Influence of Solar Shading and Orientation on Indoor Climate
A Case Study in Maputo City

Marcelino Januário Rodriguês
Key words
Energy efficiency, Sustainable buildings, Building orientation, Shading on buildings, Building envelope, Indoor temperatures, Thermal comfort, Passive cooling, Modeling, Simulations, Maputo City, Mozambique.
Preface

The project “Advancing Sustainable Construction in Mozambique-Improvement of Bioclimatic Design in Residential and Institutional Buildings” is a project built upon the research cooperation between SIDA-SAREC and Eduardo Mondlane University. This project is carried out at the Department of Construction Science, Lund Institute of Technology, Lund University, Lund, Sweden and the Department of Civil Engineering, Faculty of Engineering, Eduardo Mondlane University, Maputo City, Mozambique.

Based from the cooperation with Lund University-Department of Construction Science, a Laboratory for experimental data was installed in 3 de Fevereiro guest house of the Faculty of Engineering of Eduardo Mondlane University.

This report is part of a series of studies on Energy Efficiency in Buildings through Passive Design for hot and humid climate especially in Maputo City.
Acknowledgements

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Dedication

I dedicate this thesis to my dear mother Joaquína Januário Ngoca who died in February 2010. Mother, I love you and peace to your soul.

I also would like to devote this thesis to my children, Venâncio Marcelino Januário Rodriguês and, Mery Beatriz Marcelino Rodriguês and my wife, by pain, love, patience and tolerance that they had due to my absences. I love you.

My Father, Marcelino Venâncio Rodriguês, my brother Armando Marcelino Rodriguês, Rodolfo, and my dear Rosa Marcelino Rodriguês, I devote special thanks for the love, strength and much support they gave me in my studies. For you, thank you very much.

For you Stin, my brothers and my sisters, my families receive a big hug.
Appended Papers

Paper 1


Paper 2 (046)


Paper 3 (044)

Evidence indicates that in the developing countries, the main use of energy is attributed to lighting, cooling, heating and appliances used in buildings. According to Horsley et al. (2003), one of the most significant impacts of buildings on the environment occurs through the use of energy and therefore an effective building energy management is fundamental for construction sustainability.

Studies based from Sarah Word, (2002) indicate that if building design were improved in consideration climatic and environmental conditions as well as material specifications, significant gains would be achieved in terms of energy efficiency.

Optimum orientation of building and the use of well dimensioned external shading devices on buildings can significantly contribute to eliminate the access of sun rays and consequent reduction of thermal loads within buildings. Therefore, with less heat onto buildings reduces the needs of using electrical devices for getting thermal comfort.

Mozambique is mainly a tropical country characterized by a hot and humid climate throughout the year. One of the key methods of reducing energy use and increasing the thermal comfort to the buildings occupants is to eliminate or reduce the impact of direct solar radiation into buildings. By reducing the need to use electric fans and other cooling systems, energy can be saved and comfort levels enhanced.

This research analysed the influence of the prevalent orientation of the building and the predominant fixed shading devices used on buildings of Maputo City and to evaluate their impact on thermal comfort of the buildings occupants. The analysis also provides the optimum building orientation and the ideal dimension of the fixed shading devices for Maputo City buildings in order to improve the indoor thermal comfort in the summer.

The study reveals that the main orientation and the existing fixed shading devices in Maputo City buildings that are oriented NW-NE and NE-SW often
do not help to reduce the indoor temperature during the local summer observed from September to March.

The study concluded that in order to minimize the negative impact on occupants’ thermal comfort, the building should be E-W oriented hence reducing the dimensions of fixed shading devices and consequently reducing of building materials. Through simulations by DEROB-LTH simulation program, the results demonstrated that by optimally orientating and ideally designing shading devices for buildings in Maputo City the indoor temperatures of buildings could be improved and consequently occupant thermal comfort within such buildings could be improved significantly during peak temperature hours.

**Keywords:** Buildings Orientation, Shading on Buildings, Passive Cooling, Indoor Temperatures, Thermal Comfort, Energy Efficiency, Modelling, Simulations, Maputo City and Mozambique.
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<tbody>
<tr>
<td>AET</td>
<td>Advances in Engineering and Technology</td>
</tr>
<tr>
<td>ASCoM</td>
<td>Advancing Construction in Mozambique</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air-Conditioning Engineers</td>
</tr>
<tr>
<td>AT</td>
<td>Air Temperature</td>
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<tr>
<td>BS</td>
<td>British Standards</td>
</tr>
<tr>
<td>CEDAT</td>
<td>College of Engineering, Design, Art and Technology</td>
</tr>
<tr>
<td>Clo</td>
<td>Clothing</td>
</tr>
<tr>
<td>DEROB-LTH</td>
<td>Dynamic Energy Response of Building</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsches Institut of Normalization</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy (United State)</td>
</tr>
<tr>
<td>E</td>
<td>East</td>
</tr>
<tr>
<td>EC</td>
<td>European Community</td>
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<tr>
<td>ET</td>
<td>Effective Temperature</td>
</tr>
<tr>
<td>ET*</td>
<td>New Effective Temperature</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>FENG</td>
<td>Faculty of Engineering</td>
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<tr>
<td>GOT</td>
<td>Global Operative Temperature</td>
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<tr>
<td>Gsc</td>
<td>Solar constant</td>
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<tr>
<td>INAM</td>
<td>Instituto Nacional de Meteorologia</td>
</tr>
<tr>
<td>INE</td>
<td>Instituto Nacional de Estatistica</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>LTH</td>
<td>Lund Tekniska Hogskola</td>
</tr>
<tr>
<td>MAMS</td>
<td>Maputo Airport Meteorological Station</td>
</tr>
<tr>
<td>Met</td>
<td>Metabolism rate</td>
</tr>
<tr>
<td>MOPH</td>
<td>Ministério das Obras Públicas e Habitação</td>
</tr>
<tr>
<td>MRT</td>
<td>Mean Radiant Temperature</td>
</tr>
<tr>
<td>Mt</td>
<td>Meticais (Mozambican Currency)</td>
</tr>
<tr>
<td>N</td>
<td>North</td>
</tr>
<tr>
<td>NE</td>
<td>North East</td>
</tr>
<tr>
<td>NE-SW</td>
<td>North East - South West</td>
</tr>
<tr>
<td>Nr.</td>
<td>Number</td>
</tr>
<tr>
<td>NW</td>
<td>North West</td>
</tr>
<tr>
<td>NW-SE</td>
<td>North West - South East</td>
</tr>
<tr>
<td>PET</td>
<td>Physiological Equivalent Temperature</td>
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<tr>
<td>PMV</td>
<td>Predicted Mean Vote</td>
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<tr>
<td>SAREC</td>
<td>Swedish Agency for Research Cooperation</td>
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<tr>
<td>SE</td>
<td>South East</td>
</tr>
<tr>
<td>SET</td>
<td>Standard Effective Temperature</td>
</tr>
<tr>
<td>SIDA</td>
<td>Swedish International Development Agency</td>
</tr>
<tr>
<td>SW</td>
<td>South West</td>
</tr>
<tr>
<td>TecPro</td>
<td>Technology Processing of Natural Resources Program</td>
</tr>
<tr>
<td>UEM</td>
<td>Eduardo Mondlane University</td>
</tr>
<tr>
<td>USA</td>
<td>United State of America</td>
</tr>
<tr>
<td>W</td>
<td>West</td>
</tr>
<tr>
<td>WBGT</td>
<td>Wet-Bulb Globe Thermometer index</td>
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<th>Symbol</th>
<th>Description</th>
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<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>°</td>
<td>Degree</td>
</tr>
<tr>
<td>°C</td>
<td>Celsius degree</td>
</tr>
<tr>
<td>3-D</td>
<td>Three dimensions</td>
</tr>
<tr>
<td>Igl</td>
<td>Absorber energy</td>
</tr>
<tr>
<td>kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>kg/m³</td>
<td>kilogram per cubic meter</td>
</tr>
<tr>
<td>Km</td>
<td>kilometre</td>
</tr>
<tr>
<td>Km²</td>
<td>square kilometer</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>m/s</td>
<td>meter per second</td>
</tr>
<tr>
<td>m²</td>
<td>square meter</td>
</tr>
<tr>
<td>m³</td>
<td>cubic meter</td>
</tr>
<tr>
<td>mm</td>
<td>millimeter</td>
</tr>
<tr>
<td>s</td>
<td>second</td>
</tr>
<tr>
<td>W</td>
<td>Watts</td>
</tr>
<tr>
<td>W/m²</td>
<td>Watts per square meter</td>
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1. Introduction

Mozambique is a tropical country located in Southern east of the coast of Africa between parallels 10° 27’ and 26° 52’ South latitude and between meridians 30° 12’and 40° 50’ East longitude. Maputo City is the capital of the country with about 1,272,000 of inhabitants, (INE, Cense 2007). Maputo City is approximately 350,00km². This city is densely built and the predominant road network infrastructure is orthogonal, oriented on NE-SW and NW-SE axis.

Maputo City is located about 2° below to the Capricornia tropic. This city has sub-tropical weather conditions climate with high influences of tropical weather which consists of two seasons which are; summer and winter. This weather is characterized with high temperatures accompanied by high humidity, heavy rainfall, strong solar radiation, and a variety of wind speeds.

The local summer (October to March) is hot and humid and the local winter (April to September) is dry and cooler. During the summer, the temperature remains constantly high, (an average maximum of about 30°C, and minimum of 21°C), with little difference between day and night. The humidity is high (average of about 80%). In winter, the temperature is moderately low (an average maximum of about 26°C and minimum of 16°C) and the humidity is slightly nether (with an average about of 60%), (INAM, 2005).

During the year, the wind in Maputo City is mainly observed from N, E and SE (trade winds). The mean monthly wind speed as observed by the Maputo meteorological station varies from 2m/s during the winter and 4m/s during the summer. Winds within the bay are generally stronger compared to those observed on the main land and weaker compared to those observed in the open sea. Higher speed winds rarely occur but when they do, they often come from SW or S, (INAM, 2005).

The incident solar radiation has a major influence on Maputo City buildings’ overall performance, impacting on indoor climate and consequently influencing thermal comfort. The lack of optimum orientation of buildings associated with the absence or the presence of un-well dimensioned solar shading in buildings makes the indoor temperature of these buildings remain
constantly high almost the whole year. Due to that fact, there are massive uses of electrical devices as fans or air-conditioning as a reactive measure to combat overheating and to get thermal comfort in summer, thus increasing the use of electrical energy.

External shading devices are a passive design strategy to control solar heat gain in buildings, and influences energy performance. It can reduce solar heat gain more effectively than interior devices, and its efficiency depends on the provided shading (Olgyay and Olgyay, 1957; ASHRAE, 2005). The use of fixed shading devices ideally dimensioned for building with E-W orientation need less building materials than buildings with other orientations. Therefore, this research analysed how the thermal comfort is influenced by the buildings orientation and by the fixed shading devices commonly used in buildings of this city. The results from this study provide the optimum building orientation and the ideal dimension of the fixed shading devices for Maputo City buildings.

By using these results, the thermal comfort for inhabitants could be improved, the need of using fans and air-conditionings for getting thermal comfort could be reduced, the energy used for cooling the indoor environments could be minimized and the electrical bills could be lowered.

1.1 Background

The first contributions to climatically appropriate building in the tropics were made by leading architects of modernization, although many of their efforts were marred by serious defects. Le Corbusier and his Brazilian partners and colleagues Lúcio Costa, Oscar Niemeyer and Affonso Eduardo Reidy, as well as the American architect Louis Kahn, demonstrated with their buildings in Brazil and India how a modern architecture that is based on an ecological concept of providing protection from the climate can be achieved (Kumar, 2003).

Many traditional and vernacular houses in Africa were built in harmony with nature. Historical evidence shows that even in their greatest monuments and largest civic and religious projects, the ancient builders designed in harmony with nature. Buildings were oriented to face the warming rays of the sun and to take advantage of prevailing breezes (Denyer, 1978).
Modern architects recognized the lessons that could be learned from traditional architecture in the tropical regions and it helped them to understand the climatically influenced principles employed there and the use of those principles in order to create a new modernized suited design to the tropics (Lauber, 2005).

In hot and humid regions, the long axes of buildings should be E-W oriented in order to minimize the area of exposure to solar irradiation (Holger Koch-Nielsen, 1999).

In hot climates, the use of shading devices is desirable, intercepting the unwanted solar rays during overheating period. These elements influence heat gain, especially in relation to location and orientation (Dubois, 2001).

According to research done by the University of Stuttgart, Germany, 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 (Lauber, 2005).

In tropical climate zones the passive design through optimum orientations and appropriate protection of the envelop buildings from the direct solar radiation is an important constructive method. This ensures a comfortable indoor climate and good ventilation, as well as reduces the energy usage by electrical means for refreshing indoor environments.

Maputo City is a subtropical city with influence of the tropical weather. It is important that the architects, engineers, designers, planners and constructers consider the existing knowledge. To improve the knowledge it is important to consider the local climate conditions. By this approach, thermal comfort as well as quality of life could increase and energy could be saved.

Studies based from Sarah Word, (2002) indicate that if building design were improved taking into consideration the climatic and environmental conditions as well as material specifications significant gains would be achieved in terms of energy efficiency.

For a passive thermal design with high energy efficiency, three sustainable architecture principles such as, conserving energy; design with climate; and the materials for the envelope of buildings should be applied.

First, Conserving Energy considers the plan design in order to reduce the need of the electrical device (lights, air conditioner and others). Second, Design with Climate looks at how building forms and the disposition of building elements
can alter internal comfort through the climate. Finally, Building Envelope and Site will consider the building materials, outer walls, openings, roofs and environment. These principles can be usefully to create conducive indoor climate in residential and institutional buildings.

1.2 Problem Statement and Significance of Research

Evidence indicates that the main consumption of energy in Mozambique is attributed to lighting, cooling and appliances used in buildings. This corroborates with a recent study in Mozambique which found that approximately 50% of the energy used in buildings in Mozambique is devoted to producing an artificial indoor climate through heating, cooling, ventilation and lighting (Rodman ad Lenssen, 1995).

A typical building’s energy bill constitutes approximately 25% of the building’s total operating costs. One of the most significant impacts of buildings on the environment occurs through the consumption of energy and therefore an effective building energy management is fundamental within construction sustainability (Rodman ad Lenssen, 1995).

Many buildings are responsible for consuming more energy by using unnecessary lighting and air-conditioning than the recommended by ecological and green buildings. Ecological and green building recommend to use the potential of natural environment resources in the plan design and building construction in order to save electrical energy and to consider energy efficiency (Kumar, 2003).

The rate of energy efficiency in buildings in Mozambique is currently low for the time being and this factor often leads to high bills for the consumers, who have tight budgets for that purpose.

The amount of money spent due to inefficiencies is enormous both for private and public consumers. Conflicts in terms of non-payment of electricity bills are common. One of the strategies to improve this situation is the use of passive thermal design of buildings. Passive thermal design means using the climate for natural heating, cooling and lighting.

Related with insolation, the evidences show that many buildings of Maputo City are not optimally oriented. Therefore, the indoor climates of many buildings are negatively affected. Due to this fact, the energy used for cooling
and ventilating these buildings is high. Consequently energy costs constitute a huge expense for government, public and private sectors.

The rate of energy waste, due to inefficient use, is indeed significant. This has adverse technical, economic, environmental and social impacts. Despite that fact, little work has been done to improve the energy performance in buildings.

1.3 Objectives

The main objective of this report is to describe and analyse the influence of building orientations and solar shading on thermal comfort of the building occupants through simulations of solar radiation and indoor climate conditions of buildings and to gauge the monthly cost for using fans in order to get thermal comfort in buildings of Maputo City, Mozambique.

1.4 Research Questions

In pursuing this broad objective the research will attempt to find answers to questions such as:

- What parameters drive the passive thermal design in Mozambique and what opportunities are available?
- How can we reduce the impact of solar radiation in Maputo City buildings-Mozambique through passive thermal design?
- How to attain low indoor temperature in Maputo-City buildings-Mozambique through passive thermal design?

1.5 Delimitation

This Thesis is part of the sustainability program in Mozambique and it was conducted between June 2008 and December 2010. The research deals on thermal comfort on buildings occupants through building orientation and shading.

The study was mainly carried out through survey, measurements and simulations waiting for a complete year period of climate data collection in the
case study building where a climate weather station laboratory is placed. The collected data is still in evaluation in order to be used in the following steps of the study.

1.6 The Authors Frame of Reference

The author has a degree in Bachelor Design and Educative Technology from Eduardo Mondlane University, Maputo-Mozambique and Licentiate degree in Architecture and Territorial Plan Design from Eduardo Mondlane University.

He has worked on a number of plan design and constructions as a designer, builder, supervisor and project manager. He has a keen interest in the field of sustainability in order to improve the performance of designers and constructors in Mozambique where he has practical experience for more than 15 years.

1.7 Structure of the Thesis

This thesis is composed by four sections. The first section resumes the whole study that was been carried out, followed by the three papers. The study presents the main issues related with the Influence of Building Orientation on the Indoor Climate of Buildings and the Influence of Solar Shading on Indoor Climate of Buildings. The case study was Urban district Nr. 1 of Maputo City-Mozambique. The papers deal on Ten Years of Sustainable Construction-South Perspective, Influence of Building Orientation on the Indoor Climate of Buildings and the Influence of Solar Shading on Indoor Climate of Buildings.

1.7.1 Resume

The cover material is divided into six chapters. The first chapter presents the Introduction, background, problem statement and significance of the research, objectives, research questions, delimitation, author’s frame of reference and structure of the thesis composed by the resume, the reports and the papers.

The second chapter contains methodology that covers the introduction, field survey and measurement, the case study 1, the case study 2, literature review, climate, thermal comfort indices, thermal comfort in different regions, simulation programs, data climate and days used for simulations, thermal
comfort parameters used in the simulation program, studied parameters, thermal comfort boundaries used to analyse the results and the conclusion 1.

The third chapter is about building orientation in Maputo City which contain the introduction, historical notes of Maputo City, analyse of insolation on facades, the main orientation of the road network infrastructure, bioclimatic aspects, building regulation of Maputo City council, analyse of bioclimatic aspects, hours of irradiation and shadow on facades, Energy used in the referential building, simulated building, localization, technical description, building elements, results from simulations on different orientations, optimum orientation for buildings of Maputo City, results from simulations on volumes of buildings with NE-SW and S-W orientation, annual absorption of solar radiation in the volumes, absorbed solar radiation in the volume 2 in the hottest day, absorbed solar radiation in the volume 2 in typical days, annual indoor temperature in the volumes, indoor temperature in the volume 2 in the hottest day, indoor temperature in the volume 2 in the typical summer days, analyse of the results, optimum orientation for buildings of Maputo City, absorbed solar radiation in the volumes with NE-SW orientation, absorbed solar radiation in the volume 2 with NE-SW orientation, indoor temperatures in the volumes with NE-SW orientation, comfort hours in the volume 2 with NE-SW and E-W orientation and conclusions 2.

The fourth chapter is dealing on shading on Maputo City Buildings that contains the introduction, analyse of shading on facades, irradiated and shaded facades of buildings with NE-SW orientation, irradiated facades of buildings with E-W orientation, shading in 100% facades with different orientations, simulated building, localization, technical description, building elements-overhangs and wings used for simulations, results from simulations on non-shaded building, annual absorption of solar radiation in the volumes, absorbed solar radiation in the hottest day, absorbed solar radiation in typical summer days, hours of thermal comfort in summer months, Results from simulations on shaded building, annual absorption of solar radiation in the volumes, absorbed solar radiation in the hottest day, absorbed solar radiation in typical summer days, hours of thermal comfort in the summer months, analyse of the results-non-shaded building, annual absorption of solar radiation in the volumes, annual average of indoor temperature, indoor temperature in the hottest day, indoor temperature in the typical summer days, hours of thermal comfort in the summer months, analyse of the results-shaded building, annual absorption of solar radiation in the volumes, annual average of indoor temperature, indoor temperature in the hottest day, indoor temperature in the typical summer days, hours of thermal comfort in the summer months,
resume, comparison between the absorbed solar radiations, comparison between the indoor temperatures, comparison between the hours of thermal comforts, conclusion 3, recommendations.

Finally, the fifth chapter makes available the conclusions and the final chapter encloses the references.

1.7.2 The papers


This paper deals with sustainable construction within the North and South perspective. It describe how the international focus of sustainable construction issues has changed over the past ten years i.e., before 2008. 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 and the south perspective based on literature reviews done by the second and third authors, where the research findings reference buildings from Mozambique and Tanzania reflecting sustainability. The paper compared the earlier period with the modern day architecture in Southern Africa and the finding showed 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 based on this knowledge.


The paper provides the thermal comfort for Maputo City and present simulations in order to identify the optimum orientation for Maputo City buildings. Through simulations the thermal comfort of buildings with typical orientation of Maputo City building was compared with the optimum orientation for buildings of this City. The paper also makes available the calculations of the percentage of improvement attained by optimal orientation of the Maputo City buildings.

The paper presents simulations results that compare the indoor thermal comfort of an existing two storey non-shaded building with it after being shaded. Based on the simulations results the percentages of the thermal comfort hours attained by shading the Maputo City buildings with E-W orientation were calculated.
2. Methods

2.1 Introduction

According to the objectives and the goals of the research, different methods were used to accomplish the programmed studies. Therefore the field survey (data collection and measurements), literature review and simulations were the methods that were used in the current stage. For that, two buildings were identified. The first was selected as the representative building of those that followed the main orientation of Maputo City buildings, and the second one was chosen to represent buildings with E-W orientation and having fixed shading devices commonly used on Maputo City buildings.

The first was a single story building with NE-SW orientation used to simulate the optimum orientation to Maputo City buildings and to evaluate the thermal comfort of buildings occupants. The found optimum orientation was compared to their indoor thermal comfort with the typical orientations of Maputo City buildings.

The second is a two story building with E-W orientation. It was used to simulate the optimum dimensions of the fixed shading devices and to evaluate the thermal comfort of the buildings occupants. The found optimum dimensions for the fixed shading devices were simulated and the results were compared with the typical overhangs and wing walls commonly used to the shadowing the facades of buildings of Maputo City.

2.2 Field Survey and Measurements

The field survey was based on searching for and measuring buildings that were in accordance with the main objectives of the research. Therefore, buildings with NE-SW and E-W orientations were looked for, identified, selected and measured. The buildings were found as adequate and representative enough for carrying out the study. The first building is a private single one dwelling and
the second is a two story guest house of the Faculty of Engineering of Eduardo Mondlane University.

2.2.1 The case study 1-Residential building

The studies about the Influence of Building Orientation on the Indoor Climate of Building were based in the one story building with NE-SW orientation. This building was selected among 45 identified building and, it was found as suitable for study taking in account the required criteria. The main criteria observed for selecting the building were:

- The building should be NE-SW oriented following the main orientation of the Maputo City buildings,
- The shape of building should be representative enough to enclose common buildings with one story of the Urban Districts of the Maputo City,
- The building should not be shaded as well as not thermal insulated also representing the new trend of buildings in Urban Districts of the Maputo City apart from the Urban District nr 1,
- The used building materials of the building should be the most common and preferable building materials used today,
- The selected simulation program could cover all planned simulations for current study and,
- The owner of building should allow their building to be used as the case study without reserves.

In the building, information related to the energy use was collected in order to evaluate the energy spent by the occupants for using fans during the local summer attempting to get thermal comfort. After selection, the next step was to take measurements in order to design and to start the desk study through literature review and simulation.

Solar radiation and indoor temperature were simulated in order to evaluate the thermal comfort in the case study building. The optimum orientations to Maputo city buildings were also analysed through simulations of the indoor temperatures of 24 orientations of the volume of the building.

According to the results of simulations about the optimum orientation of buildings for Maputo City, the second building was analysed in order to continue the study about shading on building.
In the simulations the assumptions were that the apartments were empty meaning that in the flats there are no people, furniture and any kind of devices.

2.2.2 The case study II-Residential guest house of FENG

For continuing the studies in the field of thermal comfort, shading on buildings the following step of the research was taken. After have been identified the optimum orientation of the Maputo City buildings a building with E-W orientation was a challenge to find. To accomplish this survey, Google Map and Google Earth were used as preliminary method to identify the Maputo City building with E-W orientation.

The results of this survey showed that there were very few buildings that followed the E-W orientation. After preliminary visit to the identified buildings, it was observed that some buildings were not possible to go in due to many reasons. Nevertheless, the buildings where permission was granted were visited. The visited buildings were 7 with reference of the lectures residential districts of the Eduardo Mondlane University, the PH buildings-Coop, Faculty of law and the guest house of Faculty of Engineering of Eduardo Mondlane University. In all these buildings, the guest house of Faculty of Engineering of Eduardo Mondlane University was found to be appropriate to continue to carry out the research. The main points that were taken into account for choosing this building were:

- The building should be E-W oriented,
- The form of the building should be a rectangle as the prevalent buildings in Maputo City,
- The building should have the fixed shading devices,
- The building should have more than one floor (appropriate to evaluate the other factors having impact on the indoor temperature. This kind of building could also cover other building typology of Maputo City buildings),
- The building materials that were used to construct the building should be common building materials that are currently used to construct buildings today,
- The building should have a form and volumes that could be simulated by the same simulation program used in the previous simulations in the Case study 1,
- The building should be secure to install safety the weather station laboratory to collect data for further study and,
- The owner of building should allow their building to be used as the case study without reserves.

Building measurements were taken in order to design the master plan, the buildings detail and building materials were surveyed to be used as input to the DEROB-LTH simulation program. In the apartments, solar radiation and indoor temperature were simulated in order to analyse the occupants’ thermal comfort.

2.3 Literature Review

Through the literature review suitable thermal comfort boundaries for Maputo City were found in wide range of existing comfort zone for hot and humid regions. Based on literature review also the suitable simulation program in order to carry out the study was identified.

2.3.1 Climate

Climate encompasses the statistics of temperature, humidity, atmosphere pressure, wind rainfall, atmospheric particles count and other meteorological elements in given a region over a long period of time. Climate can be contrasted with weather, which is the present condition of these same elements and their variations over periods up to two weeks (Wikipedia, 2006). For this research, the rainfall and pressure will not be taken in consideration although they are important. The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation (Wikipedia, 2006).

Solar radiation

Solar radiation is the energy transmitted from the sun (the engine of all life terrestrial system) by the way of electromagnetic wave (Romero, 2000). When the radiation crosses the atmosphere it is scattered and, due to the dust and other suspension molecules, part of this solar radiation is diffuse reflected by the underside of the clouds (Olgyay, 1963). The intensity of solar energy on a surface oriented perpendicular to the sun’s rays above the Earth’s atmosphere (known as the solar constant) has been measured by a satellite to be between
Solar constant $G_{sc}$ is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere (Duffie, 2006).

Solar radiation is energy transmitted through the atmosphere and reaches the Earth’s surface at a rate that varies over time at particular location due to the angle at which the sun’s rays strike the earth (the zenith angle). This angle establishes the path length through the atmosphere for incoming sunlight and varies with latitude, date, and local time of day. The summation of the amount of solar energy arriving at a unit of area ($1\text{m}^2$) during an hour is called the solar radiation or insolation (Morse, 1976).

The Earth is heated by two types of radiation; beam radiation and diffuse radiation. Beam Radiation or direct solar radiation is the solar radiation received from the sun without having been scattered by the atmosphere. Diffuse Radiation or sky solar radiation is the solar radiation received from the sun after its direction has been changed by scattering in the atmosphere (Duffie, 2006).

In Maputo City, the strong radiation is observed throughout the year with the maximum global solar radiation reaching about 1100 $\text{W/m}^2$ on horizontal surface with average about 270 $\text{W/m}^2$ (INAM, 2005).

**Temperature**

Temperature is a physical property of matter that quantitatively expresses the common notions of hot and cold. Objects of low temperature are cold, while various degrees of higher temperatures are referred to as warm or hot. Quantitatively, temperature is measured with thermometers, which may be calibrated to a variety of temperatures scales.

Temperature relates to the thermal energy held by an object or a sample matter, which is the kinetic energy of the random motion of the particle constituents of matter. Differences in temperature between regions of matter are the driving force for heat which is the transfer of thermal energy. Spontaneously, heat flows only from regions of higher temperature to regions of lower temperature. If no heat is transferred between two objects, the objects have the same temperature.

In Maputo City the high solar radiation that is observed during the year heats the air making the air temperature very hot in summer with average about $30^\circ\text{C}$ as maximum and $21^\circ\text{C}$ as minimum with little difference between day and night (INAM, 2005). The city has essentially two seasons constituting...
summer and winter. Nationally summer begins in October and ends in March and the winter begins in April and ends in September.

Humidity

Humidity is the amount of water vapour in the air. Absolute humidity is the exact amount of water that is present in a given volume of air expressed in kg/m$^3$. This gives a precise measurement of the amount of water present. Relative humidity is the amount of moisture present in the atmosphere, at any given point in time, compared with the amount of moisture that would be in the air if the moisture was completely saturated, at the same temperature and it is expressed in percentage.

A higher amount of absolute humidity present in the atmosphere means that people will feel hotter when they are outdoors. This happens because the greater amount of water vapour in the air results in lesser amounts of perspiration, or sweat, being evaporated from a person body. As a result, the cooling effect of the evaporation of perspiration is negated. Absolute humidity levels also indicate the likelihood of dew, fog or precipitation that may occur, (Buzzle, 2009).

The ideal relative humidity value for human beings is between 30% and 60%. If the humidity is more than this, perspiration of human beings will be ineffective and they will feel hotter. If it is less than this amount, humans will suffer from excessive thirst and dry skin (Buzzle, 2009).

According to INAM, in Maputo City the humidity is almost high throughout the year. In summer the average humidity is about 80% and in the winter the average about 60% (INAM, 2005).

Wind speed

Wind is air in motion. It is produced by the uneven heating of the earth’s surface by the sun. Wind refers to any flow of air above Earth’s surface in a roughly horizontal direction. A wind is always named according to the direction from which it blows. For example, a wind blowing from west to east is called west wind.

In Maputo City, the wind is mainly observed from N, E and SE. The mean monthly wind speed as observed by the Maputo meteorological station varies from 2m/s during the winter and 4m/s during the summer. Winds within the bay are generally stronger compared to those observed on the main land and weaker compared to those observed in the open sea. Higher speed winds rarely occur but when they do, they often come from SW or S, (INAM, 2005).
2.3.2 Thermal comfort

The heat produced in the body is determined by the level of activity of the person, and also varies with age and sex. This heat is exchanged with the outside environment by conduction, convection, radiation and evaporation. The conduction usually has no great relevance. Convection depends on temperature and air velocity outside. Radiation depends on the mean radiant temperature and evaporation depends on air humidity and its speed.

Thermal comfort is a subjective sensation that varies from person to person. There are many parameters aggregated in individual and environments variables influence a person feel of comfort in certain environment. Comfort is an environment conditions that gives the thermal neutrality sensation for many people as possible with the same activity (Olgyay, 1963).

According to ASHRAE (2003), thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. There are large variations, both physiologically and psychologically, from person to person, which makes it difficult to satisfy everybody in a space. The environmental conditions required for comfort are not the same for everyone (ASHRAE, 2003).

Fanger (1970) defined thermal comfort in terms of four environment parameters that is, air temperature, mean radiant temperature, relative humidity and air velocity and two cultural parameters: clothing and activity level. This definition was also adapted by the International Standard Organization (ISO 7730-1994) that is widely used and accepted by the American Society of Heating, Refrigeration and Air conditioning Engineers ASHRAE.

The literature divides the thermal comfort into two variables. The variables are individual and environmental with a variety list of parameters that could be summarized below.

**Individual parameters:**
- Activity
- Clotting

**Environmental parameters:**
- Air temperature
- Humidity
The American Society of Heating, Refrigerating and Air-Conditioning Engineer, Standardized six primary factors that must be addressed when defining conditions for thermal comfort, (ASHRAE, 2003). A number of other secondary factors affect comfort in some circumstances. The six primary factors are:

- Metabolic rate
- Clothing insulation
- Air temperature
- Radiant temperature
- Air speed
- Humidity

All six of these factors may vary with time. However, this standard only addresses thermal comfort in steady state. People who have prior exposure to different environmental conditions and/or activity levels may not find the conditions suitable in this standard comfortable upon entry to the space. The effect of prior exposure or activity may affect comfort perceptions for approximately one hour, (ASHRAE, 2003).

The difference between these two types of variables is how the ASHREA (2003) consider the individual variables. In ASHREA (2003), the individual variable could be found together in Metabolism rate. Here, metabolism rate is related with personal activity.

There parameters that are important to consider if the thermal comfort has to be deeply considered as gender, age and health stage. Therefore, the standardised factors by ASHREA (2003) could be considered as enough to consider thermal comfort.

2.3.3 Thermal comfort factors

According to available literature, there are many factors influencing in thermal comfort as Metabolism rate (Met), Air temperature, air speed, humidity, clothing/ensemble (clo), and insulation, garment (I_{clo}) and mean radiant temperature (MRT).
Metabolism rate

Metabolism rate (Met) is defined as the rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism. Usually it is expressed in terms of unit area of the total body surface.

When measuring metabolism rates, many factors have to be taken into account. Each person has a different metabolism rate, and these rates can fluctuate when a person is performing certain activities, or under certain environmental conditions. Even people who are in the same room can feel significant temperature differences due to their metabolic rates, which makes it very hard to find an optimal temperature for everyone in a given location (Toftum, J., 2005).

Met is a unit used to describe the energy generated inside the body due to metabolic activity, defined as 58.2 \( \text{W/m}^2 \) which is equal to the energy produced per unit surface area of an average person, seated at rest. The surface area of an average person is 1.8 \( \text{m}^2 \) (ASHRAE, 2003).

There is a wide range of activity types that could be found in the literature but the most common activities considered in the comfort parameters are listed in table 2.1.

Table 2.1: Metabolism rate according to activity

<table>
<thead>
<tr>
<th>Units/Activity</th>
<th>Sleeping</th>
<th>Seating</th>
<th>Sedentary Low activity</th>
<th>Mean activity</th>
<th>High activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W/m²)</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>(met)</td>
<td>47</td>
<td>58</td>
<td>70</td>
<td>93</td>
<td>117</td>
</tr>
</tbody>
</table>

Air temperature

Air temperature is the average temperature of the air surrounding an occupant. The average is with respect to location and time. As a minimum, the spatial average is the numerical average of the air temperature at the ankle level, the waist level and the head level. These levels are 0.1 m, 0.6 m and 1.1 m respectively for seated occupants and 0.1 m, 1.1 m and 1.7 m for standing occupants. (ASHRAE, 2003).

ASHRAE (2003) has listings for suggested temperatures and air flow rates in different types of buildings and different environmental circumstances. For example, a single office in a building has an occupancy ratio per square meter of 0.1.
In the summer, the suggested temperature is between 23.5 and 25.5 degrees Celsius, and airflow velocity of 0.18 m/s. In the winter, the recommended temperature is between 21.0 and 23.0 degrees Celsius with an airflow velocity of 0.15 m/s (Olesen, B. W., 2004).

**Air speed**

Air speed is the average speed of the air to which the body is exposed. The average is with respect to location and time. Time averaging and spatial averaging are the same as for air temperature. However, the time averaging period extends only to three minutes. Variations that occur over a period greater than three minutes should be treated as multiple different air speeds.

According to the ASHRAE (2003) and Givoni (1998), the acceptable air velocity in building could range from 0.2 to 1m/s. To increase the air velocity increases than 1.0 m/s increases the temperature.

Studies done by Ruey-Lung Hwang at al. and E Prianto at al. demonstrated that to increase the air velocity to 2-3m/s should improve the comfort sensation by reducing the humidity in the body although the temperature tend to rises.

**Humidity**

Humidity is a general reference to the moisture content of the air. It may be expressed in terms of several thermodynamic variables including vapour pressure, dew point temperature, and humidity ratio. It is spatially and temporally averaged in the same manner as air temperature, (ASHRAE, 2003).

The human body has sensors that are fairly efficient in sensing heat and cold, but they are not very effective in detecting relative humidity. Relative humidity creates the perception of an extremely dry or extremely damp indoor environment.

This can then play a part in the perceived temperature and their thermal comfort. The recommended level of indoor humidity is in the range of 30-60% (Balaras, 2007).

**Clothing/ensemble**

Clothing (clo) is the resistance to sensible heat transfer provided by a clothing ensemble. The definition of clothing insulation relates to heat transfer from the whole body, and thus also includes the uncovered parts of the body, like head and hands.
Insulation, garment

Insulation, garment ($I_{clu}$) the increased resistance to sensible heat transfers obtained from adding an individual garment over the nude body (ASHRAE, 2003).

Mean Radiant Temperature

*Mean Radiant Temperature (MRT)* is a concept arising from the fact that the net exchange of radiant energy between two objects is approximately proportional to their temperature difference multiplied by their ability to emit and absorb heat (emissivity). MRT is simply the area weighted mean temperature of all the objects surrounding the body (Wikipedia, 2006).

Technically, MRT is the uniform temperature of a surrounding surface giving off blackbody radiation (emissivity $e = 1$) which results in the same radiation energy gain on a human body as the prevailing radiation fluxes which are usually very varied under open space conditions (ASHRAE, 2003).

MRT is the most important parameter governing human energy balance, especially on hot sunny days. MRT also has the strongest influence on thermo-physiological comfort indexes such as PET (Physiological Equivalent Temperature) or PMV (Predicted Mean Vote) which are derived from heat exchange models (Wikipedia, 2006).

2.3.4 Thermal comfort indices

Effective Temperature

*Effective Temperature (ET)* is the thermal comfort index proposed by Houghten and Yagloglou in 1923 (Szokolay, 1987). Effective Temperature is defined as that temperature at 50 percent of relative humidity and with mean radiant temperature equal to air temperature which produces the same thermal sensation as the actual environment, that is, ET normalizes temperatures for humidity and radiation and thereby enables comparisons of various thermal environments, (Yaglou, 1947).

ET is not adequate to be used to quantify the Tropical thermal comfort because it is not performed to evaluate the cool potential of air movement, the insulation effect of clothing are disregarded and heat loss requirement vary with human metabolism (Emmanuel, 2005).

Olgyay (1963) has done several bioclimatic charts and concluded that the level of comfort in the hot climate follows the average summer temperatures. Started from the average level could be decreased or increased by 2.8°C for minimum
and maximum thermal comfort zone. Concerning this method, though acceptable, many authors have some reservation. The latest comfort index now generally accepted is the \( ET^* \) or New Effective Temperature and is standardised, (Szokolay, 1987).

Predicted Mean Vote

Predicted Mean Vote (PMV) developed by Fanger (1970) adapted by the International Standard Organization (ISO 7730-1994) and accepted by the ASHRAE.

The PMV model is based on sweat secretion and mean skin temperature of the body. It predicts that the neutral temperature, 80 percent of the people will vote between \( \pm 1 \) on PMV scale. Neutral temperature is assumed to be associated with imperceptive rates of sweating. PMV is based on the mean vote on the seven point sensation scale, shown in the table 2.2.

The relationship between the metabolisms of activity and the mean votes of thermal sensation has been established by large number on experiments of human beings. The experimental data has been collected from tests in a climate chamber on college-aged subjects, conducted in Denmark by Professor P.O. Fanger.

<table>
<thead>
<tr>
<th>PMV</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensation</td>
<td>cold</td>
<td>cool</td>
<td>slightly cool</td>
<td>neutral</td>
<td>slightly warm</td>
<td>warm</td>
<td>hot</td>
</tr>
</tbody>
</table>

Predicted Percentage of Dissatisfied

Predicted Percentage of Dissatisfied (PPD) is an index that predicts the percentage of thermally dissatisfied people. The PDD considers the percentage of a large group of people voting in seven points of the thermal sensation scale. As PMV changes away from zero in either the positive or negative direction, PPD increases.

These methods are recommended to be used only where the air temperature lies between 10 °C to 30°C and used and accepted by ASHRAE and ISO but, they are limited for temperatures above 30°C. The air temperature in Maputo City is almost over 30°C in the summer season thus; index from PMV and PDD should be avoided.
Operative Temperature

Operative Temperature (OP) for given values of humidity, air speed, metabolic rate, and clothing insulation, a comfort zone may be determined.

The comfort zone is defined in terms of a range of operative temperatures that provides acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature that people find thermally acceptable (ASHRAE, 2003).

Global Operative Temperature

Global Operative Temperature (GOT) is the uniform temperature of a radiantly black enclosure in which the occupant would exchange the same amount of heat by radiation plus convection as in the actual no uniform environment, thereby experiencing thermal comfort, or thermal neutrality (Källblad, 1998).

Standard Effective Temperature

Standard Effective Temperature (SET) was developed by ASHRAE (2003) in order to rectify some of the shortcomings of ET, (Emmanuel, 2005). The index is a most general one, which is particularly designed to deal with the effects of high humidity and temperature.

SET is defined as “the value of an isothermal enclosure with radiant temperature equal to the air temperature, at 50% relative humidity, and air velocity of 0.1m/s, in which a person with standard clothing for the actual activity level would have a same heat loss at the same mean skin temperature and the same skin wetness as he or she does in the actual environment with the actual clothing insulation after one hour of exposure” (Bush, 1990).

Although SET takes into account all parameters of comfort identified by Fanger (1970), Gagge et al. (1986) point out that the effect of vapour permeability of the clothing is neglected.

SET is an index based on an analysis of the human thermoregulatory system. It defines the thermal condition of the body with respect to mean skin temperature and skin wetness of the body so that the environment variables always correspond to a particular thermal condition of the body. In principle, this has no limitation.
Table 2.3: SET sensation and physiological state of sedentary person

<table>
<thead>
<tr>
<th>Item</th>
<th>SET (°C)</th>
<th>Sensation</th>
<th>Physiological state of sedentary person</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Above 37.5</td>
<td>Very hot, very uncomfortable</td>
<td>Failure of regulation</td>
</tr>
<tr>
<td>2</td>
<td>34.5-37.5</td>
<td>Hot, very unacceptable</td>
<td>Profuse sweating</td>
</tr>
<tr>
<td>3</td>
<td>30.0-34.5</td>
<td>Warm uncomfortable unacceptable</td>
<td>Sweating</td>
</tr>
<tr>
<td>4</td>
<td>25.6-30.0</td>
<td>Slightly warm, Slightly unacceptable</td>
<td>Slightly sweating, vasodilatation</td>
</tr>
<tr>
<td>5</td>
<td>22.2-25.6</td>
<td>Comfortable and acceptable</td>
<td>Neutrality</td>
</tr>
<tr>
<td>6</td>
<td>17.5-22.2</td>
<td>Slightly cool, Slightly unacceptable</td>
<td>Vasconstriction</td>
</tr>
<tr>
<td>7</td>
<td>14.5-17.5</td>
<td>Slightly cold, Slightly unacceptable</td>
<td>Slow body cooling</td>
</tr>
<tr>
<td>8</td>
<td>10.0-14.5</td>
<td>Cold, very unacceptable</td>
<td>Shivering</td>
</tr>
</tbody>
</table>

SET and sensation (light clothing, sitting) \(^1\) (McIntyre, 1980)

\(^1\) The relationship between SET and sensation is not dependent on metabolic rate.

**Wet-Bulb Globe Thermometer index**

Wet-Bulb Globe Thermometer index (WBGT) is a thermal stress index emphasizing the physiological effects of direct radiation and air movement. It is therefore suitable for stressful outdoor environment (both cold and heat stress). This is the first time that ISO has accepted it as a heat stress index.

### 2.3.5 Common methods of measuring thermal comfort limits

To evaluate the thermal comfort within the buildings in hot and humidity regions, there are many method used but the most widely used methods are shown in table 2.4.
Table 2.4: Thermal comfort limits widely used

<table>
<thead>
<tr>
<th>Method</th>
<th>Seasons</th>
<th>Temperature (°C)</th>
<th>Humidity (%)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLGYAY</td>
<td>summer</td>
<td>21.1 - 27.7</td>
<td>30 - 65</td>
<td>USA</td>
</tr>
<tr>
<td>(USA)</td>
<td>winter</td>
<td>20 - 24.4</td>
<td></td>
<td>USA</td>
</tr>
<tr>
<td>Tropics</td>
<td>summer</td>
<td>23.9 - 29.5</td>
<td>20 - 80</td>
<td>Tropics</td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>18.3 - 23.9</td>
<td></td>
<td>Tropics</td>
</tr>
<tr>
<td>ASHRAE 55-92</td>
<td>summer</td>
<td>23 - 26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>winter</td>
<td>20 - 23.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIVONI Sum/win</td>
<td>20 - 27</td>
<td>80</td>
<td>Developed countries</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25 - 29</td>
<td></td>
<td>Developing countries</td>
<td></td>
</tr>
<tr>
<td>SZOKOLAY</td>
<td>TMA ±2</td>
<td></td>
<td>All countries according to site climate data</td>
<td></td>
</tr>
</tbody>
</table>

2.3.6 Thermal comfort in different regions

In different areas of the world, thermal comfort needs may vary depending on climate. In China there are hot humid summers and cold winters causing need for efficient thermal comfort. Energy conservation in relation to thermal comfort has become a large issue in China in the last several decades due to rapid economic and population growth (Yu, J., 2009).

Researchers are now looking for ways to heat and cool buildings in China for lower costs and also with less harm to the environment (da Silva, V.D., 2009). In the hot humid region of Saudi Arabia, the issue of thermal comfort has been important in mosques where people go to pray. They are very large open buildings which are used only intermittently making it hard to ventilate them properly.

Mozambique is characterized by hot and humid climate although there are some regions with cool, hot and dry climate along the year. Therefore, the thermal comfort for Maputo City will be different with these regions. Thus, for each region of the country should be considered a local climate and the native behaviours should be considered in order to evaluate and determine/calculate the appropriate thermal comfort.
2.3.7 Simulation program

Simulation is the process of imitation of a hypothetical and potential event or occurrence based on change or probability, via a model, which accurately portrays the actual experiment. Automated simulation or computer simulation technique is especially helpful when it is a statistical problem based on probability.

Simulations are techniques for conducting experiments that involve certain types of mathematical and logical relationships necessary to describe the structure and behaviours of a complex real system. It is a quantitative technique that utilises a computerised mathematical model in order to represent actual decision making under conditions of uncertainty for evaluating alternative courses of action based upon assumptions and facts.

There are a wide range of programmes that simulate the indoor climate in building which have been developed over around the world. Examples that can be mentioned are DOE, ENERGY-PLUS, ESP, TSBI, TRNSYS 16, COMBINE, TREAT, but at our Department the program JULOTA and DEROB-LTH have been used for several studies of research projects.

JULOTA Program was developed at Department of Building Science, Lund University (Källblad, 1986). This simulation program was used to control the indoor climate in Kitchen Design of Housing in Hanoi, Vietnam (Nystrom Maria, 1994). For that study the ventilation rate and humidity that influences the thermal comfort were not carried out through JULOTA simulation program due to their limitations.

The DEROB-LTH Simulation program has been used in many countries that have different climate as hot and humid regions; hot and dry zones; cold and dry countries; and cold and humid areas.

Hans Roselund (1993) conducted the desk study using DEROB-LTH Simulation program in order to find an optimal solutions for passive climatisation of buildings in hot and arid regions, especially the desert areas of North Africa using climate data from Ghardaïa, Algeria where the finding were considered acceptable.

Wang Zhiwu (1996) used DEROB-LTH Simulation program to conduct her studies in order to control the indoor climate and thermal comfort in the hot and humid regions of China. The results of the study through this program showed that the program presented good performances that was considered good and credible taking into account the field measurement that were done in the studied apartments.
The DEROB-LTH Simulation program was also used as appropriate program to control solar protection in building. During this research, the program was improved in order to meet the new needs. The improvement was related to the thermal windows model, solar and sky radiation at glazed surfaces, shading of diffuse radiation, comfort calculations and visualization of the building. The new parts of the program have been put into special program modules so that changes to the original code are minimized and subsequent maintenance of the program simplified (Maria Wall, 2001).

The study about the Impact of Solar Shading devices on Daylight Quality in Offices, Marie-Claude Dubois (2001), used DEROB-LTH simulation program carried out her research that were simulated the radiance in the laboratory in Danish building and urban research institute in Horsholm, Denmark during the summer of 2001.

The same author above mentioned above, also used the DEROB-LTH Simulation program to conduct the study about Awning and Solar-Protective Glazing for Efficient energy in a single-occupant Office Room in Lund, and The Design of Seasonal Awnings for Low Cooling and Heating in offices, a model, (Marie-Claude Dubois, 2001). The results of all simulation were considered as good compared to the field data collection.

Apart from the credibility that the program has demonstrated over time, it is also constantly improved and the high professionals who are working on it are available and they can update the program according to the new phenomenon during the daily activity. Due to the fact that the research is linked to Lund University where the program is mainly running, this was the other reason why this program was chosen.

DEROB-LTH is a dynamic and detailed energy simulation tool originally developed at Austin School of Architecture, University of Texas and further developed at Lund Institute of Technology. It has accurate models to calculate the influence of solar insulation and shading devices on the energy balance of a building.

The building is modelled in 3-D, a necessary condition for accurate calculations of the distribution of solar insulation and temperatures in the room and its surfaces. DEROB-LTH can manage rooms with irregular geometries, buildings with several zones and calculate peak loads, energy demand, temperatures and thermal comfort for a building (Källblad, 1993).

The available thermal comfort indices in DEROB-LTH simulation program based on PMV and PPD values. PMV is based on the mean vote on the seven
point sensation scale with boundaries limits from -3 to +3 and (0) is the neutral temperature.

In this index, the thermal comfort is observed from -1 to +1 where the sensations are correspondent to slightly cool, neutral and slightly warm. These methods are recommended to be used only where the air temperature lies between 10 °C to 30 °C.

The available PPD and PMV in DEROB-LTH simulation program is widely used and accepted by ASHRAE and International Standardization Organization. Therefore it would appear more scientifically more useful for these simulations to assume the available values of Global Operative Temperature to evaluate the thermal comfort in the buildings.

The DEROB-LTH simulation program also calculates the Global Operative Temperature in the buildings. Global Operative Temperature is the uniform temperature of a radiantly black enclosure in which the occupant would exchange the same amount of heat by radiation plus convection as in the actual no uniform environment, thereby experiencing thermal comfort, or thermal neutrality (Källblad, 1998).

2.3.8 Data climate and days used for simulations

The climate data used for simulations based on the data climate of the typical year from Meteonorm. Meteonorm Version 6.0 produces a Global Metrological Database for Engineers and Planners. The climate data created by Meteonorm Version 6.0 provides climate data of the typical year (2005) from 1971 to 2000 of Maputo City. The available climate data also provides information about global horizontal radiation, temperature, relative humidity, wind direction and wind speed.

To evaluate the indoor climate in buildings, the Mozambican summer, the hottest day and typical summer days were chosen. Months from October to March were selected as the summer months, December 16 with the highest outdoor temperature along the year was selected as the hottest day and, October, 11 the day with the same maximum temperature as the average of the maximum temperature of the all months of the typical year was selected to represent typical summer days.

2.3.9 Comfort parameters used in the simulation program

To simulate the comfort, the comfort indexes of the Global Operative Temperature values were used. The considered parameters for comfort were;
1.0 for clo; 70% of the absorptivity; 50% of the emissivity; 0.1 m/s of indoor air velocity; 80% of relative humidity and 1.0 met of the rate of the metabolism. The data that was used to evaluate the comfort in the volume 2 on the building NE-SW and E-W oriented were read at 1.20 meters level from the floor level.

2.3.10 Studied parameters

For these study two main parameters: the orientations of the buildings and the indoor environment were considered in order to analyse the thermal comfort in Maputo City buildings.

To analyse and compare the indoor thermal comfort, two types of indoor environment were considered for all simulations. The first indoor environment considered was the test building with closed windows and the second was the same building with 100 per cent of opened windows.

2.3.11 Thermal comfort boundaries used to analyse the results

For this study, the comfort values considered were those presented by Global Operative Temperature available in the DEROB-LTH simulation program and combined with Szokolay (1987) thermal indices. The Szokolay 1987 method was used for determining the Maputo City thermal comfort limits.

This method presents the thermal comfort zone based in thermal neutral temperature in function of medium external temperature and its comforts limits are based on Standard Effective Temperature (SET). After determination of the thermal neutral temperature, the obtained values should be decreased 2°C for minimum thermal neutral temperature and increased 2°C for maximum thermal neutral temperature.

This method can be used for all sites and only require the climate data of these places for calculation the annual average of maximum and minimum monthly outdoor temperature of the year in order to apply the equation 1.

Equation 1: Szokolay thermal comfort formula

\[ \theta_n = 17.6 + 0.31 \times \theta_m; \text{ and } 18.5 < \theta_n < 28.5°C \]

Where

\[ \theta_n \rightarrow \text{thermal neutral temperature} \ [°C] \]
\[ \theta_m \rightarrow \text{medium external temperature} \ [°C] \]
According to INAM, the average of the minimum and maximum temperature of Maputo City climate data from 1971 to 2000 was 18.7 °C for minimum and 27.4 °C for maximum.

The maximum and minimum thermal comfort limits used to evaluate the comfort of Maputo City buildings were obtained by calculation using Szokolay methods as was demonstrated before.

For Maputo City, the maximum thermal comfort limit used was 28°C, and the minimum comfort limit used was 21.4°C. These limits were obtained through the use of equation 2 and 3 respectively.

**Minimum thermal comfort**

Equation 2: Minimum thermal comfort

\[
\theta_n = 17.6 + (0.31 \times 18.7) = 23.4°C
\]

For minimum thermal comfort, the result was decreased 2°C from 23.4°C to 21.4°C as the inferior limit of Maputo City thermal comfort.

**Maximum thermal comfort**

Equation 3: Maximum thermal comfort

\[
\theta_n = 17.6 + (0.31 \times 27.4) = 26°C
\]

For maximum thermal comfort, the result was increased 2°C from 26°C to 28°C as the superior limit of Maputo City thermal comfort.

To analyse the Maputo City thermal comfort 28 °C was used as the maximum limit and 22 °C as the minimum limit. The obtained results of Maputo City thermal comfort are approximately the same limits recommended by Olgyay (1963) thermal comfort values to the tropics and by Givoni (1992) thermal comfort for developing countries.

### 2.4 Conclusion 1

Through survey two buildings were identified for the carried out the study. One is NE-SW oriented representing the typical orientation of Maputo City buildings and another is E-W oriented representing the optimum orientation to Maputo City.

By literature review a method to determine the comfort zone for each region independently of questionnaires and inquiries of people was founded. This
method was chosen due to discordance among the researchers about the thermal comfort indices for hot and humid regions hence, the researcher followed the existing formula previously developed by Olgyay (1963) and further improved by Szokolay (1987). Based in this formula that almost considers the environment factors, the boundary to Maputo City thermal comfort was calculated.

Based on literature review, also a suitable simulation program was identified. The chosen program is DEROB-LTH simulation program. This program was chosen because it has been used in many countries with different climates and the results were satisfactory. Apart from this performance, the researcher is linked to Lund University where the simulation program is widely used and it is constantly improved according to the needing.
3. Building Orientation in Maputo City

3.1 Introduction

This chapter analyses the impact of building orientation on indoor climate of Maputo City buildings. The evaluation essentially deals on insolation. Maputo City is densely built and the predominant road network infrastructure is orthogonal, oriented on NE-SW and NW-SE axis. Many buildings of the city have their facades parallels to these road network infrastructures. The historical settlement of the City was analysed in order to understand why many buildings adopted the prevalent orientation.

According to Holger Koch-Nielsen (1999), in hot and humid regions, the long axes of buildings should be E-W oriented in order to minimize the area of exposition of solar irradiation. Considering this statement, many buildings of Maputo City are not optimally oriented. Therefore, the indoor climates of many buildings are negatively affected. Due to this fact, the energy used for cooling and ventilating these buildings is high. Consequently energy costs constitute a huge expense for government, public and private sectors.

To carry out the study, literature review on thermal comfort was done in order to identify the ideal comfort boundaries to Maputo City. The literature review about the simulation program was also carried out.

Through simulation, the optimum orientation for Maputo City buildings was identified. The percentages of the comfort hours in the buildings with optimum orientation and with the typical orientation of Maputo City buildings were calculated.

3.1.1 Historical notes of Maputo City

Maputo City (former Lourenço Marques) was founded in 1782 as an administrative trading port. At this time, Lourenço Marques had two roads which were perpendicular to each other. These roads were NE-SW and NW-SE oriented. The coming streets followed the orientation of the previous roads, thus forming an orthogonal grid. By 1887, Lourenço Marques had developed into a city and in 1898 this city became the Capital of Mozambique.
From 1960s to 1970s, the city population grew rapidly since new factories, industries and other city activities began to advance and many people came to the city for work. This rapid growth was not accompanied by the development of social infrastructure and adequate site planning and the city started to be densely built and occupied on an ad-hoc basis.

The Lourenço Marques Municipal Council started to distribute small plots which were not previously earmarked in order to satisfy the demand, consequently, the city started to develop small unorganized areas (Slums) which were occupied by people coming from other places and mixed with the natives.

For those people whom were given provisory plots during the colonial period were recommended to not use conventional building materials for building their houses, because these plots were not attributed to them definitely.

These people started to build their dwellings according to space and economical condition. In these plots, all types of cheap local building materials were available to be used by them. The given plots were different in area and shape and often were very small. The roads were unordered and very narrow.

By date the Lourenço Marques Municipal Council started to consider urban planning near to the town for those who lived in provisory plots and for others. This site planning development went on continuously even after the independence period.

In June of 1975 Mozambique attained its independence and in March of 1976 Lourenço Marques name was renamed as Maputo as the Capital of Mozambique. After independence, during the late 1970s the city experienced new scenarios in terms of population growth; many people came to the city in order to increase their income in addition many people migrated from rural areas to the city for security reasons during the sixteen years of civil war from 1976 to 1992.

This rapid growth of population in the city was not accompanied by the development of social infrastructure and adequate urban planning. The city started to be densely built by shambolic dwellings which, in many case were not planned or controlled, consequently, many issues related to the environment, urbanisation, architectural and bioclimatic conditions were not observed.

From 1976 up to now, many people whom were given provisory plots for building their dwellings during the colonial period started to erect permanent structures as their residences and they started to use conventional building
materials. Many of them, started to sell remaining parts of their plots to people who migrated from rural areas to the city and others, thus leading to further uncontrolled densification.

3.2 Analyse of Insolation on Facades

The major amount of solar irradiation in Tropical countries is seen between 15° to 30° south and north longitude of the Equator where the percentage of direct solar irradiation is high due to the clean sky (Holger Koch-Nielsen, 1999).

Maputo City is located about 2° south of Capricornia tropic meaning that the city is between these intervals on 25°59’ south latitude. Nevertheless, the orientation of buildings in order to minimise the insolation effect can be one of the key methods to approach the passive design strategies.

Many buildings of Ka M’phumo (Urban District nr.1) of Maputo City have their facades with the NE-SW and NW-SE orientations. With these orientations, all facades of buildings are directly irradiated by the sun rays throughout the year.

The impact of heat due to these orientations could be seen in summer where the indoor temperatures of buildings become very high affecting negatively the thermal comforts of the occupants of buildings.

There are four main reasons associated with these orientations of buildings such as:

- First, the main orientation of the road network,
- Second, the available dimensions of the plots,
- Third, Lack of understanding of the importance of Bioclimatic Aspect and
- Finally, Building regulation of Maputo Municipal City Council.

3.2.1 The main orientation of the road network infrastructure

As mentioned before, the two first built streets in Maputo City (Former Lourenço Marques) were perpendicular to each other. These streets followed the NE-SW and NW-SE orientation. The subsequent roads took the same directions of these two firsts streets. With this layout of roads, the city was
extended with a grid shape of orthogonal roads. In the city, some organic road connections can be observed.

The spaces between these orthogonal roads form rectilinear sites with approximately one hectare each which were initially rectilinear and then divided in plots in different shapes and sizes. In such plots many erected buildings have their facades parallel to the roads.

3.2.2 Available dimensions of plots

The dimensions of plots of Maputo City varied in form and size. Initially, the dimensions of the plots were varying around 20x30 meters with a variation, according to the final use of it. By the time, these plots were subdivided in small plots where new buildings were erected.

Due to the demand of new plots, the Maputo City Municipal Council distributed plots which were small, varying around 12.5x15 meters. The buildings which were erected in these plots were small due to allowed constructive area in the plots.

3.2.3 Importance of bioclimatic aspect

During the planning process, many stakeholders such as architects, engineer, clients and builders were present. In many cases, the interactions among these stakeholders were weak, and the ad-hoc erections of buildings reflect this. An issue commonly neglected during the planning process is the bioclimatic aspects. There are many causes influencing the non-consideration of the bioclimatic aspects in the design.

Firstly, the initial high cost in the consideration of the bioclimatic aspects and many people prefer to build these building and later when financially possible, solve the bioclimatic aspect using technical equipment.

Secondly, the lack of knowledge and awareness amongst those involved in the building design and planning process about bioclimatic aspects.

Finally, the fashion played its influence; some clients imported the European building designs without observing different climate zone characteristics (Lauder, 2005).

3.2.4 Building regulations of Maputo Municipal City Council

In Maputo Municipal City Council, the Construction and Urbanisation Directorate is responsible for all activities related with construction and
urbanization. This department provides guidance for building constructions. One of the rules in this guidance recommends that, “the building construction has to be positioned in a topography plan observing three free meters from each lateral side of the plot and five free meters from the front”.

Following this recommendation, it can be seen that in 12.5x15 meter dimension plots, the available construction area will be 6.5x10 meters. If the proposed building is angled or rotated within the building plot in order to achieve the optimum climate orientation of the building, the available construction area would be considerable smaller than the optimum development available construction area.

Due to that, developers chose to take advantage of available construction areas and built the maximum permitted size of building instead of losing space by orienting the buildings with cognition to bioclimatic aspects.

3.3 Analyse of Bioclimatic Aspects

Figures 3.1 illustrate the existing relation between orientation of the road network infrastructure, plots, buildings orientation, predominant wind direction and high wind speed orientation.

The openings were placed in the facades that do not provide enough ventilation during the summer. As consequence, they are overly warm in the summer.

Facades ideally should be oriented perpendicular to the direction of the predominant air movement in the summer. The predominant wind direction in Maputo City is N, E and SE oriented. These wind directions hit the facades of many buildings with 30° to 45° of incidence angle. This factor associated with the high urban density of the buildings, obstructs good cross ventilation. With optimum indoor ventilation, the indoor humidity could be reduced, thus improving the sensation of thermal comfort.

During the summer, buildings that follow NE-SW orientation receive larger amounts of direct solar radiation and less ventilation. These factors makes the indoor climate becomes uncomfortable due to high temperatures and high humidity.
3.3.1 Hours of irradiation and shadow on facades

Table 3.1 presents the hours of irradiation and shadow on facades of a rectangular shape of Maputo City buildings during the year. In the table, the hours of shadow and irradiation were performed by one representative day of the month. Therefore, from the representative day could be added or subtracted 15 days in order to gauge the real time of the needed day.

The (NW) facades of the Maputo City buildings NE-SW oriented had presented many hours of direct solar radiation. These facades are always irradiated during the afternoon and evening and have little of irradiation hours at morning.

The (SE) facades are almost irradiated in the morning. The (NE) facades are almost irradiated for whole days of the winter and, in the summer the facades are irradiated at morning and some hours of the afternoon. The (SW) facades are irradiated at afternoon during the summer.

Table 3.1: Period of time that the facades are irradiated and shaded

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Irradiated hours</th>
<th>Irradiated hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>N E-SW</td>
<td>Front</td>
<td>Back</td>
</tr>
<tr>
<td>Months</td>
<td>SE</td>
<td>NW</td>
</tr>
<tr>
<td>June</td>
<td>06:45</td>
<td>09:00</td>
</tr>
<tr>
<td></td>
<td>09:00</td>
<td>17:00</td>
</tr>
</tbody>
</table>
3.4 Energy Used in the Referential Building

An average, the energy used in the residential building during the summer time i.e., from September 2008 to March of 2009 is about 351 kWh. This information is based on the available invoices from Electricidade de Moçambique (Mozambique Electricity Company) to the residential building.

According to the data collected from the electrical meter, the energy used by one fan during one hour was 0.1 kWh.

The information obtained from the residents of the building, about the time of occupation by volume during the day, it was possible to produce the table 3.3 which concluded that the total hours of three fans used in the building in order to get reasonable ventilation is about 22 hours which represents 2.2 kWh of energy used per day and consequently 66 kWh of energy used per month.

For 1.1 to 2.2 of the power tax of domestic energy for the consumer, the amount of energy charged per kWh is classified as; from 0 to 200 kWh is charged 2.12 Meticais (Mt) and from 201 to 500 kWh is charged 2.82.

The monthly average of energy used in this building in the summer time is about 351.28 kWh and the quantity of energy used by fans is about 66 kWh.

Assuming that the quantity of energy used by the fans is the result of the inadequate orientation and plan design, therefore, this energy can be considered as waste energy, thus, this energy can be considered as energy used after 201 kWh thus the cost of this energy can be included in the group of the energy which is charged at 2.82 Mt/ kWh.
This quantity of energy represents about 19% of total energy used per month during the summer time. The total amount of energy used per month in order to cool the indoor climate in the building is about 186.00Mt which equivalent is about 7.50USD.

In this building, the amount monthly average paid by using the energy in summer season was about 850.62Mt (about 34.00 USD) and the energy used by fans was about 186.00 (about 7.50 USD). Considering that in 2007 the minimum Mozambican salary was about 60.00 USD.

The amount average spent for payment of the total energy used in this building represents about 57% of Mozambican Minimum salary and the electrical energy used by the fans constitute approximately 13% of this salary.

Table 3.2: Energy used and the amount paid during the summer

<table>
<thead>
<tr>
<th>Energy in kWh</th>
<th>Monthly energy used and paid during summer season Aver. (M ZM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 0 to 200</td>
<td>200.00</td>
</tr>
<tr>
<td>From 201 to 500</td>
<td>155.00</td>
</tr>
<tr>
<td>Total Energy-kWh</td>
<td>355.00</td>
</tr>
<tr>
<td>From 0 to 200</td>
<td>424.00</td>
</tr>
<tr>
<td>From 201 to 500</td>
<td>437.10</td>
</tr>
<tr>
<td>Total Amount</td>
<td>861.10</td>
</tr>
</tbody>
</table>

Table 3.3: Number of daily hours of energy used by fans per volume

<table>
<thead>
<tr>
<th>Periods of the day</th>
<th>Number of daily hours of using fans by volume of the building</th>
<th>Total kWh used by fan/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume 1</td>
<td>Volume 2</td>
</tr>
<tr>
<td>From 0 to 6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>From 6 to 12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>From 12 to 18</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>From 18 to 0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>
3.5 Simulated Building

To examine the thermal comfort of buildings with the NE-SW orientation through modelling and simulations, a residential building as the case study-I was used.

The building was erected on the plot of 20 x 30 meters. This building is a terrace house containing three identical dwelling units of about 45 m² each. Each dwelling has four rooms: a one living room, two bedrooms and a kitchen. The toilet and bathroom are annexed to the main house and the residents share the yard. The building does not have veranda or any other kind of solar protection.

![Residential building-The case study-I](Photo from author)

3.5.1 Localization

This building is located in the south-eastern part of Maputo City in the Malanga neighbourhood, Canto Resende Avenue, number 12. The plot is one of six plots measuring 20x30 meters each making the urban block. The long axis is NE-SW oriented with the main facade facing SE. This form of orientation follows the road network infrastructure of the city.
3.5.2 Technical description

The structure of this building is basically composed of a foundation, columns and beams. The foundation used in this building is concrete and blocks.
The walls start at foundation level using 400x200x100mm hollow concrete blocks. The roof is 22.5% pitched.

The inside and outside of the walls are plastered and painted yellow. The openings, oriented SE are doors and single glass windows framed by wooden structures.

One panel of each window is composed by window mosquito net and a panel of 4 mm thick single glass.

3.5.3 Building elements

Walls
The internal and external walls are formed by 400x200x100mm hollow concrete blocks. The walls are plastered with cement mortar on both sides. See Figure 3.7.

Windows
The windows compose of timber a window frame and casement. The glazing is 4 mm thick single glass. The windows also have an internal timber casement with mosquito net, see Figure 3.8. The space between window mosquito net and the single glass is about 60 mm.
Curtain
The building has textile-curtains. The space between the mosquito net in the window and the curtain is about 100 mm. Figure 3.8.

Door
The external doors are composed of one door leaf 20 mm thick and a heavy timber door frame.

Colour
The building is externally painted by yellow and internally white. The external doors and the internal doors are painted yellow. The curtains are white.

Details of the building elements

3.6 Results from Simulations on Different Orientations

The simulations to exam the optimum orientation to Maputo City focus on the annual indoor temperature of the residential building differently oriented.

In the simulations, the environments with closed and opened windows were considered but, due to the similar results, it was presented a figure with the results of one environment.
3.6.1 Optimum orientation for buildings of Maputo City

Figure 3.19 illustrates the results of simulations with 24 different orientations. The results show that buildings with long facades E-W oriented presented the lowest indoor temperatures compared to all orientations of buildings.

The worst orientation was observed in buildings that have their long facades with N-S orientation. The indoor temperatures of buildings with the long facades NE-SW oriented were also not good if compared with the optimum E-W orientation.

3.7 Results from Simulations on Volumes with NE-SW and E-W Orientations

This section presents the results of the modelling and simulations of the residential building with NE-SW and E-W orientations. The results show the figures of the absorbed solar radiation by the volumes, figures of the outdoor and indoor temperatures and the indoor thermal comfort. The modelling and simulations were done taking in account the indoor environments of buildings with closed and opened windows. For that, climate data of the typical year, the hottest day of the year and typical summer days were simulated. To continue
with simulations, the volume that presented the warmest indoor temperatures was chosen.

### 3.7.1 Annual absorption of solar radiation in the volumes

Figure 3.10 show that, the volumes had different absorptions of solar radiation. Volume 3 has absorbed more solar radiation than the other volumes. The main reason for this absorption was that: This volume has the facade facing NW with many hours exposed to the solar radiation. Apart from that, this volume has one window which is exactly placed in that facade. The window does not have any kind of solar protection.

![Solar radiation absorbed by the volumes](image)

**Figure 3.10: Annual absorption of solar radiation in the volumes**

### 3.7.2 Annual indoor temperature in the volumes

The simulation showed that the annual indoor temperatures of all volumes were approximately same, although volume 2 presented the highest indoor temperatures among all volumes. These highest indoor temperatures are because of presence of a huge window that allows the penetration of much heat into the volume. The maximum and minimum temperatures within the volumes were about 4°C higher than the maximum and minimum outdoor temperature.
To continue with modelling and simulations, volume 2 as has shown maximum indoor temperatures, it was chosen.

### 3.7.3 Absorbed solar radiation in the volume 2 in the hottest day

In the hottest day, the volume with NE-SW orientation absorbed a major quantity of solar radiation in the morning. In the afternoon, the volume with E-W orientation absorbed a little more solar radiation. In average, volume with NE-SW orientation absorbed much more solar radiation.
3.7.4 Absorbed solar radiation in the volume 2 in typical summer days

In typical summer days, the volumes absorbed almost the same amount of solar radiation although the volume of the building E-W orientation had absorbed a little less solar radiation in the morning.

![Absorbed solar radiation by volumes with NE-SW and E-W orientation](image)

Figure 3.13: Absorbed solar radiation in the volume 2 during the typical summer days—Buildings with NE-SW and E-W orientations

3.7.5 Indoor temperature in the volume 2 in the hottest day

In the hottest day, the results show that during the daylight, the building with the long facades oriented to E-W had lower indoor temperature than the building with NE-SW orientation. The difference between them was about 2°C.

![Indoor Temperatures-Closed windows](image)

Figure 3.14: Indoor temperatures in the volume 2 with closed windows in the hottest day—Buildings with NE-SW and E-W orientations
With opened windows, the building with E-W orientation continued to present lower indoor temperatures than the building with NE-SW orientation but, all volumes are continued without observing thermal comfort.

![Graph: Indoor Temperatures-Opened windows](image1)

**Figure 3.15:** Indoor temperatures in the volume 2 with opened windows in the hottest day- Buildings with NE-SW and E-W orientations

### 3.7.6 Indoor temperature in the volume 2 in typical summer days

In typical summer days the building with E-W orientation with closed windows had about six hours of comfort while the building with NE-SW orientation had about three thermal comfort hours. The building with E-W orientation had about three more hours of thermal comfort than the typical model with NE-SW orientation.

![Graph: Indoor Temperatures-Closed windows](image2)

**Figure 3.16:** Indoor temperatures in the volume 2 with closed windows in typical summer days- NE-SW and E-W orientations
With opened windows, the building with NE-SW orientation continued to present inferior number of thermal comfort. It had about six hours of thermal comfort while the building with E-W orientation had about eight and half hours of thermal comfort. The building with E-W orientation had two and half hours more of thermal comfort than the typical model with NE-SW orientation.

![Indoor Temperatures-Opened windows](image)

**Figure 3.17:** Indoor temperatures within volume 2 with opened windows in typical summer days- NE-SW and E-W orientations

### 3.8 Analyse of the Results

This analyses based on the results of absorbed solar radiation, indoor temperatures and thermal comfort of buildings with the NE-SW and S-W orientation. In the analyses, the indoor environments of buildings with closed and opened windows on the hottest day, typical summer days and whole year were considered.

#### 3.8.1 Optimum orientation to Maputo City

The results obtained from simulation of different orientations demonstrated that for both environments, (buildings with opened and closed windows), the buildings with orientation from 15° to 165° and from 195° to 345° had higher indoor temperatures than the buildings with orientations from 0° to 15° and from 165° to 195°.

In summary, the buildings that have their long facades with E-W orientation (0° and 180°) presented the lowest indoor temperatures while the buildings that have their long facades with N-S (90° and 270°) orientation presented the
highest indoor temperatures. The maximum difference between the two orientations was about 4°C and 1°C as minimum.

Many buildings of the Maputo City are oriented between the group of buildings that have their long axes with orientations from 45° to 75° and from 225° to 255°, thus the indoor climate of these buildings is adversely affected.

The difference between the optimum orientations which is E-W with the typical orientation of buildings of Maputo City which is NE-SW is about 4°C as the maximum, and 1°C as the minimum. Based on these analyses, it allows affirming that the E-W orientation could provide better indoor temperatures within buildings of Maputo City.

3.8.2 Absorber solar radiation in the volumes with NE-SW orientation

In the annual absorption, the volume 2 and volume 3 of building with NE-SW orientation absorbed more solar radiation than other volumes and, volume 1 absorbed the lowest solar radiation. With this orientation, the facades located at SE and NE received the solar radiation at morning while the facades located at NW and SW was irradiated at afternoon.

3.8.3 Absorber solar radiation into volume 2 with NE-SW and E-W orientation

In the hottest day, the volume with NE-SW orientation absorbed about 700 W and, the volume with E-W orientation absorbed about 350W. Volumes with E-W orientation absorbed 100% less of solar radiation than the volumes with NE-SW orientation.

In the typical summer days, these two orientations presented almost the same absorption of solar radiation but, with slightly more absorption in building with NE-SW orientation.

3.8.4 Indoor temperatures in the volumes with NE-SW orientation

The annual indoor temperatures of the volumes were almost the same although the volume 2 presented the highest indoor temperature with about 40°C. The maximum and minimum indoor temperatures of all volumes were approximately 4°C higher than the maximum and minimum outdoor temperature at peak times of day, meaning that the indoor amplitude and outdoor amplitude were almost the same.
3.8.5 Indoor temperatures into volume 2 with NE-SW and E-W orientation

In the hottest day, the volumes with closed windows presented higher temperatures. With E-W orientation, the volume had 2°C less when compared with the volume of building with NE-SW orientation.

In typical summer days, the environments with closed windows of both orientations presented almost the same indoor temperatures. With closed windows, the volume of building with E-W orientation had lower indoor temperatures than the volume of building with NE-SW orientation.

With opened windows, the volume with E-W orientation decreased more its indoor temperatures. In the E-W orientation, the environment with opened windows presented the lowest indoor temperatures.

3.8.6 Comfort hours into volume 2 with NE-SW and E-W orientation

In the hottest day, the indoor temperatures of the buildings with closed and opened windows were out of comfort zone in both orientations although the building with E-W orientation was slightly less uncomfortable than the building with NE-SW orientation.

In typical summer days, the environments with closed windows of both orientations presented almost the same hours of indoor thermal comfort.

With closed windows, the volume with E-W orientation had 6 hours of thermal comfort while the environment of the volume with NE-SW orientation had 3 hours of thermal comfort. It means that, by the optimum orientation of the building, the volume could improve by 100% in terms of hours of thermal comfort.

With opened windows, the volume with E-W orientation had about 8½ hours of thermal comfort whereas the volume with NE-SW orientation had 6 hours of thermal comfort.

The thermal comfort hours of the building with E-W orientation had considerable improvement in relation to the building with NE-SW orientation. This improvement represents about 100% with closed windows and 42% with opened windows.
Table 3.4: Summary of thermal comfort hours in typical summer days

<table>
<thead>
<tr>
<th>Item</th>
<th>Buildings orientation</th>
<th>Thermal comfort hours in buildings-Typical summer days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Closed Windows</td>
<td>Opened Windows</td>
</tr>
<tr>
<td></td>
<td>Out.  a.m.  p.m.  Tot.</td>
<td>Out.  a.m.  p.m.  Tot.</td>
</tr>
<tr>
<td>1</td>
<td>NE-SW</td>
<td>14  3  - 3</td>
</tr>
<tr>
<td>2</td>
<td>E-W</td>
<td>6  - 6</td>
</tr>
<tr>
<td>3</td>
<td>Hours difference</td>
<td>3  - 3</td>
</tr>
<tr>
<td>4</td>
<td>Gain from outdoor</td>
<td>21%  - 21%</td>
</tr>
<tr>
<td>5</td>
<td>Gain from the previous orientation</td>
<td>100% 100%</td>
</tr>
</tbody>
</table>

3.9 Conclusions 2

Through simulation, the optimum orientation intended to Maputo City was identified and the percentage of thermal comfort hours of the buildings with NE-SW and E-W orientation was calculated. For both orientations the buildings with closed and opened windows were simulated taking into consideration the hottest day and the typical summer days.

The results showed that for Maputo City buildings, the long axis of the building should be E-W oriented and, by following this building orientation, the thermal comfort could be improved from 42-100% if compared with buildings that follow the typical orientation of Maputo City.
4. Shading on Maputo City Buildings

4.1 Introduction

This chapter analyses the impact of solar shading on indoor climate of Maputo City buildings. The analysis essentially deals on the functionality of the fixed shading devices commonly used on Maputo City buildings, and to evaluate their influence on the indoor climate of buildings. In the evaluation, the non-shaded and shaded buildings with E-W orientation were used as the main target for simulations.

The chapter also presents the shaded angles that could be used for optimizing the dimensions of the fixed shading devices for protecting the external facades from direct solar radiation during the summer and for allowing the penetration of sun rays in the winter.

4.2 Shading on Buildings

The ancient pharaohs of Egypt, termites in Africa, and vacationers in Mexico, they have known for thousands of years that it’s possible to cool the indoor climates without using air conditioners or mint juleps even if the outdoor temperature is high. Building orientation, shading, building materials, cross ventilation, plan design were key for then in order to achieve this goal, (Lauber, 2005).

From energy efficiency, indoor climate quality and occupant comfort perspectives, shading and natural ventilation is usually a better choice than air conditioning in the hot climate regions as Mozambique.

To protect the building envelop from the sun rays in the summer season by using shading can minimize the heat transfer through the walls, windows and doors, can substantial save energy by decreasing or eliminating the need for mechanical cooling, (Kumar, 2003).
In Maputo City, there are many buildings with fixed shading devices, but several of these buildings, their fixed shading devices were not carefully dimensioned in order to shade the openings and the walls during the summer period. Such shading devices often function merely as building elements to make them to look good.

4.2.1 Types of shading

Solar control shading can be provided by a wide range of building components but the most used devices for shading the buildings are describe below:

- Landscape feature such as mature trees or hedge rows,
- Fixed shading devices such as overhangs and wings or vertical fins,
- Horizontal reflecting surfaces (light shelves),
- Low shading coefficient (SC) glass and
- Interior glare control devices such as venetian blinds or adjustable louver and curtains.

This study focuses on fixed shading devices as the most effective building element which can control solar exposure of buildings. The fixed shading devices are easy to construct and maintain, they are economic, durable and secure. Such building elements can be dimensioned to shade whole facade of buildings in order to dissipate the direct solar radiation. Whilst the fixed shading devices are convenient and do not interfere with daily human activities, one disadvantage of this kind of shading is related to mobility, it cannot be moved or adjusted to different position or angles when needed thus, they should be carefully dimensioned.

4.2.2 Fixed shading devices

Fixed shading is generally used on external walls and windows since they lower the direct solar radiation from reaching inside dissipating the heat outside. The external shading is more efficient than internal fixed shading devices which dissipate the heat to the air gap between the shading device and the glazing, (Datta, 2001).

Overhangs

Overhangs are devices that block direct solar radiation to the windows, doors or walls during certain times of the day and year. The overhangs can be
constructed as verandas, or directly over the windows, (D. Kolakotsa, 2007). The shade produced by these overhangs can help to reduce the quantity of global radiation reaching in buildings and prevent uncomfortable light contrast levels around the windows. For Maputo City where the vertical direct solar radiation is not seen on south, the overhangs are more effective on north facades.

**Wings**

Wing walls or vertical fins are the most appropriated shading devices for eastern and western facing opening which receive sun radiation at low angles, and for north-eastern and north-western openings in combination with horizontal shading, (D. Kolakotsa, 2007).

4.3 Irradiated and Shaded Facades of Maputo City Buildings

The design of effective shading devices on buildings depends on the solar orientation for a particular position of building on the Earth, and the choice of facades of buildings that should be shaded.

For a properly shading design, it is necessary to understand the position of the sun in the sky during the year especially in the solstices and equinoxes. The position of the sun is expressed in terms of altitude and azimuth angles.

Solar altitude is the angular height of the sun measured from the horizon. Above the horizon it is positive and below is negative. Directly in the centre of the sky the sun has a solar altitude of 90°. Solar altitude is measured in a horizontal coordinate system.

Solar azimuth is the angular position of the sun measured around the horizon with North being 0°, East 90°, South 180° and West 270°. Solar azimuth is measured in a horizontal coordinate system. The horizontal coordinate system takes the observation point as the origin and fixes the sun's position by giving a compass direction (Azimuth) and elevation above the horizon (Altitude).

4.3.1 Irradiated and shaded facades on Maputo City buildings

Based on horizontal and vertical angles, the solar diagram for latitude 26° was done. By using this diagram it might be possible to understand how the facades of some buildings of Maputo City are directly irradiated by the sun rays during certain hours of the day during the year and to plan a better orientation of the buildings in order to minimise the impact of direct solar irradiation and to
calculate the appropriate dimensions of the fixed shading devices as the overhangs and wings. The following figure shows the solar diagram for Maputo City with the main orientations of the long axis of Maputo City buildings.

Figure 4.1: Solar diagram of the 26° South Latitude with lines of the main orientation of Maputo City buildings

For having an idea of the hours that the façades of buildings NE-SW and NW-SE oriented are directly irradiated and shaded, the table 4.1 was developed. The results in the table refer the buildings without any fixed shading devices. In this table, the shaded hours denotes the shadow produced by the envelope of building known as own shadow. This table is performed by one
representative day of the month thus, from the representative day could be added or subtracted 15 days in order to gauge the real time of the desired day.

Table 4.1: Period of time that the facades of Maputo City buildings with NE-SW orientation are irradiated and shaded

<table>
<thead>
<tr>
<th>Buildings NE-SW</th>
<th>Irradiated hours</th>
<th>Shaded hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Front SE</td>
<td>Back NW</td>
</tr>
<tr>
<td>Months</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>06:45 09:00 06:45</td>
<td>17:00 17:00</td>
</tr>
<tr>
<td>July and May</td>
<td>06:25 09:40 06:25</td>
<td>17:35 17:35</td>
</tr>
<tr>
<td>August and April</td>
<td>06:10 10:20 06:10 15:00</td>
<td>17:50 10:20 17:50</td>
</tr>
<tr>
<td>September and March</td>
<td>06:00 10:40 06:00 14:20</td>
<td>18:00 10:40 18:00</td>
</tr>
<tr>
<td>October and February</td>
<td>05:30 11:00 05:30 13:40</td>
<td>18:30 11:00 18:30</td>
</tr>
<tr>
<td>November and January</td>
<td>05:10 11:30 05:15 12:50</td>
<td>18:50 11:30 18:50</td>
</tr>
<tr>
<td>December</td>
<td>04:45 11:50 05:00 12:15</td>
<td>19:15 11:50</td>
</tr>
</tbody>
</table>

The NW facades of buildings with NE-SW orientation had many hours of direct solar radiation. These facades are always irradiated at afternoon and evening and have little of irradiation hours at morning. The SE facades are irradiated at morning. The NE facades are irradiated for almost the whole days of the winter and, in the summer the facades are irradiated at morning and some hours of the afternoon. The SW facades are irradiated at afternoon during the summer.

To minimise the direct solar irradiation on the facades of Maputo City buildings, some buildings have been using fixed shading devices. These fixed shading devices were not dimensioned according to the orientation of each building in order to minimise and control the negative impact on indoor climate of the Maputo City buildings.

According to the personal experience, the main dimensions of the fixed shading devices of Maputo City buildings that were used as verandas were mostly composed by overhangs and wings made by volumes that is ranging from 2.00x0.75x2.60 meters until 6.00x1.80x3.00 meters. These verandas
were mainly placed in connection with living rooms; kitchens and in some bedrooms.

To analyse the functionality of these verandas in term of protection of interior walls of the buildings from direct solar radiation, a model volume with 4.00 x 1.70 x 2.80 was studied as representative veranda of Maputo City buildings. Based on horizontal and vertical angles for Maputo City and to the main orientation of buildings the functionality of these fixed shading devices was evaluated.

4.3.2 Overhangs and wing walls with 1.70 meters on buildings with NW-SE orientation

The vertical and horizontal angles of latitude 26° south were used as the base to analyse the functionality of the combination of the overhangs and the wings in term of protecting at 100% of external walls. Table 4.2 contain the results of the own wall shadow and shadow produced by the combination of the wings and overhangs.

Table 4.2: Number of hours that the facades of Maputo City buildings with NW-SE orientation are irradiated and shaded

<table>
<thead>
<tr>
<th>Buildings NW-SE oriented</th>
<th>Front Facades (NE)</th>
<th>Back Facades (SW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shaded hours by the overhangs and wings</td>
<td>Shaded hours by the own wall</td>
</tr>
<tr>
<td>Months</td>
<td>Time</td>
<td>Nr. of hours</td>
</tr>
<tr>
<td>June</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July and May</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>August and April</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>September and March</td>
<td>10:40</td>
<td>3.40</td>
</tr>
<tr>
<td>October and November</td>
<td>09:45</td>
<td>3.05</td>
</tr>
<tr>
<td>December</td>
<td>09:40</td>
<td>3.00</td>
</tr>
</tbody>
</table>
### Table 4.3: Resume of the table 4.2

<table>
<thead>
<tr>
<th>Months</th>
<th>Nr. of Daylight hours per each month</th>
<th>Shadow hours produced by overhangs and wings in percentage (%)</th>
<th>Shadow hours produced by own wall in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sun rise</td>
<td>Sun set</td>
<td>Total</td>
</tr>
<tr>
<td>June</td>
<td>6.45</td>
<td>17.15</td>
<td>10.30</td>
</tr>
<tr>
<td>July and May</td>
<td>6.25</td>
<td>17.35</td>
<td>11.00</td>
</tr>
<tr>
<td>August and April</td>
<td>6.10</td>
<td>17.50</td>
<td>11.40</td>
</tr>
<tr>
<td>September and March</td>
<td>6.00</td>
<td>18.00</td>
<td>12.00</td>
</tr>
<tr>
<td>October and February</td>
<td>5.30</td>
<td>18.30</td>
<td>13.00</td>
</tr>
<tr>
<td>November and January</td>
<td>5.10</td>
<td>18.50</td>
<td>13.40</td>
</tr>
<tr>
<td>December</td>
<td>4.45</td>
<td>19.15</td>
<td>14.30</td>
</tr>
</tbody>
</table>

The combination of overhangs and wings of 1.70 meters on buildings with NW-SE orientation has presented poor performances in term of protecting the exterior walls of the buildings from direct solar radiation. This combination had about 30% as the maximum protection against the solar radiation on the walls of buildings during the summer months counted from October to March. The façades with NE orientation have presented more hours of shadow than the facades with SW orientation.

#### 4.3.3 Overhangs and wing walls with 1.70 meters into the buildings with NE-SW orientation

In term of protecting the exterior walls against the direct solar radiation, the combination of overhangs and wings with 1.70 meters on buildings with NE-SW orientation presented very poor performances. This combination had about 8% as the maximum protection against the solar radiation on the walls of buildings during the summer months counted from October to March. The façades with NW orientation have presented slightly more hours of shadow than the facades with SE orientation.
Table 4.4: Number of hours that the facades of Maputo City buildings with NE-SW orientation are irradiated and shaded

<table>
<thead>
<tr>
<th>Buildings with NE-SW orientations</th>
<th>Front Facades (SE)</th>
<th>Back Facades (NW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shaded hours by the overhangs and wings</td>
<td>Shaded hours by the own wall</td>
</tr>
<tr>
<td>Months</td>
<td>Time Nr. of hours</td>
<td>Time Nr. of hours</td>
</tr>
<tr>
<td>June</td>
<td>- - 09:00 8.15</td>
<td>- - 06:45 2.15</td>
</tr>
<tr>
<td>July and May</td>
<td>- - 09:30 8.00</td>
<td>- - 09:30 3.00</td>
</tr>
<tr>
<td>August and April</td>
<td>- - 10:00 7.45</td>
<td>- - 09:30 3.45</td>
</tr>
<tr>
<td>September and March</td>
<td>- - 10:35 7.25</td>
<td>10:35 1.00</td>
</tr>
<tr>
<td>October and February</td>
<td>10:00 1.00</td>
<td>11:00 0.45</td>
</tr>
<tr>
<td>November and January</td>
<td>10:35 0.45</td>
<td>11:20 0.30</td>
</tr>
<tr>
<td>December</td>
<td>11:20 0.20</td>
<td>11:35 0.20</td>
</tr>
</tbody>
</table>

Table 4.5: Resume of the table 4.4

<table>
<thead>
<tr>
<th>Months</th>
<th>Nr. of Daylight hours per each month</th>
<th>Shadow hours produced by overhangs and wings in percentage (%)</th>
<th>Shadow hours produced by own wall in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sun rise Sun set Total</td>
<td>Front Back Tot.1</td>
<td>Front Back Tot.2</td>
</tr>
<tr>
<td>June</td>
<td>6:45 17:15 10.30</td>
<td>- - -</td>
<td>78.6 21.4 100</td>
</tr>
<tr>
<td>July and May</td>
<td>6:25 17:35 11.00</td>
<td>- - -</td>
<td>72.7 27.3 100</td>
</tr>
<tr>
<td>August and April</td>
<td>6:10 17:50 11.40</td>
<td>- - -</td>
<td>67.4 32.6 100</td>
</tr>
<tr>
<td>September and March</td>
<td>6:00 18:00 12.00</td>
<td>- 8.3 8.3</td>
<td>61.8 38.2 100</td>
</tr>
<tr>
<td>October and February</td>
<td>5:30 18:30 13.00</td>
<td>7.7 5.8 13.5</td>
<td>57.7 42.3 100</td>
</tr>
<tr>
<td>November and January</td>
<td>5:10 18:50 13.40</td>
<td>5.4 3.6 9.0</td>
<td>54.8 45.2 100</td>
</tr>
<tr>
<td>December</td>
<td>4:45 19:15 14.30</td>
<td>2.3 2.3 4.6</td>
<td>52.9 47.1 100</td>
</tr>
</tbody>
</table>
4.3.4 Overhangs and wing walls with 1.70 meters into the buildings with E-W orientation

For this orientation, the fixed shading devices have protected the external walls against the direct solar radiation from 84.6 to 100% during the summer. This combination also presented good performance in the winter because; the external walls of buildings were not totally shaded.

Table 4.6: Number of hours that the facades of Maputo City buildings with E-W orientation are irradiated and shaded

<table>
<thead>
<tr>
<th>Months</th>
<th>Front Facades</th>
<th>Back Facades</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shaded hours by the Overhangs and Wings</td>
<td>Shaded hours by the Walls</td>
<td>Shaded hours by the Overhangs and Wings</td>
<td>Shaded hours by the Walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time N°/h</td>
<td>Time N°/h</td>
<td>Time N°/h</td>
<td>Time N°/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>06:45</td>
<td>10:30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17:15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July and May</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>06:25</td>
<td>11:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17:35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August and April</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>06:10</td>
<td>11:40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>September and March</td>
<td>10:40</td>
<td>2.40</td>
<td>-</td>
<td>-</td>
<td>06:00</td>
<td>12.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>October and February</td>
<td>10:00</td>
<td>11:00</td>
<td>-</td>
<td>-</td>
<td>05:30</td>
<td>18.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>November and January</td>
<td>05:10</td>
<td>13:40</td>
<td>-</td>
<td>-</td>
<td>05:10</td>
<td>18.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>04:45</td>
<td>14.30</td>
<td>-</td>
<td>-</td>
<td>04:45</td>
<td>19.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19:15</td>
<td></td>
<td></td>
<td></td>
<td>19:15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.7: Resume of the table 4.6

<table>
<thead>
<tr>
<th>Months</th>
<th>Daylight hours</th>
<th>Facades</th>
<th>Walls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sun rise</td>
<td>Sun set</td>
<td>Total</td>
</tr>
<tr>
<td>June</td>
<td>6:45</td>
<td>17:15</td>
<td>10.30</td>
</tr>
<tr>
<td>July &amp; May</td>
<td>6:25</td>
<td>17:35</td>
<td>11.00</td>
</tr>
<tr>
<td>August and April</td>
<td>6:10</td>
<td>17:50</td>
<td>11.40</td>
</tr>
<tr>
<td>September and March</td>
<td>6:00</td>
<td>18:00</td>
<td>12.00</td>
</tr>
<tr>
<td>October and February</td>
<td>5:30</td>
<td>18:30</td>
<td>13.00</td>
</tr>
<tr>
<td>November and January</td>
<td>5:10</td>
<td>18:50</td>
<td>13.40</td>
</tr>
<tr>
<td>December</td>
<td>4:45</td>
<td>19:15</td>
<td>14.30</td>
</tr>
</tbody>
</table>

4.4 Shading 100% Facades with Different Orientations

To shade in 100% facades of buildings with different orientation is possible, but for some shapes of buildings its aesthetic will be affected. Apart from that, the required building materials for constructing these fixed shading devices will be much. And consequently, it will influence in the final cost of its construction.

For the same dimensions of the facades differently oriented, the lengths of the fixed shading devices for shading 100% their exterior walls will be different among them for getting the same shading results. Figure 4.2 shows how the same length of the exterior walls of the buildings can be shaded by the length of the wings perpendicularly fixed on the building facades at different orientation.

The dimensions of the wing walls were varying according to the orientation of facades for getting the same shading result. For the same shading effect, the results showed that the wing walls of buildings with E-W orientation presented minor dimensions than the dimensions of other orientations. (See figure 4.2). This orientation of building could help the designers to save the building materials and could improve the quality of designs.
4.5 General Considerations about Shading on Facades of the Maputo City Buildings

The buildings located below the Capricorn tropic, where Maputo City is located, they have the south façade shaded. For taking advantage of this knowledge, the buildings should be E-W oriented so that, they will have the south facades in shadow. This orientation could minimize the number of building facades needing to be shaded and consequently the building materials could be spared.

Consider a building with a rectangular prism shape which has its long facades with E-W orientation. In this building, the number of façades that needs to be shaded is three. If the same building were obliquely oriented, the number of façades that would need to be shaded would be four.

Considering the same dimensions of the fixed shading devices placed on the verandas of buildings with NW-SE orientation and another on the verandas of buildings with E-W orientation, the results showed that, the buildings with E-W orientation presented good performances in term of number of hours with shade.

The sun trajectory is from east to west thus, from these direction there are a huge solar radiation coming from these direction, thus it is recommended to
minimize the openings in the east and west orientation and to maximize the openings in north and south orientation.

For optimizing the building materials, the east and west facades should be shaded by building components as stairs, lifts, garage and others.

4.6 Simulated Building

To examine the indoor climate of the non-shaded and shaded buildings with E-W orientation, two apartments of a two storey building were simulated. The two storey building is located at eastern part of Maputo City, in Sommerschield neighbourhood, in the Padre Antonio José de Almeida Street, in building nr. 99.

The building was built in 1994 in the open space of the main campus of Eduardo Mondlane University. The building belongs to the Faculty of Engineering and it is mainly used to accommodate guests of Eduardo Mondlane University.

It comprises of six apartments and each floor is compartmented by three flats. Both the ground floor and first floor have two apartments with two bedrooms and one apartment with one bedroom. The building materials used in these apartments is the materials commonly used in conventional buildings.

The building has two stairways, one located in the middle of the building which is used for occupants of the west and central apartments of the first floor, and other is located on the east and is used by occupants of the east apartment of access first floor.

The long axis of this building is approximately E-W oriented and the main facade of the building is south oriented. The building has openings located in south and north orientation. The east facade has no openings and it is shaded by the stairs compartment and the west facade with no opening and it is adjacent to other apartments.

The studied apartments are located at the east part of the building and for them, the west part was considered as infinitive insulated walls due to the adjacent apartments with them.

The ground floor of the studied apartment comprises of one living room, one bedroom, one kitchen, one bathroom, corridor, one laundry and one store.
The first floor comprises of: one living room, one bedroom, one kitchen, one bathroom, one balcony, corridor, one laundry and one store.

4.6.1 Localization

This building is located at the eastern part of Maputo City in the Sommerschield neighbourhood on Padre Antonio José de Almeida Street, building nr. 99. It is within the Eduardo Mondlane University Campus. The long axis is E-W oriented with the main facade facing south. This form of orientation does not follow the road network infrastructure of the city.

![Figure 4.3: Sommerschield neighbourhood](source: Google Earth)

![Figure 4.4: Front view of the building](Source: Eng. Thord Lundgren)

![Figure 4.5: Back view of the building](Source: Eng. Thord Lundgren)

4.6.2 Technical description

The structure of this building is simply composed of foundation, columns and beams. The foundation used in this building is concrete and blocks. The walls start from a shallow basement using 4.00x2.00x2.00m hollow concrete blocks.
The roof is about 16° pitched. The internal surfaces of the building are plastered and painted white and the external surfaces of the building are plastered and painted by orange and brown colour.

The openings are doors and single glazed windows framed by wood structure. One panel of each window is composed of a mosquito net and panel with 4 mm thickness single glass.
4.6.3 Building elements—overhangs and wings used for simulations

For shading the simulated building were used 40° of vertical angles to dimension the overhangs and 25° of horizontal angles to dimension the wings, thus the overhangs was dimensioned to have two meters and the wings was dimensioned to one meter and half as shown in the below figures.

![Overhangs](image1)

![Wing walls](image2)

For having the same dimensions between overhangs and wing walls, a length of 1.80 meters was used to shade the simulated building.

4.7 Results from Simulations on Non-Shaded Building

The simulations on the two apartments focus on indoor climate of non-shaded and shaded buildings with E-W orientation. The absorbed solar radiation, indoor temperatures and in thermal comfort hours for all volumes were evaluated. In all simulations, the indoor environments with closed and opened windows were carried out considering the time period of an year, summer months, the hottest day and the typical summer days.

4.7.1 Annual absorption of solar radiation in the volumes

Volume 7 at first floor absorbed more solar radiation among the volumes. This highest absorption was because of the presence of major area of its facades exposed to the outdoor and, the ceiling placed between this volume and the attic volume.

Volume 6 located under the volume 7 presented the second major absorption. These volumes also have more facades facing out of the three main orientations.
Volume 4 followed the absorption that was observed in volume 6. This volume has two of its facades exposed to the outside and, volumes 5, 2, 1 and 3 have a low solar absorption due to their minor area exposed to outside i.e., they have only one facade that was facing to the outdoor.

![Absorbed solar Radiation by volumes-Non-Shaded building](image)

**Figure 4.13:** Annual maximum and average absorption of solar radiation in the volumes

**4.7.2 Absorbed solar radiation in the hottest day**

In the hottest day, the large volumes and the volume that have more than one façades exposed to the direct solar radiation absorbed greater quantity of solar radiation than the volumes with one facade exposed to the direct solar radiation.

Volume 7 evidently absorbed more solar radiation than other volumes while the volume 3 absorbed the lowest solar radiation among all volumes.
4.7.3 Absorbed solar radiation in typical summer days

In the typical summer days, the volumes 4, 6 and 7 continued to present high absorption of solar radiation. Volume 7 presented the maximum absorption whereas the volume 3 absorbed the minor quantity of solar radiation.

4.7.4 Annual average of indoor temperature

With closed windows, the average temperature of all volumes was within the comfort zone in winter and in the first months of the summer. Many hours of comfort were observed in volume 6 and 7 followed by volume 3. Volume 4 presented less hour of comfort. The average outdoor temperature was comfortable during the summer and uncomfortable in the winter.
Figure 4.16: Annual average of temperatures in building with closed windows

With opened windows, the average indoor temperature of all volumes was almost in comfort zone from the middle of March to December. Volumes 6 and 7 were below the comfort zone in June and July. The highest average indoor temperature was seen within volume 4 and the lowest average indoor temperature was perceived in volume 7.

Figure 4.17: Annual average of temperatures in buildings with opened windows

4.7.5 Indoor temperature in the hottest day

In the environment of closed windows, the indoor temperatures of the volumes 2, 5, and 7 located at first floor presented higher temperatures than the indoor temperatures of the volumes located at the ground floor. This happened due to the influence of the heat coming from the ceiling which separates these volumes with the attic. The volume 4 also presented high indoor temperatures because its facades are facing the east and north.
With opened windows, the indoor temperatures of the volumes at ground floor and at first floor presented the same trend seen in the environment with closed windows. In both environments the temperature difference among the volumes was about 3°C.

4.7.6 Indoor temperature in typical summer days

With closed windows, volumes 4 and 5 were out of comfort during the whole day and the remaining volumes had comfort for some hours.
Figure 4.20: Indoor temperatures in the volumes with closed windows during the typical summer days

With opened windows, volumes continued to present almost the same trend observed in the environment with closed windows but, with reduction of about 2°C in the maximum indoor temperature of each volume and, the temperature difference among the volumes also reduced to about 1°C. In this environment, at least, all volumes observed comfort during the morning. In both environments, volumes at first floor presented higher temperatures.

Figure 4.21: Indoor temperatures in the volumes with opened windows during the typical summer days

4.7.7 Hours of thermal comfort in the summer months

In general, the thermal comfort hours of the environment with closed windows were less if compared with the outdoor comfort hours. Volume 3 followed by volume 6 presented respectively about 75% and 55% of the available comfort
hours at the outdoor. The remaining volumes did not achieve 50% of the available comfort hours at the outdoor.

Figure 4.22: Hours of comfort and discomfort in building with closed windows during the summer

With opened windows, the comfort hours of the volumes increased conspicuously. In general, the environments of volumes located at ground floor were more comfortable than the environments of volumes located at first floor. Volume 5 presented the highest discomfort hours whilst the volume 3 observed least discomfort hours than the other volumes.

Figure 4.23: Hours of comfort and discomfort in building with opened windows during the summer
4.8 Results from Simulations on Shaded Building

The simulation in the two apartments focuses on the absorbed solar radiation, indoor temperatures and in thermal comfort hours for all volumes. In all simulations, the indoor environments with closed and opened windows were carried out for analysing the indoor climate in the buildings for the whole year, summer months, hottest day and typical summer days.

4.8.1 Annual absorption of solar radiation in the volumes

On shaded building, the highest absorption of solar radiation was observed within volumes 6 and 7 with about 1450 and 1375 W respectively. These volumes were followed by the volume 4 with about 600W. Volume 3 absorbed the lowest solar radiation with about 50W. The remaining volumes have absorbed less than 200W each.

![Absorbed solar radiation by the volumes-Shaded building](image)

Figure 4.24: Annual maximum and average of absorbed solar radiation in the volumes

4.8.2 Absorbed solar radiation in the hottest day

The large volumes located at south have absorbed approximately the same quantity of solar radiation and the volumes located at north part of the building having nearly the same area, also have absorbed the same amount of solar radiation. The maximum absorption was seen in the larger volumes, 6 and 7, with about 1300W each and the minimum absorption was observed in the smaller volume 3, with about 50W.
4.8.3 Absorbed solar radiation in typical summer days

In the typical summer days, the volumes observed the same behaviour seen in the hottest day in term of solar radiation absorption. The maximum absorption was seen in volumes 6 and 7 with about 1200W and the minimum absorption was observed in volume 3 with less than 50W.

4.8.4 Annual average of indoor temperature

With closed windows, the average indoor temperatures of all volumes were within comfort zone from March to May and from September to December. Volume 3 and 4 had two months more of thermal comfort seen from January to May. The average outdoor temperature was in comfort in the summer and out of it in the winter.
Figure 4.27: Annual average of temperatures in volumes with closed windows

With opened windows, the average temperatures of all volumes as well the outdoor were almost the same. The difference among them was minimum in the winter and maximum in the summer. Volumes 1, 3, 4 and 6 were in comfort from August to May and, volumes 2, 5 and 7 were in comfort from March to May and from August to December. The outdoor temperature was comfortable from September to May. From May to August, the indoor and outdoor environments were below the comfort zone.

Figure 4.28: Annual average of temperatures in volumes with opened windows

4.8.5 Indoor temperature in the hottest day

The volumes located at the first floor presented higher indoor temperatures than the volumes located at the ground floor. From about 9:00 to about 21:00 the indoor temperatures of the volumes were low than the outdoor
The indoor temperature amplitude in the building was almost the same for all volumes and the maximum difference of temperatures among the volumes was about 3°C.

With opened windows, the indoor temperatures did not change much but, the difference among the volumes reduced slightly.

With closed windows, volumes located at first floor presented higher temperatures than the volumes located at the ground floor. The volumes at ground floor were comfortable during the whole day whilst the volumes located at first floor were comfortable from 23:00 up to 14:00. The maximum

Figure 4.29: Indoor temperatures in the volumes with closed windows in the hottest day

Figure 4.30: Indoor temperatures in the volumes with opened windows in the hottest day

4.8.6 Indoor temperature in typical summer days

With closed windows, volumes located at first floor presented higher temperatures than the volumes located at the ground floor. The volumes at ground floor were comfortable during the whole day whilst the volumes located at first floor were comfortable from 23:00 up to 14:00. The maximum

79
indoor temperature was observed in volume 7 and the minimum was seen in volume 3. The maximum difference of temperature among the volumes was about 4°C seen at afternoon and, about 2°C for the remaining period.

The environment of opened windows observed the same trend as seen on the environment of closed windows but, the temperatures difference among the volumes decreased to about 2°C. The indoor temperatures were more comfortable than the outdoor temperatures.

4.8.7 Hours of thermal comfort in the summer months

Volume 3 followed by volume 4 and 1 presented more hours of thermal comfort compared with the outdoor comfort hours. Volume 2 presented almost the same hours of thermal comfort as these presented by the outdoor
environment. Volumes 5, 6 and 7 had between 73-86% of the comfort hours felt at the outdoor.

Apart from volume 3 and 4 which reduced the number of comfort hours, the remaining volumes gain more hours of thermal comfort in the environment with opened windows. Even thus, volume 3 continued to present more hours of thermal comfort while the volume 7 presented the lowest number of hours of thermal comfort. The volumes located at first floor continued to have least comfort hours than the volumes located at ground floor.

Figure 4.33: Hours of comfort and discomfort in the volumes with closed windows during the summer

Figure 4.34: Hours of comfort and discomfort in the volumes with opened windows during the summer
4.9 Analyse of the Results - Non-Shaded Building

The following analyses include all simulations carried out in the two apartments considering the non-shaded and shaded building. Solar radiation, indoor temperatures and thermal comfort were evaluated taking in account the environments of volumes with closed and opened windows. Typical summer days, hottest day, summer months and whole year were the considered periods.

4.9.1 Annual absorption of solar radiation in the volumes

The volumes that have more than two façades or with huge area of façades with both transparent and opaque materials exposed to the exterior absorbed more solar radiation than the volumes with minor areas of façades opaque and transparent exposed to exterior. Thus, the volumes 7, 6 and 4 had presented the highest absorption of solar radiation. Apart from volume 6, all volumes have had at least one façade facing north.

Volume 7 with four large facades exposed to the four main orientations i.e., north, south, east and west presented the highest absorption. Concerning the huge absorption, volume 7 was followed by the volume 6 that has three large facades exposed outdoor.

Volume 4 was third positioned in term of solar radiation absorption because this volume has two facades facing to the outdoor which one at north is large and receives solar radiation for whole day and the second positioned east receive solar radiation for half day.

Volume 5 also has two slightly small facades facing outdoor which one facing that is facing north and another facing west. Volume 2 with two small areas facing outdoor followed the absorption of volume 5; this volume has one shaded facade facing east and one that are facing north.

Volume 1 absorbed less solar radiation because has one small facade exposed to north. Be noted that although this volume has one facade facing out, it also has a frontage contiguous with another apartment. Volume 3 has the lowest absorption among the volumes because it has only one facade facing outdoor.

Volumes 1, 2, 6 and 7, each have one frontage contiguous with another apartment that was not considered in this study.
4.9.2 Annual average of indoor temperature

In the environment of building with closed windows, volumes 6 and 7 had the lowest average of indoor temperatures. These volumes had thermal comfort from March to November with interruption in June and July, period that the volumes were below the comfort zone. Volume 4 that had the highest average of indoor temperature, it was comfortable from May to November. Other volumes were comfortable from the middle of April to the middle of November.

With opened windows, volumes 7 and 6 continued to present the lowest average indoor temperature and, volume 4 continued to present the highest average temperature among the volumes. Volume 7 and 6 had thermal comfort from March to November with interruption in June and July and the remaining volumes had thermal comfort from March to November without interruption.

4.9.3 Indoor temperature in the hottest day

In the hottest day, all volumes of the environment of the buildings with closed and opened windows were out of comfort zone. For both environments the volumes located at first floor and the volume 4 had higher indoor temperatures than the volumes located at ground floor.

The volumes located at first floor presented high indoor temperatures because, beyond the solar radiation that were receiving through the facades, they also were receiving additional heat coming from the attic of the building through the ceiling that was not thermally insulated. Volume 3 presented the lowest indoor temperature because this volume had only one small opaque and transparent facade that was facing out and, it also is located under the balcony that has a thermo-hydraulically floor.

4.9.4 Indoor temperature in typical summer days

The volumes located at ground floor had more hours of thermal comfort than the volumes located at first floor and the volume 4 that is located at ground floor. In the environment of closed windows, volume 4 continued to present high indoor temperatures and volumes 3 and 6 were presenting the lowest values of indoor temperatures.

In the environment of opened windows, the volume 1 and 3 that had one facade facing outdoor and the volume 6 that had not any façade facing north were presenting the lowest values of indoor temperatures. The following table
shows the comfort hours that each volume had in the typical summer days considering the two environments.

Table 4.8: Hours of comfort in the volume during the typical summer days

<table>
<thead>
<tr>
<th>Volume</th>
<th>Non-shaded</th>
<th>Closed windows</th>
<th>Opened windows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beginning</td>
<td>The end</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>03:00 a.m.</td>
<td>08:30 a.m.</td>
<td>5.30</td>
</tr>
<tr>
<td>2</td>
<td>03:00 a.m.</td>
<td>09:00 a.m.</td>
<td>6.00</td>
</tr>
<tr>
<td>3</td>
<td>01:00 a.m.</td>
<td>12:30 a.m.</td>
<td>11.00</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>11:30 p.m.</td>
<td>11:00 a.m.</td>
<td>11.30</td>
</tr>
<tr>
<td>7</td>
<td>03:30 a.m.</td>
<td>09:00 a.m.</td>
<td>5.30</td>
</tr>
</tbody>
</table>

4.9.5 Hours of thermal comfort in the summer months

In the environment of the building with closed windows, all volumes have presented more hours of discomfort than the hours of comfort. The volume 3 had major number of comfort followed by the volume 6. Volume 5 followed by the volumes 1 and 4 had less hours of thermal comfort.

In the environment with opened windows, the volumes located at ground floor had presented better performances than the volumes located at first floor and the volume 4. The volume 3 continued to present more hours of comfort while the volume 5 continued to present less hours of comfort. The volume 3 was the only one that had more hours of comfort than the discomfort hours. The remaining volumes had much more discomfort hours than the comfort hours.
Table 4.9: Hours of comfort in the volumes during the summer months

<table>
<thead>
<tr>
<th>Item</th>
<th>Vol. 1</th>
<th>Vol. 2</th>
<th>Vol. 3</th>
<th>Vol. 4</th>
<th>Vol. 5</th>
<th>Vol. 6</th>
<th>Vol. 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed windows</td>
<td>1007</td>
<td>1190</td>
<td>1907</td>
<td>1022</td>
<td>847</td>
<td>1380</td>
<td>1239</td>
</tr>
<tr>
<td>Opened windows</td>
<td>2531</td>
<td>1903</td>
<td>1827</td>
<td>2189</td>
<td>1852</td>
<td>1702</td>
<td>2025</td>
</tr>
<tr>
<td>Difference</td>
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<td>637</td>
<td>282</td>
<td>830</td>
<td>855</td>
<td>645</td>
<td>589</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>89</td>
<td>53.5</td>
<td>14.8</td>
<td>81.2</td>
<td>101.0</td>
<td>46.7</td>
<td>47.5</td>
</tr>
</tbody>
</table>

4.10 Analyse of the Results - Shaded Building

4.10.1 Annual absorption of solar radiation in the volumes

The volumes with great area of opaque and transparent facades exposed to the exterior absorbed a large quantity of solar radiation than the volumes with minor area of opaque and transparent facades exposed to exterior thus, volumes 6 and 7 absorbed much more solar radiation.

4.10.2 Annual average of indoor temperature

The larger volumes and the volumes located at first floor have presented the highest average of indoor temperatures. Volume 7 was presenting the highest average of indoor temperatures and, volume 3 continued to present the lowest average of indoor temperatures.

Volumes 1, 2, 5, 6 and 7 had thermal comfort from March to December with interruption from May to August and, the volumes 3 and 4 had thermal comfort from January to December with an interruption that was seen from May to September.

The average temperature of the volume 3 was approximately the same as the outdoor average temperature. The average temperatures of all volumes had nearly the same values although the volumes located at first floor were presenting slightly high average temperatures.

All volumes had thermal comfort from the middle of August to the middle of May although the volumes 2, 5 and 7 were about 0.5°C above the thermal
comfort zone from January to March. The outdoor temperature had nearly the same values as presented by the indoor temperatures of all volumes.

4.10.3 Indoor temperature in the hottest day

With closed windows, the volumes of the first floor and volume 6 were out of comfort and, the small volumes located at ground floor had thermal comfort observed at early morning up to the first hours of morning and, volume 3 was continued comfortable until 1:30 p.m. The highest indoor temperature into the volumes was seen in volume 7. The outdoor temperature was comfortable since 0:00 until nearly 8:00 a.m.

With opened windows, the volumes 1, 6 and all volumes located at first floor were out of thermal comfort zone. The remaining volumes, almost all located at ground floor were within the thermal comfort zone at early morning. The following table illustrates the thermal comfort in the volumes during the hottest day.

Table 4.10: Hours of comfort in the volumes in the hottest day

<table>
<thead>
<tr>
<th>Item</th>
<th>Shaded Volume</th>
<th>Closed windows</th>
<th>Opened windows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beginning</td>
<td>The end</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>Out</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>01:00 a.m.</td>
<td>08:00 a.m.</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>00:00 a.m.</td>
<td>13:00 a.m.</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>01:00 a.m.</td>
<td>09:00 a.m.</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4.10.4 Indoor temperature in typical summer days

In the typical summer days, apart from the volume 6, the indoor temperatures of the volumes located at ground floor were comfortable in both environments during the whole day. The remaining volumes were comfortable but, with interruption at afternoon and evening.

The outdoor temperature was also comfortable since evening until morning. The following table shows the comfort hours in volumes during those days considering both environments.
Table 4.11: Hours of comfort in the volumes during the typical summer days

Comparison between the comfort hours of the two environments of the volumes of the shaded building in the typical summer days.

<table>
<thead>
<tr>
<th>Item</th>
<th>Volume</th>
<th>Closed windows</th>
<th>Opened windows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Beginning</td>
<td>The end</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Whole day</td>
<td>24.00</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>07:00 p.m.</td>
<td>03:00 p.m.</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Whole day</td>
<td>24.00</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Whole day</td>
<td>24.00</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>09:30 p.m.</td>
<td>02:00 p.m.</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>05:30 p.m.</td>
<td>03:30 p.m.</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>00:00</td>
<td>12:00</td>
</tr>
</tbody>
</table>

4.10.5 Hours of thermal comfort in the summer months

With closed windows, all small volumes presented more hours of thermal comfort than the huge volumes. The volumes located at ground floor presented better thermal performances than the volumes of the first floor. Volume 3 had more hours of thermal comfort while the volume 7 had less hours of thermal comfort. Volumes 1, 2, 3 and 4 have more hours of thermal comfort than the hours of thermal comfort existing at outdoor.

With opened windows, all volumes at ground floor continued to present better performances than the volumes located at first floor. Nevertheless, all volumes had more hours of thermal comfort than the hours of discomfort.

Apart from the volumes 5 and 7, all volumes had more hours of thermal comfort than the hours of thermal comfort of the outdoor. Volume 3 continued to present more hours of thermal comfort than the remaining volumes whilst the volume 7 was continuing to present less hours of thermal comfort.

The following table shows the thermal comfort hours of the volumes throughout the summer months.
<table>
<thead>
<tr>
<th>Environments</th>
<th>Comparison between the comfort hours of the two environments of the volumes of the shaded building during the summer months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed windows</td>
<td>2712</td>
</tr>
<tr>
<td>Opened windows</td>
<td>2531</td>
</tr>
<tr>
<td>Difference</td>
<td>77</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>2.3</td>
</tr>
</tbody>
</table>

4.11 Resume

This section summarise the previous findings through comparison between the non-shaded building and the shaded building. The indoor environments of closed and opened windows were considered to evaluate and to compare the absorbed solar radiation, indoor temperatures and thermal comfort hours during the year, summer months, the hottest day and the typical summer days.

4.11.1 Comparison between the absorber solar radiations

The volumes located at north part of the non-shaded building reduced in more than 60% of their solar absorption when they were shaded and, the volumes located at south part only reduced about 13% of solar radiation absorption. This is obvious because, the south volumes were almost in shadow and the volumes located at north part of the building were severely irradiated before the building being shaded.

Apart from shading, the volumes located at first floor were receiving heat from the attic through the non-insulated ceiling. The attic was not well ventilated as well as not insulated. Thus, the volumes of the first floor had a slightly more heat if compared with the similar volumes at ground floor.
Table 4.13: Comparison between the absorbed solar radiation from non-shaded and shaded buildings

<table>
<thead>
<tr>
<th>Environments</th>
<th>Vol. 1</th>
<th>Vol. 2</th>
<th>Vol. 3</th>
<th>Vol. 4</th>
<th>Vol. 5</th>
<th>Vol. 6</th>
<th>Vol. 7</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-shaded</td>
<td>402</td>
<td>404</td>
<td>148</td>
<td>1622</td>
<td>441</td>
<td>1652</td>
<td>2018</td>
<td>6687</td>
</tr>
<tr>
<td>Shaded</td>
<td>142</td>
<td>158</td>
<td>44</td>
<td>593</td>
<td>177</td>
<td>1434</td>
<td>1386</td>
<td>3934</td>
</tr>
<tr>
<td>Difference</td>
<td>260</td>
<td>246</td>
<td>104</td>
<td>1029</td>
<td>264</td>
<td>218</td>
<td>632</td>
<td>2753</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>65</td>
<td>61</td>
<td>70</td>
<td>63</td>
<td>60</td>
<td>13</td>
<td>31</td>
<td>41.2</td>
</tr>
</tbody>
</table>

4.11.2 Comparison between the indoor temperatures

In the hottest day, the volumes of the non-shaded building were not comfortable. But after being shaded, the small volumes located at ground floor have had more hours of thermal comfort with closed windows than with opened windows.

With closed windows, the indoor temperatures were more comfortable than with opened windows. It means that, to improve thermal comfort in the hottest day, windows should be closed when the outdoor temperature is high and opened when the outdoor temperature is low in order to ventilate and to reduce the humidity.

Through shading, some volumes improved their indoor temperatures in about 17% to 54% of the daily comfort hours. These volumes improved in about 54-163% of available thermal comfort hours from outdoor.

Related to the non-shaded building, the improvement observed by the shaded building could be considered as 100% because all volumes of the non-shaded building were out of comfort.
Table 4.14: Comparison between the hours of comfort of non-shaded and shaded buildings in the hottest day

Comparison between the comfort hours that were observed in the two different environments of each building volumes expressed in number and percentage. Hottest day

<table>
<thead>
<tr>
<th>Item</th>
<th>Non-Shaded building</th>
<th>Shaded building</th>
<th>Hours difference</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Close</td>
<td>Open</td>
<td>Diff.</td>
<td>Close</td>
</tr>
<tr>
<td>Out.</td>
<td>8.00</td>
<td></td>
<td></td>
<td>8.00</td>
</tr>
<tr>
<td>Vol. 1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>7.00</td>
</tr>
<tr>
<td>Vol. 2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Vol. 3</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>13.00</td>
</tr>
<tr>
<td>Vol. 4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Vol. 5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Vol. 6</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Vol. 7</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

(A) – Difference between the comfort hours of the non-shaded and shaded building.
(B) – Difference between the outdoor comfort hours and the indoor comfort hours of the shaded building.
(C) – Percentage of (A) based on the comfort hours of correspondent volume of the non-shaded building.
(D) – Percentage of (B) based on the comfort hours of the outdoor.

In the typical summer days, the environment of the shaded building has presented more hours of thermal comfort than the hours of comfort of the environments of the non-shaded building. The indoor environment of opened windows of the non-shaded building presented more hours of comfort than the environment of closed window.

In the shaded building, it was seen the opposite, hence, the environment of closed windows presented more hours of comfort than the environment of opened windows.

Through shading, all volumes improved their indoor temperatures by about 50% to 100% of the daily hours, by about 18% to 71% in relation to hours of thermal comfort of the outdoor and by about 91% to 336% related to hours of comfort presented by the non-shaded building.
Table 4.15: Comparison among the hours of comfort of the non-shaded and shaded buildings with closed windows in typical summer days

Comparison among the comfort hours of non-shaded and shaded buildings with closed windows in typical summer days- Expressed in number and percentage.

<table>
<thead>
<tr>
<th>Volumes</th>
<th>Non-Shaded Building</th>
<th>Shaded Building</th>
<th>Hours difference in number</th>
<th>Hours difference in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A)</td>
<td>(B)</td>
<td>(C)</td>
<td>(D)</td>
</tr>
<tr>
<td>Out.</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vol. 1</td>
<td>5.30</td>
<td>24.00</td>
<td>18.30</td>
<td>10.00</td>
</tr>
<tr>
<td>Vol. 2</td>
<td>6.00</td>
<td>20.00</td>
<td>14.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Vol. 3</td>
<td>11.00</td>
<td>24.00</td>
<td>13.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Vol. 4</td>
<td>-</td>
<td>24.00</td>
<td>24.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Vol. 5</td>
<td>-</td>
<td>16.30</td>
<td>16.30</td>
<td>2.50</td>
</tr>
<tr>
<td>Vol. 6</td>
<td>11.30</td>
<td>22.00</td>
<td>10.30</td>
<td>8.00</td>
</tr>
<tr>
<td>Vol. 7</td>
<td>5.30</td>
<td>12.00</td>
<td>6.30</td>
<td>-2.00</td>
</tr>
</tbody>
</table>

(A) – Difference between the comfort hours of the non-shaded and shaded building.
(B) – Difference between the outdoor comfort hours and the indoor comfort hours of the shaded building.
(C) – Percentage of (A) based on the comfort hours of correspondent volume of the non-shaded building.
(D) – Percentage of (B) based on the comfort hours of the outdoor.

Table 4.16: Comparison among the hours of comfort of the non-shaded building and shaded building with opened windows in typical summer days

Comparison among the comfort hours of non-shaded and shaded buildings with opened windows in typical summer days- Expressed in number and percentage.

<table>
<thead>
<tr>
<th>Volumes</th>
<th>Non-Shaded Building</th>
<th>Shaded Building</th>
<th>Hours difference in number</th>
<th>Hours difference in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A)</td>
<td>(B)</td>
<td>(C)</td>
<td>(D)</td>
</tr>
<tr>
<td>Out.</td>
<td>14.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vol. 1</td>
<td>10.00</td>
<td>24.00</td>
<td>14.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Vol. 2</td>
<td>9.00</td>
<td>20.00</td>
<td>11.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Vol. 3</td>
<td>1.00</td>
<td>24.00</td>
<td>12.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Vol. 4</td>
<td>9.00</td>
<td>24.00</td>
<td>15.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Vol. 5</td>
<td>7.00</td>
<td>14.00</td>
<td>7.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Vol. 6</td>
<td>12.00</td>
<td>20.00</td>
<td>8.00</td>
<td>6.00</td>
</tr>
<tr>
<td>Vol. 7</td>
<td>9.30</td>
<td>13.00</td>
<td>3.30</td>
<td>-1.00</td>
</tr>
</tbody>
</table>

(A) – Difference between the comfort hours of the non-shaded and shaded building.
(B) – Difference between the outdoor comfort hours and the indoor comfort hours of the shaded building.
(C) – Percentage of (A) based on the comfort hours of correspondent volume of the non-shaded building.
(D) – Percentage of (B) based on the comfort hours of the outdoor.
4.11.3 Comparison between the hours of thermal comfort

During summer, the environment with opened windows of the non-shaded building had more hours of thermal comfort than the environment of closed windows but, both environments of the non-shaded building presented less hours of thermal comfort than the environments of the shaded building. No great difference in term of comfort hours was observed in the shaded building with opened and closed windows.

The large volumes and the volumes located at first floor were more comfortable when the windows were opened and the volumes at ground floor were more comfortable when the windows were closed. The volumes located at first floor were more comfortable when the volumes have had their windows opened because these volumes were receiving an additional heat from the attic and by opening the windows it was possible to reduce the accumulated heat.

Table 4.17: Comparison of the different environment during the summer

<table>
<thead>
<tr>
<th>Non-Shaded building</th>
<th>Shaded building</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed</td>
<td>Opened</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Out.</td>
<td></td>
</tr>
<tr>
<td>Vol. 1</td>
<td>1007</td>
</tr>
<tr>
<td></td>
<td>1907</td>
</tr>
<tr>
<td></td>
<td>1907</td>
</tr>
<tr>
<td></td>
<td>1022</td>
</tr>
<tr>
<td></td>
<td>847</td>
</tr>
<tr>
<td></td>
<td>1380</td>
</tr>
<tr>
<td></td>
<td>1239</td>
</tr>
</tbody>
</table>

During the summer months, the volumes of the non-shaded building presented less hours of comfort and, after the building being shaded, these volumes have had significant improvement. Therefore by shading the building, the volumes improved their thermal comfort hours in about 7-17% in relation of the total number of hours of comfort that was available at outdoor in the summer and in about 22%-55% related to the previous hours of thermal comfort that the volumes have had before the building being shaded.
Table 4.18: Comparison among the hours of comfort of non-shaded and shaded buildings with closed windows during the summer months

<table>
<thead>
<tr>
<th>Volumes</th>
<th>Non-Shaded Building</th>
<th>Shaded Building</th>
<th>Hours difference in number</th>
<th>Hours difference in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out.</td>
<td>14.00</td>
<td>1007</td>
<td>2712</td>
<td>1705</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1190</td>
<td>2521</td>
<td>1331</td>
</tr>
<tr>
<td></td>
<td>Vol. 1</td>
<td>1907</td>
<td>3511</td>
<td>1604</td>
</tr>
<tr>
<td></td>
<td>Vol. 2</td>
<td>1022</td>
<td>3066</td>
<td>2044</td>
</tr>
<tr>
<td></td>
<td>Vol. 3</td>
<td>847</td>
<td>2195</td>
<td>1348</td>
</tr>
<tr>
<td></td>
<td>Vol. 4</td>
<td>1380</td>
<td>2074</td>
<td>694</td>
</tr>
<tr>
<td></td>
<td>Vol. 5</td>
<td>1239</td>
<td>1868</td>
<td>629</td>
</tr>
</tbody>
</table>

(A) – Difference between the comfort hours of the non-shaded and shaded building.
(B) – Difference between the outdoor comfort hours and the indoor comfort hours of the shaded building.
(C) – Percentage of (A) based on the comfort hours of correspondent volume of the non-shaded building.
(D) – Percentage of (B) based on the comfort hours of the outdoor.

Table 4.19: Comparison among the hours of comfort of non-shaded and shaded buildings with opened windows during the summer months

<table>
<thead>
<tr>
<th>Volumes</th>
<th>Non-Shaded Building</th>
<th>Shaded Building</th>
<th>Hours difference in number</th>
<th>Hours difference in percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out.</td>
<td>14.00</td>
<td>2531</td>
<td>2531</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Vol. 1</td>
<td>1903</td>
<td>2789</td>
<td>886</td>
</tr>
<tr>
<td></td>
<td>Vol. 2</td>
<td>1827</td>
<td>2733</td>
<td>906</td>
</tr>
<tr>
<td></td>
<td>Vol. 3</td>
<td>2189</td>
<td>2958</td>
<td>769</td>
</tr>
<tr>
<td></td>
<td>Vol. 4</td>
<td>1852</td>
<td>2866</td>
<td>1014</td>
</tr>
<tr>
<td></td>
<td>Vol. 5</td>
<td>1702</td>
<td>2324</td>
<td>622</td>
</tr>
<tr>
<td></td>
<td>Vol. 6</td>
<td>2025</td>
<td>2695</td>
<td>670</td>
</tr>
<tr>
<td></td>
<td>Vol. 7</td>
<td>1828</td>
<td>2230</td>
<td>402</td>
</tr>
</tbody>
</table>

(A) – Difference between the comfort hours of the non-shaded and shaded building.
(B) – Difference between the outdoor comfort hours and the indoor comfort hours of the shaded building.
(C) – Percentage of (A) based on the comfort hours of correspondent volume of the non-shaded building.
(D) – Percentage of (B) based on the comfort hours of the outdoor.
4.12 Conclusion 3

In general, the simulations confirmed that the volumes of non-shaded buildings with facades facing the north absorb much solar radiation than the volumes with facades facing south. Therefore, the indoor temperatures of the volumes with facades facing north are higher than the indoor temperatures of the volumes with facades facing south.

The volumes under the ceiling had high indoor temperatures than other volumes because; these volumes were receiving heat from the non-insulated and not properly ventilated attic through the ceiling that was also not thermally insulated.

The simulations also demonstrated that the overhang and wing walls with 1.70 meters of salience on buildings with NE-SW orientation are protecting the facades of buildings against direct solar radiation in about 2-8% during the summer. By using the same dimensions of the overhang and wing walls on buildings with E-W orientation, the facades of buildings become protected in about 85-100% against the direct solar radiation during the summer.

The shaded buildings with E-W orientation improved their indoor temperatures in the volumes in about 33% in the hottest day, 129% in typical summer days and 200% during the summer when compared with similar building but, with NE-SW orientation.

The performance of the building in terms of thermal comfort, it increased in 0% on the hottest day, 71% in typical summer days and 21% during the summer period after being shaded if compared with the existing outdoor thermal comfort hours after being shaded if compared to the available outdoor comfort hours.
5. Papers Overviews

5.1 Ten Years of Sustainable Construction - Perspectives From a North Construction Manager and a South Architect Point of View

This paper deals on sustainability construction in North and South different perspective. It describes how the international focus on sustainable construction issues has changed over the past ten years i.e., 2008 past ten years. The north part is a review from four different international and regional sustainable building conferences and south perspective based on literature reviews done by the second and third authors, where the research findings reference buildings from Mozambique and Tanzania reflecting sustainability.

The paper compared the earlier period with the modern day architecture in Southern Africa and the findings showed 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 findings also demonstrated that the 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.

Keywords: Sustainable construction, conferences, differences, North and South perspectives.
5.2 Influence of Building Orientation on Indoor Climate of Maputo City Buildings

The paper describes and analyses the influence of the orientation of buildings on the indoor climate of Maputo City buildings and their impact on thermal comfort to the occupants. Case Study focuses on Maputo City - Urban district nr.1 as one example of how the indoor climates of many buildings of Mozambique cities were influenced by its orientation.

The main objective of the study was to evaluate and to gauge how much the thermal comfort was lost due to inadequate orientations of buildings and to encourage designers and builders to use passive means as the one of the key method for getting thermal comfort in the buildings.

Through simulations were carried out the studies which results demonstrated that the temperatures within the volumes of the building NE-SW oriented were about 5 to 7°C higher than the outdoor temperature and about 2°C more than the buildings E-W oriented throughout the year. In order to have different approach about the orientations of the Maputo City buildings, they were simulated in 24 different orientations.

The results concluded that the indoor temperatures of the buildings NE-SW oriented have had their thermal comfort negatively influenced in about 11%-42% compared to the buildings with E-W orientation and in about 6%-17% of the thermal comfort from outdoor.

Keywords: Building envelop, Building orientation, Passive cooling, Simulation.
5.3 Influence of Solar Shading on Indoor Climate of Maputo City Buildings

The paper describes and analyses the influence of shading in the indoor climate of Maputo City buildings and their impact on thermal comfort to the occupants. Case Study focuses on Maputo City – 3 de Fevereiro guest house of Eduardo Mondlane University as one of the example of how the temperature within many buildings of Maputo City E-W oriented were influenced by the lack of adequate fixed shading devices.

The main objective of the research was to evaluate and gauge the thermal comfort that was lost due to the lack or inadequate shading on buildings and to encourage designers and builders to use passive means for getting comfort in the buildings.

The results through simulation showed that the use of the external fixed shading devices for Maputo City buildings E-W oriented that were properly dimensioned, the indoor temperatures of these buildings could improve significantly and consequently the thermal comfort within buildings could be felt in 33% and 100% of the daily hours of the hottest day and typical summer days respectively and in more than 21% of the outdoor comfort hours during the summer period.

**Keywords**: Building envelop, Building orientation, Shading, Passive cooling, Simulation.
6. Conclusions

Through literature review a method to determine the comfort zone for each region independently of questionnaires and inquiries of people was founded. This method was chosen due to discordance among the researchers about the thermal comfort indices for hot and humid regions hence, the researcher followed the existing formula previously developed by Olgyay (1963) and further improved by Szokolay (1987). Based in this formula that almost considers the environment factors, the boundary to Maputo City thermal comfort was calculated.

Based on literature, also a suitable simulation program was identified. The chosen program is DEROB-LTH simulation program. This program was chosen because, it has been used in many countries with similar climates conditions and the results were satisfactory. Apart from this performance, the researcher is linked to Lund University where the simulation program is widely used and it is constantly improved according to the needing.

The simulation results demonstrated that the optimum orientation of buildings for Maputo City should be the E-W orientation. The calculated percentages of the thermal comfort hours of the two building orientations demonstrated that buildings with NE-SW orientations loses about 42-100% of thermal comfort compared to those with E-W Orientation.

The simulations also demonstrated that the overhang and wing walls with 1.70 meters of salience on buildings with NE-SW orientation are protecting the facades of buildings against direct solar radiation in about 2-8% during the summer. By using the same dimensions of the overhang and wing walls on buildings with E-W orientation, the facades of buildings become protected in about 85-100% against the direct solar radiation during the summer.

With E-W orientation, the comfortable indoor temperatures could be felt in about 33% on the hottest day and in about 100% in typical summer days. The improvement that the building could achieve after being shaded represents about 33% on the hottest day, 129% in typical summer days and 200% during the summer season compared to the previous results of the same building before being shaded.
The performance of the building in terms of thermal comfort, it increased in 0% on the hottest day, 71% in typical summer days and 21% during the summer period after being shaded if compared with the existing outdoor thermal comfort hours after being shaded if compared with the available outdoor comfort hours.

In both orientations, the non-shaded buildings had slightly more of hours of thermal comfort in the environments of opened windows while the shaded buildings had more hours of thermal comfort within the environments of closed windows.
7. Recommendations

For minimizing the direct solar radiation into volumes, buildings should be optimally oriented, properly shaded and correctly ventilated. Large openings on East and West should be shaded or avoided. Preferably, the main openers should be placed on shaded facades at north and on protected facades at south. For optimizing the building materials, the east and west facades should be shaded by building components as stairs, lifts, garage or others.

The research has suggest that in the subsequent studies, they should be compared the simulations results from the DEROB-LTH simulation program with the measured results on the experimental building in order to validate the application of DEROB-LTH simulation program in the climate conditions of Mozambique.

The research also recommends to be done a surveying the thermal comfort indices for Maputo City by mean of inquiries, questionnaires or interview in order to compare the thermal comfort indices found through calculations with the Szokolay formula with the comfort indices found through inquiries.

Finally, the research suggest that should be done a survey for finding the optimum period for opening and closing the vents of buildings in order to improve the thermal comfort hours through the existing natural ventilation systems.
8. References


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Appendix A

The following figure shows the solar diagram for Maputo City with the main orientations of the long axis of Maputo City buildings. Based on this diagram it was possible to analyses the functionality of the overhangs and the wings of the Maputo City buildings.

Maputo Solar Diagram 26° Latitude South.

Legend:  
- Buildings surfaces
- 21th June hours
- 23th Sept/March hours
- 1th Dec. hours
<table>
<thead>
<tr>
<th>Months</th>
<th>Vertical angles</th>
<th>Horizontal angles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For overhangs</td>
<td>For wings</td>
</tr>
<tr>
<td>21 of December</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td>23 of November and 21 of January</td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
</tr>
<tr>
<td>23 of October and 22 of February</td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>23 of September and 21 of March</td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
</tr>
<tr>
<td>Date</td>
<td>Diagram 1</td>
<td>Diagram 2</td>
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<tr>
<td>----------------------</td>
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<td>-----------</td>
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<tr>
<td>22 of July and 21 of May</td>
<td><img src="image1" alt="" /></td>
<td><img src="image2" alt="" /></td>
</tr>
<tr>
<td>23 of August and 21 of April</td>
<td><img src="image3" alt="" /></td>
<td><img src="image4" alt="" /></td>
</tr>
<tr>
<td>21 of June</td>
<td><img src="image5" alt="" /></td>
<td><img src="image6" alt="" /></td>
</tr>
</tbody>
</table>

**Legend**
- Sunrise and sunset
- Pair hours
- 07.00 O’clock
- 12.00 O’clock
- Odd hours

Horizontal and vertical angles for 26° South Latitude
Ten Years of Sustainable Construction
- Perspectives From a North Construction Manager and a South Architect Point of View

World Sustainable Building Conference, SB08.
Melbourne 2008 - Australia
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 on 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, CO2 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 CO2 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 summarised 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). Pre-colonial 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.
Paper 2

Influence of Building Orientation on the Indoor Climate of Building
- Case Study: Urban district Nr. 1 of Maputo City-Mozambique

AET2011 Conference in Entebbe - Uganda 2011
Influence of Building Orientation on the Indoor Climate of Buildings

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ABSTRACT
The paper describes and analyses the influence of the orientation of buildings on the indoor climate of Maputo City buildings and their impact on thermal comfort to the occupants. Case Study focuses on Maputo City - Urban district nr.1 as one example of how the indoor climates of many buildings of Mozambique cities were influenced by its orientation.

In Maputo city, about 70% of buildings were orientated in the way that all external facades of buildings allow to be irradiated by sun rays throughout the year. Thus, the indoor temperatures in these environments are high and consequently, the thermal comfort is affected. The main objective of the study was to evaluate and to gauge how much the thermal comfort was lost due to inadequate orientations of buildings and to encourage designers and builders to use passive means as one of the key method for getting thermal comfort in the buildings. Through simulations were carried out the studies which results demonstrated that the temperatures within the volumes of the building NE-SW orientated were about 5 to 7°C high than the outdoor temperature and about 2°C more than the buildings E-W orientated throughout the year. For having whole approach about the orientations of the Maputo City buildings were simulated 24 different orientations of buildings. The results concluded that the indoor temperatures of the buildings NE-SW orientated have had their thermal comfort negatively influenced in about 11%-42% compared to the buildings E-W orientated and in about 6,4%-17% of the thermal comfort from outdoor.

Keywords: Building envelop, Building orientation, Passive cooling, Simulation.

1.0 INTRODUCTION
Most of the research which has been carried out within the field of architectural sustainability focuses on energy efficiency because it can be a key for sustainable buildings now and in the near future. Thus buildings orientations is one of the key methods that the designers could pay attention on. Maputo City is a sub-tropical city that is located about two degrees below Capricorn tropic. This localization could be an opportunity to be taken in account for designers in order to minimize the use of the building materials to obtain the adequate indoor temperatures in the buildings. The city is densely built and the predominant road network infrastructure is orthogonal and orientated on NE-SW and NW-SE axis. Many buildings of the city have their facades parallels to these road network infrastructures. According to (Holger, 1999), in hot and humid regions, the long axes of buildings should be E-W oriented in order to minimize the area of exposition of solar irradiation. Considering this statement, many buildings of Maputo City are not optimally oriented therefore, the indoor climate of many buildings are negatively affected. Due to this fact, the energy used for cooling and ventilating these buildings is high.

2.0 GENERAL DESCRIPTION ABOUT MAPUTO CITY
Maputo City has about 350,00km² with nearly 1,272,000 of inhabitants. Climatically, the city is hot a humid with two seasons as the summer and winter. The summer is observed from October
to March and the winter is from April to September. The summer is hot and humid. During this season, the temperature is constantly high (average about 29°C maximum and 21°C minimum) with less diurnal amplitude. The humidity is high (average about 80%). The winter is dry and cool. During this season the temperature is moderately low (average about 26°C maximum and 16°C Minimum) and the humidity is less (average about 60%). During the year, the wind is mainly observed from N, E and SE. The mean monthly wind speed observed by the Maputo meteorological station varies from 2m/s in the winter and 4m/s in the summer. (INAM, 2005).

2.1 Orientation of the Buildings in Maputo City
About 70% of Maputo City buildings have their long facades NE-SW or NW-SE orientated. These orientations followed the orientation of the road network infrastructures of Maputo City. This mesh of road network infrastructure followed the two first built streets in Maputo City (Former Lourenço Marques) which were perpendicular to each other and NE-SW and NW-SE orientated making the city to be identified by a mesh of orthogonal road.

2.2 Thermal Comfort for Maputo City
For this study were considered the thermal comfort values that were a result of calculation according to the Szokolay method. This method presents the thermal comfort zone based in thermal neutral temperature in function of medium external temperature and its comforts limits are based on Standard Effective Temperature (SET). After determination of the thermal neutral temperature, the obtained values should be decreased 2°C for the minimum thermal neutral temperature and increased 2°C for the maximum thermal neutral temperature. This method can be used for all sites only require the climate data of these places for applying the following formula:

\[
\theta_n = 17.6 \times 0.31 \times \theta_{m} \quad 26.5°C < \theta_n < 28.5°C
\]  

where;

\[
\begin{align*}
\theta_n &= \text{thermal neutral temperature} \ [°C] \\
\theta_{m} &= \text{medium external temperature} \ [°C]
\end{align*}
\]

According to the Maputo City climate data, the average of the minimum and maximum temperature was 18.7 °C and 27.4 °C respectively. Thus applying the above formula, the comfort limits for Maputo City were found to be 22 °C to 28 °C. The obtained results are similar as the limits recommended by (OLGYAY, 63), thermal comfort values to the tropics and by (GIVONI, 92) thermal comfort for developing countries.

3.0 SIMULATION WITH DEROB-LTH
To understand the influencing parameters on thermal comfort, a residential building and 24 different orientations of Maputo City buildings were simulated with DEROB-LTH. DEROB-LTH is a dynamic and detailed energy simulation tool originally developed at Austin School of Architecture, University of Texas and further developed at Lund Institute of Technology. It has accurate models to calculate the influence of solar insulation and shading devices on the energy balance of a building. The building is modeled in 3-D, a necessary condition for accurate calculations of the distribution of solar insulation and temperatures in the room and its surfaces. The resolution in calculated values is one hour. DEROB-LTH can manage rooms with irregular geometries, buildings with several zones and calculate peak loads, energy demand, temperatures and thermal comfort for a building. (Källblad, 1993). The DEROB-LTH program also calculates the Global Operative Temperature in the buildings. Global Operative Temperature is the uniform temperature of a radiantly black enclosure in which the occupant would exchange the
same amount of heat by radiation plus convection as in the actual no uniform environment, thereby experiencing thermal comfort, or thermal neutrality. (Källblad, 98-12-13).

3.1 Simulated Building
The building is a terrace house containing three identical dwelling units of about 45 m² each. Each dwelling has four rooms: one living room, two bedrooms and a kitchen. The building does not have veranda and any other kind of solar protection. This building is located in the southeastern part of Maputo City in the Malanga neighborhood, Canto Resende Street, number 12. The long axis of this building is NE-SW oriented with the main facade facing SE. This form of orientation follows the general road network infrastructure orientation of the district.

3.2 Technical Description
The structure of this building is basically composed of foundation, columns and beams. The foundation used in this building is concrete and blocks. The walls start foundation level using 400x200x100mm of concrete blocks hollow. The roof is 22.5% pitched. The inside and outside of the walls are plastered and painted yellow. The openings, oriented SE are doors and single glass windows framed by wooden structures.

3.3 Studied Parameters
Two main parameters as the orientation of the buildings and the indoor environments were considered. The two indoor environments considered were; building with closed and opened windows. In the study were also simulated 24 different orientations of buildings for Maputo City.

3.4 Days and Months Used for Analysis
Annual indoor temperature, two representative days and six summer months were chosen to evaluate the indoor temperature in the buildings. December, 16 was chosen as the hottest day and, October, 11 as the typical summer days. From October to March were considered as the summer months. The thermal comfort limits used for study were from 22°C to 28°C as boundaries.

3.5 Climate Data Used for Simulations
The Input climate data used to the DEROB-LTH simulation program is based on the climate data from (Meteonorm Version 6.0, 2007), which produce a Global Metrological Database for Engineers and Planners. The climate data created by Meteonorm Version 6.0, reports the average of the Maputo City climate data from 1981 to 2000. The available climate data containing information about global horizontal radiation, temperature, relative humidity, wind direction and wind speed.
4.0 RESULTS

4.1 Solar Radiation
The table 1 shows the maximum and average annual of the global radiation absorbed by volumes.

<table>
<thead>
<tr>
<th>Solar radiation absorbed by the volumes</th>
<th>IgI (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor Vol.1 Vol.2 Vol.3 Vol.4</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>1122 640,5 970,4 1344,7 581,1</td>
</tr>
<tr>
<td>Average</td>
<td>205,1 70,7 107,0 193,8 67,7</td>
</tr>
</tbody>
</table>

4.2 Indoor Temperatures Within the Volumes of the Buildings NE-SW Orientated
The table 2 shows the maximum, average and minimum annual outdoor and indoor temperature of the building’s volumes NE-SW orientated taking in consideration the two environments.

<table>
<thead>
<tr>
<th>Building with closed windows</th>
<th>Building with opened windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor Vol.1 Vol.2 Vol.3 Vol.4</td>
<td>Vol.1 Vol.2 Vol.3 Vol.4</td>
</tr>
<tr>
<td>Maximum</td>
<td>36,3 38,7 39,8 39,3 39,3 38,6 38,6 38,9 39,0</td>
</tr>
<tr>
<td>Average</td>
<td>23,6 27,0 27,5 28,1 27,5 26,0 26,2 26,4 26,2</td>
</tr>
<tr>
<td>Minimum</td>
<td>11,1 16,0 16,5 17,6 17,1 16,5 16,5 17,6 17,6</td>
</tr>
</tbody>
</table>

4.3 Indoor Temperature in the Volumes 2 NE-SW and E-W Orientated
To evaluate the indoor temperatures in the buildings NE-SW and E-W orientated, the volume 2 was used to be simulated in the hottest day of the year and in the typical summer days. The front facades of the buildings were facing to SE and south respectively.

Chart nr. 1: Indoor temperatures of the building in the hottest day of the year.

Chart nr. 2: Indoor temperatures of the building in the typical summer days.
4.4 Thermal Comfort Hours
To evaluate the comfort hours of the all volumes in the summer (from October to March) all environments of the buildings NE-SW and E-W orientated were simulated, see table 3.

Table 3: Comfort hours by the volumes of the buildings NE-SW and E-W orientated.

<table>
<thead>
<tr>
<th>Environments</th>
<th>Building NE-SW orientated</th>
<th>Building E-W orientated</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI. Windows</td>
<td>994 885 812 870</td>
<td>1063 1066 972 942</td>
</tr>
<tr>
<td>Op. Windows</td>
<td>1487 1471 1462 1476</td>
<td>1614 1633 1618 1554</td>
</tr>
</tbody>
</table>

4.5 Indoor Temperature in the Volume 2 Differently Orientated
For choosing the appropriate orientation in term of insolation for Maputo City buildings were simulated twenty four different orientations of the volume 2. This volume is a rectangle with 5.00x3.00 meters and it has two facades that are part of the envelop and the other two are internal walls which are adjacent to the volumes 1, 3 and 4. In the chart 5, the orientation 0° is that the main facades of the building a facing north and the orientation 180° are facing south.

Chart 3: Different orientations of the volume 2 from 0° to 360°.

5.0 FINDINGS

5.1 Solar Radiation
In the maximum global radiation, the volume 3 absorbed more solar radiation than other volumes. The volume 4 absorbed less solar radiation.

5.2 Indoor Temperatures
The annual maximum indoor temperatures of the volumes were approximately the same although the volume 2 with closed windows was presenting the highest indoor temperature among them with about 40°C. The maximum indoor temperatures were slightly fresh when the windows were opened and the minimum were slightly warm when the windows were closed. The maximum indoor temperatures of all volumes were about 4°C high than the maximum outdoor temperature at peak times of day. In the hottest day, the environment of the two orientations did not have comfort although the building E-W orientated with opened window was almost 2°C bellow than the building NE-SW orientated. In typical summer days, the indoor temperature of the building E-W orientated with opened windows presented 8½ hours of thermal comfort while the building NE-SW orientated presented about 6 hours. Mostly, the hours of comfort were observed at early hours of the morning and at morning. During afternoon and evening these studied buildings did not observe thermal comfort. The building orientated E-W provided an additional 2½ hours of comfort compared to the number of comfort hours of the typically NE-SW orientated model.
5.3 Thermal Comfort Hours
For each environment, the volumes presented almost the same numbers of comfort hours although the volume 4 presented the highest improvement. For both orientations, the thermal comfort hours of the environment with opened windows had more hours of comfort than those presented by the environments of closed windows. In the environments with opened windows of the two orientations, the volumes of the building NE-SW orientated have had around 1500 hours of comfort for each, the volumes of the building E-W orientated have had more than 1600 hours of comfort and the outdoor temperature presented 2531 hours of comfort. The outdoor temperature has had more than 900 and 1000 hours of comfort than the volumes of the building E-W and NE-SW orientated respectively.

5.4 Indoor Temperature in the Volume 2 Differently Orientated
The results of simulation of the volume 2 in different orientations had demonstrated that the buildings oriented from 15° to 165° and from 195° to 345° had their indoor temperatures higher than the buildings that were oriented from 0° to 15° and from 165° to 195°. The highest indoor temperature was seen in the orientation 90° and 270° i.e., N-S orientation and the lowest indoor temperature was observed in the orientation 0° and 180° i.e., E-W orientation. For all orientations, the environment with opened windows presented good results than the building with closed windows and, the outdoor temperature were better than the indoor temperatures of the volumes.

6.0 ANALYSIS
6.1 Solar Radiation
All volumes had two facades that were receiving the global radiation. The facades that were located at SE and NE were receiving the global radiation at morning and the facades located at NW and SW was irradiated at afternoon. The two facades of the volume 2 and 4 were irradiated in one period of the day and the volume 1 and 3 were irradiated by the whole day, one facade at morning and another at afternoon. Although the volume 1 has been irradiated twice, this volume has had interruption on its radiation that was almost seen in the transition of the morning to afternoon while the volume 3 was consecutively hence presented the highest absorption.

6.2 Indoor Temperatures
In general the indoor temperatures of the volumes were high although the indoor temperatures of the volumes with opened windows have observed a slightly reduction. This improvement was because of the influence of outdoor air temperature that was 4°C less than the indoor temperatures of the volumes that by stack ventilation, the volumes were removing their heat and receiving the fresh air from outside. Due to low amplitude of the outdoor temperature associated at the high U-Value of the building envelop, the process of heat exchange between the outdoor and indoor temperature until to achieve the thermal balance took many hours. Thus the thermal comfort on the volumes were seen at early morning after the envelop has been lost their thermal heat. In the typical summer days, the outdoor temperature had about 14½ hours of thermal comfort, the volume E-W orientated had about 8½ hours of comfort and the volume NE-SW orientated had 6 hours of comfort. The difference between the volumes represents about 41,7% of the improvement of the volume E-W orientated compared to the previous orientation and about 17,2% of the improvement in relation of the outdoor temperature comfort hours.

6.3 Thermal Comfort Hours
The thermal comfort hours of the building E-W orientated had improvement in relation of the comfort hours of the building NE-SW orientated. The maximum improvement was observed in the volume 2 with about 162 hours of comfort more than the previous thermal comfort hours.
presented by the same volume when it was NE-SW orientated. This improvement represents about 11.1% of the gain on the building E-W orientated in relation of the hours of comfort of the building NE-SW orientated and about 6.4% in relation of the hours of comfort of the outdoor.

6.4 Indoor Temperature in the Volume 2 Differently Orientated

In the different orientation of the buildings, the building that was E-W orientated has presented about 2°C less than the building N-E orientated and about 1½ °C less than the building NE-SW orientated. This difference was observed because the rectangular buildings that had their long facades orientated beyond -2° to 2° of the E-W line are subjected to have all facades irradiated by sun rays and, the buildings that have their long facades orientated between -2° to 2° of the E-W line have advantage to see one of their facades shaded because one of its facades will be facing to south where it will never experiment direct solar radiation. In that orientation, the volumes that have one facades facing to south were privileged than those that had one facade facing north thus, the temperatures within the volumes at south were about ½ °C less than the volumes at north.

7.0 CONCLUSIONS

Independently of the orientation of the buildings, the buildings that have had not insulated nor shaded presented high indoor temperature when they have had their windows closed and they improved their indoor temperatures when they have had their windows opened but the buildings that have had the long facades E-W orientated had presented a good performance among all buildings orientations that were simulated. The way how the buildings of Maputo City were orientated, all facades of the rectangular buildings shapes were subjected to direct solar radiation throughout the year. Thus, the global radiations that was been absorbed by the volumes was high and consequently the temperatures within the volumes were great, reducing in that way the thermal comfort hours in the buildings making the environment of the volumes uncomfortable. The simulations results showed that many buildings of Maputo City were not ideally orientated. Thus, the indoor temperatures of these buildings were affected in about 11%-42% than the buildings E-W orientated and in about 6.4%-17% of the thermal comfort from outdoor.

8.0 ACKNOWLEDGEMENTS

The author would like to acknowledge the financial support from Sida/SAREC and the Supervisors from Department of Construction Science, Lund University and Eduardo Mondlane.

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Paper 3

Influence of Solar Shading on Indoor Climate of Building
- Case Study: Urban District Nr. 1 of Maputo City-Mozambique

AET2011 Conference in Entebbe - Uganda 2011
Influence of Solar Shading on Indoor Climate of Buildings

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ABSTRACT
The paper describes and analyses the influence of shading on the indoor climate of Maputo City buildings and its impact on thermal comfort to the occupants. The case study focuses on Maputo City – 3 de Fevereiro Guest House of Eduardo Mondlane University and is one example of how the temperatures within any buildings of Maputo City E-W orientation are influenced by the lack of adequately fixed shading devices. Mozambique is mainly a tropical country that is characterized by a strong solar radiation throughout the year. The elimination or reduction of the incident direct solar radiation on the external walls of the buildings could be a key method of reducing electrical energy consumption and increasing occupant thermal comfort. The main objective of the research was to evaluate the thermal comfort that was lost due to the lack or inadequate shading on buildings and to encourage designers and builders to use passive means to attain better conditions in the buildings. The simulation results showed that by using properly dimensioned external fixed shading devices on E-W orientated buildings in Maputo City, the indoor temperatures and the thermal comfort could improve significantly. The improvement in comfort hours during the hottest day and typical summer days is 33 % and 100 % respectively.

Keywords: Building envelop, Building orientation, Passive cooling, Simulation.

1.0 INTRODUCTION
The strong solar radiation observed in Maputo City-Mozambique from October to March make the indoor temperatures of non shaded buildings become very high and, consequently, such buildings are often not comfortable for occupants for most of the year. Thus, to minimize the negative impact, the occupant uses devices such as fans and air conditioners to get comfort. The rate of energy waste due to inefficient use is indeed significant, hence the amount of money spent for this purpose is enormous both for private and public consumers. Conflicts in terms of non-payment of electricity duty are common. Despite that fact, little work has been done to improve the energy performance in buildings. Solar shading can contribute positively to energy use in buildings by improving the shading coefficients of the envelope. The exterior shading of building is widely used and it is a very effective method to create lower direct solar radiation to the internal. The strategy leads to lower indoor temperature condition and reduced energy use for active cooling (Kolokotsa, 2007). There is a wide range of solar shading components. Most used devices for shading the buildings are; landscape feature; fixed shading devices; horizontal reflecting surfaces; solar control glass and interior glare control devices such as Venetian blinds or adjustable louvers and curtains. External shading is more efficient than internal shading devices which dissipate the heat to the air gap between the shading device and the glazing (Datta, 2001).
2.0 SIMULATIONS WITH DEROB-LTH PROGRAM

To understand the influencing parameters on the thermal comfort, a residential building was simulated. The program used for this purpose was DEROB-LTH. The program performs transient calculations of the heat balance for the building. The resolution in calculated values is one hour.

2.1 Simulated Apartments

The two apartments studied are part of the building with two storey located at eastern part of Maputo City, in Sommerschield neighbourhood, P. A. J. de Almeida Street. The building contains totally six apartments with three flats on each floor. The long axis of this building is approximately in E-W orientation, and the main facade of the building is in south orientation. The building has openings facing South and North. The studied apartments are located in the East. Its eastern facade is shaded by the stair compartment, and the west facade is adjacent to the next apartments. The apartment on ground and first floor are composed of living room, bedroom, kitchen, bathroom, corridor, laundry and storeroom. The apartment at the first floor has a balcony (see Figures 1 to 5). The structure of this building is composed of foundations, columns and beams. The foundation is constructed of concrete and blocks. The walls start from a shallow basement using 400x200x200mm hollow concrete blocks. The roof has 16° pitch. Internal surfaces of the building are plastered and painted white and the external surfaces are plastered and painted with orange and brown colour. The openings to doors and single glazed windows are framed by wood structure. One panel of each window is made up of a mosquito net and a 4 mm thickness single glass. For simulation, the following U-values and g-values were considered for each building element shown in Table 1.

Table 1: U-values and g-values of the Building Elements

<table>
<thead>
<tr>
<th>Building Elements</th>
<th>U-value (W/m²°C)</th>
<th>Building Elements</th>
<th>U-value (W/m²°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>External walls</td>
<td>1.603</td>
<td>Ceiling of the Ground</td>
<td>2.895</td>
</tr>
<tr>
<td></td>
<td></td>
<td>floor</td>
<td></td>
</tr>
<tr>
<td>Internal walls</td>
<td>1.909</td>
<td>Ceiling of the first floor</td>
<td>3.575</td>
</tr>
<tr>
<td>Floor</td>
<td>1.008</td>
<td>Roof</td>
<td>4.641</td>
</tr>
<tr>
<td>External doors</td>
<td>3.390</td>
<td>Glazing G-value</td>
<td>0.867</td>
</tr>
</tbody>
</table>

2.2 Plan Design, Section and the Volumes Identification

![Figure 1: Ground floor](image1)

![Figure 2: First floor](image2)

![Figure 3: Section A-A’](image3)

![Figure 4: Ground Floor Volumes](image4)

![Figure 5: First Floor Volumes](image5)
2.3 Studied Parameters
When analyzing the indoor climate the following parameters were varied; shaded and non-shaded building with opened or closed windows. The dimensions used in fixed devices for shading were 1.75 meters.

Two representative days and six summer months were chosen to evaluate the thermal comfort. The 16th of December was chosen as the hottest day and 11th of October as a typical summer day. The duration of summer months are from October to March. The considered thermal comfort limits were from 22°C to 28°C.

3.0 RESULTS AND FINDINGS

3.1 Indoor temperatures in the volumes of the non-shaded and shaded Buildings
The following charts present the simulation results of the non-shaded and shaded buildings. In the charts, the curved lines represent the indoor temperature of the seven volumes and the outdoor temperature. The shaded area represents the comfort zone limits of the Maputo City.

**Figure 6:** Maximum monthly indoor temperatures in the volumes of the non-shaded buildings.

Figure 6 shows that the volume 6 and 7 were comfortable from April to August whereas the remaining volumes and outdoor temperature were above the comfort zone. Volume 4 presented the highest and volume 6 the lowest indoor temperatures among the volumes.

**Figure 7:** Minimum monthly indoor temperatures in the volumes of the non-shaded buildings

The lowest minimum indoor temperature was seen in volume 7 and, it was almost 6°C above the outdoor temperature. Volume 1 presented higher minimum temperature and it was comfortable
since March until December. The minimum outdoor temperatures were under the comfort zone throughout the year. The other volumes were comfortable since September until April.

![Maximum indoor temperature in the shaded building](image)

**Figure 8**: Monthly maximum indoor temperatures in the volumes of the shaded buildings.

Figure 8 shows that the lowest maximum temperature was observed in the volume 3 and the highest was seen in the volume 7. All volumes presented their maximum temperatures below 34°C. Volume 1 and 3 had comfort from April to November. Volume 2, 4, 5 and 6 were comfortable from April to October and the volume 7 was comfortable from April to September. The maximum outdoor temperatures were above the comfort zone during whole year.

![Minimum indoor temperature in the shaded building](image)

**Figure 9**: Minimum monthly indoor temperatures in the volumes of the shaded buildings

The difference of the annual minimum indoor temperature among volumes was little. The lowest minimum indoor temperature was seen in volume 3 and 4 and the maximum was observed in volume 6 and 7. The minimum annual outdoor temperatures were below the comfort zone and, it was almost 6°C lower than the minimum temperature of volume 3, 4 and 5. From November to April, all volumes were comfortable and, from April to October, they were uncomfortable.

3.2 Absorbed Radiation and Indoor Temperature in the Volume 4

To evaluate the performance in the shaded buildings, volume 4 was chosen because it was the most remarkable in terms of high temperature among the volumes of the non-shaded buildings.

During the hottest day and the typical summer days, the absorbed radiation that was absorbed by the exterior walls to the non-shaded volume was as expected higher than for the shaded volume. The absorbed radiation was reduced of about 3 times when using shading. Opening and closing windows did not influence in the absorbed radiation due to the g-value of the used glass (see the Figure 10).
The indoor environments of the shaded buildings as well as the outdoor temperature had about 8 and 9 comfort hours seen from 1 a.m. to 9 a.m. and from 0:00 to 9 a.m. respectively. The environments of the non-shaded buildings were uncomfortable and they had almost 3°C more than indoor temperatures of the shaded buildings. The peak indoor temperature of the shaded buildings was about 5°C under the peak outdoor temperature.

During the typical summer days, the shaded building was comfortable throughout the day. The non-shaded building with closed windows was not comfortable and the environment with opened windows had 10½ hours of comfort observed from 0:00 to 10½ a.m. From 20.30 p.m. to 10.30 a.m., the outdoor was comfortable for about 14 hours.
3.3 Thermal Comfort Hours
To analyse the comfort hours in the all environments of the simulated volumes, months from October to March were considered as the summer months in order to conduct the study. All volumes of the shaded buildings had more hours of comfort than the volumes of the non-shaded buildings. The number of the outdoor comfort hours was higher than the number of the comfort hours in all volumes of the non-shaded building. In the shaded buildings, the thermal comfort hours of the volume 1, 2, 3, 4 and 6 were high. These volumes also had more hours of comfort than outdoor. Volume 5 and 7 had less hours of comfort than outdoor (see the Table 2).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Shaded-Closed</td>
<td>2531</td>
<td>1007</td>
<td>1190</td>
<td>1907</td>
<td>1022</td>
<td>847</td>
<td>1380</td>
<td>1239</td>
</tr>
<tr>
<td>Non-Shaded-opened</td>
<td>1903</td>
<td>1827</td>
<td>2189</td>
<td>1852</td>
<td>1702</td>
<td>2025</td>
<td>1828</td>
<td></td>
</tr>
<tr>
<td>Shaded-Closed</td>
<td>2712</td>
<td>2521</td>
<td>3511</td>
<td>3066</td>
<td>2195</td>
<td>2074</td>
<td>1868</td>
<td></td>
</tr>
<tr>
<td>Shaded-opened</td>
<td>2789</td>
<td>2733</td>
<td>2958</td>
<td>2866</td>
<td>2324</td>
<td>2695</td>
<td>2230</td>
<td></td>
</tr>
</tbody>
</table>

4.0 ANALYSIS OF THE RESULT

4.1 Indoor temperature in the buildings
In all environments the results showed that the maximum indoor temperature of the volumes located at south part of the building with large area of its facades facing towards south had thermal comfort in the winter. The maximum indoor temperature of the volumes of the non-shaded buildings located at north part of the building having one or two facades facing north/east did not have the comfort but after it being shaded, they also observed comfort in the winter. Apart from the volumes located in the south, the maximum indoor temperatures of the volumes at first floor of the non-shaded building as well as the volume 4 were high than the indoor temperatures of the volumes at ground floor. The high indoor temperatures of the volumes at first floor were due to the high U-Value of the building materials used to the ceiling. The attic was not properly ventilated.

Volume 4 presented the highest indoor temperature among the volumes because this volume had two facades facing to the outdoor, one facing to north and another facing to east. The facade facing to the north was subject to solar radiation during the whole day and the east facade was exposed to solar radiation in the morning. This volume had great improvement in terms of comfort after the building was shaded. In general, the indoor temperatures of the volumes of the non-shaded buildings presented a great improvement after the building becomes shaded. The volume 6 presented the lowest indoor temperature among the volumes because this volume did not have any facade that was receiving direct solar radiation and above the ceiling is volume 7 that is shaded and enough ventilated.

4.2 Indoor temperature in the volume 4
In the hottest day, the environments of the non-shaded building were uncomfortable. This happened because this volume had two facades that were receiving solar radiation throughout the day. The area of the walls that were receiving the direct and diffuse radiation represents about 50% of the total area of the walls of the volume. The remaining 50% of the area of the walls was adjacent to the volume 3, 6 and of the stairs compartment. After the building being shaded, the indoor temperature of the volume had about 8 hours of comfort. This is an improvement of about 33% of comfort hours in that day. In the typical summer days, the non-shaded building with
opened windows has 10½ hours of comfort. After the building being shaded the volume was 100% comfortable.

4.3 Thermal comfort hours in summer season
Comparing the non-shaded building and the shaded building both with closed windows showed that the minimum improvement was about 51% that was observed in the volume 7 and the maximum improvement was about 200% that was seen in the volume 4 and, the minimum improvement observed in the environments with opened windows was about 22% and the maximum was about 55% as that was seen in the volume 7 and 4 respectively.

Comparing the improvements achieved among the volumes and the outdoor comfort hours, the results showed that in the non-shaded building as well as volume 5 and 7 of the shaded building, the outdoor temperature had more hours of comfort. When the building was shaded the maximum improvement was about 39% that was observed in the volume 3. Volume 4 that was the worst in terms of indoor temperature before it being shaded was in second position in terms of comfort hours with 21% of the improvement than the outdoor comfort hours.

5.0 CONCLUSION
In the non-shaded buildings, the volumes situated at north part of the building having more than one facades facing to the north, east or west received and absorbed much solar radiation, and thus they presented high indoor temperature. The volumes located at south part of the building having their long facades E-W orientated only absorbed diffuse radiation hence their indoor temperature was more comfortable than other volumes. The annual indoor temperature of the volumes showed that the volumes under the ceiling of the first floor, had their indoor temperature high than other volumes because, the attic was not properly ventilated and the ceiling was not thermal insulated.

The simulated building also demonstrated that to shade the Maputo city buildings E-W orientation taking into consideration the same building materials that were used in the simulated building, the indoor temperature in the buildings could be felt for about 33% of the daily hours in the hottest day and in about 100% of the daily hours in typical summer days. The improvement that the building could achieve after being shaded represents about 33% in the hottest day, 129% in typical summer days and 200% during the summer season in relation of the previous results of the same building before being shaded. The performance of the building in term of comfort after being shaded compared to the available outdoor comfort hours, the building could increase in 0% in hottest day, 71% in typical summer days and 21% during the summer period.

6.0 ACKNOWLEDGEMENTS
The author would like to acknowledge the financial support from Sida/SAREC and the Supervisors from Department of Construction Science, Lund University and Eduardo Mondlane University. The author also would like to thanks Professor Bertil Fredlund, Dr. Kurt Källblad by their effort in ideas and correcting this paper and to Professor Goran Sandberg and Professor Daniel Baloi by their encouragement and advice in this research field.

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