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Bioclimatic Design for Global Projects: The Case of Maranatha One-Day Church

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Bioclimatic Design for Global Projects: The Case of Maranatha One-Day Church

by

Cibele Eller Rodrigues

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Architecture

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Bioclimatic Design for Global Projects: The Case of Maranatha One-Day Church
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Abstract

Bioclimatic design is an effective architectural approach for creating environmentally responsive buildings, improving comfort and quality of life for its users while using fewer resources. However, globalization of construction strategies and standardized systems are often applied to various locations without considering the specificity of each climate and site. Thus, working contrary to bioclimatic premises and reducing the overall building performance. This work analyzes the case of the One-Day Church (ODC) global project from Maranatha Volunteers International (MVI), which consists of building churches around the world using a standard roof and frame kit, and local materials. It proposes design improvements for three macro-climates, namely hot-humid, hot-arid, and temperate.

This study reviews the concepts of environmental design for each climate and takes into consideration the organization values and church architecture for this religious group. The baseline model and proposed changes are simulated, and the results show that the strategies were responsible for improving daylighting levels, natural ventilation, envelope performance, and overall hours of comfort. In conclusion, applying a set of variations on the design based on macro-climate requirements can significantly improve the environmental performance of one-size-fits-all designs, creating a better space for those building users. These bioclimatic strategies may be applied to other standardized construction projects, such as emergency shelters, and in general to demonstrate the benefits of a bioclimatic approach.
## Contents

Signature Page i

Abstract iii

Table of Contents iv

List of Figures vi

List of Tables ix

1 Introduction 1
   1.1 Outline .............................. 3
   1.2 Bioclimatic Design ..................... 4
      1.2.1 Climate and Comfort ............... 4
      1.2.2 Strategies for Hot-Humid Climates 7
      1.2.3 Strategies for Hot-Arid Climates 9
      1.2.4 Strategies for Temperate Climates 11
   1.3 Case Studies .......................... 14
      1.3.1 The Windcatcher House .............. 14
      1.3.2 Nel Sedone House .................. 15
   1.4 Maranatha Volunteers International ... 18
      1.4.1 One-Day Church Project ............. 21
      1.4.2 Architectural Characteristics of Adventist Churches 24

2 Methodology 26
   2.1 Metrics ................................ 26
   2.2 Baseline One-Day Church ................ 28
   2.3 Climate Characterization ................ 33
      2.3.1 Belem, Brazil ...................... 34
      2.3.2 Cairo, Egypt ....................... 36
      2.3.3 Shillong, India ..................... 40

3 Results 43
   3.1 ODC Belem ............................ 44
      3.1.1 Strategies ......................... 45
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.2 Design</td>
<td>50</td>
</tr>
<tr>
<td>3.1.3 Analysis</td>
<td>54</td>
</tr>
<tr>
<td>3.2 ODC Cairo</td>
<td>56</td>
</tr>
<tr>
<td>3.2.1 Strategies</td>
<td>57</td>
</tr>
<tr>
<td>3.2.2 Design</td>
<td>64</td>
</tr>
<tr>
<td>3.2.3 Analysis</td>
<td>67</td>
</tr>
<tr>
<td>3.3 ODC Shillong</td>
<td>69</td>
</tr>
<tr>
<td>3.3.1 Strategies</td>
<td>70</td>
</tr>
<tr>
<td>3.3.2 Design</td>
<td>74</td>
</tr>
<tr>
<td>3.3.3 Analysis</td>
<td>77</td>
</tr>
<tr>
<td>4 Conclusions</td>
<td>80</td>
</tr>
<tr>
<td>4.1 Future Considerations</td>
<td>82</td>
</tr>
<tr>
<td>Bibliography</td>
<td>83</td>
</tr>
<tr>
<td>A Climate Data</td>
<td>85</td>
</tr>
</tbody>
</table>
List of Figures

1.1 Psychometric Chart and Design Strategies. 6
1.2 Illustration of a building in a hot-humid climate [1]. 7
1.3 Illustration of a building in a hot-arid climate [1]. 9
1.4 Illustration of a building in a temperate climate [1]. 12
1.5 The Windcatcher House [2]. Scale not defined. 14
1.6 Floor Plan - Windcatcher House [3]. 15
1.7 Detail of the windcatcher [3]. Scale not defined. 16
1.8 Nel Sedone House interior. 17
1.9 Bioclimatic strategies for the Nel Sedone House. 17
1.10 Maranatha work around the world, indicated in blue. 18
1.11 Maranatha Volunteers International Main Projects. 20
1.12 ODCs around the world. 22

2.1 One-Day Church built in Belem, Brazil. Source: Maranatha Volunteers International. 28
2.2 Plan and Section - ODC Baseline. Scale 1/16"=1'-0" 29
2.3 Perspective - ODC Baseline. 29
2.4 Elevations - ODC Baseline. Scale 1/16"=1'-0" 30
2.5 Illuminance levels of the ODC for Belem, Cairo, and Shillong respectively. 31
2.6 Baseline Heating and Cooling Loads. 32
2.7 Spatial distribution of the five main Köppen climate types determined for the period 1951 - 2000 [4]. 33
2.8 Monthly Diurnal Averages for Belem, Brazil. Source: Climate Consultant 6.0. 35
2.9 Solar Chart and Wind Wheel of Belem, Brazil. Source: MeteoBlue and Climate Consultant 6.0. 36
2.10 Psychometric chart for Belem, Brazil - ASHRAE 55-2010. 36
2.11 Monthly Diurnal Averages for Cairo, Egypt. Source: Climate Consultant 6.0. 37
2.12 Solar Chart and Wind Wheel of Cairo, Egypt. Source: MeteoBlue and Climate Consultant 6.0. 38
2.13 Psychometric chart for Cairo, Egypt - ASHRAE 55-2010. 39
2.14 Monthly Diurnal Averages for Shillong, India. Source: Climate Consultant 6.0. ......................................................... 40
2.15 Solar Chart and Wind Wheel of Shillong, India. Source: Meteoblue and Climate Consultant 6.0. ................................. 41
2.16 Psychometric chart for Shillong, India - ASHRAE 55-2010. ............ 42
3.1 Strategies applied to the ODC Belem. .................................................. 44
3.2 Strategies for natural ventilation applied to the ODC Belem. ............. 45
3.3 Summer Solar Study for Belem, Brazil (Winter in the Northern Hemisphere). ................................................................. 48
3.4 Winter Solar Study for Belem, Brazil (Summer in the Northern Hemisphere). ................................................................. 49
3.5 Perspective - ODC Belem. ................................................................. 51
3.6 Section AA - ODC Belem. Scale 1/16”=1’-0”. ................................. 51
3.7 Plan - ODC Belem. Scale 1/16”=1’-0”. .............................................. 52
3.8 Elevations - ODC Belem. Scale 1/16”=1’-0”. .................................. 53
3.9 Lighting Analysis - ODC Baseline vs. ODC Belem. ......................... 54
3.10 Cooling Loads - ODC Belem. .......................................................... 55
3.11 Psychometric chart for Belem, Brazil - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies. ............... 56
3.12 Strategies applied to the ODC Cairo. ................................................. 57
3.13 Strategies for natural ventilation applied to the ODC Cairo. .......... 58
3.14 Liter of Light. .................................................................................. 59
3.15 Summer Solar Study for Cairo, Egypt. .............................................. 60
3.16 Fall Solar Study for Cairo, Egypt. ..................................................... 61
3.17 Winter Solar Study for Cairo, Egypt. ............................................... 62
3.18 Perspective - ODC Cairo. ................................................................. 64
3.19 Plan - ODC Cairo. Scale 1/16”=1’-0”. .............................................. 65
3.20 Sections - ODC Cairo. Scale 1/16”=1’-0”. ..................................... 65
3.21 Elevations - ODC Cairo. Scale 1/16”=1’-0”. .................................. 66
3.22 Lighting Analysis - ODC Baseline vs. ODC Cairo. ......................... 67
3.23 Heating Loads - ODC Cairo. .......................................................... 68
3.24 Cooling Loads - ODC Cairo. .......................................................... 68
3.25 Psychometric chart for Cairo, Egypt - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies. ............... 69
3.26 Strategies applied to the ODC Shillong. ........................................... 70
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.27</td>
<td>Strategies for natural ventilation applied to the ODC Shillong.</td>
<td>70</td>
</tr>
<tr>
<td>3.28</td>
<td>Summer Solar Study for Shillong, India.</td>
<td>72</td>
</tr>
<tr>
<td>3.29</td>
<td>Winter Solar Study for Shillong, India.</td>
<td>73</td>
</tr>
<tr>
<td>3.30</td>
<td>Perspective - ODC Shillong.</td>
<td>75</td>
</tr>
<tr>
<td>3.31</td>
<td>Plan - ODC Shillong. Scale 1/16”=1'-0&quot;.</td>
<td>75</td>
</tr>
<tr>
<td>3.32</td>
<td>Section AA - ODC Shillong. Scale 1/16”=1'-0&quot;.</td>
<td>76</td>
</tr>
<tr>
<td>3.33</td>
<td>Elevations - ODC Shillong. Scale 1/16”=1'-0&quot;.</td>
<td>76</td>
</tr>
<tr>
<td>3.34</td>
<td>Lighting Analysis - ODC Baseline vs. ODC Shillong.</td>
<td>77</td>
</tr>
<tr>
<td>3.35</td>
<td>Heating Loads - ODC Shillong.</td>
<td>77</td>
</tr>
<tr>
<td>3.36</td>
<td>Cooling Loads - ODC Shillong.</td>
<td>78</td>
</tr>
<tr>
<td>3.37</td>
<td>Psychometric chart for Shillong, India - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies.</td>
<td>79</td>
</tr>
<tr>
<td>4.1</td>
<td>Total Energy Use Intensity.</td>
<td>81</td>
</tr>
</tbody>
</table>
List of Tables

2.1 Building materials - Baseline. ........................................... 30
3.1 Building Materials - ODC Belem. ................................. 50
3.2 EUI Improvements - ODC Belem. ................................. 55
3.3 Building Materials - ODC Cairo. ................................. 63
3.4 EUI Improvements - ODC Cairo. ................................. 68
3.5 Building Materials - ODC Shillong. ............................. 74
3.6 EUI Improvements - ODC Shillong. ............................. 78
A.1 Weather Data Summary - Belem, Brazil. Climate Consultant 6.0. 85
A.2 Comfort Criteria - Belem, Brazil. Climate Consultant 6.0. 86
A.3 Weather Data Summary - Cairo, Egypt. Climate Consultant 6.0. 87
A.4 Comfort Criteria - Cairo, Egypt. Climate Consultant 6.0. 88
A.5 Weather Data Summary - Shillong, India. Climate Consultant 6.0. 89
A.6 Comfort Criteria - Shillong, India. Climate Consultant 6.0. 90
Chapter 1

Introduction

The advancements in building technology over the past century and the phenomenon of globalization have revolutionized the way we design and build today. Traditionally, buildings were the result of empirical work using local resources and strategies that used to respond to the surrounding environment and culture. However, the advent of mechanical and electrical systems, such as air-conditioning and artificial lighting took away the apparent need of a climatic responsive construction [5]. Requirements such as optimal orientation, correct sizing, and placement of fenestration, solar protection, and thermal characteristics of building materials were no longer imperative to the overall performance of a building [6].

Such innovations were beneficial for providing improved comfort levels almost effortlessly. Other technological advancements, such as improvements on transportation and structural systems, were equally important to speed up the construction time and to allow internationalization of building systems and techniques. However, relying on artificial systems despite the site and climatic conditions increases the energy consumption of building operations, as well as the burden on natural resources. Currently, buildings are responsible for about 40% of the total annual energy consumption in the world, primarily due to lighting, heating, and cooling systems [7].

In response to this scenario, bioclimatic design is an architectural approach that takes into account the climatic and environmental conditions to directly shape the
CHAPTER 1. INTRODUCTION

building design, using building form, materials, and systems to work responsively
to the environment. It does not mean the absence of artificial systems, but instead
seeks to optimize passive strategies in the building, which do not require energy use,
so as to alleviate stresses and reduce the need for active strategies. Fundamental
bioclimatic design concepts were first researched by the Olgay brothers in the 1950’s
and it gained popularity at the end of the twentieth century when concerns with
energy conservation were widespread, and the need for sustainable design became
more apparent [5].

The bioclimatic approach has an intrinsically local character, and therefore is a
challenge for global projects that replicate the same building type throughout the
globe. This is the case, for example, of projects from emergency & disaster relief
agencies and international institutions. A standardized solution, on one hand, off-
ers the advantages of being faster, easier, and more affordable than localized ones.
On the other hand, it does not account for the specificities of each location and cli-
mate, leaving room for improvements on the overall environmental performance of
the building. In this case, a balanced approach is desired; one that can incorporate
bioclimatic strategies to each location, without significantly changing the core of the
standardized design.

The One-Day Church (ODC) has been selected as the case study to demonstrate
the feasibility and potential benefits of bioclimatic design applied to global projects.
The ODC initiative, which is managed by Maranatha Volunteers International of
the Seventh-Day Adventist (SDA) religious denomination, is a project that seeks to
build churches around the world in a timely and cost-effective manner. The program
provides a standard “ODC kit”, which consists of a roof and frame structure, while the
walls and fenestration are selected and installed upon local availability. The majority
of the communities granted an ODC does not have means to artificially conditioned
the building, which further justifies the need for passive strategies in order to improve
indoor comfort levels.

This work aims to present three design adaptations for three different macro-climates, based on bioclimatic strategies while preserving the main structure of the ODC. The design also takes in consideration aesthetics and identity, recognizing the importance of a religious building to a community. The final designs are compared to a baseline for each climate in terms of heating and cooling loads and illuminance levels. The final results are analyzed in terms of relative energy use intensity (EUI) and a priority list of strategies is suggested.

### 1.1 Outline

The remainder of this study is structured as follows:

Chapter 1 provides background information for this work and is divided into three sections. The first section gives information about bioclimatic design and presents bioclimatic strategies that are commonly used for three macro-climates. Section two exemplifies the strategies through three case studies, one for each macro-climate. The third section presents an overview the Maranatha Volunteers Organization, presents the One-Day Church project, and discusses the architectural style of Seventh-Day Adventist (SDA) churches and the symbols that mainly contribute to church design.

In Chapter 2, the first section presents the metrics with which each design will be evaluated. Section two defines the baseline One-Day Church that is further used to be compared to the design improvements for each macro-climate. The third section characterizes the climate of the three specific cities where the proposed designs are located.

Chapter 3 presents the strategies used in the design process, the proposed design for three and analysis of the results. Strategies are classified into three categories—namely, daylighting, natural ventilation, and envelope performance. Overall performance is analyzed with respect to relative daylighting levels, hours of comfort, and
CHAPTER 1. INTRODUCTION

energy use intensity (EUI) between the baseline and proposed bioclimatic designs, ranking the impact of each strategy.

Chapter 4 concludes the main findings of this study and proposes areas for future work. The appendix gives more information about the climate data used in the analysis.

1.2 Bioclimatic Design

The term "bioclimatic design" was coined in 1953 by the Olgay brothers to refer to an architectural approach that takes into consideration the characteristics and requirements of the climate and site where the project is located [5]. It is the understanding that the same building performs differently depending on climatic conditions such as the amount of solar radiation, air temperature, wind speed, atmospheric humidity, precipitation, and site-specific characteristics such as surrounding buildings and vegetation [8]. Architectural decisions such as building orientation, percentage of openings, material selection, among others, can have a significant impact on the building’s overall performance by either alleviating or eliminating the use of artificial systems to achieve accepted indoor levels of comfort. This approach is intrinsically sustainable, as it encourages the use of passive strategies and reduces resource usage and energy demand.

1.2.1 Climate and Comfort

Climate has a direct impact on human’s health and energy. Our body is constantly regulating internal temperatures and adjusting itself to the environment. Ellsworth Huntington’s study in [9] demonstrates that human energy and health levels tend to fluctuate by season, achieving a peak at different seasons for different climatic zones. At higher latitudes, or cold climates, the most desired period of the year is the summer, while worst periods of health concentrate during colder months. At
mid-latitudes in temperate climates the best periods are fall and spring, whereas the extreme heat of summer and cold of winter have negative effects on human productivity and health. At lower latitudes in warm climates the periods of good health concentrate during winter, which has milder temperatures. In all latitudes, nonetheless, there is a consistent range of temperature and other climatic conditions that indicate a select zone where humans tend to feel comfortable [9].

This set of climatic conditions in which the body feels comfortable is called the Comfort Zone. The main climatic conditions that define comfort are essentially the interaction between air temperature, humidity, radiation and air movement. Physiological aspects also play an important role in defining comfort, such as the type of activity being carried out, the type of clothing, and geographic location, as individuals in colder climates can bear lower temperatures than individuals in warm climates [9].

The Comfort Zone varies slightly depending on which comfort model is being used. This work utilizes ASHRAE 55 and the ASHRAE 55 Adaptive Comfort Standard (ACS) models. ASHRAE 55 defines the comfort zone based on dry bulb temperature between 68.5°F and 75.7°F during winter and maximum temperature of 84.6°F during summer, maximum humidity of 84.6%, clothing level of 1.0 clo for winter and 0.5 clo for summer, and metabolic activity level of 1.1 met. ACS is used for naturally ventilated spaces and considers a wider range of comfort and acceptability levels [10].

The psychometric chart, represented in Figure 1.1, is a resource that allows the visualization of the annual climatic conditions for specific weather stations or cities, as well as whether this data is within the comfort zone or within an area outlined by bioclimatic design strategies. This chart represents the interaction of (1) dry-bulb temperatures, shown by the vertical lines, (2) wet-bulb temperatures, which are the diagonal lines, (3) and relative humidity, represented by the curved lines. The blue areas on the graph mark the comfort zone for winter on the left, and the comfort
CHAPTER 1. INTRODUCTION

zone for the summer on the right. This means that the plotted weather data that fall within this area represents the portion of the year where the climatic conditions are comfortable and no additional strategy is needed. The other areas on the chart represent the design strategies that can be incorporated to extend the comfort zone [11].

![Psychometric Chart and Design Strategies.](image)

**Figure 1.1:** Psychometric Chart and Design Strategies.

A climate is more humid as data concentrate in the upper part of the chart and hotter as the plotted data situate towards the right. The recommended design strategies follow the characteristics of the climate. For example, using high thermal mass can be effective in hot and dry climates to cool interior temperatures at hot times. Internal heat gain and passive solar direct gain are effective for heating up spaces in cool climates, either humid or dry. In some cases, shown in Fig. 1.1 by the numbers 15 and 16, a room cannot reach comfort if not through mechanical systems. However, for most climates, a large percentage of comfort can be achieved through passive strategies alone [9].
1.2.2 Strategies for Hot-Humid Climates

Figure 1.2: Illustration of a building in a hot-humid climate [1].

Hot-humid climates have warm temperatures all throughout the year that vary little between day and night, and present heavy precipitation and air humidity [1]. Based on these characteristics, effective bioclimatic strategies for this climate seek to prevent heat gain, maximize heat dissipation, and protect from the rain and humidity levels.

Heat gain can be optimally minimized by protecting the building from direct sun [5]. This can be done by shading the windows, and by orienting openings away from facades that receive more radiation. In fact, the orientation of a building in this climate can affect energy use by 30% with the west facade being the biggest contributor to heat gain [12]. Orienting the building along the east-west axis is best to avoid the radiation of west facades and to more easily control the high sun on south and north facades.

Heat dissipation can be obtained through natural ventilation, and the use of light colors and vegetation. Passive cooling through air flow may be achieved by two processes: (1) cross-ventilation, which is driven by the difference in air pressure and openings located in opposite facades, and (2) stack-effect ventilation, which is caused by the buoyancy of heated air even when there is no wind pressure [5]. The use
of light colors and vegetation help to reflect the heat and prevent radiant heating. Furthermore, a combined system leveraging shading and correct sizing and placement of openings can reduce cooling energy demand by 40% [12].

Keeping moisture out of the building can be achieved using sloped roofs, site work that drains the water out of the edifice, and building for low thermal mass. Elevating the construction or building on hills is an effective strategy that achieves this goal, whilst also improving indoor air circulation. [1].

These concepts can be applied to each building system as follows [9, 1, 12]:

- **Roof**: Because hot-humid climates are concentrated in low latitudes, the roof is subjected to the majority of the radiation. Therefore, a large portion of the thermal stresses occurs in this system. The roof type recommended is ventilated, insulated, watertight, light-colored to reflect sun rays, and sloped with wide overhangs or verandas to protect against the rain and minimize sky glare.

- **Walls**: The use of thin, low-thermal-mass walls prevents moisture from accumulating, making it easy to dry after precipitation events. In this climate, high thermal mass is not advantageous since the temperature variation between night and day is not significant. The use of walls is primarily for screening and wind penetration, as opposed to responding to thermal stresses.

- **Openings**: The windows need to be operable and large to improve ventilation. For cross-ventilation, larger openings should be facing up-wind. All openings, however, should be shaded. An example strategy to improve ventilation, while also blocking solar radiation, is to employ the use of louvers. Furthermore, it is not optimal to have openings on the east and west facades due to increased radiation gain and challenges to control the sun at lower angles.

- **Floor and Foundation**: The ground floor should be elevated to avoid the earth’s
humidity.

- **Shading Devices**: Shading devices should be located on the exterior to block direct sun before it enters the building. Horizontal slats and projections efficiently shade openings on both the south and north facades. The west and east facades may employ sun-breakers such as vegetation to prevent excessive radiation.

Bioclimatic strategies applied in Olgay’s study for hot-humid regions were able to reduce 89% of the heat loss during winter, and 55% of the heat gain in summer [9]. The strategies used were optimal orientation, rearrangement of openings, ventilated roof construction, weather stripping, and sun shading using overhangs and vegetation.

### 1.2.3 Strategies for Hot-Arid Climates

![Illustration of a building in a hot-arid climate](image)

(Hot-arid climates also have warm temperatures, but present large temperature variation between day and night, scarce precipitation, and low humidity percentage [1]. Considering these aspects, the bioclimatic strategies for this climate seek to prevent heat gain, to delay periodic heat flow, and to promote evaporative cooling and stack ventilation [5].

Preventing heat gain can be achieved through insulation and sun protection. Insulation minimizes conductive heat flow, and therefore maintains indoor temperatures...
for longer despite outdoor temperatures. Sun protection may be achieved by using the building mass, screening and shading devices [5]. External sun protection can decrease energy demand by 20% [12].

Delaying the periodic heat flow through high thermal mass is essential to take advantage of the fact that hot-arid climates have extremely hot temperatures during the day, but cool temperatures during the night. This strategy allows surfaces to trap the heat during the day and slowly transfer it to the interior at night, while these same surfaces are being cooled during the night and helping to cool the interior during the day. Thus, the time-tag helps reduce the temperature variation, offsetting temperature peaks [5].

Evaporative cooling works through sensible cooling by converting liquid water into vapor. This can be obtained by wet medias oriented to incoming air [5]. The use of ceramic pots filled with water, and courtyard pools are ancient strategies that use this principle [1]. Currently, systems like evaporative media and water sprinklers can be used in conjunction with air intakes.

Air in most hot-arid climates has a tendency to be dry, dusty, and windy, leading to discomfort. Therefore, in order to use natural ventilation, the air needs to be treated through filtration and pre-cooling. A bioclimatic strategy often used is called windcatchers. These structures are tall towers that capture higher and cleaner air, cool it through evaporative means, and then force it down to the interior. Windcatchers have different configurations, but they are usually designed for omni-directional wind capture. Night flushing is also a strategy recommended for this climate to cool the spaces with the cooler air at night and to work along the high thermal mass [1]. Studies show that this strategy can lower indoor temperatures below outdoor maximum temperatures [13].

These concepts can be applied to each building system as follows [9, 1, 12]:

- Roof: The roof should have high solar reflectivity and emissivity to avoid over-
heating. Leveraging materials that enable heat storage insulation is highly recommended.

- **Walls**: Walls should be thick for thermal storage and made of materials such as stones, adobe, bricks, and blocks. It is recommended an insulation of 2 inches to prevent heat conductivity.

- **Openings**: Openings should be concentrated in north and south facades. Should be small and shaded to reduce intense radiation and dust, and operable for night flushing.

- **Floor and Foundation**: Building the ground floor on the earth’s surface helps to take advantage of the relatively cool ground temperatures.

- **Shading Devices**: External shading devices are necessary for all opening. It is recommended that devices are separated from the building structure and subjected to wind convection. Designing the buildings for self-shading is also recommended.

In Olgay’s studies, applying bioclimatic strategies to hot-arid climates yielded 89% reduction in heat losses, similar to the hot-humid climate, and a slightly smaller decrease in heat gain during summer of 42%. The strategies used included: adjusting orientation, providing shades and overhangs, use of masonry walls to increase thermal inertia, a ventilated roof construction, weather stripping, and the installation of cooling garden plants [9].

### 1.2.4 Strategies for Temperate Climates

Temperate climates are characterized by a very cold season and cold nights [1]. Bioclimatic strategies, in this case, should be focused on minimizing conductive heat flow, minimizing infiltration and promoting solar and internal heat gain [5]. In the summer, the building should be adaptive to allow for reducing heat gain.
Minimizing conductive heat flow from is achieved by using insulation [5]. This is important for temperate climates to prevent that the heat gained is directed back to the outside when the outdoor temperatures are lower and vice-versa. For this same reason, windows should be double or triple paned and the building needs to be built for air tightness, minimizing air infiltration. Good thermal protection can save 30% of energy [12].

Promoting solar and internal heat gain ensures that a major portion of the heating demand in winter is met through passive strategies. The use of atria, greenhouses, and equatorial-facing windows can maximize heat gain. Other strategies, such as the use of thermal mass, trombe walls, and dark colors can aid in the collection, storage and transfer of heat [5].

To prevent excessive heat gain during the summer season, it is important to shade the openings and use night ventilation to cool the building [12]. Protection against solar radiation may be achieved through shading devices that block the higher summer sun but allow the lower winter sun to reach the building.

These concepts can be applied to each building system as follows [9, 1, 12]:

- Roof: Roofs should be sloped to avoid water accumulation, and equipped with operable windows, which can be closed during winter and opened during the summer for ventilation.
• Walls: Insulate the walls to prevent heat from escaping, and avoid materials that can hold moisture. Using a west-facing wall as a thermal mass balances the internal heat distribution.

• Openings: Windows must be concentrated on facades facing the Equator for maximized heat gain and on the opposite facade for cross ventilation. Openings on the west facade should be avoided. Windows should be double or triple paned to avoid heat loss. Night ventilation openings can improve comfort levels in summer.

• Floor and Foundation: During winter months, the relatively warmer ground temperature serves as a useful heat-source to the cooler building. The use of earth berms is recommended.

• Shading Devices: If well-oriented, deciduous trees protect both eastward and westward facades from solar radiation during the summer. Horizontal devices or overhangs on equatorial-facing facades can be sized to prevent direct sun in summer and allow it in winter. The opposite facade can have vertical devices to protect openings from the summer sun.

Olgay’s study of a house in a temperate climate was able to reduce heat loss in winter by 49% and heat gain during summer by 71%. The strategies were optimized orientation, south facing windows with double glazing (for Northern Hemisphere), west-side stone wall for time-lag, concentration of openings on the south facade, overhangs for shading during summer, use of vegetation to shade east and west facades, and white ventilated roof [9]. In temperate climates, the need for artificial conditioning can be eliminated if the right bioclimatic strategies are applied [12].
1.3 Case Studies

The following case studies exemplify the impact bioclimatic strategies may have in a building. Both examples are houses because, even though the ODC is a religious building, its size is comparable to the houses presented here. Key differences to be taken into consideration is that ODC have an occupancy of up to 125 people, whereas the examples are family residences.

1.3.1 The Windcatcher House

![The Windcatcher House](image)

**Figure 1.5:** The Windcatcher House [2]. Scale not defined.

The Windcatcher House (Fig. 1.5) is located near the city of Bluff, Utah, on a Navajo reservation in the arid Great Basin desert. The climate in this region is semi-arid (BSk), having hot to extremely hot summers and warm winters. The building was designed and built by a group of architects and students of DesignBuildBLUFF at the University of Utah, under a budget of $43,800. The project had the intention to teach students about passive design and increase familiarity with the Navajo culture [2].

The house, depicted in Fig.1.6, is divided into two blocks—one features an integrated living room and kitchen; and the second is more private having two bedrooms and a bathroom. At the heart of the house is the windcatcher, a tower that is able
to bring in air from any direction, to filter it and cool it (Fig. 1.7). The air is filtered and cooled using evaporative media located at each of the four openings at the top of the tower, and then distributed to the house. The tower also has a wood stove at the bottom that helps to warm up the interior during cold nights. The windcatcher is an ancient technology from Persia, used to naturally ventilate a space in places where the wind is hot, arid, and dusty [2].

The walls 24 inches thick of rammed-earth and insulation. This thermal inertia offsets the swing in temperatures due to the arid climate, making the interior of the house more comfortable both during the day and night. The walls also protect the house from harsh winds and shade the small openings from direct sunlight [3].

1.3.2 Nel Sedone House

Nel Sedone is a retrofitting project for a house in Shillong, India by EarthStudio (Fig. 1.8). The climate in this region is subtropical highland (Cwb) with mild and rainy summers and cool winters. The intent of the owners, Habari Warjri and Gerald Pde, was to incorporate sustainable strategies into the renovation effort so as to showcase an environmental design for single family houses in this region. The project focuses on reusing existing materials, recycling waste, improving thermal comfort and
CHAPTER 1. INTRODUCTION

Figure 1.7: Detail of the windcatcher [3]. Scale not defined.

air quality, and saving energy [14].

Of the strategies used in the design, three are relevant to this study—namely, daylighting, natural ventilation, and envelope performance—as illustrated in Figure 1.9. Optimal daylighting was achieved by sizing the windows to receive diffuse sunlight throughout the year and by shading them with verandas and overhangs for the summer, to avoid unwanted heat gain. The shape of the roof was changed to allow sunlight to reach deeper areas of the floor plan. These strategies resulted not only in improved visual comfort but also in energy savings both by reducing the need for artificial lighting and by increasing solar heat gain during winter and the opposite during summer.

The roof form also plays a major role in natural ventilation. The difference in
Figure 1.8: Nel Sedone House interior.

Figure 1.9: Bioclimatic strategies for the Nel Sedone House.

elevation creates a stack effect, which exhausts warm air from the upper openings and consequently brings fresh and cooler air from the lower openings. During winter, the upper windows are closed to allow the stratification of warm air while the glass surfaces bring more solar heat. To minimize heat loss in this season, the roof is insulated with fiber-wool between two layers of board and below a layer of corrugated steel sheets, and the windows have double glass panels for added insulation. The use of insulation is not common in this region of India, so the house is an experiment in this sense. No analytic data of the house has been produced yet, but the owners reported that indoor temperatures are comfortable and no additional heating has been necessary [14].
1.4 Maranatha Volunteers International

Maranatha Volunteers International is a non-profit organization that responds to the need of construction services from churches and communities around the world. This organization is run by members of the Seventh-Day Adventist Church (SDA), which is a global Christian institution that has nearly 18.5 million members around the world and has established work in 216 countries [15]. The name Maranatha means “Our Lord is coming” which points to the organization’s mission to spread the message of the second-coming of Jesus to every part of the world, through construction and mission trips. Maranatha headquarters is based in Roseville, California. Currently, the organization employs 31 full-time staff in the U.S and 28 in international offices. The organization operates solely on donations from private donors and independent business investments.

Maranatha works through requests for construction assistance. These requests come through Adventist church leadership from all parts of the world. Maranatha international branches then assess the feasibility of the request, such as costs, country
barriers, logistics and potential construction sites. Once a request is accepted, the organization starts fund-raising, preparing the site and organizing the mission trip for volunteers that will build the requested structure. In places where there are limited access or safety issues, Maranatha has field staff works instead of volunteers. The crew is also responsible for finishing any work that was left and to hand over the building to the local community [16].

In 2015 alone, Maranatha mobilized 2,207 volunteers, built 594 churches, 73 classrooms, 24 water wells, and worked in 12 different countries. Overall Maranatha has worked in 80 different countries, as marked in Figure 1.10, and has built over 4,600 One-Day churches.

**History:** Maranatha history goes back to 1969 when John Freeman, an amateur pilot, decided to involve his family and friends on a mission trip to teach them the value of serving. The first idea was to invite private pilots that he knew to fly out volunteers to build a church in the Bahamas. Out of this first mission the Eight Mile Rock Seventh-day Adventist Church was built and the Maranatha Flights International was created.

In 1989 Maranatha Flights International merged with Volunteers International and the Maranatha Volunteers International was established. The organization used to work on a few projects every year, but the year 1992 it shifted its focus to higher number of projects in urgent situations and drew the attention of thousands of volunteers.

In 2007, Maranatha had the idea of creating a basic frame and roof kit for church construction. This would centralize the manufacturing of the main parts of a church and would speed up the process. Maranatha released the One-Day Church project in 2008 and two years later the One-Day School project, based on the same concept of simple and fast construction and affordability. Currently, Maranatha organizes about
50 mission trips every year and has thousands of volunteers involved. The simplified process allows volunteers that have no experience to work in construction and the diversified tasks welcome any age group [17].

![One-Day Church](image1)

![One-Day School](image2)

![Education & Evangelism Center](image3)

![Water Well](image4)

**Figure 1.11:** Maranatha Volunteers International Main Projects.

**Main Projects:** Maranatha Volunteers international has seven main projects [18]:

- **One-Day Church:** This is the most popular project of Maranatha International Volunteers. A simple frame and roof kit for churches allow it to be built in just one day, and few additional days to complete the walls and fenestration. The One-Day Church will be presented in more detail below (Fig. 1.11a).

- **One-Day School:** This project has a similar concept of the One-Day Church. The One-Day School kit is a full-classroom that includes a galvanized-steel frame, roof and walls, and also classroom furniture and chalkboard. The building has natural ventilation and plenty of daylighting (Fig. 1.11b).
• Education and Evangelism Center: This is the largest structure that Maranatha offers. It is a flexible building that can be used as a school, a community center, and as a place of worship. It is composed of 6 to 12 classrooms, an open space, and an auditorium that can seat from 500 to 1,000 people (Fig. 1.11c).

• North America Project Assistance: Even though Maranatha concentrates its efforts outside the U.S., every year a couple of projects are done here. The projects are broader in scope and can range from small renovations to new building construction. The organization developed a simple and cost-effective design for North American churches in need.

• Water Wells: Since 2007, Maranatha has helped to drill water wells. The organization has drilled over 700 wells in Mozambique and is currently drilling in Zimbabwe in locations where there are also churches or schools being built (Fig. 1.11d).

• The $10 Church: This project is a fundraising initiative that invites people to donate $10 every month. The many donations are combined to help build churches around the world. The donors receive a report from the churches that their donation helped to build.

• Ultimate Workout: This is a mission project designed for high-school teenagers. During the project the volunteers work on construction, community service, and personal growth.

1.4.1 One-Day Church Project

The One-Day Church was created to meet the needs of a growing membership for places of worship. Since 2008, Maranatha has built more than 4,500 around the world. The 18.5 million membership keeps increasing in number. In many places, however, many congregations meet under a tree or in temporary structures, either
due to financial struggle, to difficult access to construction material or access at all, or to natural disasters that has destroyed their previous building. Most communities are able to build the wall, but they lack material for a permanent roof and structure.

Figure 1.12: ODCs around the world.

The reality of many villages are shelters made of sticks, mud, and grass, and the access to other construction materials is very limited. These structures take a long
CHAPTER 1. INTRODUCTION

time to build and are usually replaced one after another because they do not endure the weather. Churches are larger structures and thus present even more challenges. Other places struggle financially and the One-Day church might be the only resource that a community has. The donations help to offset the cost for the local community making it possible to build churches that otherwise would not exist. When a One-Day Church is built in such places, it generates growth in membership and strengthens the community.

The One-Day Church is a simple structure of galvanized steel frame and roof that is lightweight and durable. The dimensions of the standard unit are twenty feet wide and thirty-eight feet deep, and can seat approximately 125 people [19]. The structure is built in less than a day by groups of volunteers or, in some specific cases, by Maranatha field staff. There are two options: the local church can request only the kit construction, which are the structural frame and roof, or request the entire construction. In either case, the volunteers and the local church members are involved in the process.

In the beginning of the project, the ODC kit was only manufactured in Dodge Center, Minneapolis, transported to a port in Baltimore and then shipped overseas. However, due to extra fees encountered in some of the country’s customs and motivated by the possibility of expansion of the work in specific countries, Maranatha has recently started to manufacture the ODC kit in Zimbabwe, India, and Brazil. Still maintaining the same concept, Maranatha is now able to build more churches and slightly adapt the kit for each country.

Even though an ODC starts as a basic one-size-fits all solution, the customization of each of the thousands of ODCs that have already been built around the world shows the potential of this global project (Fig. 1.12). Each country, city, and community has its own peculiarities and traditions, while united by the same organization and core values. This thesis aims to broaden the possibilities of an ODC to meet the aspirations
of each community by incorporating strategies that improve indoor comfort and sense of identity.

1.4.2 Architectural Characteristics of Adventist Churches

Churches are buildings that not only serve the purpose of housing religious assemblies but also represent the beliefs and culture of a religious institution. In defining basic church design patterns, Kieckhefer [20] proposes four ways to look at a church combined in two categories—namely, Liturgical Use: spatial dynamics and centering focus, and Response Elicited: aesthetic impact and symbolic resonance. Spatial dynamics has to do with the overall configuration of space in terms of shape, flow, and liturgical dynamics. Centering focus is recognizing which part or aspects of the church are most important. Aesthetic impact is the immediate impact that a church causes on a person walking through the door. Symbolic resonance is the impact over time in the way that the building shapes one’s experience and understanding of the church values. Based on these four aspects, Kieckhefer recognizes three traditions in church building design, which are: classic sacramental church, classic evangelical church, and modern communal church.

In general SDA churches can be classified as classic evangelical church, where the main room is primarily for preaching. The interior space is divided into two areas, the audience pews, and a front stage-like configuration that has the pulpit and the baptismal pool. The centering focus is the preacher and externally, the front facade that has the church logo. The main aesthetic goal is to provide a place that is conducive to learning and ornament is not the focus. In fact, Adventists has traditionally emphasized the value of ”plain beauty” over extravagance [21]. The building itself has low symbolic resonance and it is more influenced by the construction culture of where it is located.

Furst and Denig [21] studied how religious schools transmit their beliefs and cul-
ture through symbols. In this study, the authors surveyed school principals of Catholic schools and Adventist schools. Even though the object of the study were schools, the results to a certain extent can be applied to SDA churches. The findings are that although SDA as an institution has many symbols, they are not intentionally incorporated into the architecture like it is in Catholic buildings and remounts to the concept of plain beauty. The main symbol found on the exterior was a sign that contained the word Christian or Adventist.

Pictures of SDA churches around the world show that similarities between buildings are more related to where the churches are located than to the institutional values of the organization. Arguably this is due to the lack of importance given to architecture to express church’s beliefs. The only common element is the church logo applied to the front facade. Other church symbols are sometimes integrated to the church architecture, without any institutional rule or consistency—namely, the number seven pointing to the seventh-day of the week, the cross, and the three angels of Revelation.
Chapter 2

Methodology

The methodology for this work is divided into three main phases—namely, investigation phase, design proposal, and analysis of the design. The investigation phase is comprised of a broad understanding of the topic, research on bioclimatic design and strategies per macro-climate, and an in-depth study of the One-Day Church project. The results of the Investigation phase lead to applying the concepts researched to the One-Day Church case study for three specific cities that represent three macro-climate. The cities are: Belem, Brazil, representing a hot-humid climate; Cairo, Egypt, for hot-arid climate; and Shillong, India, which is a temperate climate. The designs will be compared to a baseline building, according to the metrics described below, to assess the efficacy of the strategies applied. The tools used are Autodesk Revit and Green Building Studio for lighting, energy, and solar analysis; and Climate Consultant for climate characterization and qualitative analysis of hours of comfort [22].

2.1 Metrics

The baseline model will be compared to each proposed model taking into consideration the climate where each is located. The following metrics will be analyzed to show the strengths and weaknesses of each model.
CHAPTER 2. METHODOLOGY

**Lighting:** Lighting levels will be based on the Daylight credit, option 2, of the LEED BD+C: New Construction v4. The requirements are to achieve illuminance levels between 300 lux and 3,000 lux for 9AM and 3PM, clear-sky day at the equinox, for a minimum of 75% of the floor area and ideally 90% and over of the floor area [23].

**Envelope Performance:** The envelope performance will be analyzed through plots of heating and cooling loads per month in mBtu. A comparison between the baseline and the proposed design will show the improvements. The plots breakdown the load sources, such as walls, roofs, window solar, etc. Positive numbers in both plots refer to heat gain, and negative numbers to heat loss. Thus, for the heating plot the lower the number, the higher is the need for heating, and for cooling plot, the higher the number, the higher is the need for cooling.

**Energy Use Intensity:** Energy Use Intensity (EUI) is a measurement of a building’s energy use based off its size and characteristics, that allows for comparison of different buildings. The EUI is calculated by dividing the total annual energy consumed by the gross square footage of a building [24]. In the case of a building in the design phase, the EUI is estimated based on the building characteristics, such as thermal properties of material and area, building program, number of occupants, and other variables.

Energy analysis in Revit has a number of pre-defined assumptions, including the fact that the building will be mechanically ventilated, and a set number of occupants. For this work, the EUI is understood as a parameter that can be translated in relative improvements between baseline and proposed design, rather than an absolute number.

**Hours of Comfort:** The percentage of hours of comfort will be analyzed qualitatively through the data plot on the psychometric chart. Comfort levels defined by
ASHRAE 55-2010 will be compared to comfort levels defined by the Adaptive Comfort Standard of ASHRAE 55-2010 added the design strategies incorporated in the design.

2.2 Baseline One-Day Church

The baseline ODC is defined in this chapter to allow for a comparison between current practices and the design changes that this work will propose. Each ODC is unique because the walls and fenestration materials are local resources that each community has the opportunity to customize the church as they please. These features are generally limited by construction costs and frame layout, for example, the ODCs tend to have four windows on each long side because of the placement of the metal stud columns. A church in Brazil was taken as the base for the sizing of the openings and wall material, with some modifications, because it reflects the aesthetics of a good number of ODCs (Fig. 2.1). The frame and roof characteristics are defined following the standard ODC kit.

![Figure 2.1: One-Day Church built in Belem, Brazil. Source: Maranatha Volunteers International.](image)

The baseline ODC is 20 feet wide by 38 feet deep (Fig. 2.2a). The orientation chosen is the longer dimension of the church along the east/west axis; this default
orientation tends to be more energy efficient because north and south facades are easier to control than east and west facades, which receive the sun at lower angles. The ODC has a wall height of 10 feet and a 5 1/2” by 1’-0” gable roof (Fig. 2.2b). The north facade has three 32”x48” windows and one door for rear access (Fig. 2.4a). The east facade is the main entrance of the church, it has a double door and a side window (Fig. 2.4b). The south facade has four 32”x48” windows (Fig. 2.4c), and the west facade the rear of the church and it does not have any openings (Fig. 2.4d).

![Diagram](image)

Figure 2.2: Plan and Section - ODC Baseline. Scale 1/16” = 1’-0”

![Perspective](image)

Figure 2.3: Perspective - ODC Baseline.
Materials: The baseline ODC church is composed of a concrete slab floor, concrete block walls, galvanized steel gable roof, steel-framed doors, and single-paned clear glass windows. The structure of the church is a lightweight steel frame. For the purposes of this thesis, the structure will not be analyzed and will, therefore, be omitted from most of the drawings, because it does not impact significantly the thermal performance. Table 2.1 shows each assembly and material properties.

Performance: The baseline ODC has openings on opposite sides that allow for cross-ventilation when the windows are opened. The roof overhangs are minimal and the windows are single pane clear glass, which does not contribute to sun shading. The roof is lightweight and reflective, which is good for climates that require low thermal mass. However, the high transmittance value tends to overheat the interior.
for warm climates and allow too much heat loss in cold climates.

![Images of Belem, Cairo, and Shillong illuminance levels](image)

**Figure 2.5:** Illuminance levels of the ODC for Belem, Cairo, and Shillong respectively.

Even though the baseline is the same building for all three locations, it was simulated separately because the results vary per climate. Figure 2.5 shows the levels of illuminance for the baseline for each city. Cairo is the city that has the higher levels of illuminance, but also that has the variance between levels, which suggests glare problems. Shillong however, is the city that receives less sunlight, with levels ranging from 35 lux to 623 lux. The churches have an average of 40%, 57%, and 18% of floor area within accepted levels of 300 lux to 3000 lux, for Belem, Cairo, and Shillong respectively.

Figure 2.6 presents the heating and cooling loads for the baselines. Belem has no need for heating because the temperatures are constantly hot throughout the year. Cairo and Shillong have similar heating loads during the winter, and Shillong being the only city that has heating loads in summer. In terms of cooling needs, Belem in average has higher levels, but Cairo has maximum absolute loads during the summer. In average Shillong has less than half of cooling loads that Belem and those are concentrated in the summer. The graphs show infiltration because the
results were simulated considering a mechanically ventilated building, for naturally ventilated spaces this value can be disregarded. Next section will present in detail the climate of each city.
2.3 Climate Characterization

Köppen Climate Classification is the most widely used system to classify the different climates in the world. It is based on an annual average of temperature and precipitation. This system defines five broad types of climate, which are: tropical rain climates (A), arid climates (B), temperate rain climates (C), boreal forest and snow climates (D), and cold snow climates (E) [4].

For the purpose of this thesis, the climates A, B, and C will be analyzed because they represent the majority of the places where ODCs are built. The following three cities were chosen to exemplify the bioclimatic strategies that can be incorporated into the design and construction of the ODC for the three chosen macro-climates and respective cities:

- Hot-Humid: Belem, Brazil. Tropical Rainforest Climate (Af)
- Hot-Arid: Cairo, Egypt. Hot Desert Climate (BWh)
- Temperate: Shillong, India. Temperate Highland Climate (Cwb)

![Figure 2.7: Spatial distribution of the five main Köppen climate types determined for the period 1951 - 2000 [4].](image)
The main characteristics of type A, Hot-Humid Climate, are very warm temperatures throughout the year, little temperature variation between day and night, heavy precipitation, high levels of solar radiation, and abundant vegetation [1]. Köppen’s standard for this climate type is that the mean temperatures of each month need to be higher than +18.0°C (+64.4°F) [4]. As it can be seen in Fig 2.7, type A climates are concentrated in lower latitudes, following the Equator line ±20°.

Hot-Arid type B climates also present hot temperatures and high solar radiation, but there is a significant temperature variation between day and night, little precipitation, and scarce vegetation [1]. This type of climates can be found in low to mid-latitudes, heavily concentrated in the northern part of Africa, in the Middle East and Australia, and in portions of China, South Africa, West of the United States and along the Andes Mountains in South America.

Type C Temperate climates have a very cold season, a warm summer, cool nights, variable amount of precipitation, and strong seasonal pattern. Köppen Classification defines that the mean temperature of the coldest month is between –3.0°C (26.6°F) and +18.0°C (+64.4°F), and the mean temperature of the warmest month exceeds 10.0°C (50°F) [4]. This type of climate occurs in mid-latitudes, as shown by the green area of Figure 2.7.

2.3.1 Belem, Brazil

Belem is located in the north of the Brazil in the Southern Hemisphere, close to the Equator line. The geographic coordinates are latitude 1.38° South and longitude of 48.48° West. The city has nearly 1.5 million inhabitants and is the capital of Para state. The climate is Af—Tropical Rainforest Climate— which is very hot and very humid. Belem is part of the Amazon Forest and it is located in the margins of the Atlantic Ocean. The data source used for this climatic analysis is IWEC Data 821930 WMO. More details can be found in Appendix A.
The temperatures in Belem are fairly constant throughout the year, with an annual average of 80°F. The climate has two defined seasons: a wet season in Summer and Fall and a dryer season in Winter and Spring, which are respectively January to June and July to December in the Southern Hemisphere. Figure 2.8 shows the influence of precipitation on the temperature and radiation, in which wetter months have less variation between diurnal temperatures and drier months have higher have direct normal radiation due to the clear sky and consequently higher overall radiation.

At just 1.38° away from Equator line, Belem has nearly even length of days and nights throughout the year, at about twelve hours each. At noon the sun is almost overhead in the equinoxes and between 20° and 30° in the solstices. Such positions confer similar characteristics to northern and southern facades of building, as well as to eastern and western facades (Fig. 2.9a). Figure 2.9b shows that predominant winds come from the Northeast with an average direction mode of 53.4° (Fig. A.3).

The psychometric chart in Figure 2.10 shows that the climate in Belem is out of the comfort zone defined by ASHRAE Standard 55-2010 during all of the hours of the year. The data are concentrated in the upper part of the graphic where the weather is too hot and humid for comfort standards. The main passive design strategies for
Figure 2.9: Solar Chart and Wind Wheel of Belem, Brazil. Source: MeteoBlue and Climate Consultant 6.0.

Belem is therefore improved ventilation, which also helps in dehumidification, shading the openings for the sun, and rain/moisture control.

Figure 2.10: Psychometric chart for Belem, Brazil - ASHRAE 55-2010.

2.3.2 Cairo, Egypt

Cairo is the capital of Egypt and the largest city of Africa with a population of 12 million inhabitants in the city of Cairo and of 20 million in the Great Cairo. The city
is situated in the Northeast of the country along the Nile River. Cairo has a latitude of 30.13° North and longitude of 31.4° East. The climate classification is BWh–Hot Desert Climate–, being an overall dry climate with nearly zero precipitation and extreme temperatures, which are hot during the day and cold at night. For this analysis, the data source is from IWEC Data 623660 WMO (Fig. A.3).

[Image: Monthly Diurnal Averages for Cairo, Egypt. Source: Climate Consultant 6.0.]

The Monthly Diurnal Averages (Fig. 2.11) show that the hot desert climate has a wide variation of temperature throughout the day, due to the low humidity. In dryer months the difference between daytime and nighttime temperatures can even exceed 50°F. The low occurrence of precipitation increases the direct normal radiation, making it important to shade the openings. Overall compared to Belem and Shillong, this climate has the highest levels of global radiation and the lowest levels of air humidity, shown by the difference between dry and wet bulb mean temperature.

The sun path in Cairo (Fig. 2.12a) is mainly concentrated on the southern facade, however, during the hottest and driest period of the summer, the sun is on the northern facade for more than half of the day. Both eastern and western facades also receive a considerable amount of radiation, and must be protected as well. The
prevailing winds in Cairo come from the North, from the Mediterranean Sea down to the south of the country (Fig. 2.12b).

![Solar Chart](image1)

![Wind Wheel](image2)

**Figure 2.12:** Solar Chart and Wind Wheel of Cairo, Egypt. Source: MeteoBlue and Climate Consultant 6.0.

The climate in Cairo is in the comfort zone for 17.6% of the hours of the year, as shown in Figure 2.13. The climate is dry and either too hot or too cold in other times of the year. In this case, it is important to have small and shaded openings to prevent overheating during the day and heat loss during the night. The ventilation has to be filtered from the dust carried by the high-speed winds and to preferably be humidified before reaching the occupants. Lastly, high mass, night flushing and evaporative cooling can help regulate the temperature variation between daytime and nighttime.
CHAPTER 2. METHODOLOGY

JANUARY through DECEMBER

DESIGN STRATEGIES:
1. Comfort (1538 hrs)
2. Sun Shading of Windows (0 hrs)
3. High Thermal Mass (0 hrs)
4. High Thermal Mass Night Flushed (0 hrs)
5. Direct Evaporative Cooling (0 hrs)
6. Two-Stage Evaporative Cooling (0 hrs)
7. Natural Ventilation Cooling (0 hrs)
8. Fan-Forced Ventilation Cooling (0 hrs)
9. Internal Heat Gain (0 hrs)
10. Passive Solar Direct Gain Low Mass (0 hrs)
11. Passive Solar Direct Gain High Mass (0 hrs)
12. Wind Protection of Outdoor Spaces (0 hrs)
13. Humidification Only (0 hrs)
14. Dehumidification Only (0 hrs)
15. Cooling, add Dehumidification if needed (0 hrs)
16. Heating, add Humidification if needed (0 hrs)

17.6% Comfortable Hours using Selected Strategies (1538 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

Figure 2.13: Psychometric chart for Cairo, Egypt - ASHRAE 55-2010.
2.3.3 Shillong, India

Shillong is the capital of Meghalaya state in north-eastern India. This is a hilly region with an average elevation of about 4,900 feet. The population of the city is about 150 million inhabitants. Shillong is located in the Northern Hemisphere at 25.57° North and 91.88° East. The climate in this region is Subtropical Highland Climate (Cwb), which has cool and rainy summers due to the monsoons and cool winters. The data source of this analysis is ISHRAE 425160 WMO (Fig. A.5).

Figure 2.14 shows that the temperature range of Shillong is below the comfort zone for most of the time. The high levels of precipitation during the summer months are emphasized by the dry bulb mean temperatures being closer to the wet bulb mean temperatures. Likewise, the winter months have little precipitation. The sky is cloudy or partially cloudy most of the year and the global radiation is not as high as the other two cities analyzed.

The sun in Shillong shines most of the day on southern facade, as well as in the morning and afternoon respectively on eastern and western facades, and on northern facades during some hours in the summer (Fig. 2.15a). Due to low temperatures
in the winter season, it is recommended that the openings allow the sun to enter
the building and thus contribute to heat gain. The wind in Shillong is distributed
in almost all directions, however prevailing winds come from South-southwest (Fig.
2.15b).

![Solar Chart](image1.png)

(a) Solar Chart

![Wind Wheel](image2.png)

(b) Wind Wheel

**Figure 2.15**: Solar Chart and Wind Wheel of Shillong, India. Source: Meteoblue and Climate Consultant 6.0.

The psychometric chart of Shillong (Fig. 2.16) shows that the climate has mainly
cool temperatures and it is predominantly humid with a dry season. According to
the requirements of ASHRAE 55-2010 Shillong is in the comfort zone for 5.5% of the
hours of the year. The main strategies are to use passive heating by optimizing solar
heat gain and by insulating the building to keep internal heat gain.
Figure 2.16: Psychometric chart for Shillong, India - ASHRAE 55-2010.
Chapter 3

Results

The results here presented are the proposed design and performance analysis for three churches in Belem, Cairo, and Shillong, respectively. The primary focus is to create a space that is more comfortable and pleasant for the users, focusing on bioclimatic and aesthetic aspects. It takes into consideration that the churches will most likely not be mechanically conditioned, which means that the goal is not to save energy but to improve the levels of indoor comfort as much as possible. The only expected energy use is from artificial lighting when and if the church is being used in the evenings, and from sound equipment, if any.

Bioclimatic strategies are incorporated into the architecture in three main areas, namely, natural ventilation, daylighting, and envelope performance. Natural ventilation and daylighting often work together, considering that the wider the openings, the higher the ventilation rate and the levels of illuminance through sunlight. However, increasing the glazing area can negatively affect the envelope performance and the overall construction cost, so a balance of the three aspects was considered.

Aesthetically, the main objectives are to give the ODC a church-like appearance and to include in the architecture elements that are symbolic of the SDA faith. The first approach is to increase the vertically of the building, taking advantage of bioclimatic strategies. For example, the windcatcher tower used to improve the ventilation in the hot-arid climate is placed on the front facade, elongating the view and dif-
ferentiating the ODC from ordinary buildings. The second strategy is to create a prominent space for the church logo. For this, the main door is switched to the side and the logo is placed in the forefront. Due to its symbolic significance, the number seven is suggested in the main facade shape and highlighted with an accent color. The difference in the designs are to show that the ODC structure is flexible enough to incorporate different styles and yet to bring about the unity of this international institution.

3.1 ODC Belem

![Figure 3.1: Strategies applied to the ODC Belem.](image)

ODC Belem design responds to the three main concerns of a hot-humid climate, which are increasing ventilation rate, shading the openings, and protecting the building from the rain. The final design is an extension of the roof to provide stack ventilation, an extension of a portion of the front facade to create an interstitial space that hides the front door and places the logo in the front center, and an extension of the roof overhangs to maximize shade and rain protection. Figure 3.1 summarizes
the strategies employed in the design of the ODC Belem, which will be presented in detail below.

3.1.1 Strategies

![Diagram of Orientation](image1)

![Diagram of Window Detail](image2)

![Diagram of Stack and Cross Ventilation](image3)

**Figure 3.2:** Strategies for natural ventilation applied to the ODC Belem.

**Natural Ventilation:** To maximize natural ventilation the first strategy was to optimize the orientation. For radiation and sun control, the best orientation is to place the larger facades facing North and South and concentrate the openings there, but for ventilation, the best is to place the larger openings facing the prevailing winds.
Wind is effective up to a 45° degree angle. Since predominant winds in Belem come from the Northeast, the building was rotated ten degrees to improve ventilation, without substantially increasing the wall area that faces East and West to prevent excessive radiation. Planting trees on the northeastern corner also helped direct the wind to reach the windows more perpendicularly (Fig. 3.2a).

Another strategy was to increase the opening area from the baseline to maximize air intake and exhaustion. Larger openings were placed facing the up-wind direction to improve air distribution in the space through cross-ventilation. To allow natural ventilation even when it is raining, a louver system that prevents water from entering the building is proposed for all windows (Fig. 3.2b).

Stack ventilation was used through a shed roof to boost indoor ventilation even when outdoor wind speed is low. This method, achieved by placing openings in two different heights, is able to generate air flow by the buoyancy of heated air. As the air warms up it goes to the upper part of the building, and when there is opening there, the hot air exits and forces fresh cooler air to enter through the lower openings (Fig. 3.2c).

**Daylighting and Sun Control:** Belem has plenty of sunshine throughout the year. The challenge here is to avoid direct sunlight, allowing diffuse light only, in order to reduce unwanted heat gain. The openings were purposefully located on the north and south facades only, which are both easier to control because the sun hits them at a higher angle, and receive less radiation than the west facade. All the openings were shaded using roof overhangs and vegetation.

The roof overhang was extended from 1 foot of baseline to 4 feet and trees were placed on the northeastern and southwestern corners to shade the morning sun during winter, and the afternoon sun of the summer. The overhang creates a 35° alpha angle between a vertical line and the line connecting the bottom of the window and the
end of the overhang. The solar study for Summer, December 21 (Fig. 3.3), and Winter, June 21 (Fig. 3.4) for 9AM, 12PM, and 3PM demonstrates the effectiveness of this strategy. Extending the roof instead of using a horizontal shading device was preferred because it also keeps the water out when it rain, and it is seamless to the design.
Figure 3.3: Summer Solar Study for Belem, Brazil (Winter in the Northern Hemisphere).
Figure 3.4: Winter Solar Study for Belem, Brazil (Summer in the Northern Hemisphere).
CHAPTER 3. RESULTS

Envelope Performance: The materials used in the ODC Belem are described in Table 3.1. The strategy was to use lightweight and affordable materials. In the baseline analysis of cooling loads for Belem, the roof was the major responsible for heat gain, so a 1-inch insulation was added to it, as well as a ventilation system as described before. The walls received single-leaf ceramic brick cavity instead of a concrete block because it has better thermal performance and is widely used in Brazil. The doors and windows are made of wood and single glass panels to allow daylighting. The choice of keeping single glazing is because hot-humid climate does not benefit from insulation as much as other climates and consequently because this technology is less present in such countries. Additionally to the main building systems, a layer of tiles was added below the window line to protect the church from rain damage and water retention in the walls.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimensions</th>
<th>U-value BTU/(h·ft²·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roof</strong></td>
<td>Steel sheet insulated</td>
<td>1” insulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope 5.5”/12”</td>
</tr>
<tr>
<td><strong>Walls</strong></td>
<td>Brick cavity</td>
<td>6” thick</td>
</tr>
<tr>
<td><strong>Doors</strong></td>
<td>Wood and glass</td>
<td>(1) 72”x80”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1) 36”x80”</td>
</tr>
<tr>
<td><strong>Windows</strong></td>
<td>Single glazing + operable louvers</td>
<td>(5) 60”x48”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3) 48”x48”</td>
</tr>
</tbody>
</table>

3.1.2 Design

The following images show the final design of the ODC Belem:
CHAPTER 3. RESULTS

Figure 3.5: Perspective - ODC Belem.

Figure 3.6: Section AA - ODC Belem. Scale 1/16"=1'-0".
Figure 3.7: Plan - ODC Belem. Scale 1/16"=1'-0". 
Figure 3.8: Elevations - ODC Belem. Scale 1/16”=1’-0”. 
3.1.3 Analysis

Figure 3.9: Lighting Analysis - ODC Baseline vs. ODC Belem.

Strategies to improve daylighting were successful for providing adequate levels of illuminance and distributing the light more evenly (Fig. 3.9). 94% of the area was within the acceptable levels against 40% of the baseline, considering LEED Daylight Credit, which is between 300 and 3000 lux. The remaining 6% was below threshold and it is concentrated at the edges of the building. The highest level measured was 1508 lux and the lowest 124 lux, against 1067 lux and 46 lux from the baseline.

Regarding envelope performance, there is a decrease in the overall cooling demand (Fig. 3.10). Notice that the scale changes between images, which emphasizes this difference. High loads caused by the roof is the most significant change observed. This result was obtained by adding just one inch of insulation to the roof. There is almost no difference between the baseline and proposed wall results and the window solar load increased due to larger openings. This analysis does not account for natural
ventilation, which will be qualitatively discussed in the psychometric chart analysis.

Table 3.2: EUI Improvements - ODC Belem.

<table>
<thead>
<tr>
<th>Cumulative EUI (kBtu/sf/yr)</th>
<th>Improvements (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>135</td>
</tr>
<tr>
<td>Layout and openings</td>
<td>140</td>
</tr>
<tr>
<td>Roof</td>
<td>119</td>
</tr>
<tr>
<td>Walls</td>
<td>103</td>
</tr>
<tr>
<td>Windows &amp; Doors</td>
<td>103</td>
</tr>
<tr>
<td>Final Proposed</td>
<td>103</td>
</tr>
</tbody>
</table>

Table 3.2 shows the energy use intensity (EUI) for each modification made to the church design and materials. The first column shows the cumulative EUI of the strategies as they are being simulated, and the second column presents the percentage of improvements caused by each strategy. "Baseline" is the church as is, simulated for the city of Belem; "layout and openings" are the changes to the church configuration, without changing the materials of the baseline; the next three items are the changes of material and the final is the sum of all individual contributions.

The results show that "layout and openings" increased the EUI by 4%. This was expected because enlarging the glazing area and adding walls would tend to raise this coefficient. As mentioned before, this is a tradeoff to consider the aspects of daylighting and natural ventilation, which is not included in the EUI analysis. The most significant change again was caused by modifying the roof composition (16%),
followed by the walls (12%). The windows and doors had zero impact, partially because they are a smaller area of the building and partly because single glass was maintained in this case. Overall the EUI was improved by 24%. Analyzing the psychometric chart (Fig. 3.11), the strategies applied—sun shading of windows and adaptive cooling ventilation—are able to increase the hours of comfort from 0% to 65.4%.

Figure 3.11: Psychometric chart for Belem, Brazil - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies.

3.2 ODC Cairo

The deep walls, the use of screens and earth colors, and the windcatcher as the main element of the front facade give a unique appearance the ODC Cairo. These architectural elements suit the arid climate by minimizing heat gain and treating the dusty air for natural ventilation and confers an identity to this church. The main design strategies are summarized in Figure 3.12 and presented in detail in the sections below.
3.2.1 Strategies

**Natural Ventilation:** Natural ventilation in arid climates can be unwanted because the air can be too hot and dusty. To avoid that, the air needs to be treated to filter the dust out and to get cooler. The windcatcher is a bioclimatic strategy used in the ODC Cairo that does both. The tall tower captures higher winds, which carry less dust than lower winds. Inside, the windcatcher is shaped like an x to capture the wind from any direction, and to serve as both air inlet and outlet depending on the wind pressure. When the air enters the tower it cools down because of the lower temperatures in the shaded space and even more when it passes through ceramic water jars placed at the bottom due to evaporative cooling (Fig. 3.13a).

Evaporative cooling is a strategy to cool the air through sensible heat, as the moisture transforms into water vapor it absorbs heat and leaves a cooling sensation. The ceramic jars are a simple way to have a constant moist area since the water particles travel to the outer surface of the jars and are easily carried by the wind. Maranatha Volunteers currently builds water wells, so for this design, it is proposed the placement of this feature right outside the church. This would supply water for
the jars, for an external planting, and for the community needs.

The windows were designed in a similar way that the windcatcher to filter and cool the air through the bottom louvers and ceramic jars. The upper openings let the hot air out, forcing fresher air inside (Fig. 3.13b). These openings are constantly shaded to prevent over heating. Windows can be opened at night for night flushing that helps to cool the space for the following morning.

**Daylighting and Sun Control:** As seen in the analysis of the baseline, Cairo has the highest amount of illuminance levels, above the desired. The strategies for daylighting and sun control were to decrease and shade the openings. The openings

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**Figure 3.13:** Strategies for natural ventilation applied to the ODC Cairo.
were placed in the south and north facade for easier control and the main door in the east facade was protected by a screen. Most of the sun protection is self-shading of the thick walls. In the south facade, external horizontal devices were placed for additional shading. Shading is provided between March and October, during Summer (Fig. 3.15), Spring and Fall (Fig. 3.16) which are warmer periods. Some sunlight reaches the building during Winter (Fig. 3.17), when temperatures are below the comfort zone.

![Image of Liter of Light](image)

Figure 3.14: Liter of Light.

The first attempt to reduce the window size was beneficial to the thermal performance of the building, but it did not provide adequate illuminance levels to all the areas, especially the middle part of the church. To increase levels, the windows were elongated to ensure that they would be shaded. For additional lighting in the middle part of the church, the use of ”liter of light” is proposed. This device is a low-cost solution for capturing daylighting and refracting it into the space. It is basically a plastic bottle filled with water and chlorine that works as a 55-watt bulb (Fig. 3.14). An additional advantage of this system is that because of water it does not overheat like standard skylights.
Figure 3.15: Summer Solar Study for Cairo, Egypt.
Figure 3.16: Fall Solar Study for Cairo, Egypt.
Figure 3.17: Winter Solar Study for Cairo, Egypt.
CHAPTER 3. RESULTS

Envelope Performance: The ODC Cairo uses thermal mass, night flushing, shading, and insulation for thermal performance. The roof, similar to ODC Belem, has a one-inch insulation board in between the metal sheets and is light colored. The decision not to make the roof flat, as it is in most arid climates to reduce the roof surface and heat transfer, was to maintain the main structure of the ODC.

The walls are thick, made of two layers of brick and a middle layer of insulation. The one-foot thickness provides high thermal mass that delays temperature swings in the inside, allowing for cooler temperatures during the day and warmer temperatures during the night. The openings are relatively small and shaded to prevent conductive heat, but not too small to prevent enough light from coming in the space.

Planting trees around the church are proposed to help filter the air and to create a buffer zone. The plants add to the evaporative cooling effect and to shading. The water to irrigation such plants would come from the proposed water well. The entrance of the church is also shaded with a wood screen that shades the space while allowing plenty of ventilation. All materials and its thermal properties are listed on Table 3.3.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimensions</th>
<th>U-value BTU/(h·ft²·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>Steel sheet insulated</td>
<td>1” insulation Slope 5.5”/12”</td>
</tr>
<tr>
<td>Walls</td>
<td>Brick, insulation, brick</td>
<td>4”/2”/4” thick</td>
</tr>
<tr>
<td>Doors</td>
<td>Wood and glass</td>
<td>(1) 72”x80” (1) 36”x80”</td>
</tr>
<tr>
<td>Windows</td>
<td>Double glazing</td>
<td>(3) 54”x36” (4) 54”x24”</td>
</tr>
</tbody>
</table>
3.2.2 Design

The following images show the final design of the ODC Cairo:

Figure 3.18: Perspective - ODC Cairo.
Figure 3.19: Plan - ODC Cairo. Scale 1/16" = 1'-0".

Figure 3.20: Sections - ODC Cairo. Scale 1/16" = 1'-0".
Figure 3.21: Elevations - ODC Cairo. Scale 1/16" = 1'-0".
3.2.3 Analysis

Daylighting strategies applied to the ODC Cairo were able to reduce the excessive sunlight that can be seen in the baseline from maximum levels of 6000 lux to a maximum of 968 lux (Fig. 3.22). Lower levels improved from 47 lux in the baseline to 92 lux in the proposed design. However, the levels of illuminance remained acceptable for just about 50% of the area, compared to 57% of the baseline, which means that the middle portion of the church would still be below 300 lux. In order to improve the lighting levels without compromising the thermal performance, the "liter of light" was proposed. Its impact was not included in the simulation, but this system can be added as needed.

For the envelope performance, there is a reduction in both heating and cooling loads more significant than in the ODC church. Figure 3.23 shows that heating loss from the roof and walls was reduced due to added insulation and thermal inertia.
need for heating was eliminated for the months of May through October. Window solar adds to solar gain during winter when heating is needed. Cooling loads due to roof and window conductivity decreased an average of 3 mBtu (Fig. 3.24).

Table 3.4: EUI Improvements - ODC Cairo.

<table>
<thead>
<tr>
<th></th>
<th>Cumulative EUI (kBtu/sf/yr)</th>
<th>Improvements (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>116</td>
<td>0%</td>
</tr>
<tr>
<td>Layout and openings</td>
<td>118</td>
<td>-2%</td>
</tr>
<tr>
<td>Roof</td>
<td>97</td>
<td>18%</td>
</tr>
<tr>
<td>Walls</td>
<td>78</td>
<td>16%</td>
</tr>
<tr>
<td>Windows &amp; Doors</td>
<td>77</td>
<td>1%</td>
</tr>
<tr>
<td>Final Proposed</td>
<td>77</td>
<td>34%</td>
</tr>
</tbody>
</table>

EUI results in Table 3.4 shows an improvement of 34% compared to the baseline. The changes in the layout and openings only decreased the performance by 2%. Similarly to ODC Belem, the roof had the biggest impact in enhancing the building’s
CHAPTER 3. RESULTS

EUI, followed by the changes in the wall material. Windows and doors did have an impact in this case, even though small because single-paned glazing was modified to double-paned glazing. Applying the strategies used in the ODC Cairo to the psychometric chart—namely, sun shading of windows, high thermal mass night flushing, adaptive ventilation, internal heat gain, and passive solar gain through high mass—the hours of comfort achieved are 75% (Fig. 3.25).

![Psychometric chart for Cairo, Egypt - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies.](image)

**Figure 3.25:** Psychometric chart for Cairo, Egypt - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies.

### 3.3 ODC Shillong

ODC Shillong responds to the temperate and humid climate of where it is located by increasing solar and internal heat gain and keeping the rain away. Aesthetically it is similar to ODB Belem. Both churches are located in humid areas and can benefit from large openings and stack ventilation. Here again, the church logo is placed in the center of the main facade and the entrance door is moved to the side. Differently from ODC Belem, this church have fewer overhangs on the south facade and stone
finishing to enhance heat gain. The summary of the bioclimatic strategies applied to ODC Shillong is shown in Figure 3.26.

![Figure 3.26: Strategies applied to the ODC Shillong.](image)

### 3.3.1 Strategies

![Figure 3.27: Strategies for natural ventilation applied to the ODC Shillong.](image)

**Natural Ventilation:** Shillong is below the comfort zone for most of the year, but when ventilation is wanted, the church is designed for optimal performance. Natural ventilation is not only beneficial when interior temperatures are hot, but it also prevents mold and moisture accumulation. The two strategies used are cross-ventilation and stack ventilation. Prevailing winds in Shillong come from South-Southwest, so
the openings on the south facade were designed to be larger than the openings on the north facade. The middle portion of the roof was extended and operable windows were placed to allow for stack ventilation. During Winter the roof windows can be closed to prevent cool air to lower internal temperatures and the glazing surface can contribute to solar heat gain (Fig. 3.27). A vestibule was included to the church layout near the entrance to prevent direct air flow in colder months, creating a buffer between inside and outside.

**Daylighting and Sun Control:** For daylighting and sun control the strategies are to shade in summer, and promote heat gain and glare control in winter. The north facade that receives most of the summer sun has the roof overhang extended 2 feet, creating an alpha angle of 20° and shading the entire facade during this season (Fig. 3.28). The tree planted on the western side provides shade to the afternoon radiation and prevents overheating. On the south facade, which gets most of the sun during winter, the glazing area was increased to enhance solar heat gain, both by enlarging the lower openings and by the roof extension in this direction (Fig. 3.29). To control glare due to the direct sunlight in winter, internal blinds were proposed. This strategy allows the radiation to enter and warm up the room while blocking direct daylight when not desired.
Figure 3.28: Summer Solar Study for Shillong, India.
Figure 3.29: Winter Solar Study for Shillong, India.
**CHAPTER 3. RESULTS**

**Envelope Performance:** The ODC Shillong has to be adapted to both warm and cool seasons due to the nature of temperate climates, and in this case to high levels of humidity as well. The roof is sloped to avoid water accumulation from higher levels of rain. It is insulated to retain internal temperatures, especially in the colder season when outdoor temperatures are lower and the tendency of the heat is to flow from inside to outside. Operable windows are placed on the roof so that it can be closed during the winter and opened during summer for ventilation.

The walls are lightweight not to hold moisture and also insulated to minimize conductive heat. Below the window line is proposed an additional layer of stones to protect the building from rain damage and improve heat gain during the winter by storing and distributing the heat to the interior. The same stone layer is proposed for the west wall that receives most of the radiation, working as thermal mass to balance internal heat distribution. Windows and doors have double-paned glazing because the air barrier acts like an insulation material to minimize heat flow. The floor is insulated for this same reason. Table 3.5 presents each material used in the simulation for the ODC Shillong and its thermal properties.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimensions</th>
<th>U-value BTU/(h-ft²·°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roof</strong></td>
<td>Steel sheet insulated</td>
<td>1” insulation, Slope 5.5”/12”</td>
</tr>
<tr>
<td><strong>Walls</strong></td>
<td>Brick + insulation</td>
<td>Assembly 6” thick, Brick 4” thick</td>
</tr>
<tr>
<td><strong>Doors</strong></td>
<td>Wood and glass</td>
<td>(1) 72”x80”, (1) 36”x80” thick</td>
</tr>
<tr>
<td><strong>Windows</strong></td>
<td>Uncoated double glazing</td>
<td>(3) 54”x36”, (4) 54”x24”</td>
</tr>
</tbody>
</table>

### 3.3.2 Design

The following images show the final design of the ODC Shillong:
Figure 3.30: Perspective - ODC Shillong.

Figure 3.31: Plan - ODC Shillong. Scale 1/16” = 1’-0”.
CHAPTER 3. RESULTS

Figure 3.32: Section AA - ODC Shillong. Scale 1/16”=1'-0”.

Figure 3.33: Elevations - ODC Shillong. Scale 1/16”=1'-0”.
3.3.3 Analysis

Figure 3.34: Lighting Analysis - ODC Baseline vs. ODC Shillong.

Daylighting strategies were successful to provide accepted levels of illuminance for 98% of the floor area of ODC Shillong, against an average of 18% for the baseline. All levels in the proposed design are between 251 lux and 1187 lux. As demonstrated in Figure 3.34, the south facade receives more direct sunlight than the north facade.

Figure 3.35: Heating Loads - ODC Shillong.
The envelope performance of the ODC Shillong presents lower heating and cooling loads. Figure 3.35 shows that the walls and roof were the major change to alleviate winter heating loads and eliminate the need for heating during summer. This is indicative of the effectiveness of adding insulation layers to building systems. This figure also shows an increase in window solar during winter due to the design of larger openings facing south, which aids in passively heating the interior. The thermal mass of the stone walls below the window line serves as heat storage, increasing the effectiveness of heat gain. Figure 3.36 demonstrates how effective the measures for the roof and walls were to decrease cooling loads, whereas window sizing and placement increased solar gain in winter.

EUI results for ODC Shillong were the best compared to the other two churches. Changing the roof material, which is the same for all three examples, improved the coefficient by 29% in contrast to 16% for ODC Belem and 18% for ODC Cairo. The
brick and insulation walls were responsible for 27% of improvements and windows 1%. Overall, this design improved energy use intensity by 50% (Table 3.6). Comparing the psychometric chart of ASHRAE-55 and the ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies in Figure 3.37, the hours comfort increased from 5.5% to 68%. The strategies included were sun shading of windows, adaptive ventilation, internal heat gain, and passive solar gain through low mass.

![Psychometric chart for Shillong, India - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies.](image)

**Figure 3.37:** Psychometric chart for Shillong, India - ASHRAE 55-2010 Adaptive Comfort Model and best set of design strategies.
Chapter 4

Conclusions

A bioclimatic approach to the design creates buildings that respond to the characteristics of the climate and site of where they are located, producing structures that naturally have high levels of comfort and reduced or zero energy demand. This work presented three design proposals for the case study of the One-Day Church from Maranatha Volunteers International. It demonstrated how small changes to the design can improve the perceived quality and comfort of the building for users while meeting the constraints of a global project and keeping it simple for volunteer labor. The modifications to the baseline also improved the symbolic aspect of the church and enhanced its identification with the SDA institution.

Natural ventilation strategies, such as the lateral roof extension and the windcatcher, were important to enhance air flow through stack ventilation but also to contribute to the church aesthetics. Appropriate sizing and placement of openings provided adequate daylighting and thermal balance. In general, the default optimal orientation for thermal performance was placing the larger facades facing north and south to minimize excessive radiation from the west and to control the sun more easily as it is at a higher angle on these facades.

This study also showed the importance of shading and how it can be achieved through different strategies. Extending the roof overhangs proved to be an easy and effective solution for both shading and rain protection. Vegetation can also be used for
this purpose and to redirect the wind to where it is desired. Envelope performance was improved by choosing low thermal mass systems for hot-humid climate, high thermal mass for hot-arid, and a hybrid strategy for the temperate climate. Figure 4.1 shows the impact of the design changes on the proposed buildings compared to the baseline. Adding one-inch insulation to the roof in all climates had the highest impact and it is an aspect highly recommended for implementation. The temperate climate was the one that had the highest EUI and the applied strategies were the most effective for the building materials.

![Figure 4.1: Total Energy Use Intensity.](image)

Having a general understanding of bioclimatic design can help global projects to perform better at a high level. Broader strategies can be pointed for macro-climates as it was done here, however, their application needs to be carefully studied for each case. For example, the wind direction in Belem comes from the Northeast which
allowed a small shift of the ideal orientation for radiation control. If, however, the prevailing winds were coming from East or West, additional strategies to either control the sun penetration or to deflect the wind would have to be taken.

Overall, this study was able to demonstrate how standard projects can be minimally customized to improve user comfort and building performance. The use of local materials for the walls and fenestration was important to confer the flexibility needed to adequately to each situation, and also to lower the embodied energy of the construction by reducing transportation loads. Maranatha Volunteers International can implement the proposed strategies where feasible and get inspiration for further ODC projects. Similar initiatives that have standardized buildings can benefit from the strategies presented here, and finally, this work can inspire other projects to understand the importance of a bioclimatic approach.

4.1 Future Considerations

- Develop an in-depth study per strategy or per macro-climate to identify quantifiable guidelines that can be readily applied to the design. For example, a study could simulate the impact of different window-to-wall ratios to the thermal performance and levels of illuminance to define an optimal proportion.

- Apply bioclimatic strategies for different orientations in the same climate to provide a wider range of possibilities when the site limits the building placement.

- Survey the members of ODCs around the world to understand deeper needs and potential strategies.

- Build a prototype of a proposed ODC and quantify the improvements.

- Analyze the cost impact of the design changes and the business model of Maranatha International Volunteers.


Appendix A: Climate Data

<table>
<thead>
<tr>
<th>MONTHLY MEANS</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Horiz Radiation (Avg Hourly)</td>
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<td>131</td>
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Table A.1: Weather Data Summary - Belem, Brazil. Climate Consultant 6.0.
### Table A.2: Comfort Criteria - Belem, Brazil. Climate Consultant 6.0.
### APPENDIX A. CLIMATE DATA

#### Table A.3: Weather Data Summary - Cairo, Egypt. Climate Consultant 6.0.

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LOCATION:
Latitude/Longitude: 30° 13' North, 31° 4' East
Data Source: MEC Data - 623660 WMO Station Number, Elevation 242 ft.

Table A.3: Weather Data Summary - Cairo, Egypt. Climate Consultant 6.0.
Table A.4: Comfort Criteria - Cairo, Egypt. Climate Consultant 6.0.
### WEATHER DATA SUMMARY

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**Table A.5:** Weather Data Summary - Shillong, India. Climate Consultant 6.0.
Table A.6: Comfort Criteria - Shillong, India. Climate Consultant 6.0.