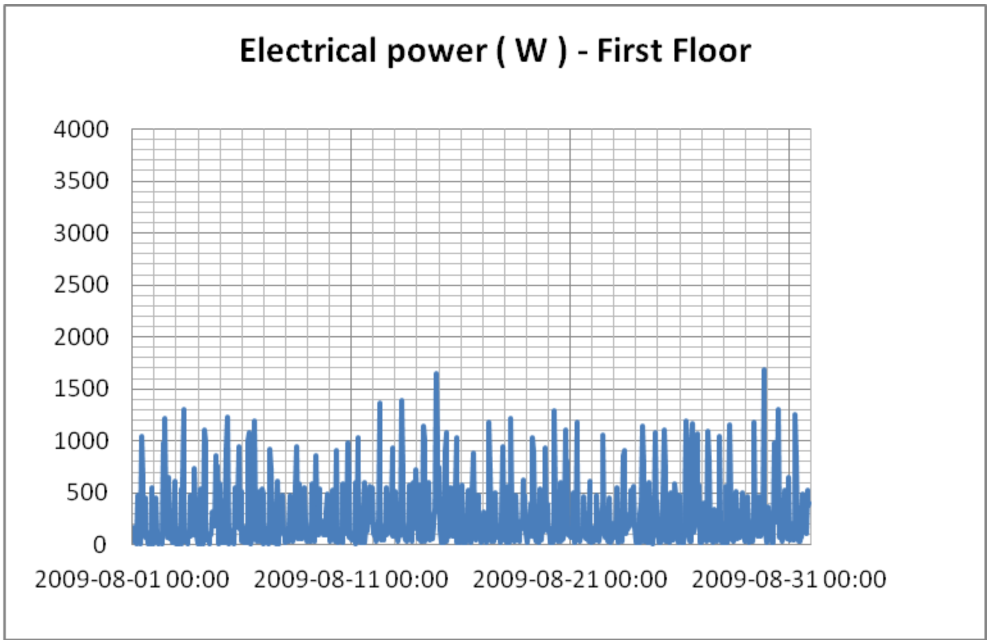

Figure d.8 (d) Elect. power on the first floor in July, 2009

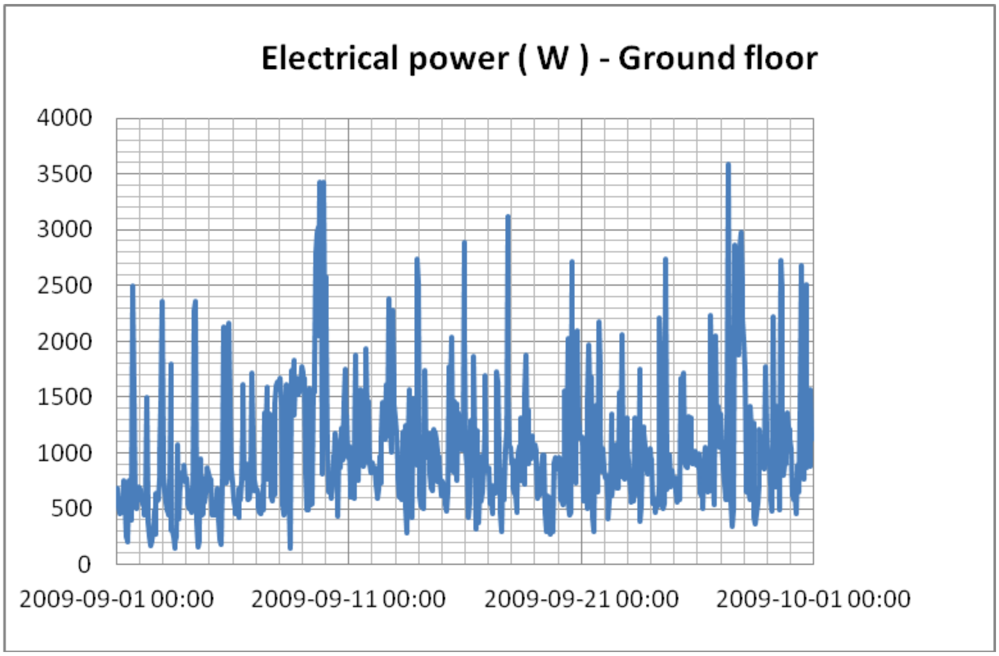

Figure D.8 (e) Elect. power on the ground floor in September, 2009

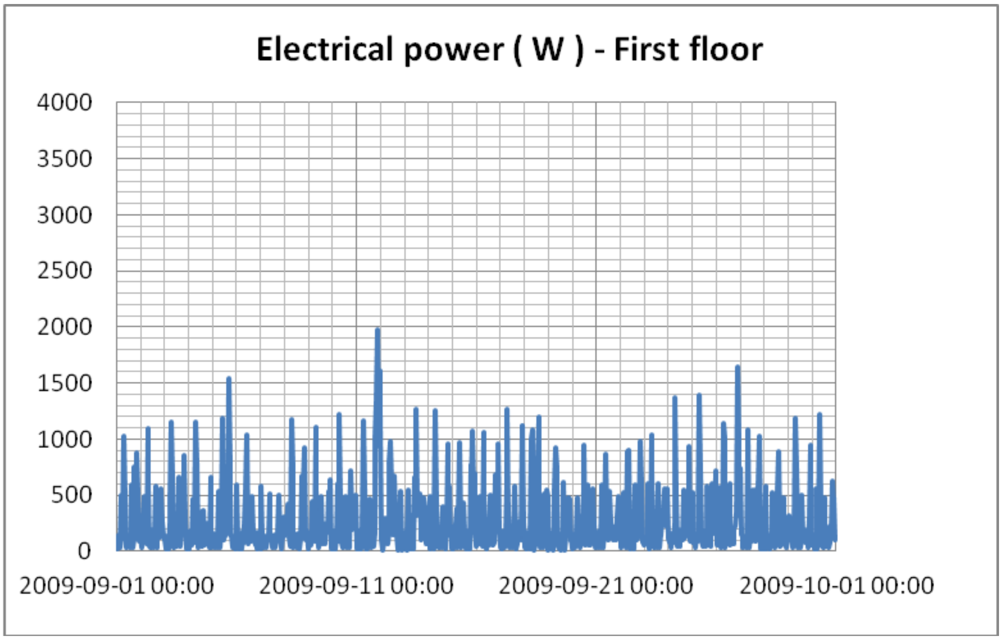

Figure D.8 (f) Elect. power on the first floor in September, 2009

Appendix E

E.1 – Maputo Airport Meteorological Station

The Figure E.1 shows the typical sub-tropical climate of Maputo City from Maputo Airport Meteorological Station.

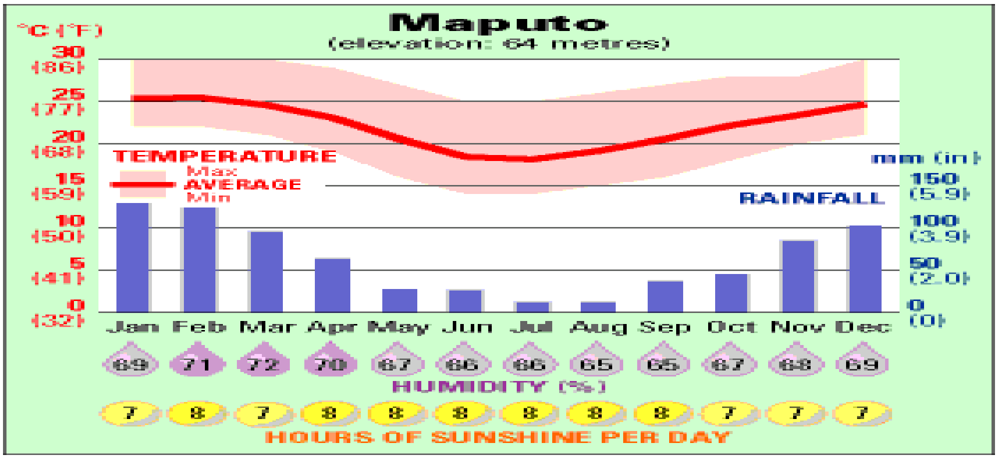

Figure E.1- Climatic conditions of Maputo City, 2009
Source: www.unicef.org/mozambique.

Appendix F

Table F.1 Presents the values during the period of the ascent and descent of solar radiation due to the clouded sky.

	Ascent and descent of solar radiation due to sky clouded (W/m^2)		
	2009-06-08		
	high	low	high
Global	215.8	88.0	262.8
Diffuse	152.6	71.5	206.00
Time	10:00	11:00	12:00

Table F.2 Values during the period of the ascent and descent of solar radiation due to the clouded sky and global and diffuse solar radiation on 5th July, 2009.

	Ascent and descent of solar radiation due to the clouded sky (W/m^2)					
	2009-07-13					2009-07-05
	high	low	high	low	high	high
Global	238.4	226.1	370.00	362.4	412.5	527.8
Time	9:00	10:00	11:00	12:00	13:00	12:00
Diffuse	114.7	177.2	212.2	277.2	194.9	87.2
Time	9:00	10:00	11:00	12:00	13:00	13:00