A Comparative Model for Selection of Opaque Wall Constructions in Hot and Humid Climates

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ABSTRACT

With the advent of the Industrial Revolution and its worldwide occurrence, the increased use of fossil fuels in the building sector have raised which caused energy crisis and global warming as a result of carbon dioxide emissions. The stated issues have led the authorities to develop a creative approach to confronting the crisis through energy efficiency policies. However, optimizing energy consumption should not result in losing thermal comfort in buildings. Therefore, these two approaches must be considered in the same direction and from the early stage of the building design. One of the main causes of excessive use of energy in buildings of severe climates (i.e., for heating and cooling purposes) is heat conduction through building external walls. Therefore selecting the optimal walls, with the approaches of energy efficiency and thermal comfort can be a great step in this direction particularly in regions with the severe climatic condition. However, the process of walls selection itself is another issue that requires comprehensive research on the subject, influential factors, evaluation criterion as well as the decision-making process. Accordingly, the present study, oriented to develop a comparative model selecting optimal opaque wall constructions in hot and humid climates based on four main evaluation criterion namely energy saving (by means of dynamic thermal simulation), thermal comfort (by means of Fanger's PMV model), moisture control (by means of steady-state Glaser analysis) as well as the cost efficiency (by means of amortization time calculation). The reason why "hot and humid climate" was chosen was that the thermal behavior of the walls in such climates faces unpredictable factors due to the climate characteristics, such as moisture condensation and heat behavior in different periods of the year. Both research methods of qualitative and quantitative were employed in this study including

literature survey, field survey, computer-based simulation, temperature monitoring, thermal and cost analysis as well as a simple multi-attribute rating technique (SMART) for the final assessment and the decision making process. To indicate the application of the developed multi-factor optimization model, a case study methodology was employed by means of a two-bedroom flat in Kish Island, Iran which is characterized by a "hot and humid climate". The number of 10 wall cases were selected in accordance with the most commonly used wall constructions in the context (walls 1-5 and 10) besides suitable ones suggested by the literature review after a process of localization (in accordance with the context building code; walls 6-9). Based on the results wall 6 obtained the highest performance for energy saving and thermal comfort hours followed by walls 7, 8, 10 and 9 respectively. On the contrary, wall 3 obtained the worst result for energy saving and thermal comfort hours, followed by walls 1, 2, 5 and 4. In addition to energy saving and thermal comfort, based on Glaser analysis, condensation was occurred for walls 6 and 7, which employed insulation internally and externally respectively. However, since the results for the condensation rate is below the limit, the walls are not at the risk for condensation at all. Further, the results for cost efficiency indicated that the entire wall cases amortized their initial cost less than the limit of 10 years while wall 3 considered to be the wall with the longest amortization time period of 9.1 years. On the contrary, wall 10 considered being the wall with the shortest amortization time period of 4.8 years. As a result for the final assessment and overall grading of the SMART in terms of energy saving, thermal comfort and cost efficiency for the entire simulated wall constructions, wall 6 obtained the highest overall grade; this is the opposite for wall 3, obtaining the lowest grade among the entire simulated cases. Paying attention to the results, it can be deducted that the walls that suggested by the literature review and as a result of localization

process (employing thermal insulation) showed more energy saving and thermal comfort potential at all. It also should be highlighted that since the developed model is inherently comparative in which multiple evaluation factors are considered, the result is obtained generally, on aggregate. Based on the findings and in accordance with the walls total grades through the SMART, the most efficient walls were the ones formed during the localization process (i.e., walls 6-9) in addition to a 40-cm adobe wall (i.e., wall 10) as the representative case for traditional walls used in ancient architecture of Kish Island. As a consequence, the results of the case study revealed that the application of the developed model has the potential to save cost and energy, improve the thermal quality of the indoor environment as well as predicting the risk of condensation in buildings' walls of hot and humid climates.

Keywords: Multi-Factor Optimization Model, Energy saving, Thermal Comfort, Moisture Control, Cost Efficiency, Localization

ÖZ

Endüstri Devrimi'nin gelişi ve dünya çapında yaygınlaşması ile birlikte, karbon dioksit emisyonlarının bir sonucu olarak enerji krizine ve küresel ısınmaya neden olan inşaat sektöründe fosil yakıtların kullanımının azaltılması gündeme gelmiştir. Dolayısıyla, bunun sonucunda enerji koruma politikaları geliştirmesine yol açılmıştır. Bununla birlikte, enerji tüketimini optimize etmek binalarda ısıl konforun gözardı edilmesi anlamını taşımaz. Bu nedenle, bu iki yaklaşım, bina enerji kullanımı stratejilerinin tasarımında eşit ve aynı yönde düşünülmelidir. Binalarda enerji tüketiminin ana nedenlerinden biri, dış duvarlar (yani opak kısım) yoluyla ısı transferidir. İster içten dışa, ister tersi olsun, bu değişim, bina sakinleri için ısıl rahatsızlığa neden olur ve ısıtma ve soğutma mekanik cihazlarının kullanılması ihtiyacını ortaya çıkarır. Bu nedenle, uygun duvarların seçimi, enerji verimliliği ve ısıl konfor yaklaşımı parametreleri dikkate alınarak yapılmalıdır. Ancak, uygun duvar uygulamasının nasıl belirleneceği, kapsamlı bir seçim ve karar verme yöntemi gerektiren bir diğer konudur. Buna göre, bu çalışma, sıcak iklimlerde opak duvar konstrüksiyonlarını karşılaştırmalı olarak seçmek için bir yöntem geliştirmeye yöneliktir. Sıcak iklimin seçilmesinin sebebi, iklim özelliklerinden dolayı bu iklimlerde duvarların ısıl davranışlarının tahmin edilemeyen faktörlerle karşı karşıya kalması, kapsamlı bir araştırma için daha uygun olan birkaç yaklaşımı tanımlamaktır. Çok faktörlü optimizasyon yönteminin geliştirilmesi, literatür taramasının öne sürdüğü uygun duvarların yanı sıra, yerel kullanım alanı bulmuş yaygın uvar türleri arasında yapılacak seçimin, enerji verimliliği, ısıl konfor ve ekonomik analizleri de içeren çok faktörlü optimizasyon yöntemini geliştirilerek değerlendirilmesi hedeflenmiştir. Önerilen model yapılan saha çalışması ile test edilmiştir. Saha çalışmasında literatür taraması ile önerilen iç

duvarlar, yerel kullanım alanı bulmuş duvar seçenekleri ile mukayese edilerek sonuca ulaşılmıştır. Açıkçası, önerilen yöntemin, sıcak ve nemli bir iklimde opak duvarları seçmek için kapsamlı bir yöntem olduğu söylenemez, ancak bu yöntemin, olası seçenekleri kullanarak, daha iyi bir seçim tekniğine yol açabileceği söylenebilir.

Anahtar Kelimeler: Enerji verimliliği, İsıl Konfor, Optimizasyon Yöntemi, Duvar Yapımı, Sıcak ve Nemli İklim

Dedicated to my Family

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INTRODUCTION OF THE STUDY

1.1 Introduction

The industrial transformation of man from life in nature to life in the city, with the advancement of technology, the pattern of life has undergone a transformation so that humans used fossil fuels to warm themselves instead of covering more and using warm clothes. Windbreakers, canopies, and lighters in the building replaced their heating and cooling facilities. In this way, technology has provided human comfort and convenience. As a result of urbanization, many natural lands and forests have undergone changes. For traffic, construction, cooling, and heating, energy consumption has increased and resulted in increased air pollution and noise pollution. Cities use energy and create garbage and pollution instead. As a result of this industry progress, the need to exploit natural resources has also increased, so that unreasonable exploitation of natural resources leads to their destruction. To continue living in this cycle, the human need for energy has increased, but now we are at a stage where energy resources are coming to an end. With this attitude and the need to mitigate the obstacles, sustainable buildings are highlighted also due to the existing environmental issues.

As it was briefly discussed, with the onset of modernity, buildings have grown with the advancement of mechanical ventilation to provide users with the comfort without resorting to the principles of passive building design to get the most benefits of the context natural potential. The passive architecture elements such as wind catcher, canopies, pools, lighters, etc. in the building replaced with mechanical heating and cooling plants and as a result of urbanization, many natural lands and forests have undergone great changes for the mass constructions. In this circumstance, the human need for energy has intensified and the use of fossil fuels for building sector has dramatically raised, where accordingly, the building sector is responsible for a significant amount of the energy use and diffuse one-third of the carbon deoxide emissions worldwide. However, at the moment, we are at a stage where environmental issues such as air pollution, ozone layer depletion, climate change, global warming, etc. are threatening people health and well-being. With this attitude, sustainable buildings based on the principals of passive and climate responsive design are highlighted while many factors in this context should be taken into account such as the selection of optimal building components, materials and construction techniques.

In addition to energy saving, thermal comfort is another pivotal subject that should be taken into account to improve the quality of indoor environments. Nowadays, thermal comfort issues have become a priority of concern especially in the regions with the hot climatic condition, where the continuous use of mechanical cooling is a must. It is always a misconception that buildings using a significant amount of energy for cooling are also optimal in terms of achieving comfort condition. However, this cannot be a valid source of evidence, like many buildings, despite the high energy consumption quantity, still have to meet the users' basic comfort needs. Therefore, an accurate cognition over building physics and its properties besides a true understanding of climate characteristics, energy saving and thermal comfort issues require identifying the basic principles through a profound literature survey.

There are numerous research works over energy saving in buildings by implementing optimal constructional techniques, building component's design and material use [1-32]. Among all, the most significant point that most of the previous research works were strived to deal with is to conserve energy through optimum design for building envelope in general [32- 54] and external walls in particular[55-67, 70-73]. As a matter of fact, the key components of the building envelope are external walls, which are of particular importance due to their most connection to the outdoor environment and climatic factors.

1.2 Problem Statement

Forty percent of the world's primary energy consumption is spent on building operations such as heating, cooling, and ventilation, which likewise accounts for one-third of global greenhouse gas emissions [68]. Air conditioners are the largest energy consumers in buildings, which alone account for about 15% of total energy consumption throughout the world [69].

In hot climates, with an efficient design for external walls of the building, a considerable amount of cooling energy can be conserved by minimizing the heat transfer through building external walls surfaces [70]. Therefore, a major step towards having energy-efficient buildings might be achieved by improving wall constructions techniques as an effective way to reduce building energy needs [55-67, 70-73] and should hence be taken into consideration from the early stages of design. However, despite the wide range of external wall constructions, it is not easy to decide on the most suitable case or a series of alternatives for each and every climate. This has become one of the major challenges and issues in the choice of design and/or selection of optimal wall constructions exclusively in regions with no specified building codes and construction details to be observed. In addition to the stated issues, architects and designers are not assured that the selection of optimal walls should be based on what evaluation criterion and context parameters such as local market and/or historical background; novel and innovative alternatives advertised by known companies or cases that suggested by previous research studies in similar climates. It is clear that each climatic region, although it has similar characteristics with its own kind, in practice, it cannot take into account from each and every aspects.

Reviewing the previous research works in the same field, it can be deducted that most of the references address the subject from thermodynamics points of view [5-11] while neglecting the architectural aspects such as climatic factors, thermal quality of the indoor environment, economy, construction techniques, etc.; only dealing with the energy quantities, the thing that is not all to be taken into account. Accordingly, employing optimal wall constructions for buildings (in the severe climatic condition in particular) should be based on a systematic approach considering various factors as the main guidelines for the maximum efficiency. Further, the role and effect of local construction techniques and materials should be evaluated and compared to the other types in order to indicate how they may effect on construction sector; even if using them are not that suitable and efficient in today's construction industry.

1.3 Aim and Objective

Based on the discussed problem statement which is deficiency of systematic methods for selecting opaque wall constructions in regions with severe climatic condition as well as investigating the role and effect of local construction techniques and materials on construction sector, the present study aims at developing a local based model for comparative selection of opaque wall constructions in hot and humid climate. In view of that, a multi-factor optimization model is developed based on four main evaluation criterion namely energy saving; thermal comfort; moisture control and the cost efficiency as the key criterion for selecting optimal wall constructions in a hot and humid climate.

1.4 Questions of the Study

In accordance with the problem statement and aim and objectives stated above, the foremost questions that this study strives to deal with are:

- What systematic approach should architects and designers follow for employing suitable wall constructions in a hot and humid climate?
- What evaluation criterion should be incorporated in a model selecting optimal wall constructions in a hot and humid climate?
- How local construction techniques and materials effect on construction sector selecting optimal wall constructions for maximum efficiency?

1.5 Research Methods

Both qualitative and quantitative methods were employed during the research process including empirical data collection; observation; data monitoring; simulation as well as validating the results. It should be highlighted that all results were evaluated based on four main evaluation criterion of this study (i.e., energy saving; thermal comfort; moisture control; cost efficiency) finalizing with a simple multi-attribute rating technique (SMART) for the final assessment and decision-making process since a multi-criteria evaluation model is developed and considered.

Explaining in a brief, the qualitative research methods referred to a comprehensive data collection containing literature survey (i.e. empirical investigation) and field survey (i.e. author’s observations) while the quantitative research methods referred to the context temperature monitoring and analysis (i.e. experimental investigation), computer-based simulation, results validation, thermal and cost analysis as well as the SMART for the final assessment and decision making process.

Accordingly, a workflow diagram of the research methods and materials are prepared and shown in (Fig.1.1) indicating how the research process initiated and finalized.

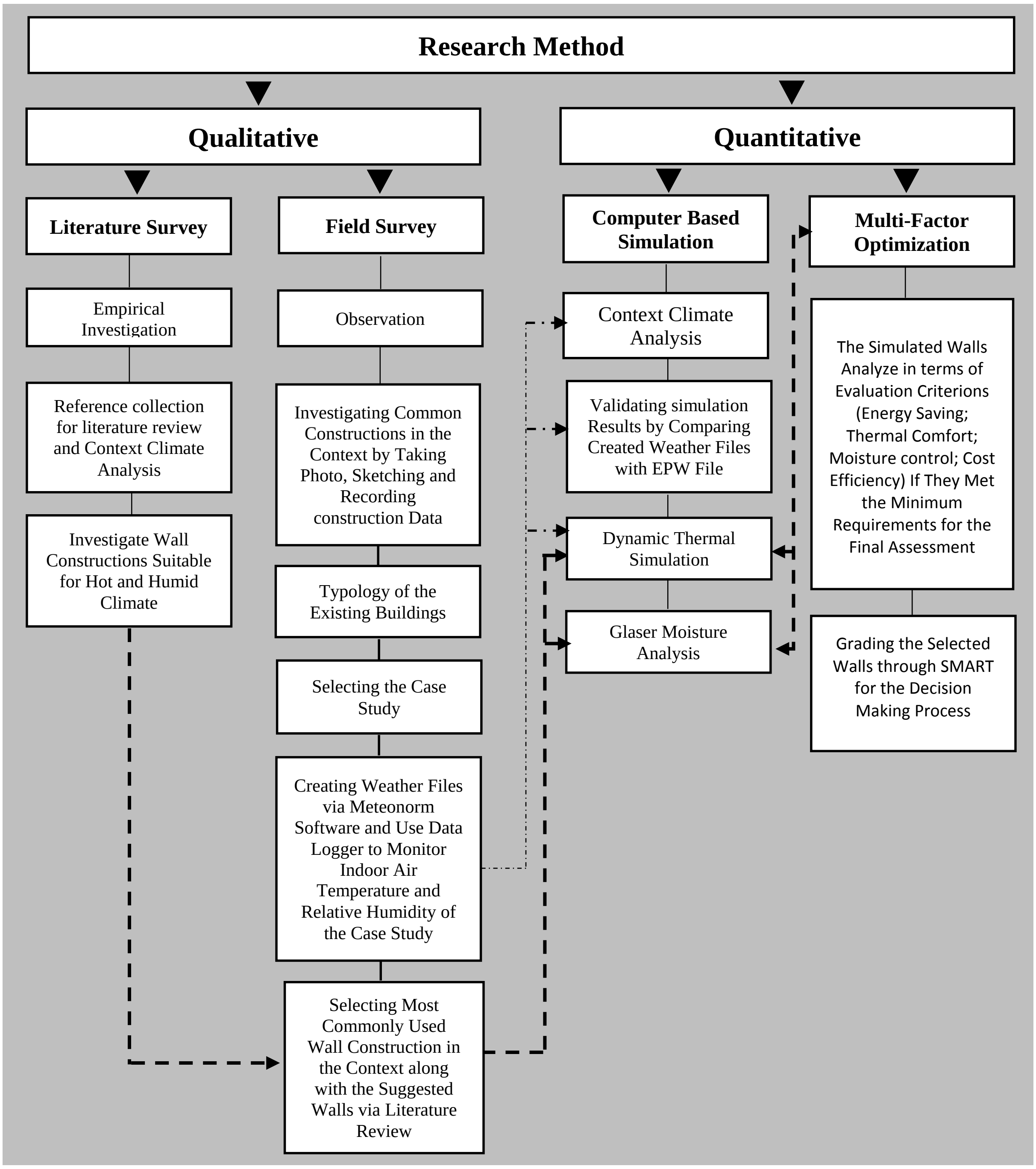


Figure 1.1: Research Methods Work Flow

1.5.1 Qualitative Method

1.5.1.1 Literature Survey (Empirical Investigation)

The empirical investigation is based on two phases considering the most relative and reliable sources by implementing varied scholarly journals. Table 1.1 demonstrated how the source investigation was initiated and carried out based on the fundamental keywords of the subject.

Correspondingly, during the second phase, a list comprised of the most commonly used wall constructions with promising performances (in optimizing building energy consumption) were prepared and shown in Table 1.2. It is worth mentioning that a précised and directed keyword search was carried out to develop both lists for both phase 1 and 2 in accordance.

Moreover, it was tried to list the most known and important journal names and the publishers in Table 1.1; more preferred to be mentioned.

Table 1.1: Implemented Journals Finding Relative Papers (Phase 1)

Key Words	The Most Known Journals	The publishers
Buildings; Building Design; Building Construction; Building Physics; Sustainable Buildings; Sustainable Design; Sustainable Constructions; Energy Efficient Buildings; Energy Efficient Design; Energy Efficient Constructions; Energy Efficient Architecture; Passive Buildings; Passive Design; Green Buildings; Green Architecture; Green Design;	Buildings; Sustainability; Energies; Materials;	MDPI
	Building and Environment; Energy and Buildings; Sustainable Energy Reviews; Construction and Building Materials; Building Engineering; Sustainable Cities and Societies; Energies; Solar Energy; Procedia Engineering; Procedia Energies; Heat and Mass Transfer;	Elsevier
	Journal of Building Performance Simulation; Building Research and Information; Advances in Building Energy Research;	Taylor & Francis
	Journal of Building Physics; Building Acoustics; Building Services Engineering Research & Technology;	SAGE

Table 1.2: The Most Common Keywords to Search for the Optimal Walls (Phase 2)

The Most Commonly Used Wall Constructions
• Heavyweight Walls (i.e., comprised of heavyweight structure and/or materials) • Lightweight walls (i.e., comprised of lightweight structure and/or materials) • Masonry Walls (i.e., commonly brick works) • Framed Walls (i.e., made of different materials' frame system) • Sandwich Walls (i.e., comprised of several layers and/or assemblies) • Bracing Walls • Studding walls (i.e., generally comprised of two main parts including insulation core and pre-welded steel networks) • Cladding Walls (i.e., mostly use in buildings' facade as the second skin or as the double and/or second layer of building envelope)

1.5.1.2 Field Survey

A comprehensive field survey was carried out in Kish Island; located in the southern part of Iran and Persian Gulf as the field study and selected context of this study from fall 2015 to summer 2018, identifying building typology, construction techniques as well as building materials in construction sector of Kish Island, Iran, as it is a proper representative of a hot and humid climate condition.

1.5.1.3 Selecting the Wall Cases

As the methodology of the study suggests, the process of wall constructions' selection is divided into two main phases and is based on two approaches as "Via Field Survey" and "Via Literature Survey". Accordingly, Based on both literature and field survey, the number of seven wall constructions were identified and selected as the most frequently used wall cases in the context and the numbers of suitable wall cases suggested by the literature survey after the process of localization which is one of the important aims of this study to be simulated for evaluation and the final assessment.

1.5.1.4 Generating the Weather Files

To make sure that the thermal simulations operate accurately, the employed dynamic inputs such as hourly weather data file of the context must be reliable. There are two types of weather data file used in this study as annual and the energy plus weather (epw).

The annual weather data file was prepared from a local weather station based in Kish Island airport, includes dry bulb temperature; relative humidity; solar radiation; wind speed and etc. The epw file was generated via Meteonorm software using altitude and longitude of the Kish Island as the main inputs.

1.5.2 Quantitative Method

1.5.2.1 Dynamic Thermal Simulation

The phenomenon of heat transfer in the building has dynamic behavior. Therefore, the accurate analysis of the energy consumption of heating and cooling systems in buildings highly depends on a dynamic model, in other words, it is time-dependent.

In this study, a series of dynamic thermal simulations were carried out using hourly climatic data of the context in order to investigate the heat behavior and performance of selected wall constructions.

The simulation outputs include electrical energy consumption (i.e., heating and cooling energy consumptions), level of thermal comfort (PMV) besides the comfort and discomfort hours.

1.5.2.2 Validating Simulation Results

In order to validate the simulation outputs, the results were compared to the generated weather data files including annual weather data file (prepared through local weather station based in Kish Island airport) as well as a short time weather data file (monitored by the author) within the case study.

To have a more accurate result, the short time weather data is necessary for the validation process to indicate the difference between actual indoor weather condition and the indoor weather condition taken from software outputs (i.e. the epw weather file, which may give an error to some extent).

1.5.2.3 Condensation Analysis

Moisture condensation occurs in building walls mostly when they integrated with an insulation layer. To predict the condensation in this study, the steady-state Glaser method was employed based on the following variables which should be taken into consideration in the calculation process:

- Max. external air temperature;
- Min. internal air temperature;
- Max. mean monthly humidity;
- Relative humidity;

- External/internal surface temperatures;
- Condensation period.

1.5.2.4 Cost Analysis

Cost efficiency or in other words Life Cycle Cost (LCC) analysis of a building is a comprehensive approach to assess the initial costs versus the productivity of a building. These costs include the initial cost of building materials, systems, as well as the cost of building maintenance, retrofitting, HVAC efficiency and etc.

An analysis of the cost of a building's life cycle is useful when the initial costs and operating costs are significantly different. Hence, selecting the type of materials, systems, and services must be in a way that maximizes the net savings. For the purpose of this study, the economic analysis was considered based on the amortization time period method. In amortization calculation, the walls of more energy-saving payback on a short run, and the walls of less energy saving pays back over a relatively long run. (i.e., this time period is called time of amortization). The key factors calculating amortization time periods are:

- Initial wall cost
- Annual HVAC energy cost
- Rate of interest
- Inflation
- The maintenance cost

The amortization time period of the wall constructions will be considered on the basis of the wall with most cooling energy consumption (since based on context climatic condition, the heating energy consumption is not considerable).

1.5.3 Research Tools

The entire climatic analysis of the field study was carried out via climate consultant software (V.6).

Series of dynamic thermal simulation was carried out using Design Builder computer software (V.5) as the main research tool.

Meteonorm (V.6.1) was employed for generating "epw" file as the most important simulation tool input.

A temperature and humidity data logger (Benetech, model: GM 1365) was used to create short time weather file which monitored internal temperature and relative humidity of the case study to validate the weather data files.

1.6 Limitation of the Study

Hot and humid climate condition was selected as the climate of the study Kish Island, Iran was considered as the context and field of the study. The reason why Kish Island is considered as the field of this study is for being a decent representative of a hot and humid climate, where in one hand as an Island have a high level of humidity and on the other hand the cooling period is dominant and the use of mechanical cooling considers continuously for the entire days of the year (even in winter time). This situation faces a critical circumstance and is worth to deal with since energy saving, thermal comfort, as well as moisture control, are among the main evaluation criterion of this study.

The numbers of four main evaluation criterion were employed for this study namely: energy saving (by means of dynamic thermal simulation); thermal comfort (by means of Fanger’s PMV model for air-conditioned buildings; PMV scales -0.5 to 0.5); moisture control (by means of steady-state Glaser analysis) as well as the cost efficiency (by means of amortization time calculation). The results for the aforementioned criterion were then finalized with the Simple Multi-Attribute Rating Technique (SMART) for decision-making process while the entire evaluation criterion was taken as equally significant for the final assessment.

Life Cycle Cost Analysis (LCCA) was considered for the cost efficiency of the entire selected wall cases. It should be highlighted that environmental impacts and costs are not included.

A two bedroom (63m2) residential flat located in the center of Kish Island, Iran, was selected as the case study (based on the result of the field survey). The main reason why this flat was selected is not only the flat met desired architectural, but the flat also had no residents and that facilitated access to all interior spaces in order to monitor indoor temperatures for simulation results validation process.

The numbers of 10 wall constructions were selected for simulation where walls 1-5 and 10 accounts for the most commonly used wall constructions in the context (as a result of field survey) and walls 6-9 account for the most suitable wall constructions recommended for hot and humid climate condition based on the result of literature survey and the process of localization in accordance with building code 19; the one and only building code observes in the context.

Design Builder (V.5) was selected as the main simulation tool. However, since most of the simulation software and Design Builder, in particular, evaluate the heat performance of the wall constructions based on their U-values, the wall constructions with same similar U-Values have no significant differences in case. Further, since Design Builder uses steady-state Glaser method for condensation analysis, the present study considered the same method of assessment for condensation analysis via Glaser diagram.

The climate consultant (V.6) software was employed for the entire weather analysis. The energy plus weather (epw) file was generated on the basis of the latitude and longitude of Kish Island and arranged via metronome (V.7.1) software. Consequently, the climate consultant outputs used for climate analysis contain Kish temperature range diagram, dry bulb, and relative humidity diagram, climate calendar, psychometric chart as well as the wind rose diagram.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The evolutionary history of mankind is, in fact, the history of the transformation of energy into different forms and is full of inventions and discoveries in this direction. The industrial revolution itself is a clear example of this energy transformation. Generally, energy is divided into two categories: renewable and non-renewable. As the name suggests, non-renewable energies refer to those sources which do not produce in any condition while renewable ones are those which can be obtained by natural resources such as sun, wind, water and etc. Most of the energy that is used by mankind is included as the form of non-renewable energy.

Non-renewable energy has two basic weaknesses or in other word, disadvantages as follows: one is that the source of such energy is limited and finally comes to an end. The second disadvantages of non-renewable energy sources are the cause of environmental pollutions as a result of carbon dioxide or carbon dioxide emission which has harmful results for human, nature and any living creature. Renewable energies also are known as clean energies, which the most important sources among the others refer to solar radiation, has endless resources and is not contaminated.

Nowadays, the increasing concern over environmental issues besides the energy crisis has increased dramatically. On the other hand, the share of the building sector in energy consumption and this crisis is significant. As one of the prevalent issues in countries that are rich in fossil fuels or those located in developing countries (with have no sufficient amenities), architects have always focused on issues such as building form, building aesthetics, function, interior design, etc., while they pay less attention to the energy issue and its optimal use in buildings.

As discussed previously and given that fossil fuel resources are limited, the use of this type of fuel as the dominant type is a logical decision. In recent years, building design with less energy consumption has received more attention from architects and engineers. In large, mega and densely populated cities facing a variety of environmental problems, optimizing energy consumption in residential areas is a necessity and should be considered more than any other topic in the construction sector. However, in most industrialized countries, major steps have been taken to reform the consumption pattern by true education besides implementing renewable energy sources, including the rules and regulations for designing sustainable and energy efficient buildings. Additionally, creating a comfortable environment for building occupants is another vital goal of designing buildings based on sustainable architecture principals. Undoubtedly designing comfortable indoor spaces is important due to raising the level of physical and mental performance of the users, reducing the incidence of diseases as well as reducing the amount of non-renewable and environmentally polluting fuels.

Based on numerous studies [74-87], the characteristics of the climate for providing thermal comfort are very imperative and should be observed by architectural design from the very beginning of the process. In this chapter, the issues related to thermal comfort in a hot and humid climate in different periods of the year (i.e. overheated and under heated periods) will be discussed in detail. Further, the number of solutions for energy saving and energy conservation through designing and using suitable materials and construction techniques for designing external wall constructions, in particular, are debated. Consequently, in the end, and as the core objective of this study, the walls and construction techniques that provide more thermal comfort using less energy in buildings of hot and humid climate are introduced and discussed.

2.2 Energy Saving in Buildings

Using architectural strategies and methods to save on fuel and reduce energy consumption in buildings from every perspective and angle we look at is an essential and fundamental requirement both at the national and international levels [68]. Most of the environmental issues that the world now faces are related to the consumption of fossil fuels, by the construction sector and for mechanical heating and cooling plants in particular [69].

Apart from the harmful effects of energy and fuel waste on the Earth's biomass, the waste of energy and fuel can be considered as a loss of resources that could be consumed for the sake of excellence and welfare of the people of the society. In general, in the design of buildings and cities in particular, all aspects of social, psychological and individual of human beings must be considered, and a building that is constructed regardless of the mentioned aspects would not be desirable. However, it can certainly be said that developing societies not paying too much attention to the waste of energy while they will not have a place in the current competitive world. The importance of energy saving (using energy efficient design strategies in comparison with traditional construction strategies) is that using traditional methods, the energy should be consumed, while in the use of energy efficient design strategies, the possibly least amount of energy is needed. Therefore, it is all about knowledge and creativity which can be considered vital for any society and country.

In general, the purpose of energy saving in buildings is to select patterns; adopt and apply policies for the correct use of energy sources, desirable from the point of the national economy and guarantees the continuity of the existence and durability leads to the continuation of life and industry [70]. In this framework, identifying the contribution of different forms of energy (i.e., renewable and non-renewable) in each society, taking into account the long-term facilities of that society, as well as the most effective use of them (involves reducing the destruction of national resources and reducing the negative effects of improper use of energy), on other factors such as human life and the environment are very important.

Accordingly, the proper use of energy not only ensures the sustainability of life and sustainable development of the community, but it also leads to the survival of the universe and energy for all and the future generations. It also constitutes a barrier to the production and spread of environmental pollution caused by the misuse of energy and emissions of greenhouse gases (i.e., CO_2 emissions).

2.3 Thermal Comfort

One of the most important issues in designing buildings is to provide thermal comfort for building residents and/or users. Explaining in the simplest form, thermal comfort is a condition in which a person does not behave in a way to change the temperature conditions of the environment or reduce the level of clothing.

Thermal comfort is important because it affects the productivity and health of users in the building. The employees of the offices who are satisfied with their own thermal environment are more likely to work, and this can be quite the opposite for employees who are not satisfied with the thermal comfort of their work environment.

The combination of high temperature and high relative humidity reduces thermal comfort and low air quality inside the building. In ASHRAE standard 55 [181] thermal comfort is defined as a mental condition that expresses the satisfaction of a person with the surrounding ambient temperature. Maintaining this thermal comfort standard for building residents is one of the major goals of the design engineer for mechanical building systems. The feeling of comfort for the individual occurs when the heat produced by the body's metabolism is allowed to air out and disperse in order to preserve the ambient temperature balance with the individual's body temperature.

The main factors that affect human thermal comfort are those that refer to personal and environmental factors including the metabolic rate, amount of insulating clothes of a person, air temperature, the average radiant temperature of the inner surfaces, air velocity, and relative humidity, etc. Also, psychological parameters, such as individual expectations and human definition of comfort condition within the built environment, also affect thermal comfort. The Predicted Mean Vote (PMV) model is superior among well-known comfort models, based on the principles of thermal equilibrium and experimental data taken from a room under constant weather conditions. On the other hand, an adaptive model in accordance with the huge number of field studies have been created, based on the studies that inhabitants interact dynamically with their surroundings based on the personal control such as defining the level of clothing in different periods, employing operable windows for natural ventilation when it is possible, using manual fans, natural and traditional heaters, shading, curtains and so on [179-181].

It is important to highlight that the PMV model can be used for buildings with an air conditioning system, while the adaptive model can only be used for buildings that have no mechanical system. Rather than the ANSI / ASHRAE standard 55 [179], there are also other standards of comfort such as EN 1525 and ISO 77307 [180] with specific methods of assessment. However, they are not as famous as the PMV model is in general.

Since there are many differences between people’s thermal expectation and thermal satisfaction, it's hard to find a certain comfort temperature for each and every individual in a given space. In this context, there are different factors that directly affect the individual's thermal comfort, which can be divided into two categories as personal and environmental factors. Personal factors are related to the characteristics of building residents that include gender, age, metabolic rate, clothing level, etc., while environmental factors include air temperature, the average radiant temperature of internal surfaces, air velocity and relative humidity inside the building.

2.3.1 Thermal Comfort Issues in Hot and Humid Climates

One of the most pivotal aspects of building design in hot and humid climates is providing comfort condition for the users in an indoor environment. As it is clear, the state of thermal comfort refers to a condition in which a person feels comfortable and cannot behave in order to change the condition by an increase or decrease the temperature of the environment. Accordingly, it was found in [88] that, there are two crucial factors affecting the user’s comfort condition in buildings of hot and humid climates as heat and moisture.

Based on the stated factors, see (Fig 2.1) for a better understanding of how the stated factors pose thermal discomfort in indoor environments [89], while in the following section the issue is discussed in more detail.

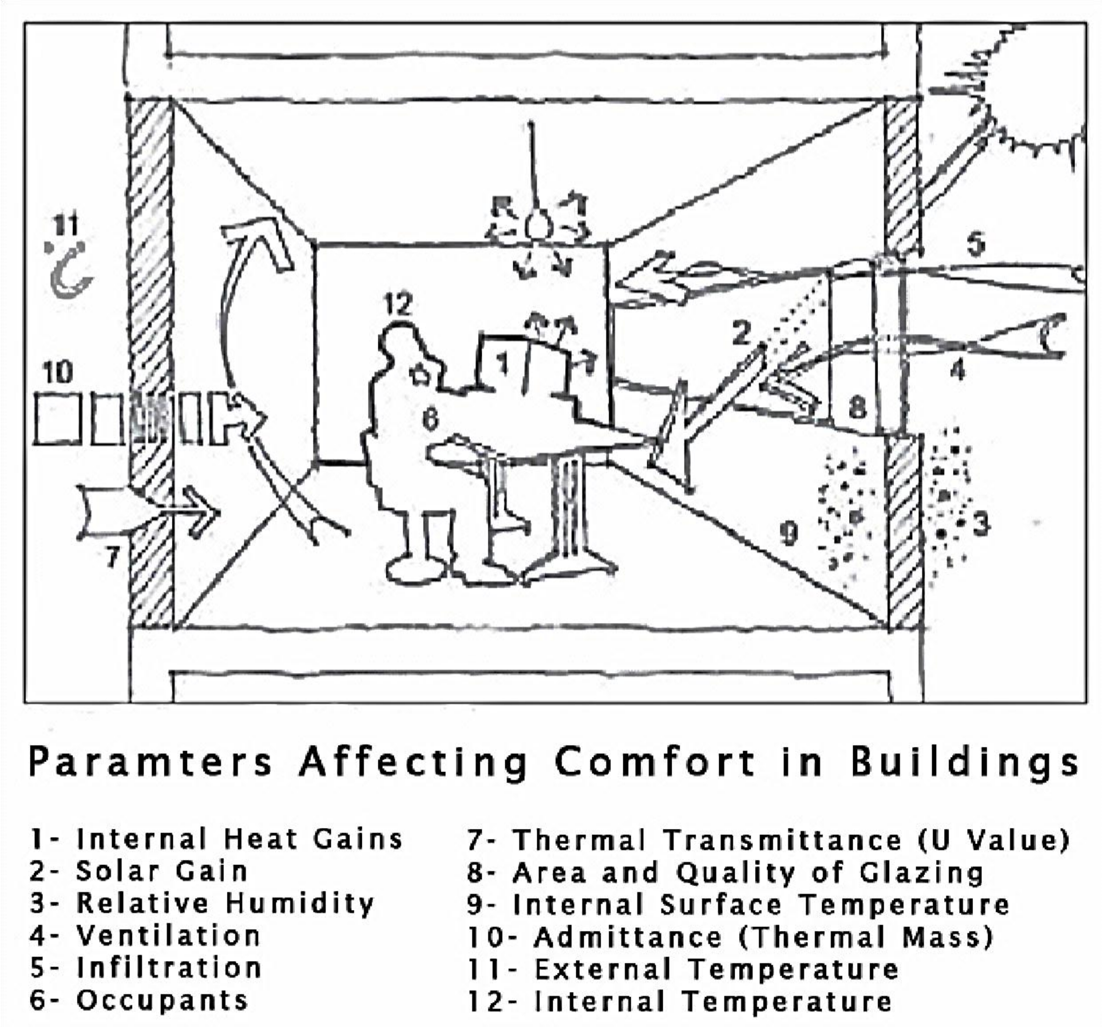


Figure 2.1: Parameters Affecting Thermal Comfort in Buildings [89]

2.3.2 Heat Gain Reduction in Under-heated Periods

Generally, providing thermal comfort in buildings of severe climatic condition will be difficult where the overheated periods are longer than under-heated periods and the continuous use of mechanical cooling is a must.

In view of that, the architectural design required to be in accordance with some key strategies such as decreasing internal air temperature by using passive design techniques including the protection of the building from sunlight by maximizing shading and using air flow to create natural ventilation [103-108].

Further, by employing passive design strategies, building envelope may be designed in a way to reduce the amount of heat gain in overheated periods by its optimal form (i.e. having overhangs or implementing movable shading) as well as implementing light and reflective envelope materials to reject the excessive gain of solar radiation as well as implementing high capacitive materials to store the heat at the day time and release it at the night time when building is provided with night ventilation techniques [109-114].

2.3.3 Heat Loss Reduction in Under-heated Periods

It is clear that the optimal selection of building envelope can reduce the heat loss in under heated periods and have a direct impact on amount of building energy consumption in different periods. As a matter of the fact, during under heated periods the heated air transfers from building indoor spaces to the outdoor environment due to the temperature differences between indoor and outdoor environment (i.e. due to the fact that the heated air normally transfers from hotter to colder environment). In addition, the absorption of solar radiation from outside or loss of heat from indoor environment through building envelope components such as windows, external walls, floors and roofs are highly in relation with proper design of envelope components and the use of materials. Accordingly, employing high thermal mass, thermal insulation in roofs, external walls as well as implementing insulated glazing and window frames are the most influential passive strategies to control building indoor condition and are significant in heat loss reduction in under heated periods respectively [115-118].

2.4 External Wall Design in Hot and Humid Climate

In the design of building external walls, the analysis of the type and category of the envelope, along with the materials and techniques of construction in accordance with the architecture of the context and context's climatic condition, should be considered from the very early stage of building design. Generally, the building envelope can be categorized into two main categories as opaque and transparent.

In any of these cases, different design strategies, materials, and construction techniques should be applied to have successful solar control in buildings of hot and humid climates [119-127] which are the most important factors in the design of building external walls in general (Fig. 2.4).

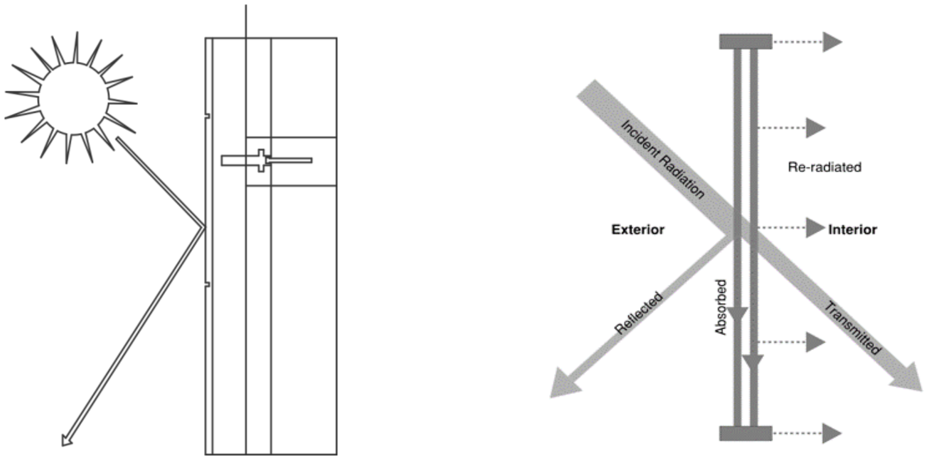


Figure 2.2: Reflective Surface to Reduce Heat Gain (Source: Author)

To avoid the issues emanate from excessive heat transfer in overheated periods, one of the most efficient and well-known techniques is to insulate building external walls [128]. To have a comprehensive overview on how thermal insulation behaves against heat gain and heat loss in different periods of the year, thermal insulation materials, their heat transfer mechanism, and heat behavior will be introduced and discussed in the following sections.

2.4.1 Thermal Insulation

The term isolation in a building refers to covering the surface of the roofs, walls, and floors to prevent the penetration of heat, moisture and water by using efficient materials. Insulation layer/s mostly consist of materials that are resistive against the stated factors and may be employed as a single or multi-layered [129-133]. Therefore, insulation can play a very important role in keeping the building warm in winter and keeping it cool during the summer. However, insulation can work properly if they are properly selected and installed based on their potential and heat performances.

2.4.2 Thermal Insulation Heat Performance

Thermal insulation mechanism and heat performance can be described based on the value of heat transfer through building surfaces and can be obtained by the following equation:

$$k = q / A (\Delta T) \qquad \text{(eq. 2.1. [134])}$$

Where (k) is heat transfer coefficient; (q) is the amount of transferred heat; (A) is the surface to which heat is transferred from or to and (Δ T) is the difference in temperature between the indoor and outdoor surfaces and the surrounding fluid.

2.4.3 Thermal Insulation Materials Resistance Indicators

There are two main indicators for evaluating the heat performance of the insulation materials and insulation as a unit system, defined as R and U values [135]. Both are main indicators and have a converse relationship with each other as shown in the following equation:

$$U = \frac{1}{R} = \frac{QA}{\Delta T} = \frac{K}{L} \qquad \text{(eq.2.2 [135])}$$

In general, the greater R-value is more efficient and this fact is vice versa for the U-value. Additionally, to calculate the R-value, the following equation (eq.2.4) can be connected to the previous one (eq.2.3) as a complementary source:

$R = \Delta T / Q_A$ (eq.2.3 [135])

In addition to U and R-values which consider as the main thermal indicators for insulation materials, there are other two important indicators as time lag and decrement factor. The classification and types of insulation materials have a direct impact on the values of time lag and decrement factor. The following picture shows the mechanism and relationship of the time lag and decrements factor as a unit system (Fig. 2.3).

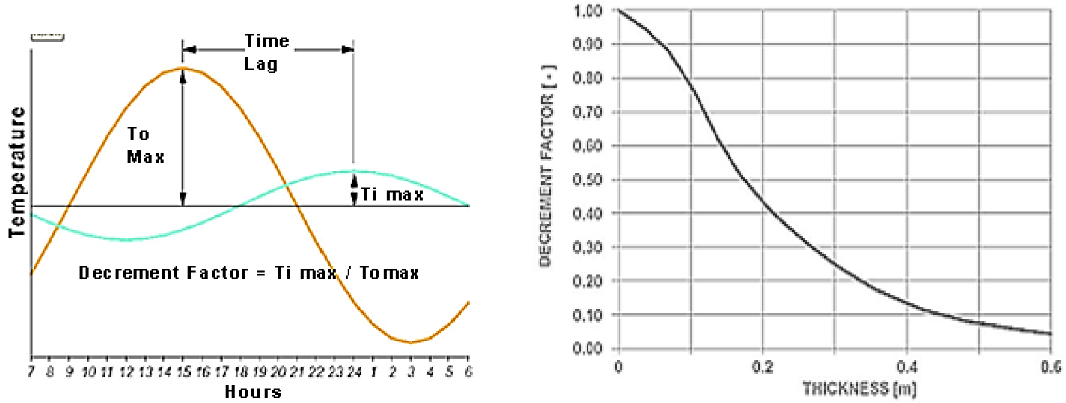


Figure 2.3: Time lag (left) and Decrement Factor (right) Diagrams [135]

2.4.4 Thermal Insulations Classification

The characteristic of thermal insulation is mainly determined by its composition. In general, there are three types of insulating system as resistive, capacitive and reflective. According to Pongsuwan [136] thermal insulations materials can be studied from three main aspects and are classified in terms of basic materials and composites, produced in different forms and thermal resistance (Fig. 2.4).

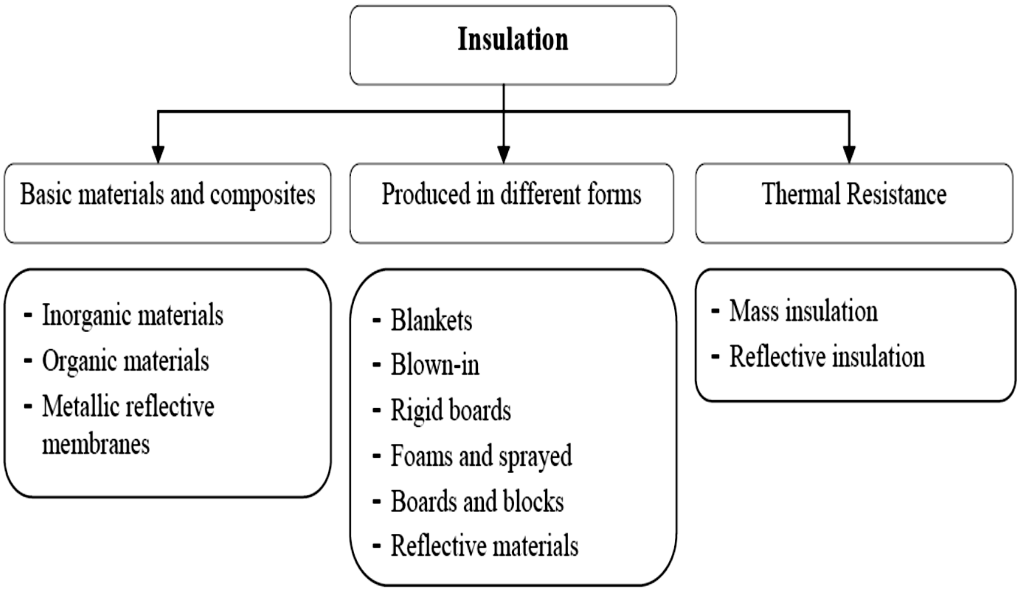


Figure 2.4: The Classification of Thermal Insulation Materials from Different Aspects [136]

The most important factors for the selection of insulating materials are based on:

- Thermal insulation materials with high R-Value and/or low U-Value
- Organic materials which are environmentally friendly and do not cause toxics
- Thermal insulation materials which prevent moisture transfer in humid climate condition by using water vapors retarder properties

2.4.5 Suitable Insulation Materials for Hot and Humid Climate

Suitable thermal insulation and insulation materials in hot and humid climates are discussed in the following research works [100,105,129,130,133,137-140]. In general, materials like polystyrene, polyurethane, glass wool and rock wool are the most proper and efficient materials suitable for the hot and humid climatic condition [141-143].

2.4.6 Location of the Insulation Material

The most important characteristic of insulation materials in buildings is reducing the amount of heat to be gain and heat to be lost in different periods of the year. In practice, insulation layer and the application of the suitable materials for wall constructions can be used in the middle of the wall mass as well as facing outside of the mass part [144].

To Ozel and Pihitli [145], the optimized order and configuration of thermal insulation in external walls of a building are based on dividing insulation into three equal layers (with same thickness) and place them externally, internally and at the middle sides of a wall respectively. However, to Al-Sanea and Zedan [146], placing the insulation material externally and as a single layer gives a better thermal behavior results in reducing the cooling load in summer as well as heating loads in the winter time.

There are numerous researches carried out on the location of thermal insulation in buildings [147-151]. However, the outcome varies due to the different influential factors such as climate, building orientation, building form, neighbouring elements, and type of thermal mass as well as insulating materials characteristics.

2.4.7 Thickness of Insulation Materials

In designing efficient external walls to reduce the amount of energy consumption in general and provide thermal comfort in particular, the optimum insulation thickness is very important. Based on the literature review [152-157] the proper thickness of insulating materials in wall constructions varies between 5 cm to 10 cm depending on the climate condition, cost and efficiency of the peripheral materials.

2.5 External Wall Constructions

The role of walls in a building is to separate existing spaces in order to create variable functions. In general and considering the function, building walls are categorized in two main groups of internal and external while these two groups also can be categorized in some other sub-groups based on their structure and construction technique as load bearing and non-load bearing walls [158].

As the name suggests, the load-bearing walls refer to the walls that carry the whole structural loads of the buildings and have a crucial role in maintaining building stability while it is vice versa for the non-load bearing walls as they only separates the spaces and define internal functions. Accordingly, due to the most connection of external walls with the outdoor environment and climatic factors, the design strategy, construction techniques as well as used materials are three main factors that affect heat and structural behaviors of the entire external walls [159]. In the following sections, a comprehensive overview of external walls classification is discussed.

2.5.1 Systematic Classification of the Wall Constructions

Talking about wall constructions, there are many categories, groups and types are available as it was briefly stated in the previous section. However, to have a systematic categorization and with respect to the existing wall types, they can be classified into five main groups in terms of construction techniques [160], regardless of the materials, as follow:

1. Masonry walls (Fig. 2.5 a)
2. Frame walls (Fig. 2.5 b)
3. Cladding walls (Fig. 2.5 c)
4. Sandwich walls (Fig. 2.5 d)
5. Stud walls (Fig. 2.5 e)

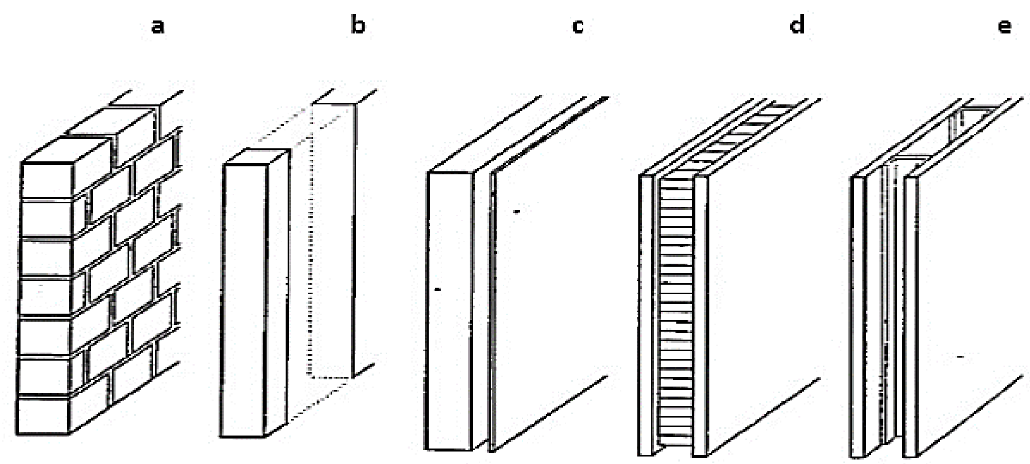


Figure 2.5: Wall Classification in terms of Construction Techniques [160]

2.5.2 Masonry Walls

Masonry walls are recognized to be a type of structure, which is used in the construction of independent units in one layer where the mortar is used in between. Usually, in the construction of the masonry walls, materials such as bricks, cement blocks, glass blocks, plaster, cement, and tiles are used [160]. However, in rare cases, a masonry structure is also implemented without the use of mortar, and in this method, which is the most basic type of building structure and refers to the centuries ago, only pieces of stone or block are placed on each other. It is clear that this method has very low resistance and is only used for temporary or low-value buildings or walls [161].

2.5.3 Frame Walls

Nowadays, framed walls are the most frequently used construction systems worldwide and are investigated through many research works considering different aspects from structure to thermal behavior [162-166]. Three most important types of frame walls are including:

- Framed walls made of Steel
- Frame walls made of Timber
- Framed walls made of concrete

Framed walls are a combination of mentioned materials as the main frame and the gypsum or cement board plates that install in between of the wooden or steel frames.

2.5.4 Cladding Walls

Cladding walls mostly used in the buildings' facade and for the purpose of the second skin or as the double and/or second layer of the envelope [167-169]. The most commonly used cladding materials are:

- Aluminum
- Timber

Apart from the structure, cladding walls are also used as an insulator in passive designs to keep the cool or heated air between the cladding material and the wall due to the potential that the envelope form in general and cladding walls, in particular, create [170-172].

2.5.5 Sandwich Walls

The types of sandwich walls commonly refer to the walls that are composed of multi-layered lightweight materials, and on both sides, bounded by two layers of the sheet while there is a layer of insulation in between. Sandwich walls are mainly lightweight and flexible while they are not considered as load-bearing types. The internal panels are usually produced from materials such as polyurethane, polystyrene, rock wool and fiberglass [173].

2.5.6 Stud Walls

Stud walls generally are comprised of two main parts including the insulation core and pre-welded steel networks (i.e., mesh), that encompasses the insulation core by the connection of wire trusses [174]. In rare cases gypsum panels or lightweight concrete boards replace with insulation core, depending on the wall function as well as wall position in the building [175].

2.6 Summary of the Literature Review

The efficient design of building external walls for a hot and humid climate is the key concept to have sustainable buildings by decreasing the demand for energy, improving thermal quality of the indoor environments, reducing the costs and controlling moisture diffusion.

Reviewing the literature over external wall design in hot and humid climate shows that many methods use the passive design strategies most of which addressed the subject from material and construction technique perspectives for energy conserving objectives.

In this context a categorized list of previous research works is prepared [176-200] and based on four main evaluation criterion that this study deals with, a table is presented (Table 2.1) indicating what are the research gaps and what methods and materials scholars were employed evaluating and selecting wall constructions in hot and humid climates.

Table 2.1: Categorization of the Research Works in terms of Evaluation Criteria

Evaluation criterion	**Reference Number**
Energy saving	[176], [177], [178], [179], [180], [181], [182], [183], [144], [147], [184], [150], [185], [186], [187], [188], [189], [152], [190], [191], [192], [193]
Thermal comfort	[188]
Moisture control	[194], [195], [196], [197], [198], [199], [200]
Cost efficiency	[144], [147], [184], [150], 189], [152], [190], [191], [192], [193]

Based on the numbers of previous research works (listed in Table 2.1) and by considering the evaluation criteria that the scholars employed in the works, it can be deducted that almost all of the stated studies have investigated the subject based on 1 or maximum 2 evaluation criterion which in all, the consideration of energy measures as the most important evaluation criteria is significant.

As a results, almost none of the listed works have considered the entire evaluation criterion that this study strives to deal with like 1- energy saving; 2- thermal comfort; 3- moisture control; 4- cost efficiency, and almost none have mentioned the advantages of considering multi-factor optimization and evaluation criterion methods in an independent research work.

In addition, the subject of the user and its comfort in the built environment was not totally addressed since most of the studies were based on mechanical viewpoints that dealt only with energy measures and the quantities.

2.7 Summary of the Chapter

In this chapter, energy saving in buildings besides thermal comfort and thermal comfort problems in hot and humid climate were investigated and the strategies to cope with such issues were identified such as heat gain reduction in overheated periods besides heat loss reduction in under heated periods.

The chapter continued by discussing design principles of external wall constructions in hot and humid climate and different passive strategies such as the incorporation of different types of thermal insulation in wall construction.

To summarize, the discussed capabilities were including the efficient location of thermal insulation, efficient thickness, and efficient materials to be integrated with the walls' mass.

In the following, a comprehensive wall construction investigation was conducted classifying external walls in terms of different characteristics such as structure, construction techniques as well as implemented materials. Accordingly, the entire description and suggested solutions were made to reduce energy consumption while maintaining thermal comfort within buildings in a hot and humid climate.

Further, the chapter has come up with a description of different wall constructions including masonry walls, solid walls, cavity walls, cladding walls, framed walls, sandwich walls, studying walls and etc. Moreover, to end the chapter the summary of the literature review was added as a section which highlighted the main evaluation criteria employed by the previous research works deducting on what are the gaps in the realm of external wall construction design and selection in hot and humid climate and finally, what this study exactly strive to deal with in the upcoming chapter.

Chapter 3

METHODOLOGY

3.1 Introduction

The methodology is a set of general principles of methods that, in any situation, should be converted into a particular scheme appropriate to that state. A set of routines, techniques, tools, and documentation that scholars trying to implement as a new system. Technically, the methodology consists of various stages that each in turn comprised of the sub-stages. With the help of the hierarchical process, researchers can at any stage select the appropriate tools and methods to manage, control and evaluate their research findings. When researchers decide to carry out research works, they usually employ or develop a method or methodology. In this context, sometimes, the question arises that the method is a suitable term or methodology? The issue is so controversial when the American Heritage Dictionary (AHD) points out that the term "methodology and method" has a serious difference, and although they have been used in recent years, scientists and the experts should be aware of this issue at least in the scientific realm, even if this difference is not taken into account in public discussions.

In the first chapter, the research methods that were used to collect and observe data were discussed. However, in this chapter, the methodology of research, retrieved from existing methods, As a result, the outcome represents a multi-factor optimization model for the comparative selection of optimum wall constructions for buildings in hot and humid climate. It should be noted that the developed model is processed based on four main evaluation criterion namely energy saving; thermal comfort; moisture control and cost efficiency.

3.2 Methodology

According to the problem statement as well as the aim and objectives stated in the first chapter of this study, a methodology is designed in 7 phases (i.e., 1- literature survey; 2- climate analysis; 3- field survey; 4- defining evaluation criterion; 5- localization; 6- simulation; 7- final assessment and decision making) developing a model for comparative selection of opaque external wall constructions for buildings in hot and humid climates (Fig.3.1). As a matter of fact, this model has been taken into consideration in the light of most commonly used methods and approaches (merging them as a group of key criterion) to be used by architects and designers.

In the following sections, the hierarchy that leads to the development of the model will be discussed by highlighting the methods and their phase sequences. It should be noted that the first phase of the methodology (i.e. literature survey) is done previously and presented in the first and second chapter (part by part) to give an overview on the subject, particularly to identify the research problem, aim and objectives, evaluation criterion as well as the research tools. In the following, after presenting the workflow diagram of the methodology (Fig. 3.1), each and every phases (i.e., from 1 to 7) will be explained and discussed in sections 3.2.1 to 3.2.6 while at the end of each section a summary workflow presents the phasing procedure.

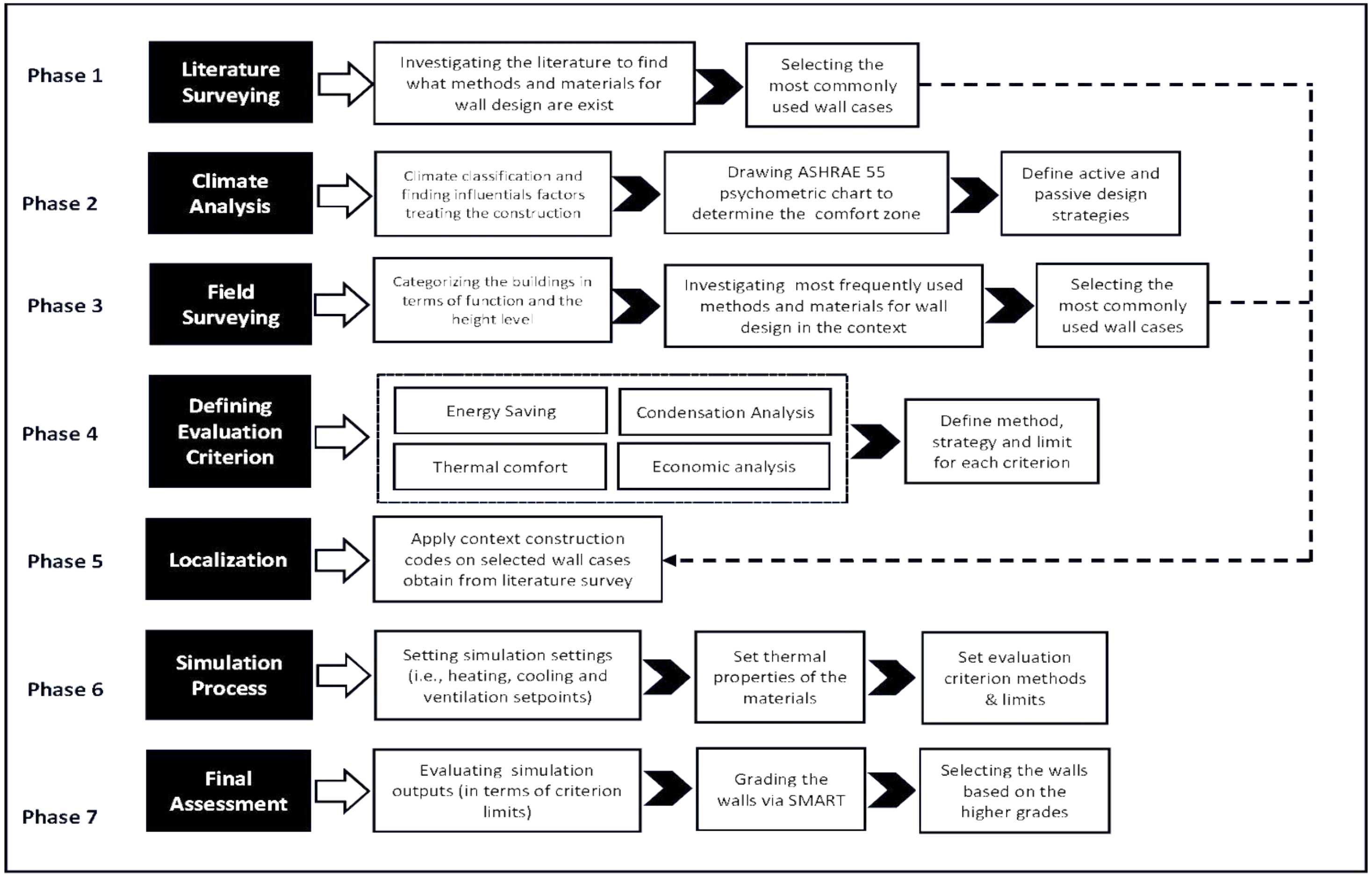


Figure 3.1: Methodology Work Flow

3.2.1 Climate Analysis

The second phase of the methodology as shown in (Fig. 3.1) is to identify the context climatic condition (i.e., climate classification) for comprehensive weather analysis. However, the first step towards is to have the weather classified. There are numerous methods have been introduced by the researchers to identify and classify the climatic condition. Among all, Koppen climate classification [201] is one of the most known and reliable methods for classifying the climates. It divides the world's climate into five main groups along with twenty-four sub-groups based on rainfall amount, vegetation and the temperatures (Table. 3.1).

Table 3.1: Koppen Climate Classification Main Groups & Sub Groups [201].

Main Groups	Sub-groups 1	Sub-groups 2
A (Tropical)	f (Rain forest); m (Mansoon); w (Savana, Wet); S (Savana, Dry)	
B (Arid)	w (Desert); s (Steppe)	h (Hot); k (Cold); n (with frequent fog)
C (Temperate)	S (Dry summer); w (Dry winter); f (without dry season)	a (Hot summer); b (Warm summer); c (Cold summer)
D (Cold continental)	S (Dry summer); w (Dry winter); f (without dry season)	a (Hot summer); b (Warm summer); c (Cold summer); d (Very cold winter)
E (Polar)	T (Tundra); F (Eternal winter (ice cap)	

After identifying the field study climatic condition through the Koppen classification table, it should be analyzed in order to define the comfort zone includes passive and active strategies to achieve thermal comfort within the building. There are various climate analysis methods which the most famous and applicable one refers to the psychometric chart (Fig. 3.2) recommended by Szokolay [202]. The Psychometric chart can be drawn manually or via computer simulation tools. Both methods, consider active and passive design strategies for achieving thermal comfort within the building.

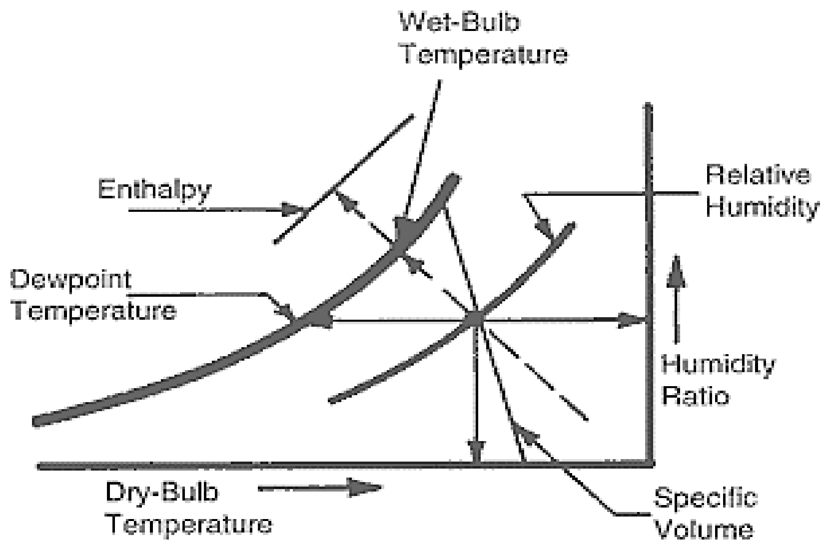


Figure 3.2: Psychometric Chart Main Indicators [202]

Defining passive and active design strategies for a climate responsive building is one of the most important steps towards energy saving and meeting thermal comfort for building's occupants.

As explained in the previous section, using the psychometric chart, is a must to determine the comfort zone of the building in the selected context, and if the chart is done by software, the active and passive strategies will be recommended by the software itself. The main active strategies that can be retrieved from the psychometric chart are heating and cooling (via mechanical air-conditioning devices) along with de-humidification with the same plant when relative humidity levels exceed the permissible level. Besides active strategies, passive strategies can be used in three main areas including shading, thermal mass and natural ventilation. The summary of phase 2 (i.e., climate analysis) is presented in Fig. 3.3.

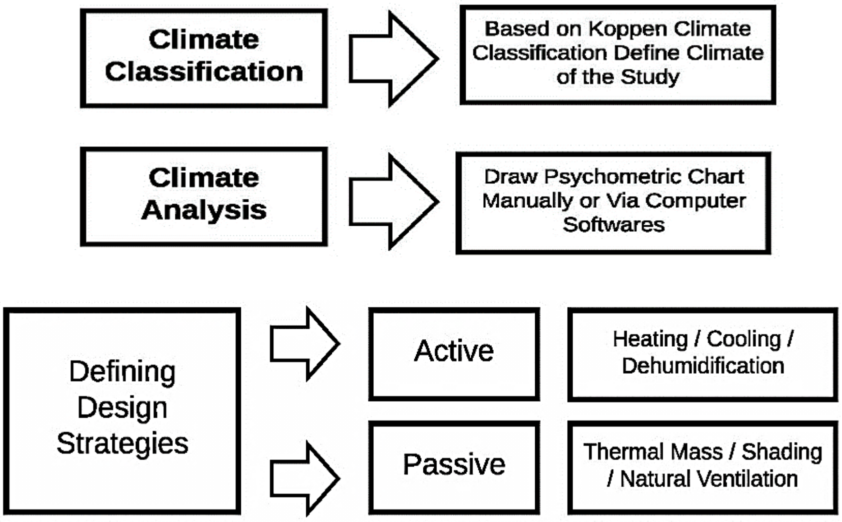


Figure 3.3: The Summary of the Phase 2 Work Flow

3.2.2 Field Survey

Surveying the field study can provide significant information about construction systems, types of structure, used materials, building function, building typology, occupant's patterns and etc. In general, buildings can be categorized based on their application and types of services they offer to the users. As such, the present study have categorized the existing buildings in the field study based on six main functions including residential buildings, office buildings, commercial buildings, educational buildings, service buildings, and industrial buildings. In all categories and applications, the energy saving and thermal comfort need to be considered parallel to the type of service that the building should provide for the users. Furthermore, each building category needs to define schedule and occupancy patterns (occupancy hours), from residential to industrial and educational.

For instance, residential buildings offer unlimited or continuous service (24 hours) due to the needs of the occupants while industrial buildings service to the workers mostly in the daytime.

Apart from the function, types of services and the occupancy patterns, buildings can be classified in terms of structure and the height level. The present study categorized the buildings into three main categories in terms of height level. Accordingly, three and/or fewer than three-story buildings are generally considered as residential buildings or house villas. The next category is a building of more than three stories and a height of fewer than eight stories which this study has placed them in the category of apartments, and in the end, buildings with a height of more than eight stories. These buildings' types consider as high-rise buildings or most known as the towers.

As a matter fact, the height of the buildings has a significant role in designing strategies consistent with providing thermal comfort and energy saving, which should be taken into account from the very first steps of the design process. The discussed classification is necessary since each building type, according to the form and the height level uses walls that act in accordance with its structure as well as the application. For instance, in high-rise buildings and towers in particular, walls with heavyweight materials are not commonly used. Hence, it is tried to implement thin envelopes or walls with lightweight materials filling external surfaces to decrease the structural loads of such building types. Showing the procedure of this section, the summary of phase 3 is presented in (Fig. 3.4).

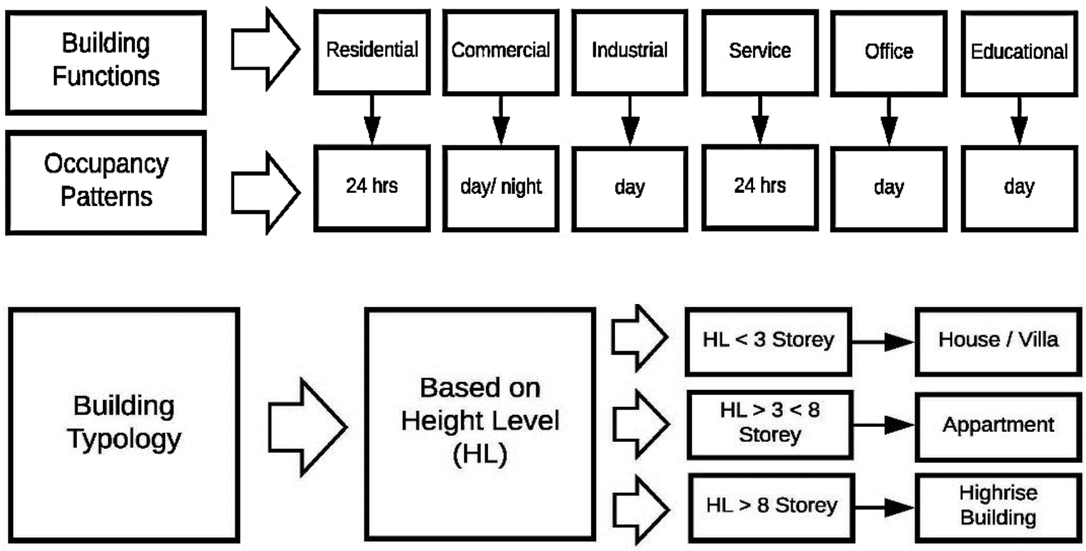


Figure 3.4: The Summary of the Phase 3 Work Flow

3.2.3 Defining Evaluation Criterion

Based on Phase 4 of the methodology, the evaluation criterion, methods of assessments, as well as the limits, must be defined as the core concept of the model. Accordingly, in the following sections, the main four evaluation criterion along with their methods of assessments that this study strives to deal with will be introduced and discussed in detail.

3.2.3.1 Energy Saving

Energy saving refers to saving or/and conserving energy while having the same quality and services. The total and saved amount of energy can be achieved by using different thermal calculation methods such as steady state, transient and dynamic, to predict the amount of energy required for building operations; heating and cooling in particular.

Dynamic thermal simulation commonly carried out via computer-based simulations using a three dimensional model of a building to simulate its thermal behavior hourly based on the weather data file which should be attached as the primary inputs at the early stage of the simulation process [203].

Simulating external wall constructions in a hot and humid climate condition, the importance of moisture control and moisture behavior in wall surfaces should accurately be considered in detail.

3.2.3.2 Thermal Comfort

As stated previously in the second chapter, thermal comfort is another evaluation criteria that should be paid much attention when constructing a building in severe climatic condition. There are two known models for calculation of thermal comfort in buildings namely Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), established by Fanger [204] and recommended by ASHRAE standard 55 [205]. The model gives Predicted Mean Voted (PMV) in accordance with the scales listed in (Table 3.2) as follows:

Table 3.2: ASHRAE Thermal Sensation Scales for the PMV Models [205]

Cold	Cool	Slightly Cool	Neutral (Comfort Range)	Slightly Warm	Warm	Hot
-3	-2	-1	-0.5 0 +0.5	+1	+2	+3

As specified in (Table 3.2) the amount of (- 0.5 to + 0.5) are recognized as the comfort scale range for air-conditioned buildings as “acceptable thermal environment for general comfort” [205].

3.2.3.3 Moisture Control in Building

When talking about the thermal calculations of the exterior walls of a building, the discussion of moisture control and Water Vapor Condensation (WVC) is one of the key factors that should definitely be considered as one of the characteristics of an appropriate and optimal wall of the building.

The WVC commonly occurs when the external surfaces of the building (walls and roofs) are exposed to significant temperature fluctuations and humid condition. Accordingly, water vapor transfers from the colder external surface, where the building surfaces expose to moisture, both internally and externally [206].

Moisture condensation occurs in building wall surfaces mostly when they integrated with an insulation layer. One of the most known methods for condensation assessment is the steady-state Glaser method [207]. Based on Glaser method, the condensed water should not exceed 1.0 kg/m^3, beyond which damage may occur in wall surfaces. Accordingly, the following variables should be taken into consideration:

- Max. external air temperature
- Min. internal air temperature
- Max. mean monthly humidity
- Relative humidity
- External/internal surface temperatures
- Condensation period

It should be highlighted that the Glaser method is based on the sol-air temperature which affected the external surface of the building walls measured continuously half-hour interval during a year. In this study, evaluations are based on the maximum and minimum grade of these values to find out if there is condensation risk for simulated wall constructions.

3.2.3.4 Cost Efficiency

Talking about cost efficiency for a building or building component, etc., the Life Cycle Cost Analysis (LCCA) is a comprehensive approach to assess the initial costs versus the productivity of a building, component, etc. These costs include the initial cost of building materials, systems, as well as the cost of building maintenance, retrofitting, HVAC efficiency and etc. An analysis of the cost of a building's life cycle is useful when the initial costs and operating costs are significantly different. Hence, selecting the type of materials, systems, and services must be in a way that maximizes the net savings [208]. For example, the use of a system or high-performance material or component's system that may increase the initial cost should result in a significant reduction in operating costs.

It should be highlighted that Life Cycle Cost Analysis (LCCA) differs from Life Cycle Analysis (LCA) since the LCA encompasses a wider scope including the aforementioned parameters associated with the environmental impacts' costs.

One of the most applicable methods for analyzing the life cycle cost is to calculate amortization time period. The amortization time period can be obtained by the following equation:

$$F = \frac{C}{B} \qquad \text{(eq. 3.1 [208])}$$

Where (F) is any building component, material, system, etc cost coefficient; (C) is the cost difference between any building component, material, system, etc. compared to the same type with the lowest budget; (B) is the annual saving of any building component, material, system, etc. compared to the same type with the lowest budget [186]. In the context of the LCC, the obtained values should be used for the following equation calculating the amortization time period as:

$$y = \frac{\log\left[1 - F\left(\frac{i - f}{1 + f + r}\right)\right]}{\log\left(\frac{1 + f}{1 + i}\right)} \qquad \text{(eq.3.2. [208])}$$

Where (y) is amortization time period, here considered for each wall constructions; (F) is the coefficient value; (i) is refers to the annual rate of interest; (f) refers to the studied region's rate of inflation and lastly, (r) is the cost for the maintenance.

3.2.4 Localization

For the purpose of localization and as a primary stage, the present study recommends the selection of the wall constructions based on two main strategies as it is specified in (Fig.3.1) through the dash lines. The first strategy relies on the cases suggested by the literature review.

In this direction, considering the context climate besides the building's function as well as building typology, the literature review suggests suitable wall cases compatible with the mentioned parameters. Hence for the purpose of this study, the aforementioned strategy of wall selection is considered as "via literature review". The second strategy relies on selecting suitable wall constructions based on a comprehensive field survey which will be called "via literature survey". In this way, the most commonly used wall constructions in the context will be identified through observation and will be added to the outcomes of the "via literature review" selected wall cases.

As a result, the selected wall constrictions (via two mentioned strategies) should be localized based on the context building codes. Moreover, the localization process contains the adoption of thermal properties of wall materials besides the thickness and location of thermal insulation if it is recommended by the context code. The summary of phase 5 is presented in (Fig. 3.5).

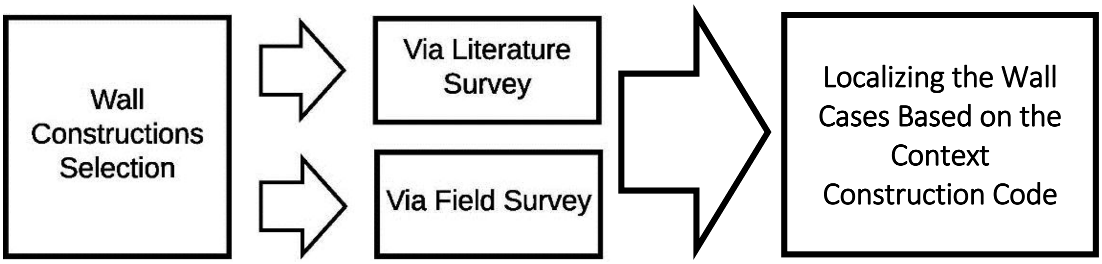


Figure 3.5: The Summary of Phase 5 Work Flow

3.2.5 Simulation Process

As it is mentioned in the methodology workflow (Fig.3.1), phase 6 is all about computer-based simulation and the inputs setting. Computer-based simulations are known methods for optimization and are able to create real conditions for thermal calculations of a building to predict the amount of energy consumed and the thermal behavior of the components. However, selecting relevant and most applicable software based on simulation objectives besides the organized and précised inputs setting are of the most important parts of a simulation which should be taken into account with each and every detail. Generally, simulation inputs can be defined in five main areas as it is shown in (Fig. 3.6).

Although simulation tools are intelligently based on the basic inputs (according to the climate, building codes, thermal standards, thermal properties of the materials and etc.) and they propose specific values for each variables (by default), the indicators and their limit value should be identified and adjusted manually (by referring to software material set and thermal properties library) in order to be set based on the simulation objectives. In figure 3.6 it is tried to indicate the number of common orders besides the set options as a whole.

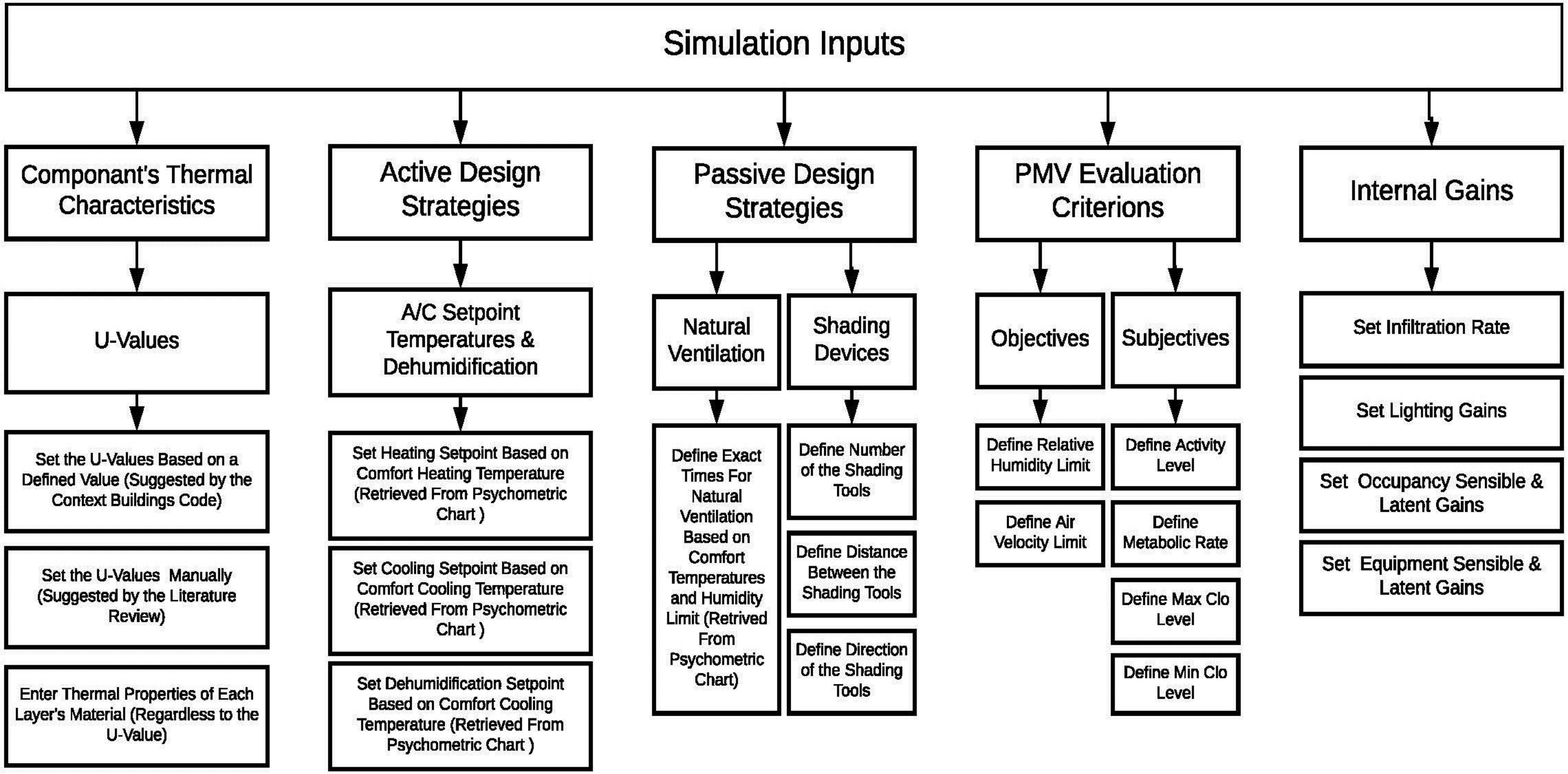


Figure 3.6: Simulation Inputs Setting Process

3.2.6 Final Assessment

In accordance with the study objectives, the outcome of the simulation for each selected wall construction should be evaluated in accordance with the entire evaluation criterion's methods of assessments' as well as the limits for each and every criteria to be used for a final assessment and decision-making process [209]. Therefore, if any of the wall cases meet the minimum requirements to be considered for the last stage of the assessment, they should be graded for decision-making process based on the Simple Multi-Attribute Rating Technique (SMART). The SMART was first introduced by Edwards and Barons [210] and in time revised and developed by Edwards and Newman in 1982 and Edwards in 1988.

The SMART was developed based on the theory that each alternative consists of some criterion that has values while each criterion has weights that describe its quality compared to other criteria. This weighting is used to assess the alternatives to obtain the best choice, grading them based on their performance grade. Accordingly, in the grading process, the highest grade obtains by the alternative with the highest performance and the grading will be followed by the alternatives with lower quality. Hence the number of alternatives define the highest grade and the grades follow the priority of order based on the alternative weight and performances.

Giving a simple example for a better understanding, if the entire criterion is taken as equally significant and there are 10 alternatives comparing in terms of 4 evaluation criterion, the highest grade an alternative can obtain is 10. Grades would be followed by alternatives with lower performance varies from 9 to 1 where at the end the total grade of each alternative is the summation of those 4 evaluation criterion grades and the alternative with the highest grade would be selected as the optimum one. It is also important to define the limit for each and every criteria so that if any alternative exceeds the limit then the grade would be considered as 0 with which has no value. The summary of stage six is presented in Fig. 3.7.

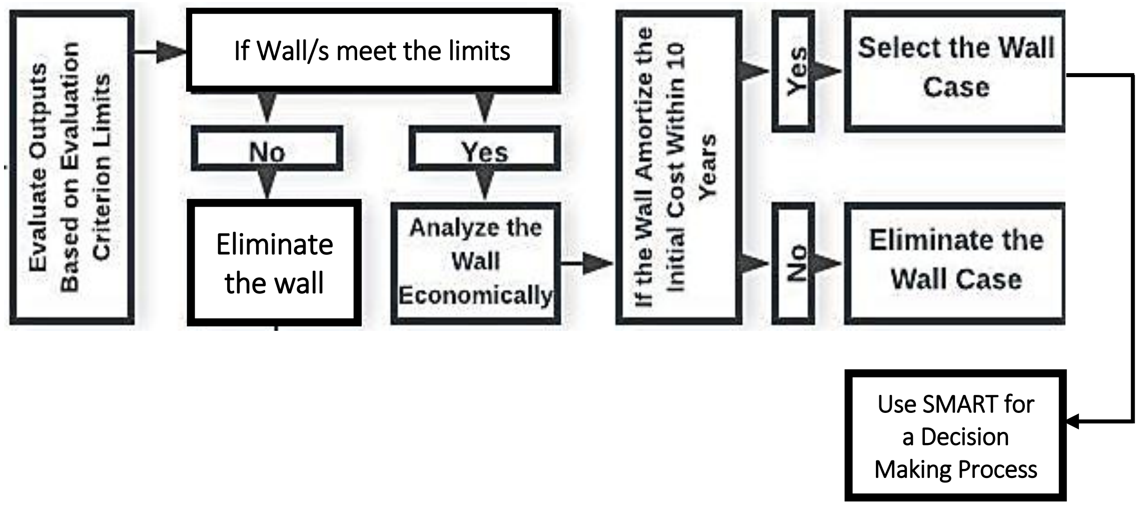


Figure 3.7: The summary of the Phase 7 Work Flow

3.3 The Model Conceptualization

According to the mentioned phases of the methodology and based on the discussed evaluation criterion along with the methods of their assessments as well as the localization process, a multi-factor optimization model for the selection of the opaque wall constructions in hot and humid climates is developed as the foremost purpose of the present study.

The model significance relies on the specification of evaluation criterion, their methods of assessments as well as the localization process of the wall cases via literature and field survey. Therefore, the model mainly strives to highlight the roles of above-mentioned items; how they come together as a whole for a process of building external walls' selection in hot and humid climates. Figure 3.8 shows the conceptual model of multi-factor optimization for selection of the opaque wall constructions in hot and humid climates comprised of fundamental parts and the items.

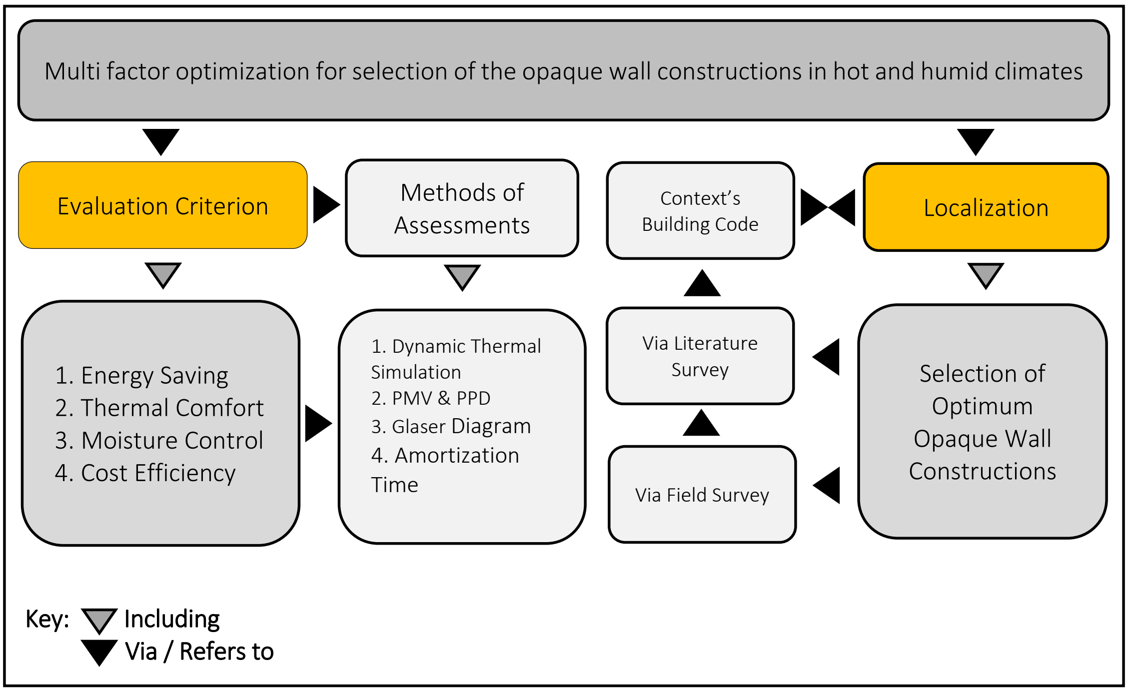


Figure 3.8: The Conceptual Model of Multi Factor Optimization for Selection of the Opaque Wall Constructions in Hot and Humid Climates

3.4 Summary of the Chapter

In this chapter, initially, in the form of a general methodology, the points for the case study to be considered in the entire process of the research and assessments were identified such as climate analysis; field survey; building typology as well as simulation process and the final assessments. Moreover, the main evaluation criterion based on the research aim and objectives including energy saving; thermal comfort; moisture control and cost efficiency besides the methods of their assessments and the limits were investigated in detail such as dynamic thermal simulation for energy saving; PMV model for thermal comfort assessments were taken into consideration.

The steady-state Glaser method for investigating the risk of condensation in building external walls and moisture control in buildings envelope was also discussed in brief. Lastly, the cost analysis through amortization time period calculation for cost efficiency was discussed and accordingly the affecting parameters such as building maintenance, energy calculations, the annual rate of interest and etc. The chapter then finalized by the developed multi-factor optimization model according to the discussed phases of the methodology and based on the mentioned evaluation criterion as well as the methods of their assessments.

In the following chapter, the entire phases that were discussed from sections 3.2.1 to 3.2.6 (phase 2 to phase 7) will be applied to the context and a selected case study in Kish Island, categorized by a hot and humid climate.

Chapter 4

THE STUDY

4.1 Introduction

Kish Island is one of the Persian Gulf islands and is part of the Kish region, Bandar Lengeh city in Hormozgan province and is one of the most famous places in Hormozgan province in southern Iran (Fig. 4.1), with longitude 53°58 East and latitude 26°32′ North. The shape of the island is elliptical and considers oceanic with an area of 44 km, with a length of about 15.45 km and a width of about 7.5 km, gives the area about 91.5 km^2 (Fig. 4.2). The highest area of the island is about 35 meters above sea level. Kish Island also lacks a permanent river and has a large number of underground freshwater resources [211]. The reason why this region is considered as the field study is for being a decent representative field of a hot and humid climate, where the cooling period is dominant and the use of mechanical cooling considers continuously. As a result, it gives a critical condition and is worth to deal with since energy saving, thermal comfort as well as moisture control are three out of four main evaluation criterion of this study.

In this chapter, after analyzing Kish Island climate and weather condition as the field study, the comfort design strategies that should be taken into consideration in this climate were defined and the study was continued by identifying the residential buildings in the Island. As a result of this section, a comprehensive building typology was conducted including houses, apartments as well as the high rise buildings and/or towers.

In the following, the study investigated the most commonly used construction techniques and building materials for wall construction in the context to highlight local rules and regulations. The entire findings were adopted for the next stage which is the simulation process.

All finds were used as simulation inputs including materials' thermal properties, building occupancy patterns, construction details as well as active and passive design strategies which firstly was defined for achieving thermal comfort within the buildings. The outputs then were evaluated in terms of the study evaluation criterion for the final assessments.

Figure 4.1: Kish Island Location on Iran’s Map (Source: Google Image)

Figure 4.2: Kish Island Location on Persian Gulf and Kish Island on Google Earth (Source: Google Image)

4.2 Kish Island Climatic Condition

Kish Island has hot and humid (semi-equatorial) climate [212]. Climatic studies in Kish Island show that overheated periods decrease from the beginning of October, and until April, very pleasant weather is available. Since then, the heat is increasing and by the end of the summer (August in particular), it gradually reaches the highest level, which needs continuous (i.e., 24 hours) cooling in the buildings.

The rainfall level on Kish Island is very low, so the vegetation of the island is composed of species that are more resistant to dehydration as well as warm and severe climatic conditions. The particular climatic location of the island, like other parts of the Persian Gulf, causes the relative humidity of the air to rise; almost at most in the year.

The humid condition begins gradually in April and lasts up to January. At some point in the year, and especially late in the summer, the degree of humidity reaches the extent that its symptoms on the vegetation of the island and the impenetrable levels of the rock can be seen every morning as if the rainy night falls on the island's surface.

4.3 Kish Island Climate Analysis

The climate consultant (V.6) software [213-216] was employed for the entire weather analysis. For the purpose of this study, the energy plus weather “epw” data file was generated on the basis of the latitude and longitude of Kish Island and arranged via Metronome (V.7.1) software. Consequently, the climate consultant outputs used in this section contain Kish temperature range diagram (Fig. 4.3), dry bulb and relative humidity diagram (Fig. 4.4), climate calendar (Fig. 4.5), psychometric chart (Fig. 4.6) as well as the wind rose diagram (Fig. 4.7) [217, 222].

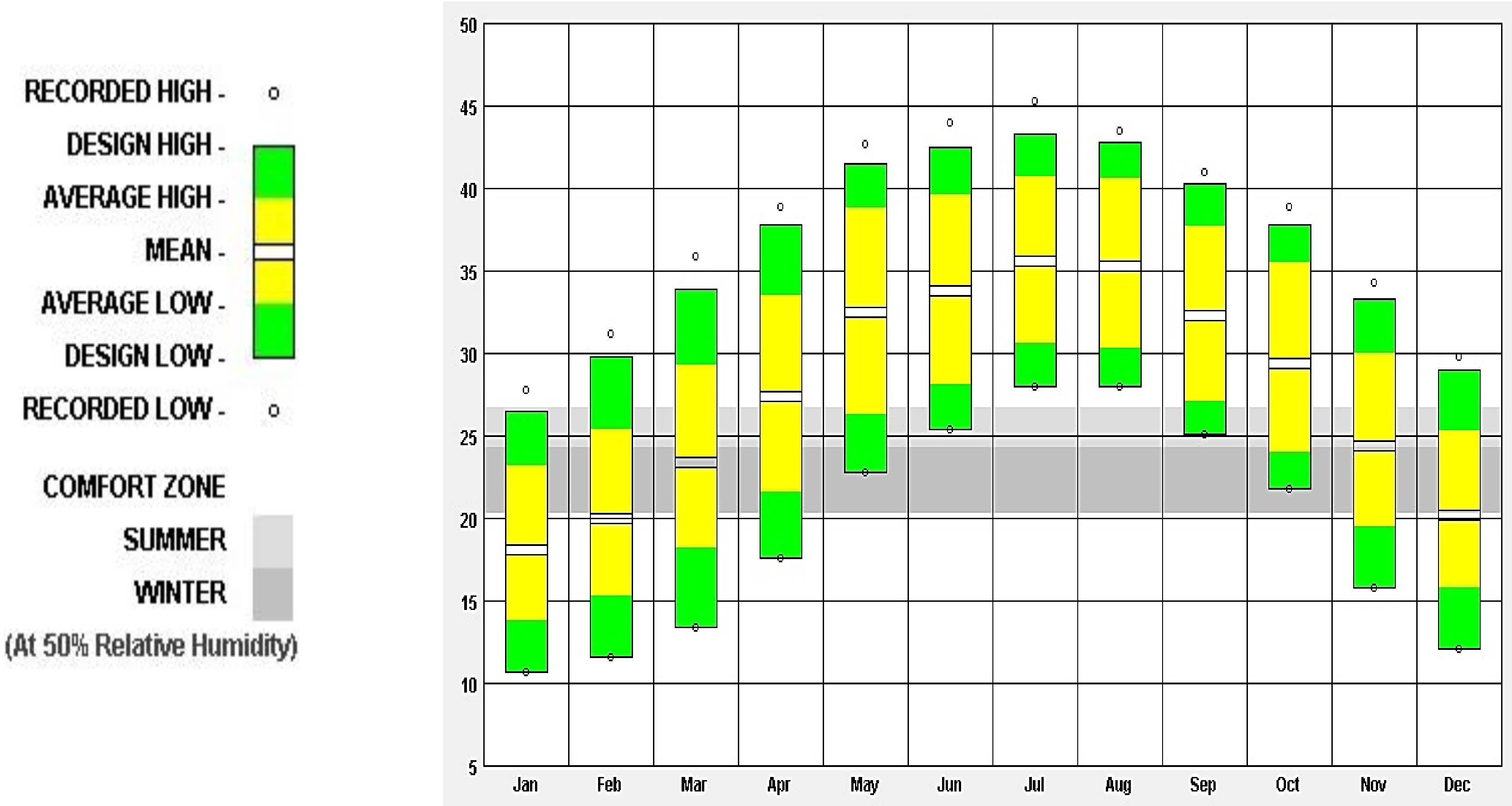


Figure 4.3: Temperature Range Diagram (Source: Climate Consultant)

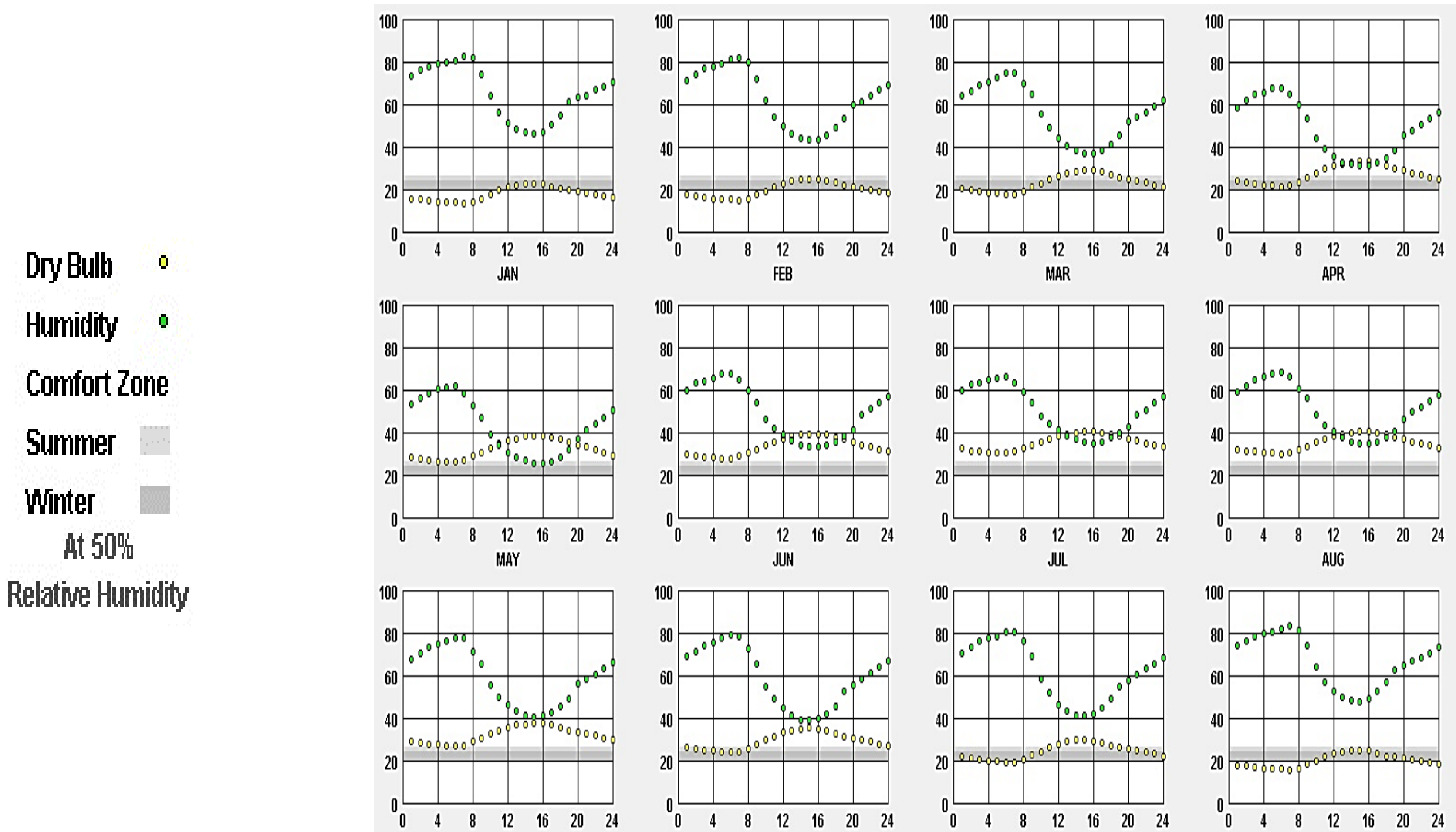


Figure 4.4: Dry Bulb and Relative Humidity Diagram (Source: Climate Consultant)

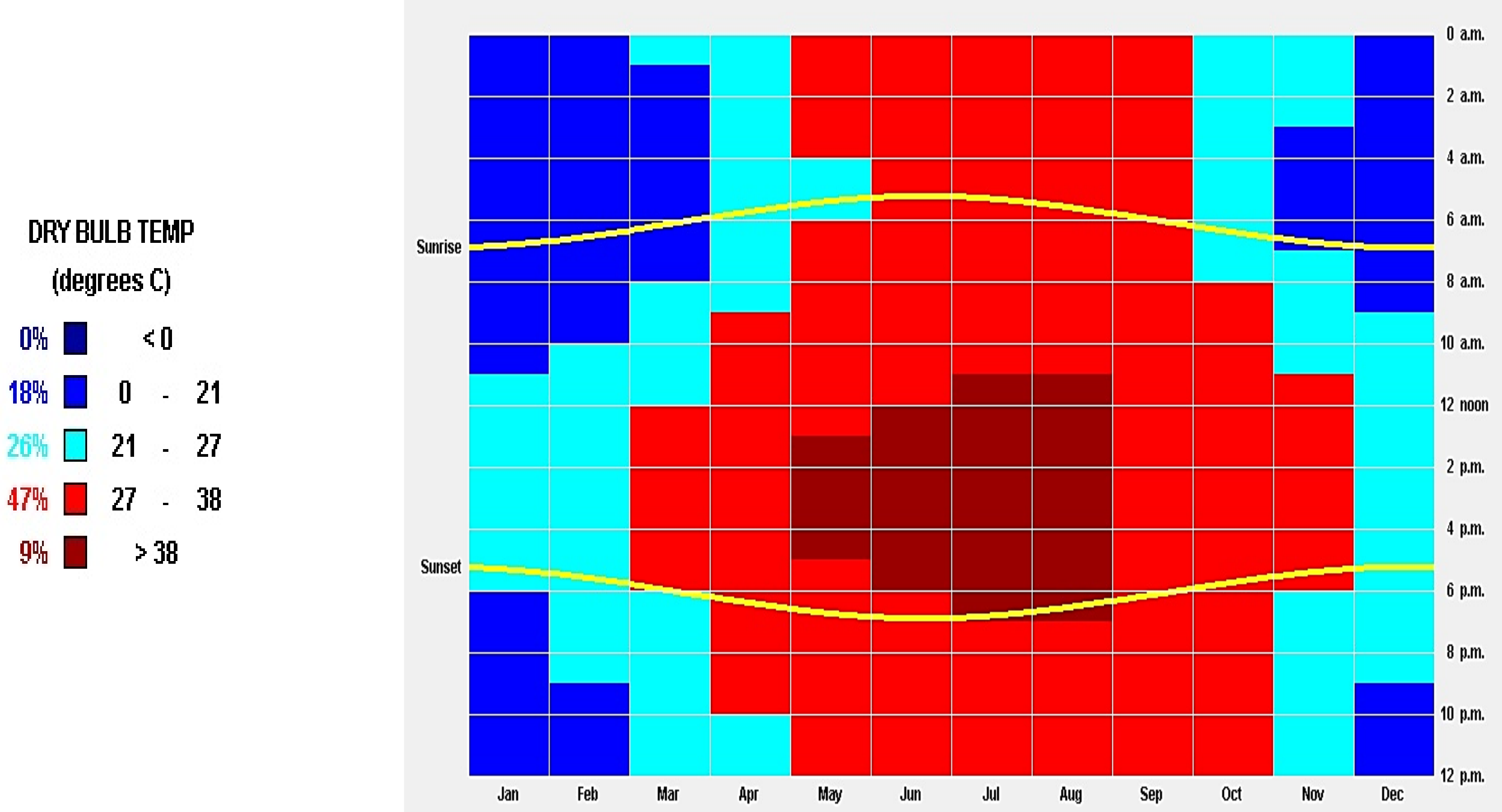


Figure 4.5: Kish Climate Calendar (Source: Climate Consultant Software)

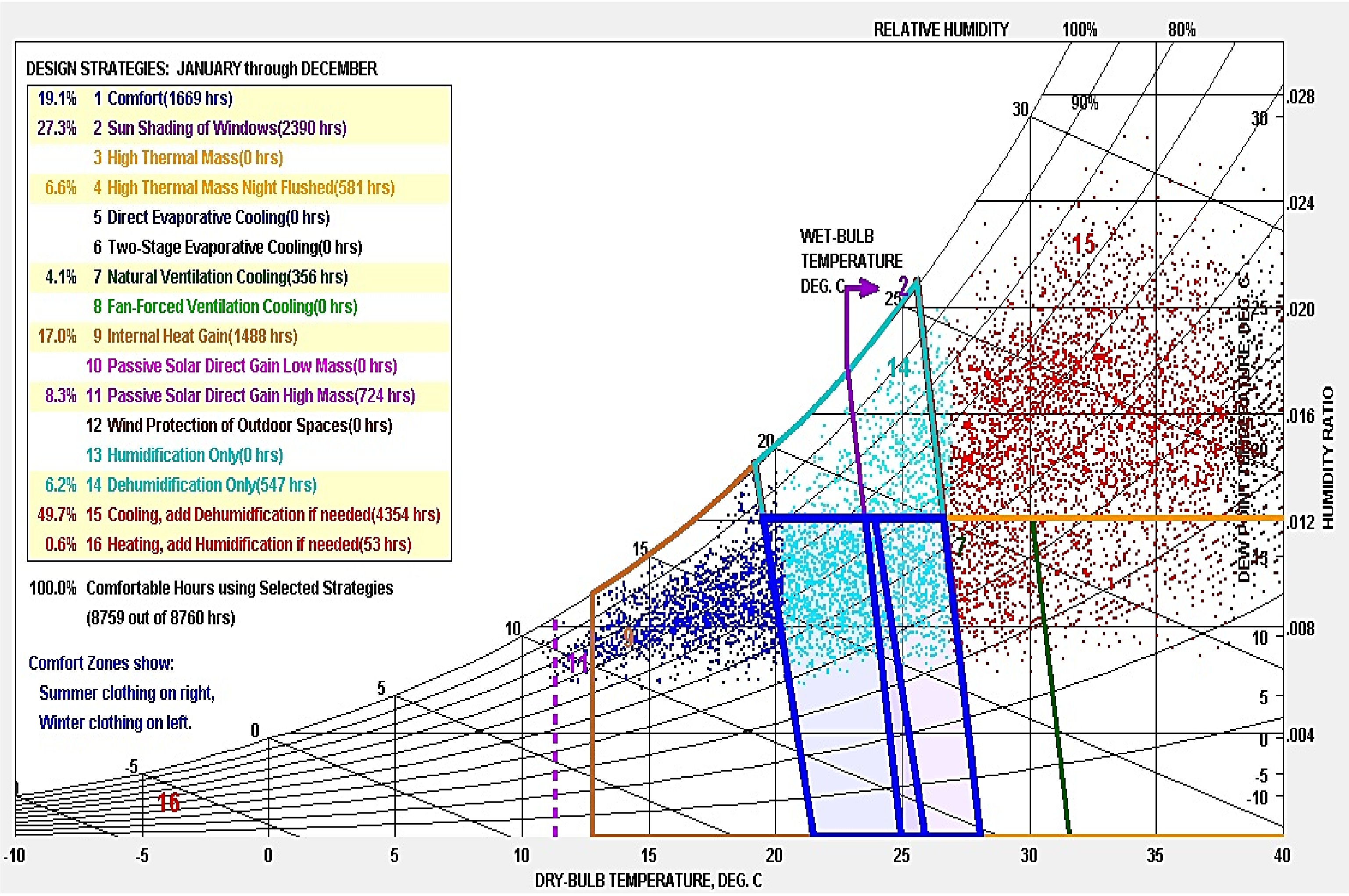


Figure 4.6: Kish Psychometric Chart (Source: Climate Consultant Software)

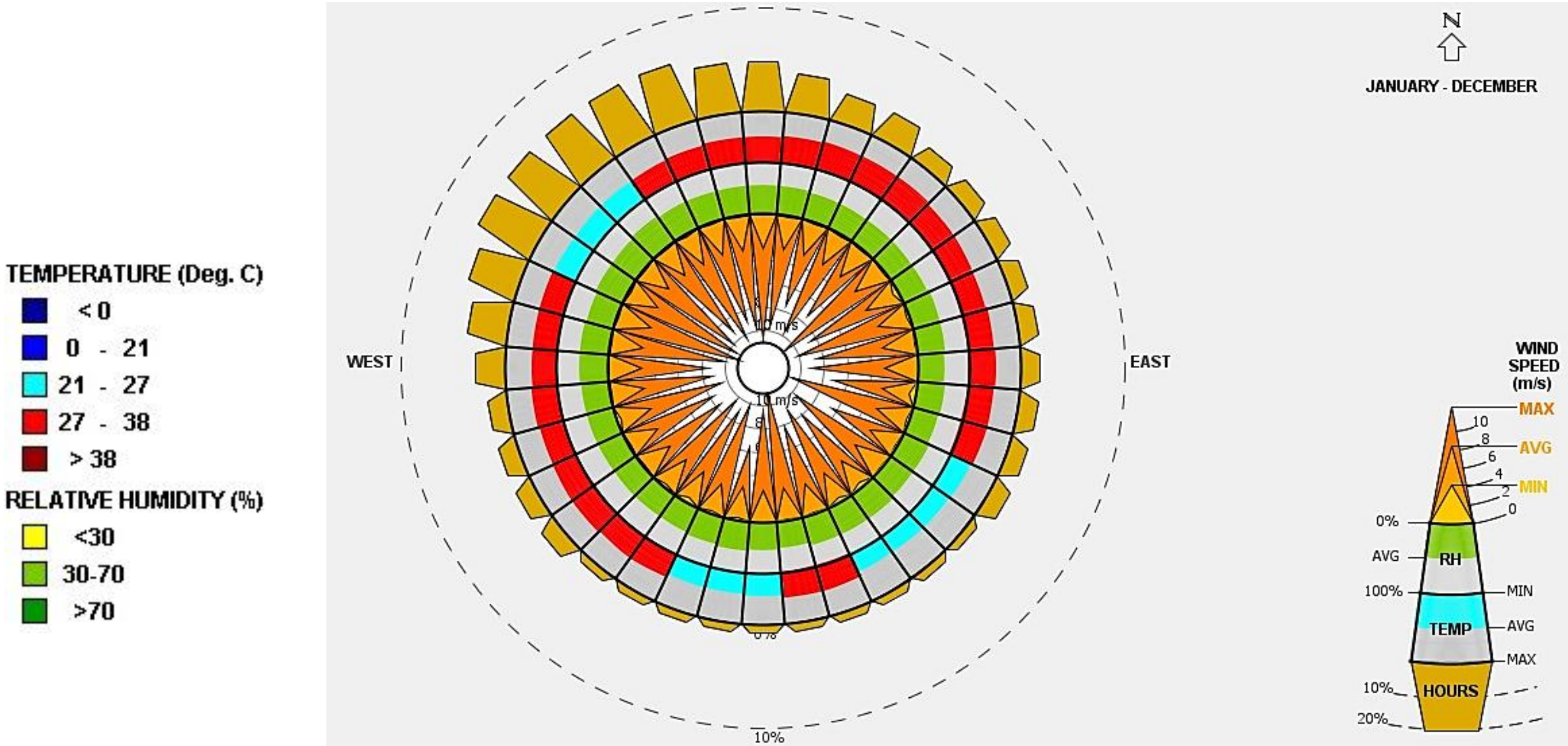


Figure 4.7: Wind Rose Diagram (Source: Climate Consultant Software)

By considering the climate calendar of Kish Island which is shown in (Fig. 4.5) the outside dry bulb temperature in 18% of the year is between 0°C to 21°C. It is additionally indicated that there is no specified time in a year that dropped into the comfort zone without the need for mechanical heating or cooling even a few hours.

In December the comfort condition is closed to the maximum when only early in the morning there is a need for heating indoor spaces (from 7 am to 9 am). Furthermore, it is the same in January and February when only a few hours more heating is needed (from 7 am to 10 am and 7 am to 11 am respectively). However, from May to September there is a need for cooling both for day and night time where 26% of the year the temperature is between 21° C to 27° C.

The critical condition is observed for 9% of the year-round when in July and August the temperature exceeds 38° C; day time only. Moreover, by considering the wind rose diagram of Kish Island which is shown in (Fig. 4.7) the Northwest wind (8 m/s) with temperatures varies from 21° C to 27° C and humidity of 30% to 70%, are considered the dominant and pleasant winds in the Island.

In the consequence, based on the psychometric chart of Kish Island which is shown in (Fig.4.6) besides climatic analysis of the context, the passive and active design strategies that should be taken into consideration providing thermal comfort in Kish Island buildings are shown in Table 4.1.

Table 4.1: Comfort Strategies for Kish Island Based on Climate Calendar & Psychometric Chart (Drown by the Author)

Months	Active & Passive Strategies						
	Shading	Natural Ventilation	Air Conditioning		Dehumidification	Thermal Mass	Solar Gain
			Heating	Cooling			
JAN	—	(12 am-4 pm)	(7-10 am)	—	×	×	×
FEB	—	(11 am-5 pm)	(7-11 am)	—	×	×	×
MAR	×	(8-11 am, 7pm-1 am)	×	E.N.V.P	×	—	—
APR	×	(10 pm-10 am)	—	E.N.V.P	—	—	—
MAY	×	—	—	×	—	—	—
JUN	×	—	—	×	—	—	—
JUL	×	—	—	×	—	—	—
AUG	×	—	—	×	×	—	—
SEP	×	—	—	×	×	—	—
OCT	×	(12pm -7am)	—	E.N.V.P	×	—	—
NOV	×	(7 pm-3 am, 9-11 am)	—	E.N.V.P	×	—	—
DEC	—	(12 am-7 pm)	(7-9 am)	—	×	×	×

∗E.N.V.P: Excluding Natural Ventilation Periods

4.4 Field Survey

A field survey was carried out from September 2017 to March 2018 in order to identify the buildings of Kish Island. Based on the observations there are three main types of buildings in the context that can be categorized as houses, apartments and the towers (See Fig. 4.8).

Houses contained 2 stories, mostly with a living and dining room in addition to a WC and a kitchen in the first floor where bedroom/s are located in the second floor (Fig. 4.9).

Apartments include 2-3 stories which build on the top of the parking space locates in the ground floor (Fig. 4.10).

High-rise buildings (the towers) are above 8 stories and in the context, such buildings' type is mostly up to eighteen or in rare cases up to twenty-four stories (Fig. 4.11). For a targeted and detailed classification of the mentioned buildings in the context, a general typology has been made categorizing the buildings based on the specified key parameters (Table.4.2). The key parameters in this typology were considered as follow:

- Area: the approximate area of the common buildings type in the context from minimum to maximum;
- Story: from the minimum to the maximum for each building type;
- Flats in the story: only available for apartments and the towers;
- Window to Wall Ratio (WWR)
- Orientation: in the case of towers, there is no specified direction since the sea view determines the direction;

Figure 4.8: Types of Residential Buildings in Kish Island (Source: Google Earth and the Author)

In accordance with the observations in the context over construction techniques and commonly used materials for external surfaces (walls in particular), it was found that in most of the buildings, lightweight and masonry materials were used such as different types of brick (heavyweight, and hollowed) along with the cement lightweight aggregated blocks such as pumice and autoclaved aerated concrete (Fig. 4.12). As the sample and representatives of the context constructions, the number of observed cases is presented in (Fig.4.13).

Moreover, it should be reported that as the result of the field survey as well as observations there is an ancient city located in the rural part of the Island as “Harireh city” (Fig.4.14). Noticing the pictures clears that the buildings on that area used thick adobe (i.e., 40-50 cm) as the most commonly used material for the building exterior walls. It was because bulky walls have been considered as optimum cases with a high time lag and low decrement factor. Although nowadays adobe is replaced with thin lightweight materials such as brick or cement blocks it should not be neglected as an efficient wall material for hot and humid climate condition.

Table 4.2: Building Typology in Kish Island

Building Type	Storey	Area (m^2)	Flats in Storey	WWR (%)	Orientation
House	2	90-300	_	30-60	North-South
Apartment	2-4	50-120	2-4	20-50	North-South
Tower	8-24	60-470	4-16	70-90	To Seaside

Figure 4.9: Plan and Elevation of a Typical House in Kish Island

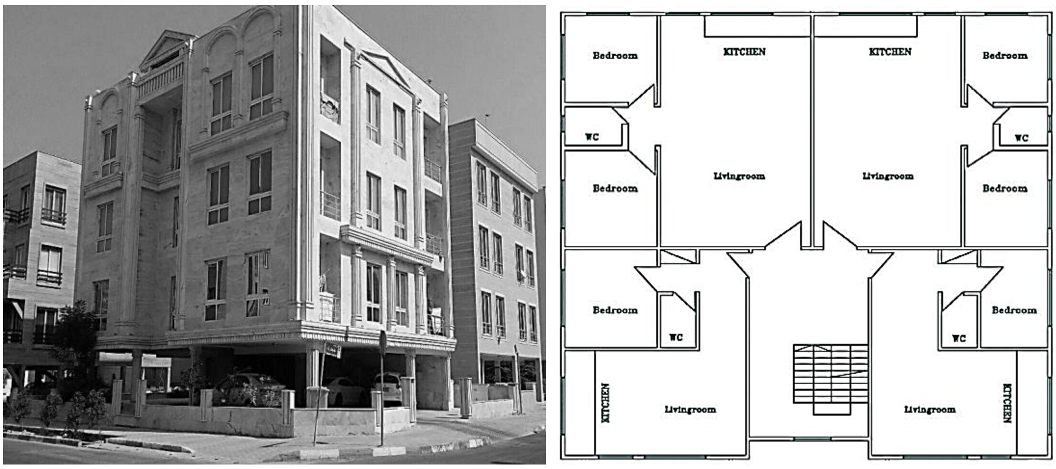


Figure 4.10: Plan and Elevation of a Typical Apt in Kish

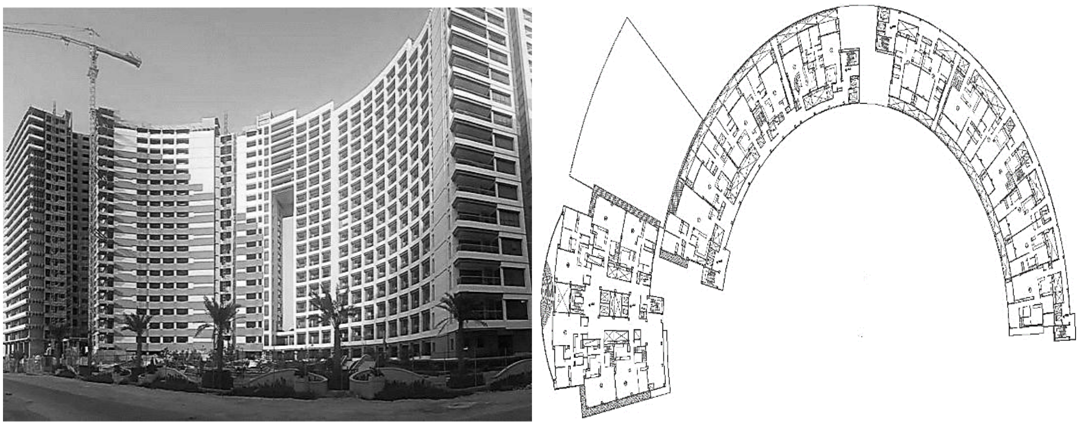


Figure 4.11: Plan and Elevation of Persian Beach Tower in Kish Island

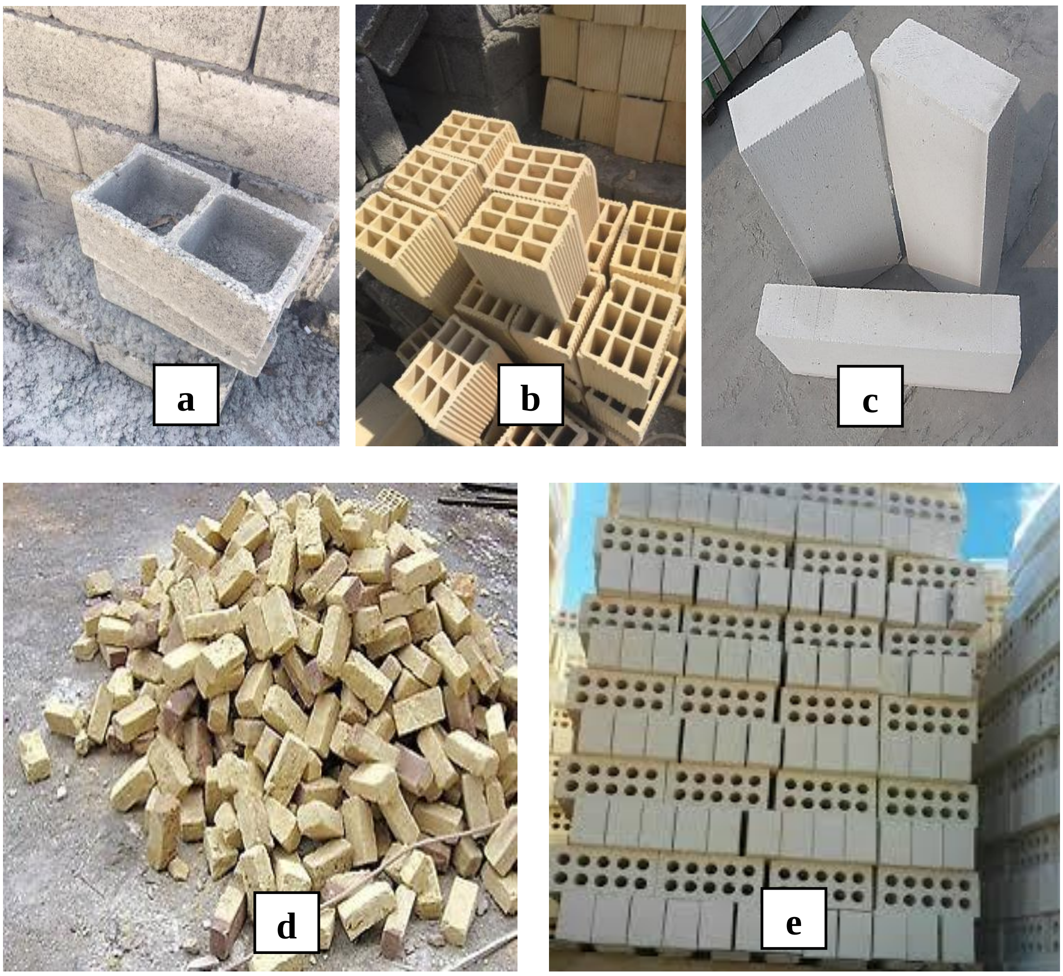


Figure 4.12: Commonly Used Materials in Kish Island; Lightweight Cement Block with Pumice Aggregate (a); Vertical Perforated Fired Clay Block (b); Autoclaved Aerated Concrete (AAC) Block (c); Fired Clay Solid Brick (d); Fired Clay Hollow Brick (e) (Source: Author)

Figure 4.13: Buildings and Constructions Including House, Apartment and the Towers in the Context (Source: Author)

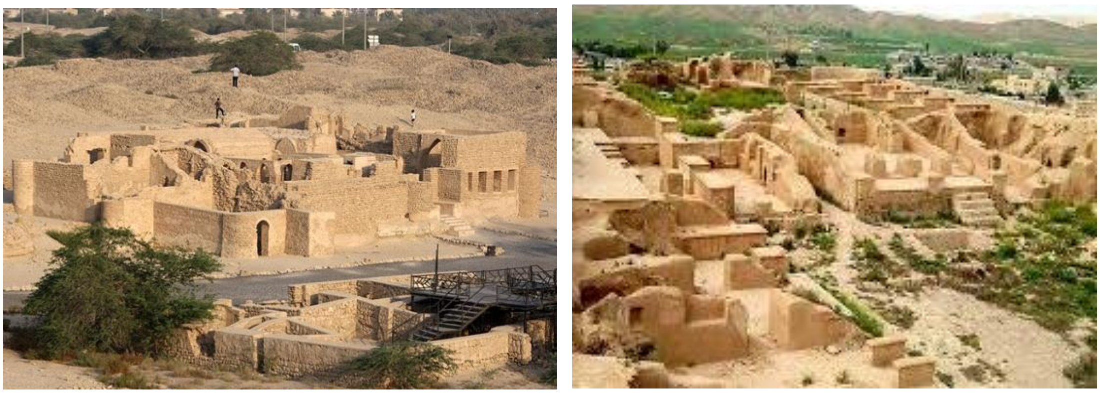


Figure 4.14: Harireh City in Rural Part of Kish Island (Source: Author)

Based on the field survey and typology of the residential buildings in Kish Island, it was found that apartments have more potential to work on in comparison with other two types of buildings (i.e. houses and the high-rise buildings) since they reflect more parameters compatible with the problem statement of the study including low WWR which gives a better condition for simulating different types of wall constructions selecting the optimum case/s among the others. Therefore the study here represents deal with the case study in this category.

4.4.1 Case Study Selection

As it was discussed in the previous section and in accordance with the key parameters of residential buildings in Kish Island, a second floor flat in a three-story apartment with the area of $63m^2$ including two bedrooms which is located in Kish Island central area was selected as the case study. The building exterior (Fig. 4.15) and architectural plan can be seen in (Fig.4.16; marked with the solid hatch).

Further to the discussed reasons why this case study was selected, it also was empty of occupants which provides complete access for the case survey (i.e., monitoring temperature and humidity data through a data logger for simulation inputs) as well as two of the flat external walls facing the exterior which gives more critical condition due to climatic factors adjacency. The case study thermal properties of the solid and transparent components are listed in Table 4.3.

Figure 4.15: Case Study External View (Source: Author)

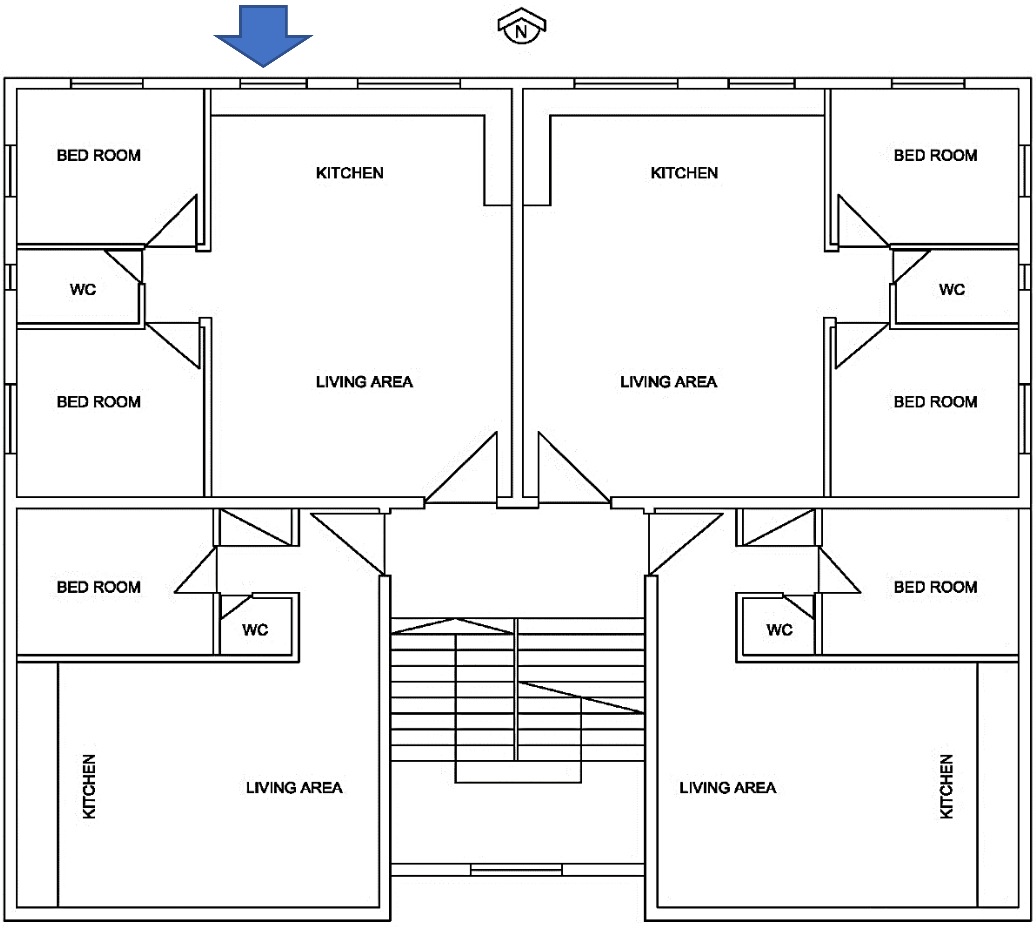


Figure 4.16: The Case Study Architectural Plan (Source: Author)

Table 4.3: The Case Study Components Data & Thermal Properties

Parameters	Description
Total Window Area	18.7 m^2
Shading Device	None
Overhang	None
Possibility of Natural Ventilation	Includes
Type of Window	Double glazing (pane)
Window Air Gap	6mm
Window Frame Thickness	5-8 cm
Window Frame Material	Aluminium
Window U-Value (W/m2-K)	3.91
Exterior Walls U-Value (W/m2-K)	1.34

4.4.2 Generating Context Weather Files

To make sure that the thermal simulations operate accurately, the employed dynamic inputs such as hourly weather data file must be reliable. There are two types of weather data file used in this study as annual and energy plus weather “epw”. The annual weather data file was prepared from a local weather station based in Kish Island airport. It is due to the fact that there is no official Meteorological Organization in Kish Island, hence, the task of collecting climatic data is on the local bases.

The prepared file includes dry bulb temperature; relative humidity; solar radiation; wind speed and etc. However, the “epw” data file for simulation tool running was generated via version 7.1 of Meteonorm software [233], using longitude and latitude of Kish Island (i.e., longitude 53°58 East and latitude 26°32′ North).

4.5 Computer Based Simulation

Dynamic thermal simulation was carried out using Design Builder software version 6.0 as the main research tool. It is worth mentioning that Design Builder uses energy plus engine for the outputs which are designed for three types of users such as energy assessors, architects, and engineers [234].

4.6 Simulation Results Validation

In order to validate the simulation outputs, the results were compared to generated weather data files including annual weather data file as well as a short time weather data file monitored and recorded by the author from March 3 to March 10, 2018, through an automatic temperature and humidity data logger shown in (Fig. 4.17) hanged on the case study's living room central wall. The short time weather data file is necessary for simulation results validation to indicate the difference between actual indoor weather condition and the indoor weather condition taken from software outputs (i.e. the epw weather file, which may contain error to some extent). The results of this comparison is presented in Fig. 4.18 to Fig. 4.21.

Figure 4.17: Data Logger

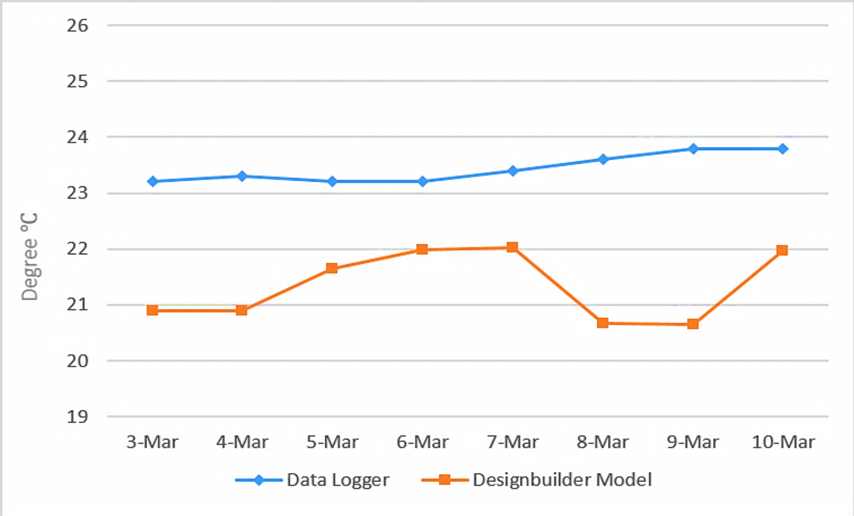


Figure 4.18: The Comparison of Data Logger Air Temp with Design Builder Model

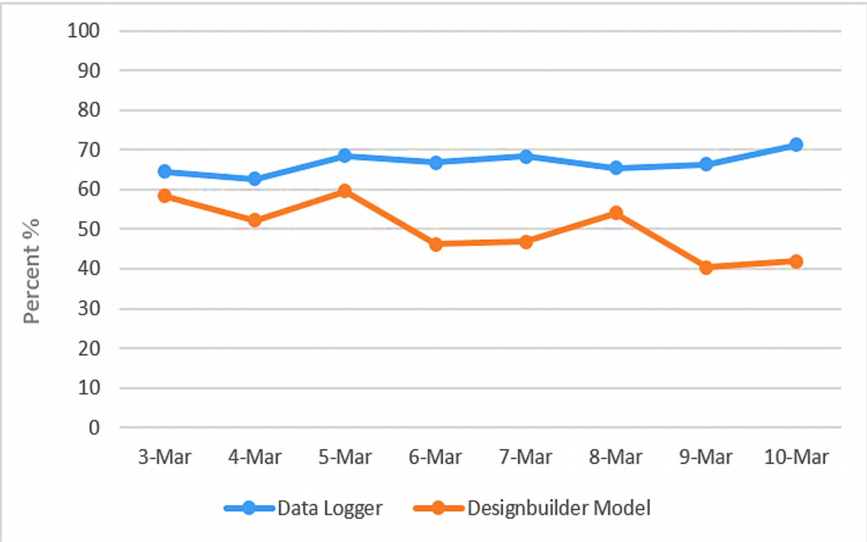


Figure 4.19: The Comparison of Data Logger Relative Humidity with Design Builder Model

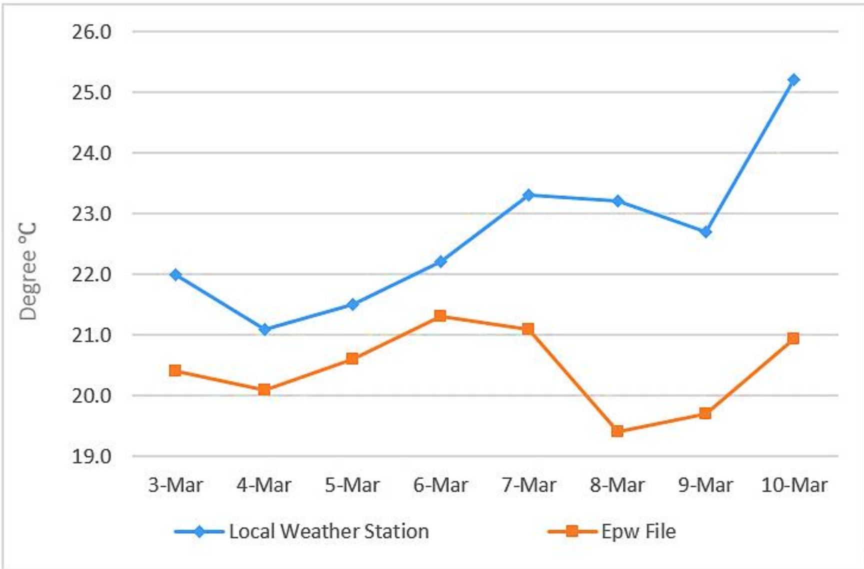


Figure 4.20: The Comparison of Local Weather Station Air Temperature with “epw” File

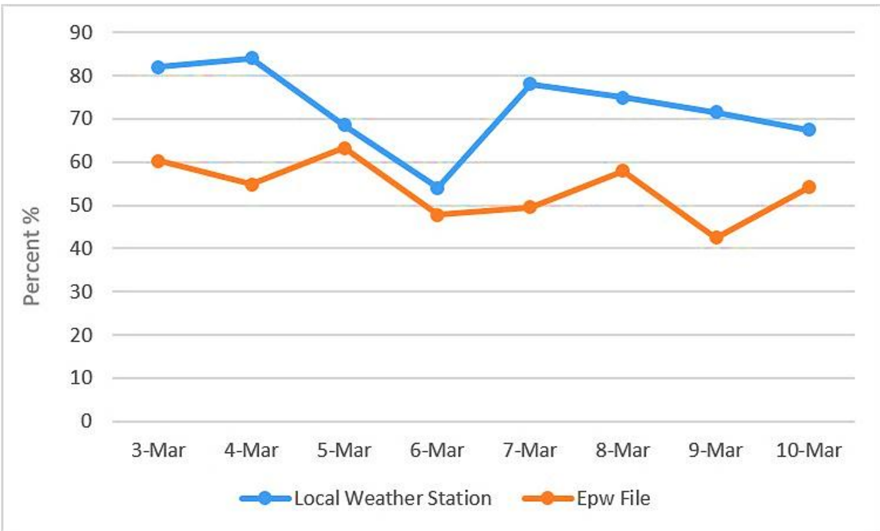


Figure 4.21: The Comparison of Local Weather Station Relative Humidity with “epw” File

As seen in (Figs.4.17 and 4.18), the average difference between data logger outputs and Design Builder simulated outputs for indoor air temperature and relative humidity is about 2 °C and 18% respectively. Accordingly, when the results are compared to the local weather station and “epw” file shown in (Figs.4.19 and 4.20), the average difference is about 2.2 °C for indoor air temperature and 20% for relative humidity.

A more detailed results validation is shown in Table 4.4, indicating the error percentage of data logger outputs and Design Builder simulated outputs, varies from 5.1% to 13.3% which confirms that the results of the simulation are reliable. For a better understanding and giving more information, the error percentage is obtained from the following relationship:

Error = (Data Logger outputs - Simulated outputs / Data Logger outputs) × 100 [235]

Table 4.4: The Average of the Data Logger and Simulated Indoor Temperature

Date	3 Mar	4 Mar	5 Mar	6 Mar	7 Mar	8 Mar	9 Mar	10 Mar
Data Logger (°C)	23.2	23.4	23.3	23.3	23.5	23.7	23.9	23.9
Simulated (°C)	20.9	20.8	21.7	22.1	22.2	20.8	20.7	22.1
Error (%)	9.9	11.1	6.8	5.1	5.5	12.2	13.3	7.5

4.7 Selection of the Wall Constructions and Localization

In many developed and developing countries, the construction sector has already initiated and established sustainable standards in order to improve the thermal performance of buildings via compliance to building codes.

In Iran, the Ministry of Housing and Urbanism devised Code No. 19 in 1991 [236], which proposed a series of guidelines to improve the energy performance of the buildings. In 2001, the code was totally revised in order to improve the methods and consideration. Based on the latest issue of code 19 (2001), external walls design and considerations should be as follow:

- Provide guidance for facilitating and matching the calculation method of the thermal insulation of the building envelope in accordance with the necessities;
- Adding technical data and numerical values needed to calculate the types of thermal bridges in the building external walls;
- Completion of the thermal data related to the materials and products used in the current construction of the country, as well as new products such as multilayered walls, passive wall systems, energy efficient coatings and, etc., to improve the thermal performance of the external walls of the buildings;

However, due to non-acquaintance of building specialists and controlling bodies with calculation methods inscribed in the code and unfamiliarity of constructors with methods of insulating building components, the code somehow remains inefficient. Further, the guidelines are still far from broadly used codes such as LEED, BREEAM, CASBEE, DGNB, etc. and needs to be improved. By the latest research, the foremost obstacles that code 19 faces with all revision efforts are:

- Lack of high-level aims and objectives, addressing the characteristics of Iranian buildings;
- Non-separation of rules for buildings in different climatic condition of the country;
- Failure to implement thermal comfort strategies and lack of consideration on user comfort condition;

In accordance with the field surveying conducted in Kish Island from September 2017 to March 2018, although this region categorized by a severe climatic condition (i.e., hot and humid), almost none of the construction projects use thermal insulation and above stated strategies for energy saving and improving thermal quality of the indoor environments. Therefore, in this section, regarding the most commonly used wall constructions in the context (walls 1-5; Fig.4.22) obtained via field survey while new alternatives are introduced as the result of a localization process based on the outcomes of previous studies and via literature survey (walls 6-10; Fig.4.22) suggesting the use of insulation as an efficient strategy for improving the thermal performance of the wall constructions in hot and humid climates [100, 105, 129, 130, 133, 137-143] as well as employing high time lag low decrement factor and bio-composite wall materials such as Adobe and/or different types of mud-bricks as efficient wall materials used in traditional architecture of hot and humid climates [180]. It should be noted that localizing the suggested strategies through the literature should be based on the context construction limits including prevalent materials and their thermo-physical properties of the wall constructions entirely based on construction guidelines and thermal insulation regulations of code 19 (2001). The entire wall sections along with their thermal properties are presented in (Fig 4.22) and Table 4.5.

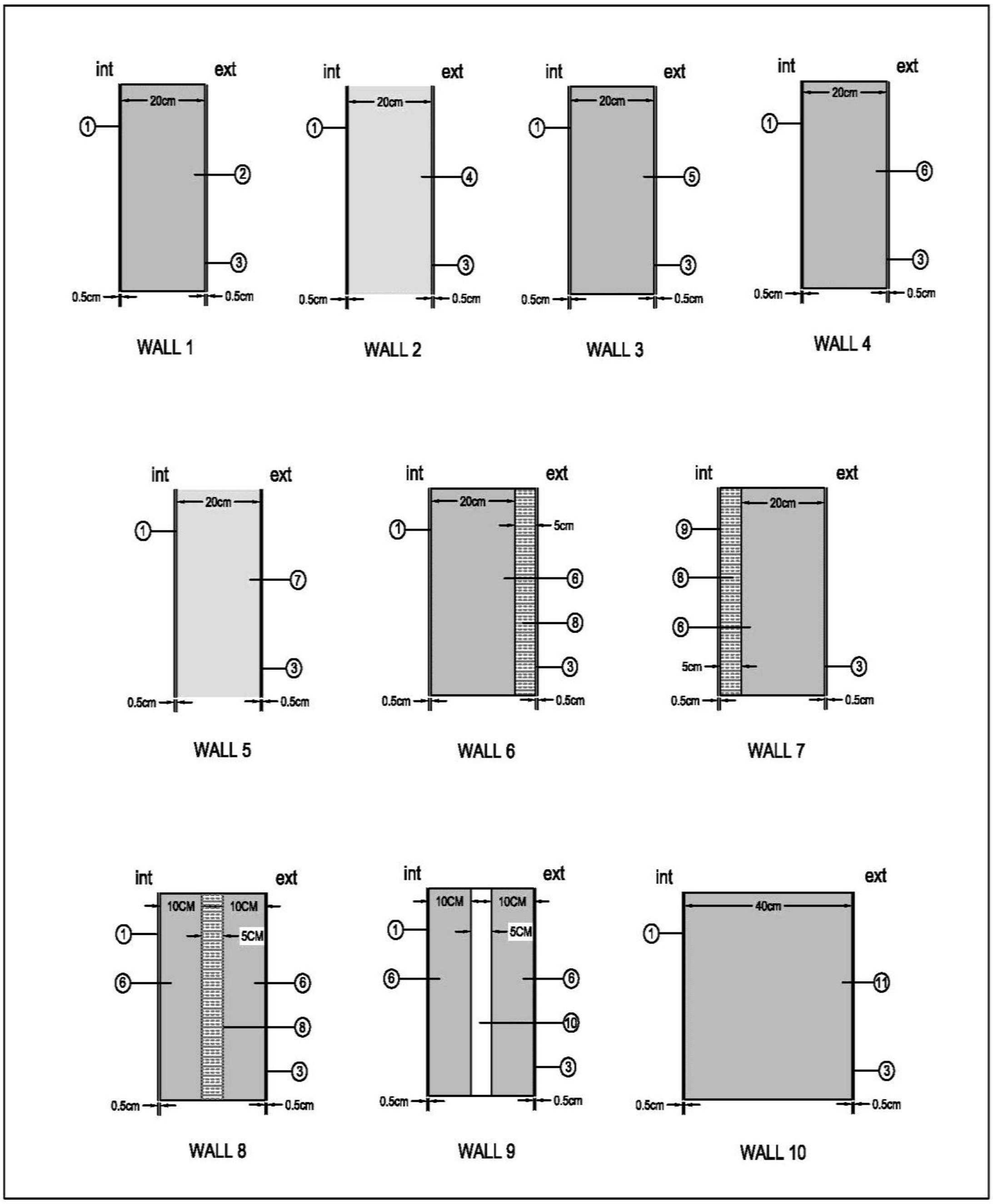


Figure 4.22: The Walls' Sections (Source: Author)

Table 4.5: Thermal Properties of the Walls' Materials (Source: Design Builder Material Liberary)

Material	Density (kg/m^3)	Conductivity (W/mK)	Specific Heat (J/kg °C)	Vapour Diffusion (factor)
1. Gypsum Plaster	900	0.46	1090	10.7
2. Fired Clay Hollow Brick	1200	0.80	840	8.0
3. Cement Plaster	1050	0.70	837	6.8
4. Vertical Perforated Fired Clay Block	950	0.59	880	7.6
5. Fired Clay Solid Brick	1300	0.84	820	8.2
6. Autoclaved Aerated Concrete (AAC) Block	700	0.18	1071	5.7
7. Lightweight Cement Block with Pumice Aggregate	800	0.20	769	6.8
8. Extruded Polystyrene Foam	40.8	0.036	1320	32
9. Gypsum Board	800	0.16	1090	11
10. Air Gap	-	-	-	1
11. Adobe	1420	0.35	840	9

4.8 Simulation Inputs

As it was discussed in case study section, a two-bedroom 63m^2 residential flat located in the central part of Kish Island was selected as the case study to examine walls 1-10 as its external wall constructions for simulation process.

With regard to the internal sources, four people were considered in the flat, with 120 W/person activity level. The occupancy schedule considered equivalent to the heat gains schedule. The internal gains are presented in Table 4.6. The HVAC system that was selected for the simulation is a split-system air conditioner; which was operated according to heating and cooling set point temperatures, 20°C and 25°C respectively. As a result, the energy requirement of the flat was equal to the amount of energy consumed by the HVAC, systems, excluding the auxiliary energy use, lighting, and Domestic Water Heater (DWH) systems.

Table 4.6: Simulation Internal Gains

Gain	Value
Infiltration	0.5 ACH
Lighting gain	12.0 W/m^2
Occupancy sensible gain	10.0 W/m^2
Occupancy latent gain	5. 0 W/m^2
Equipment sensible gain	15.0 W/m^2
Equipment latent gain	0.0 W/m^2
Pollutant generation	0.01 (CO2)/h/ m^2

For thermal comfort calculations, the PMV parameters were assumed to be as follows:

- Metabolic rate: 1.2 met
- External work: 0 w/m^2
- Relative humidity: 50%
- Air velocity: 0 m/s
- Max. clothing value: 0.8 clo
- Min. clothing value: 0.5 clo

It should be pointed out that the maximum and minimum clothing values for summer and winter were assigned to the hottest and coldest months of the year (July and January, respectively), and for the remaining ten months, the clothing level were assumed to vary from 0.5 clo to 0.8 clo depending on the outdoor temperature.

4.9 Results

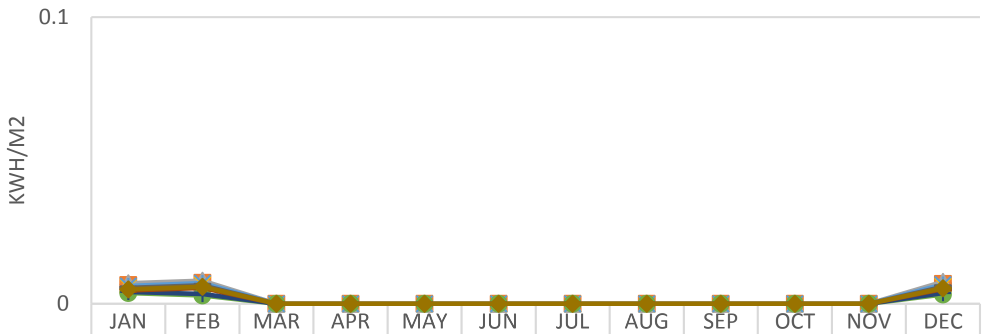
4.9.1 Thermal Analysis

The dynamic thermal simulation results for wall constructions 1-10 in terms of monthly and annual heating and cooling energy consumption are demonstrated in (Figs 4.23 to 4.27), divided by the floor area. In addition, the results for the Predicted Mean Vote (PMV) values and comfort hours are demonstrated in (Figs. 4.28 and 4.29) while the discomfort hours for the entire walls of 1-10 are shown in (Figs. 4.30).

Based on the results in terms of annual heating energy consumption (Fig.4.24), wall 6 consumed the least amount of energy compared to that of the walls 7, 8, 10, 9, 4, 5, 2 and 1 respectively. On the contrary, wall 3 showed the worst heat performance among the entire walls with the highest quantity of heating energy consumption. Additionally, based on the results for the annual cooling energy consumption (Fig.4.26), wall 6 consumed the least amount of energy compared to that of the walls 7, 8, 10, 9, 4, 5, 2 and 1 respectively. On the contrary, wall 3 showed the worst performance among the entire walls with the highest quantity of cooling energy consumption. As a deduction for this evaluation, total heating, and cooling (HVAC energy) consumption chart is presented in (Fig.4.27) indicating that wall 6 consumed the least total heating and cooling energy. It is followed by 7, 8, 10, 9, 4, 5, 2 and 1 respectively while wall 3 consumed the most HVAC energy among the entire wall cases.

In addition to the HVAC energy consumption and according to the dynamic thermal simulation results for the PMV values and comfort hours presented in (Figs.4.28 to 4.30), wall 6 provided the most comfort condition (hours) among the entire simulated wall cases. It is followed by the walls 7, 8, 10, 9, 4, 5, 2 and 1 respectively while wall 3 provided the least comfort hours among the entire wall cases.

Moreover, based on the results reporting the discomfort hours presented in (Fig.4.31), wall 3 obtained the least discomfort hours, confirming the result for the highest comfort hours and comfort condition. This is the opposite of wall 6 which also confirms the result for the comfort hours.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wall 1	0.0068	0.0076	0	0	0	0	0	0	0	0	0	0.0072
Wall 2	0.0065	0.0073	0	0	0	0	0	0	0	0	0	0.0069
Wall 3	0.0071	0.008	0	0	0	0	0	0	0	0	0	0.0076
Wall 4	0.0058	0.0067	0	0	0	0	0	0	0	0	0	0.0062
Wall 5	0.0062	0.0072	0	0	0	0	0	0	0	0	0	0.0067
Wall 6	0.0037	0.0029	0	0	0	0	0	0	0	0	0	0.0032
Wall 7	0.0041	0.0034	0	0	0	0	0	0	0	0	0	0.0037
Wall 8	0.0046	0.0055	0	0	0	0	0	0	0	0	0	0.0051
Wall 9	0.0055	0.0064	0	0	0	0	0	0	0	0	0	0.0059
Wall 10	0.005	0.0059	0	0	0	0	0	0	0	0	0	0.0054

Figure 4. 23: Monthly Heating Energy Consumption for Walls 1-10

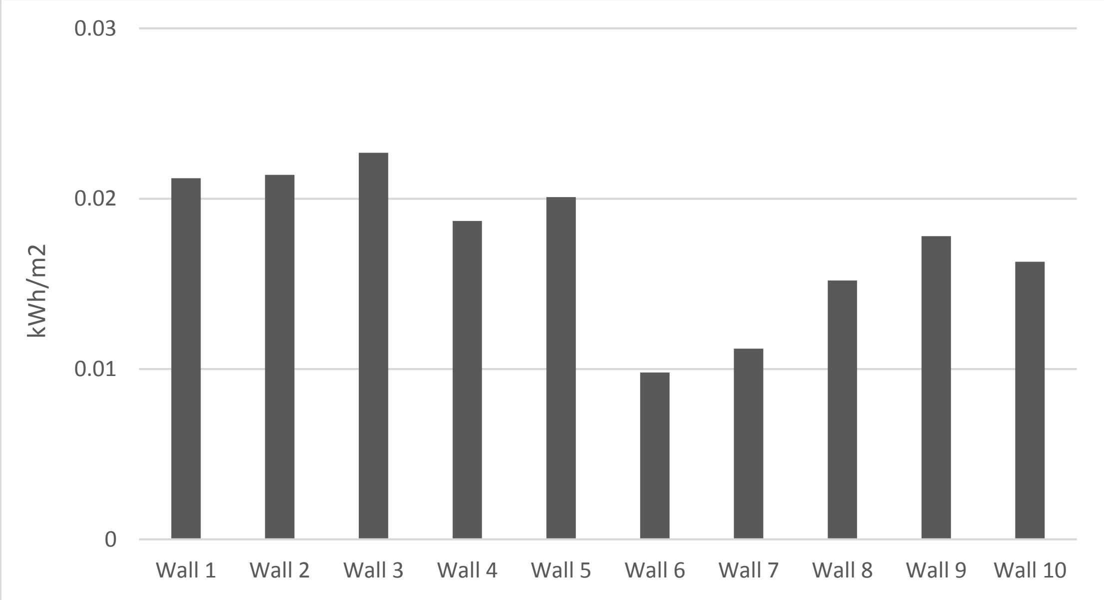
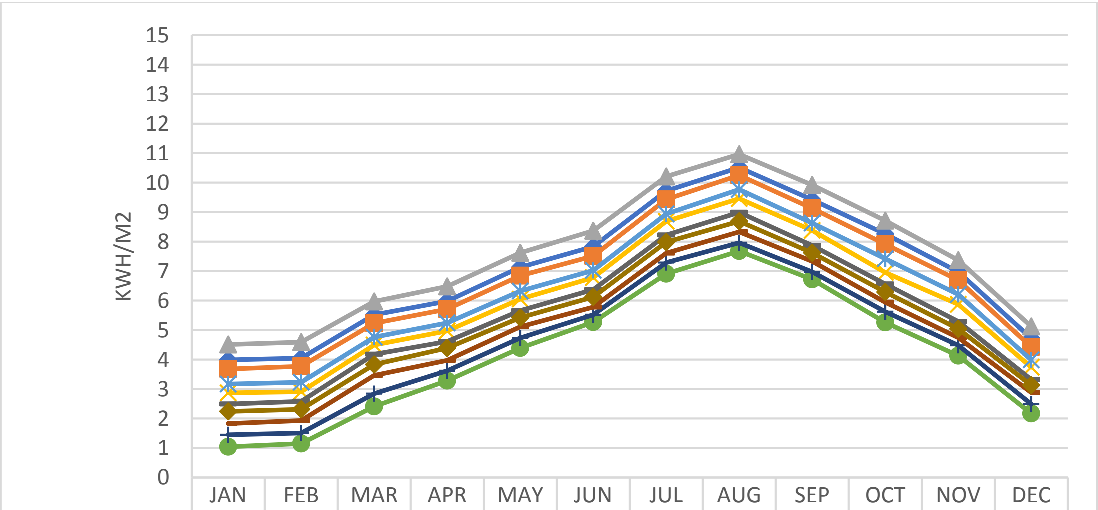


Figure 4. 24: Annual Heating Energy Consumption for Walls 1-10



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wall 1	3.99	4.05	5.52	5.98	7.13	7.83	9.72	10.51	9.42	8.26	6.97	4.72
Wall 2	3.68	3.77	5.23	5.71	6.84	7.51	9.43	10.25	9.13	7.91	6.69	4.43
Wall 3	4.51	4.59	5.97	6.48	7.62	8.37	10.21	10.96	9.92	8.71	7.37	5.12
Wall 4	2.87	2.91	4.49	4.97	6.05	6.78	8.69	9.46	8.38	6.95	5.87	3.74
Wall 5	3.17	3.23	4.76	5.24	6.32	7.02	8.94	9.77	8.63	7.42	6.21	3.99
Wall 6	1.04	1.15	2.41	3.28	4.39	5.27	6.91	7.68	6.72	5.26	4.13	2.17
Wall 7	1.45	1.51	2.84	3.62	4.73	5.52	7.29	7.96	6.97	5.62	4.48	2.49
Wall 8	1.83	1.93	3.46	3.97	5.11	5.78	7.61	8.33	7.33	5.94	4.74	2.88
Wall 9	2.49	2.58	4.18	4.61	5.66	6.37	8.22	8.99	7.87	6.56	5.29	3.32
Wall 10	2.24	2.31	3.83	4.39	5.42	6.12	7.98	8.69	7.62	6.29	5.04	3.13

Figure 4. 25: Monthly Cooling Energy Consumption for Walls 1-10

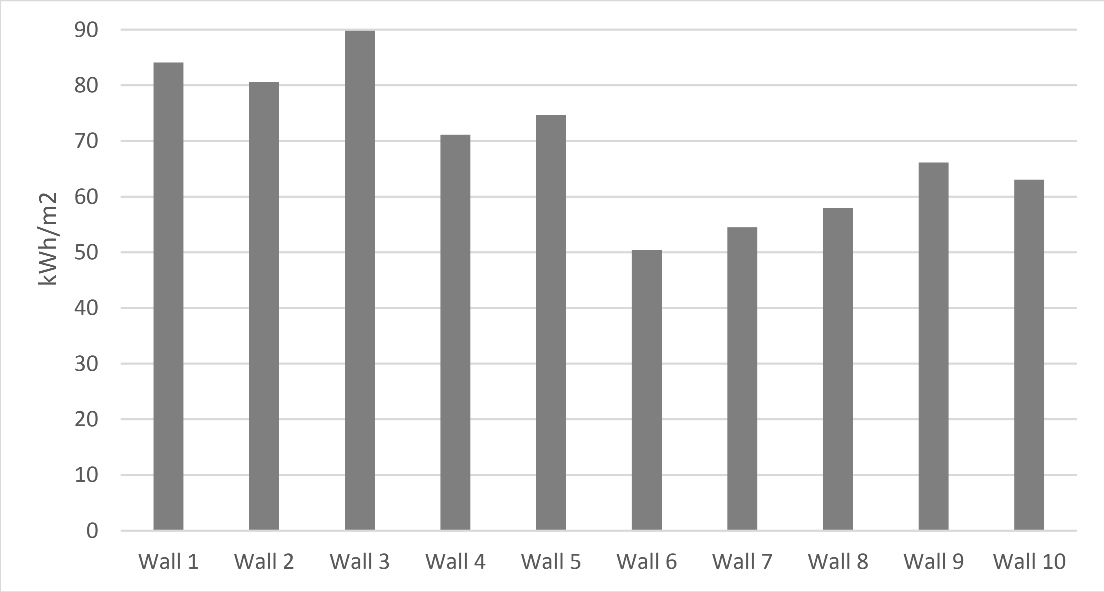


Figure 4. 26: Annual Cooling Energy Consumption for Walls 1-10

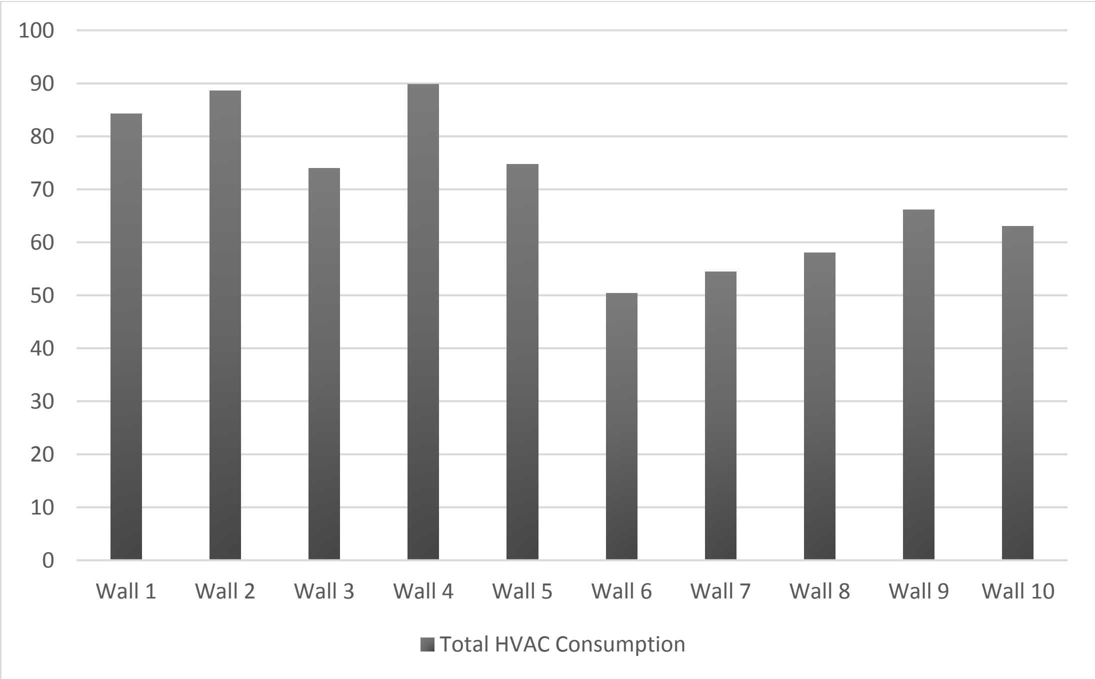
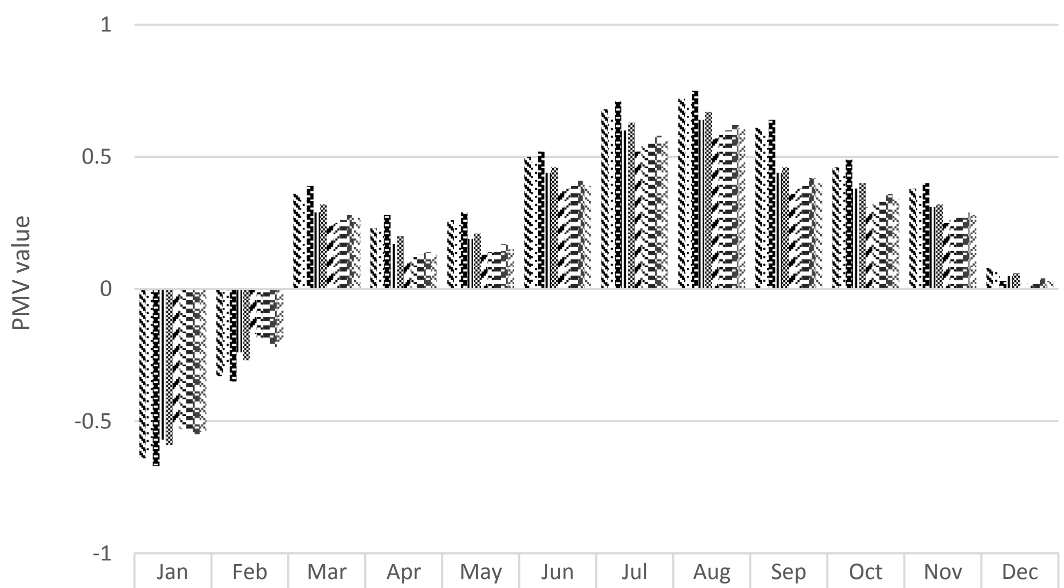


Figure 4. 27: Total HVAC Energy Consumption for Walls 1-10



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wall 1	-0.64	-0.33	0.36	0.23	0.26	0.5	0.68	0.72	0.61	0.46	0.38	0.08
Wall 2	-0.61	-0.3	0.34	0.22	0.24	0.48	0.65	0.7	0.58	0.43	0.35	0.07
Wall 3	-0.67	-0.35	0.39	0.28	0.29	0.52	0.71	0.75	0.64	0.49	0.4	0.03
Wall 4	-0.57	-0.24	0.29	0.17	0.19	0.44	0.6	0.64	0.44	0.38	0.31	0.05
Wall 5	-0.59	-0.27	0.32	0.2	0.21	0.46	0.63	0.67	0.46	0.4	0.32	0.06
Wall 6	-0.52	-0.17	0.24	0.1	0.13	0.37	0.52	0.57	0.36	0.31	0.25	0.02
Wall 7	-0.53	-0.19	0.25	0.12	0.14	0.38	0.54	0.59	0.38	0.32	0.26	0.02
Wall 8	-0.53	-0.19	0.26	0.13	0.14	0.39	0.55	0.6	0.39	0.33	0.27	0.03
Wall 9	-0.55	-0.22	0.28	0.14	0.17	0.41	0.58	0.62	0.42	0.36	0.29	0.04
Wall 10	-0.54	-0.2	0.27	0.13	0.15	0.39	0.56	0.61	0.4	0.34	0.28	0.03

Figure 4. 28: Monthly PMV Values for Walls 1-10

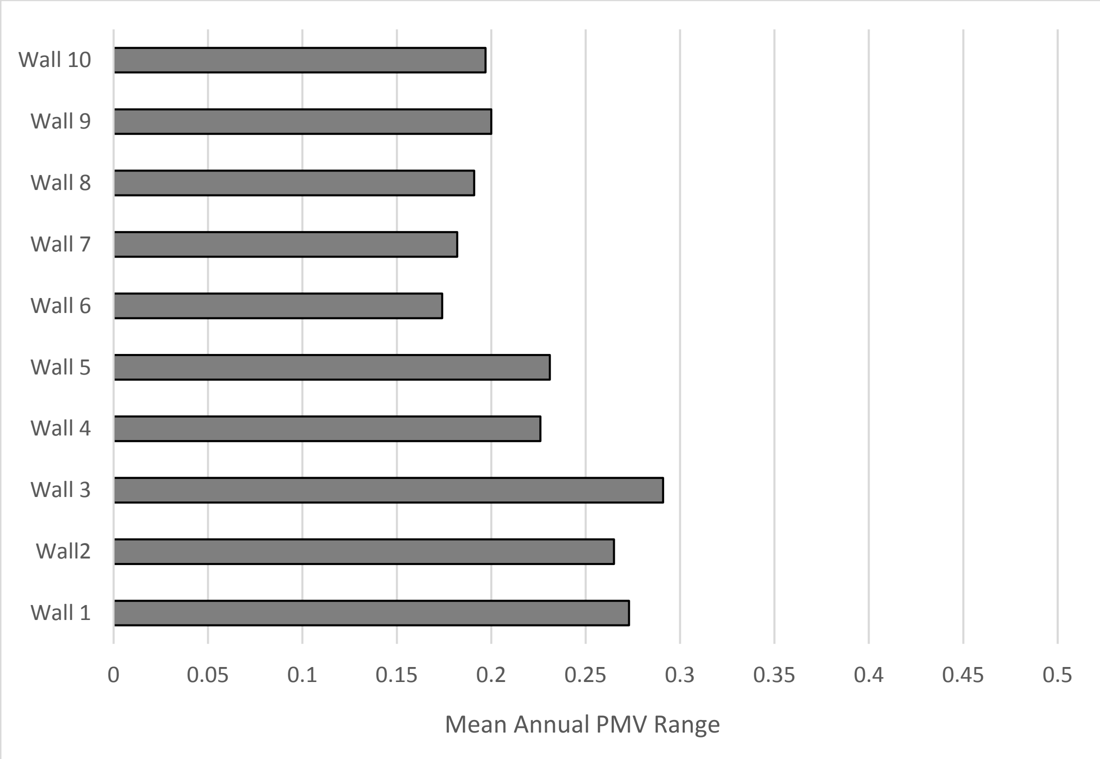


Figure 4.29: Mean Annual PMV Range for Walls 1-10

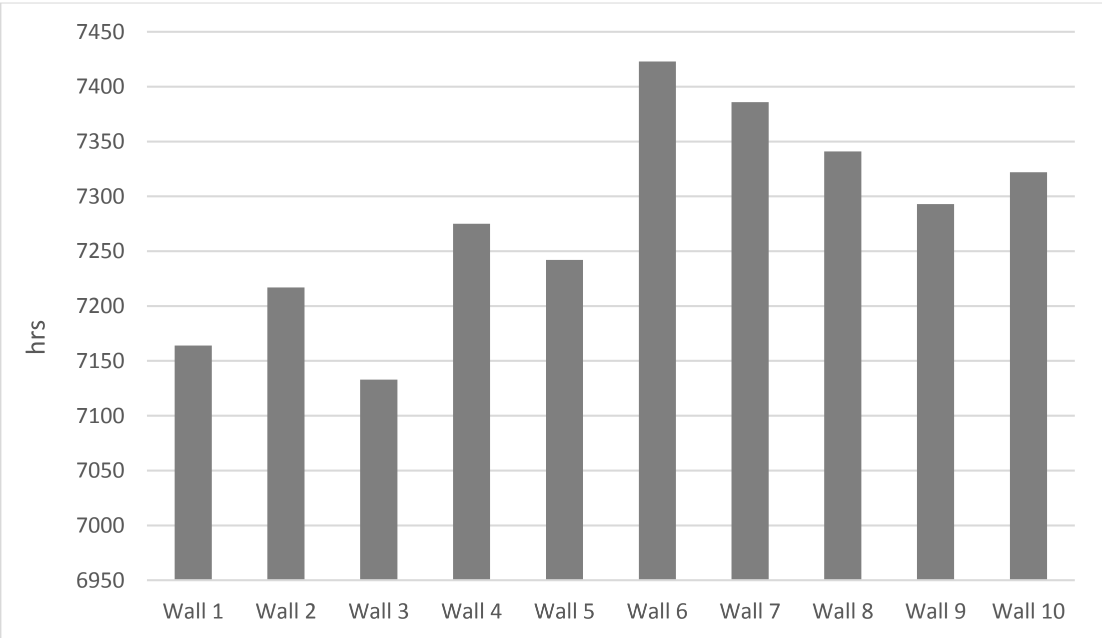


Figure 4. 30: Annual Comfort Hours for Walls 1-10 (-0.5 < PMV < 0.5)

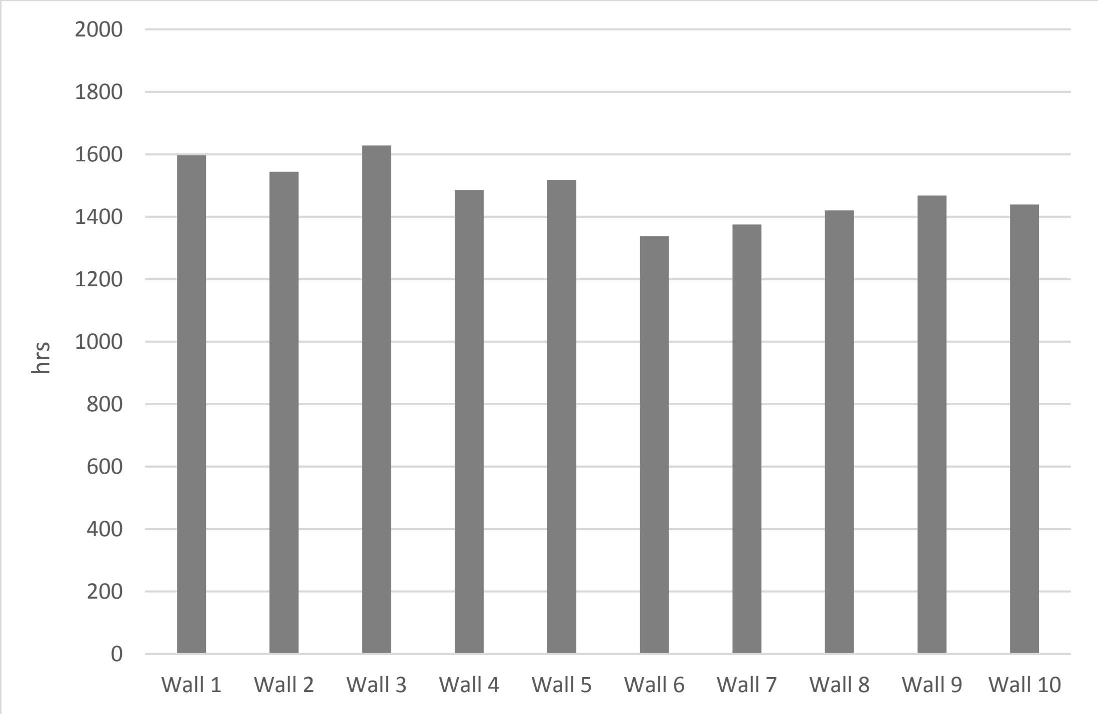


Figure 4. 31: Annual Discomfort Hours for Walls 1-10

4.9.2 Condensation Analysis

In addition to energy consumption and the PMV model for thermal comfort assessments besides comfort and discomfort hours, the steady-state Glaser analysis for the entire wall cases was carried out via Design Builder software, the condensation section.

The results indicating that a very little rate of condensation for walls 6 and 7 was observed in the under-heated periods (January and February) which is less than the limit (i.e., 1.0 kg/m2) and would be removed in overheated periods. Accordingly, the walls of 1-5 and 8-10 indicated no condensation rate as the results for the entire wall constructions are listed in Table 4.7. To finalize the moisture control and condensation analysis, the entire wall cases are not at the risk for condensation at all.

Table 4.7: Walls 1-10 Condensation Rate

Wall NO.	Amount of Condensed Water within Months of the Year (kg/m^3)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0.20	0.24	0	0	0	0	0	0	0	0	0	0
7	0.14	0.16	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0

4.9.3 Economic Analysis

For the purpose of cost efficiency in this study, the amortization time period in Kish Island was considered < 10 years. It should be highlighted that the amortization time period for each wall construction was obtained based on wall 4 which its initial cost was found the most expensive among the other six walls due to the used materials (i.e., insulating layer, type of cement block as well as an extra gypsum board as the internal finishing).

For the entire wall cases, the life cycle cost of 10 years was assumed and calculated with 18.2 % bank yearly interest rate as well as the 8% inflation average besides the initial costs of each wall constructions are listed in Table 4.8.

Table 4.8: The Selected Wall Constructions' Initial Cost

Wall Number	**Wall Initial Cost ($ / m^2)**
1	1.37
2	1.93
3	1.12
4	3.51
5	2.86
6	3.85
7	4.03
8	3.77
9	3.18
10	1.69

It should be mentioned that the maintenance cost was not considered at all. As it was mentioned in the cost evaluation section (chapter 3; section 3.2.3.4) the HVAC fuel energy cost is one of the foremost important parameters in this relationship and in the context, it considers as (0.04 $). According to the primary cost analysis for walls 1-

10 considered based on equations 3.1 and 3.2. The amortization time periods for each wall construction shown in (Fig. 4.31).

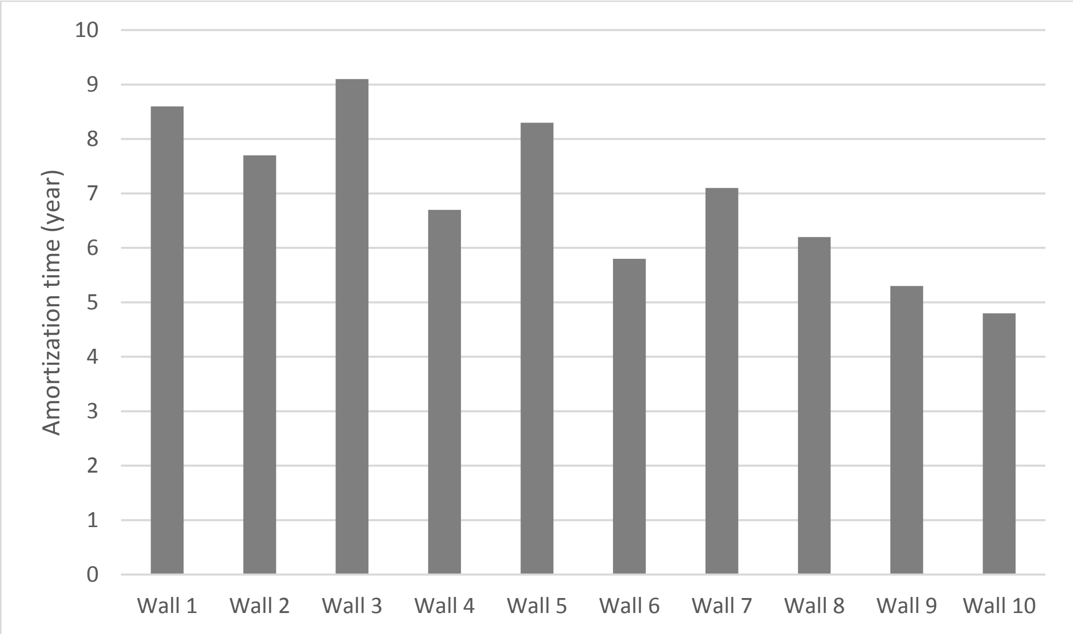


Figure 4.32: Amortization Time Results for Walls 1-10

4.9.4 Multi Criteria Evaluation

For the purpose of this study, a Simple Multi-Attribute Rating Technique (SMART) was employed grading the simulated wall constructions in terms of specified evaluation criterion.

It should be highlighted that each evaluation criteria used for the entire wall constructions was taken as equally significant and the normalized weight was taken as equal to the number of selected wall cases. Therefore, due to the number of walls which are 10, the grade for each wall varies from 1 to 10 based on the wall performance.

It also should be pointed out that since in this study the entire walls were not found at the risk for condensation and most showed the value of (zero/0) for condensation rate, this evaluation criteria is not considered at the SMART and grading process. The results for the three remained evaluation criterion (i.e., energy saving; thermal comfort; cost efficiency) and for the entire walls are shown in Table 4.9, taken as equally significant while the maximum grade for a wall was assumed to be 10, equal to the numbers of the wall cases. Hence, it indicates that the best performance wall will obtain a grade of 10 (out of 10). Accordingly, the results follow with the walls with a lower performance from 9 to 1 respectively. It should be pointed out if any of the wall cases do not meet the criteria limit, the grade would be considered as zero (0) on that criteria.

Considering the result for the calculation of amortization time period shown in (Fig. 4.32), the entire wall cases amortized their initial cost less than the limit of 10 years while wall 3 considered to be the wall with the longest amortization time period of 9.1 years. On the contrary, wall 10 was considered to be the wall with the shortest amortization time period of 4.8 years. It should be highlighted that wall 10 initial costs were found to be the cheapest among the entire wall cases which on the other hand represented decent heat performance (i.e., low total heating and cooling energy consumption besides high comfort hours).

Table 4.9: Walls Grading Based on the SMART

Wall No.	**Evaluation Criterion & Methods of Assessments**			
	Energy Saving	**Thermal Comfort**	**Cost Efficiency**	
	HVAC Consumption	Comfort Hours	Amortization Time	Total Grade
1	2	2	2	6
2	3	3	4	10
3	1	1	1	3
4	5	5	6	16
5	4	4	3	11
6	10	10	8	28
7	9	9	5	23
8	8	8	7	23
9	6	6	9	21
10	7	7	10	24

As it can be seen in Table 4.9, based on total grades obtained by summing evaluation criterion grades, wall 6 obtained the highest grade in terms of energy saving and thermal comfort where its total grade in the SMART indicated the highest total grade of 28 among the other wall cases where walls 10, 7, 8, 9, 4, 5, 2 obtained the grades of 24, 23, 16, 11, and 10 respectively. On the contrary of wall 6, wall 3 obtained the lowest grade of 3 where it is also obtained the lowest weight in each and every evaluation criteria.

4.9.5 Results Discussion

In brief, the results indicated that wall 6 obtained the highest performance for energy saving and thermal comfort hours followed by walls 7, 8, 10 and 9 respectively. On the contrary, wall 3 obtained the worst result for energy saving and thermal comfort hours, followed by walls 1, 2, 5 and 4.

The results indicated that the walls that suggested by the literature review and as a result of the localization process (employing thermal insulation) showed more energy saving and thermal comfort potential at all. Moreover, based on the PMV model of thermal comfort assessments, the entire wall constructions are within the comfort range of (PMV scales: -0.5 to 0.5) which can be seen in (Fig. 4.29).

In addition to energy saving and thermal comfort and based on Glaser analysis, condensation was occurred for walls 6 and 7, insulated internally and externally respectively. However, since the condensation rate is below the critical condition and the specified limit, it has no risk at all. Further, the results for cost efficiency indicated that the entire wall cases amortized their initial cost less than the limit of 10 years while wall 3 considered to be the wall with the longest amortization time period of 9.1 years.

On the contrary, wall 10 considered being the wall with the shortest amortization time period of 4.8 years. As a result for the final assessment and overall grading of the SMART in terms of energy saving, thermal comfort and cost efficiency for the entire simulated wall constructions, wall 6 obtained the highest overall grade; this is the opposite for wall 3, obtaining the lowest grade among the entire simulated cases. It also should be highlighted that since the developed model is inherently comparative in which multiple evaluation factors are considered, the result is obtained generally, on aggregate. Based on the findings and in accordance with the walls total grades through the SMART, the most efficient walls were the ones formed during the localization process (i.e., walls 6-9) in addition to a 40-cm adobe wall (i.e., wall 10) as the representative case for traditional walls used in ancient architecture of Kish Island.

4.10 Summary of the Chapter

In this chapter after a comprehensive discussion over climate characteristics of Kish Island, the climate was simulated and analyzed via climate consultant software in order to determine the necessary active and passive design strategies for buildings achieving comfort condition in the context.

By a filed survey, types of construction, materials, construction techniques and the existing types of building were identified and as a result, a building typology was selected for carrying out the case study for a later computer simulation. To do that, the weather files were prepared and generated in two forms; the first file was the energy plus weather (epw) generated via Meteonorm software while the second weather file was prepared on the basis of a short time temperature and relative humidity monitoring in the selected case study for the purpose of simulation results validation.

In the following, the simulation inputs were determined and the most commonly used wall constructions in the context were selected via field survey. Moreover, other wall construction types recommended by the outcomes of the literature survey as well as a localization process (based on the context construction code 19) were selected and simulated through series of dynamic thermal simulations.

The results of the simulation were then evaluated in terms of four main evaluation criterion (i.e., thermal comfort, energy saving, moisture control and cost efficiency) while by using Simple Multi-Attribute Rating Technique (SMART) the results for each and every evaluation criteria were graded based on the walls performances for the final assessment and decision making process. The entire findings of this chapter are presented in the conclusion where it is comprised of three main sections including introduction, conclusion findings as well as conclusion recommendation.

Chapter 5

CONCLUSION

5.1 Introduction

The present study was carried out to achieve a systematic and local based model for the comparative selection of the optimal opaque wall constructions in hot and humid climates. In order to achieve the aim and objectives of the research, this study was planned in five main steps, discussed in chapters one to five.

In the first step (chapter 1), the problem statement was introduced and the aim and objectives of the study were defined. In the following sections, the questions, research methods, and materials of the study were discussed and the chapter was finalized by the limitation of the study.

In the second step (chapter 2), the evaluation criteria of the study were briefly explained and the recent studies over the subject were reviewed. Moreover, building envelope, envelope design, methods of external wall design and the most commonly used external walls in the building sector were introduced and discussed in detail.

As a deduction, a section namely summary of the literature review was considered explaining how efficient design of building external walls for a hot and humid climate can be considered as the key concept to have sustainable buildings by decreasing the demand for energy, improving thermal quality of the indoor environments, reducing the costs and controlling moisture diffusion which is one of the crucial factors to be taken into account designing and selecting external walls in hot and humid climates.

Consequently, reviewing the literature over external wall design in a hot and humid climate indicated that many methods use the passive design strategies most of which addressed the subject from material and construction technique perspectives.

A categorized list of reviewed literature was prepared based on four main evaluation criterion that this study aims at dealing with. Thus, the most commonly used methods and materials that scholars employed evaluating and selecting wall constructions in hot and humid climates were identified and by that, the research gaps were determined. In this accordance, in the third step of the research (chapter 3) which mainly was focused on the study's main methods and materials, the gaps of the subject were considered to be carried out systematically.

In the following, the four main evaluation criterion besides their methods of assessments as well as their limits were discussed in detail while the methodology of the study was explained phase by phase, indicating graphically the entire steps sequences in detail.

In the next step (chapter 4) the study carried out initiating from the first phase of the methodology which is field study (i.e., Kish Island, Iran) climate analysis. Thus a comprehensive climate analysis was considered using climate consultant software analyzing the most important and influential factors as well as indicators for a systematic active and passive design strategies guideline. The guidelines were later on employed for simulation inputs settings. Moreover, the results were afterward validated through experimental data monitoring results within the selected case study. It should be noted that in between the process of generating the weather files, field surveying, building typology as well as identifying commonly used wall constructions and materials in the context were carried out came up with a process of localization based on construction code 19 (i.e., the one and only construction code observes in Iran).

It also should be highlighted that the computer-based simulation then examined the findings based on the multi-criteria optimization process to select the optimized wall constructions based on the previously mentioned evaluation criterion of the study. In the end, by using a Simple Multi-Attribute Rating Technique (SMART) the findings were categorized and graded based on the performances for the purpose of the decision-making process. As the last step (chapter 5) indicated the study finding, results and recommendation briefly.

5.2 Findings of the Study

The number of 10 wall constructions which were most commonly used in the context and the proposed alternatives based on the literature survey suggested as suitable wall constructions in hot and humid climate were localized based on Iran construction code (i.e., code 19). The selected wall cases then simulated and compared in terms of four main evaluation criterion which are key parameters of the proposed model as the foremost objectives of this study.

Based on the results in terms of annual heating energy consumption, wall 6 consumed the least amount of energy compared to that of the walls 7, 8, 10, 9, 4, 5, 2 and 1 respectively. On the contrary, wall 3 showed the worst heat performance among the entire walls with the highest quantity of heating energy consumption. Additionally, based on the results for the annual cooling energy consumption, wall 6 consumed the least amount of energy compared to that of the walls 7, 8, 10, 9, 4, 5, 2 and 1 respectively. On the contrary, wall 3 showed the worst performance among the entire walls with the highest quantity of cooling energy consumption. As a deduction for this evaluation wall 6 consumed the least total heating and cooling energy. It is followed by 7, 8, 10, 9, 4, 5, 2 and 1 respectively while wall 3 consumed the most HVAC energy among the entire wall cases.

In addition to the HVAC energy consumption and according to the dynamic thermal simulation results for the PMV values and comfort hours, wall 6 provided the most comfort condition (hours) among the entire simulated wall cases. It is followed by the walls 7, 8, 10, 9, 4, 5, 2 and 1 respectively while wall 3 provided the least comfort hours among the entire wall cases. Further, based on the results reporting the discomfort hours, wall 3 obtained the least discomfort hours, confirming the result for the highest comfort hours and comfort condition. This is the opposite of wall 6 which also confirms the result for the comfort hours.

Based on condensation analysis which is another evaluation criteria, the condensation has occurred for wall 6 and wall 7 which were insulated face the interior and exterior respectively at the node connection of insulation layer with the solid material (AAC blocks). However, since the condensation rate is below the critical condition, it evaporates during the overheated months and has no serious effect on the walls performances where the mold growth also found unlikely.

The last stage of evaluation considered the economic analysis and the cost efficiency which includes energy efficiency since the energy consumption is one of the most important alternatives in amortization time calculation formula. As a result, based on a 10-year amortization time period, the entire walls are able to amortize the initial cost during the specified period while.

The final assessment and overall grading of the SMART in terms of energy saving, thermal comfort and cost efficiency for the simulated wall constructions indicated that wall 6 obtained the highest grade; this is the opposite for wall 3, obtaining the lowest grade among the entire wall cases.

It should be highlighted that since the developed model is inherently comparative in which multiple evaluation factors are considered, the result is obtained generally, on aggregate. Based on the findings and in accordance with the walls total grades through the SMART (presented in Table 4.9), the most efficient walls were the ones formed during the localization process (i.e., walls 6-9) in addition to a 40-cm adobe wall (i.e., wall 10) as the representative case for traditional walls used in ancient architecture of Kish Island.

It also should be highlighted that although the field study is characterized by a severe climate condition (hot and humid), the most commonly used wall constructions do not employ insulation, regardless of the code 19 (2001) guidelines. As a matter of the fact, and due to the outcomes of literature and field survey, lightweight wall materials in general and concrete blocks in particular, as well as Adobe, were recognized as high thermal resistance wall materials with greater thermal performances in comparison with other simulated materials. However, this is no guarantee for the maximum efficiency since the incorporation of insulation with such materials may have more potential for energy saving as well as improving comfort condition as it has been investigated and proved by the results of this study. Therefore, it is necessary to consider the building codes and combine the guidelines with that of the broad and local construction techniques and materials for maximum efficiency.

It is worth mentioning that besides benefiting from insulation potential for energy saving, generally, employing insulation in wall configurations escalates the risk for condensation due to the physical properties of the insulating materials (as also seen in the results of this study). Therefore, by using condensation analysis which is one of the main evaluation criteria of the developed model, the risk of condensation is predictable and can be dealt with from the very beginning, if the moisture quantity does not exceed the limit.

5.3 Conclusion Recommendations

In brief, the achievement of the present study is in two areas that can be exploited by the experts and is recommended to two groups of experts include:

- Designers and architects in order to achieve a codified model and methodology for comparative selection of the optimal wall constructions in hot and humid climates.
- Technology designers, algorithm writers, and energy utilization software experts in building simulation field, using the present methodology to optimize the simulation process to be more précised, faster and immediate.

Further, the presented model is applicable for the selection of roof constructions in the same climate conditions as well as other building components such as windows by substituting evaluation criterion those are the key criterion.

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