ECOLOGICAL BUILDING DESIGN: A PROOF OF CONCEPT AND IDENTIFYING THE FACTORS WHICH DETER THE USE OF IRANIAN VERNACULAR PRINCIPLES IN MODERN ARCHITECTURE

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A thesis submitted in partial fulfilment of the requirements of London South Bank University for the degree of Doctor of Philosophy

August 2016

Dedication

With thanks to my parents Mahdi Mohammadzadeh Miri, Elahe Maasomi and my brother Hadi Miri: I dedicate this dissertation to my family members.

Abstract

Previous research has shown that there is a strong link between people, buildings and climate: the building sector contributes up to 30 per cent of global annual greenhouse gas emissions and consumes up to 40 per cent of all energy. Most 20th-century buildings in the world are currently reliant on electro-mechanical cooling systems. Researchers and scholars have studied and analysed the sustainability issues in architecture casting light from different perspectives. However, such studies have seldom paid significant attention to the principles of sustainable Iranian architecture. Environmental sustainability and sustainable architecture in Iran are still relatively new concepts. This research fills the gap on the application of vernacular architecture to modern building design, particularly in the context of Iran and its climate by creating an informed and tested understanding of how vernacular architecture can inform modern building design and techniques. There have been limited studies on vernacular design as a source of knowledge which can contribute to 21st century challenges. The scope of this study is not only limited to Iran as its finding are also applicable to other countries with hot climates.

As one of the key contributions, this thesis demonstrates how energy use in buildings can be minimised using such principles that are adopted from Iranian vernacular architecture. The study firstly relies on the state of the art literature review on vernacular architecture in Iran using secondary analysis, and then offers comparisons, analysis and hypotheses testing in the following sections. The challenge of extracting Iranian vernacular architecture principles (IVAP) has been achieved by a multi-method approach. Site observations, sketches, drawings and measurements at the early stages were reinforced by further detailed analysis of the literature beyond IVAP, and supplemented by studies in sustainable design such as passive design. It was found that IVAP have many common elements which are shared today by passive design. The methodology for the above consists of simulation modelling and comparisons of the energy in use for building designed using IVAP versus designs using conventional building techniques in Iran. By using energy software packages (Integrated Environmental Solutions, Design Builder, CC5) it is found that the application of IVAP can significantly improve energy consumption in buildings. The research also explores a novel approach and tests the feasibility of using ‘adobe’ as an insulation material for construction of walls. The analysis involves construction of a wall using this new approach (inspired by IVAP) and testing it in the lab for its energy performance. The findings confirm that as a building material, ‘adobe’ could be potentially a feasible and environmentally friendly substitute to conventional insulation with additional sustainable benefits such as using local materials and preservation of traditional culture in the region.

Another contribution of this study is to offer a deeper understanding of the drivers and barriers to the implementation of IVAP in today’s architecture in Tehran, Iran. To achieve this a survey was conducted which revealed that an integral part of the implementation and application of IVAP is education and design of the UG and PG curricula. Recommendations are made to highlight the necessary and critical adjustment to policies regarding promotion of IVAP to safeguard the environment and national and cultural identities.

Acknowledgement

With a growing interest in sustainable architecture, I have been striving to learn more about sustainability ever since I started my higher education. This research would not have been possible without the guidance, support, motivation and patient co-operation of several people. I would like to take this opportunity to thank them and express my gratitude for giving their time and assistance for this research. I want to acknowledge my supervising team and administrative team such as; Prof. Andy Ford, Prof, John Parkin, Dr. Catherine Boyle, Prof Graeme Maidment, Dr. Mahtab Farshchi, Dr. Alan Foster, Louise Thompson, and Cosimina Drago. I am truly grateful for their support to find my research path. I genuinely appreciate supervisor's constructive criticism and valuable information throughout the last four years.

I would also like to express my appreciation for the guidance and help received from many people and many disciplines in the cities of Tehran, and Yazd who helped me in achieving the goals of this study. and I would like to thank officials from different organisation such as Housing and Town planning, Environmental and Geography Departments, as well as experts in the field of sustainability, within Yazd municipality (Historical and Vernacular Architecture Department). More importantly, I want to thank the Deputy Mayor and the President of Tehran Urban Planning and Research Centre, for their time and by informing me of the most recent developments in building regulations and legal and professional documents.

I want to thank my parents for their unreserved support and encouragement by letting me explore different opportunities and pursue higher education. In addition, I owe a great debt for the completion of this study to three very supportive family members. My dad for his financial support throughout my academic years to enable a comfortable environment to finish my studies, my mother for her concern towards my studies and continuous moral and emotional support, and her understating and willingness to keep up with new challenges arising from this journey. Last and certainly not least my helpful brother, an architect himself, for sparing his time and by offering intellectual support throughout this journey.

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Glossary of abbreviations and acronyms

ACRE: Action with Communities in Rural England

BP: British Petroleum

CC5: Climate Consultant 5

CFD: Computational Fluid Dynamics

Co_2: Carbon dioxide

COP: Coefficient of Performance

CWC: Canadian Wood Council

DOE: US Department of Energy

EPA: Environmental Protection Agency

GRI: Global Reporting Initiative

IEEPC: Iran Energy and Electricity Planning Committee

IEO: International Energy Outlook

IES: Integrated Environmental Solutions

IPCC: Intergovernmental Panel on Climate Change

SLF: Shade Line Factor

SUNA: Iran Renewable Energy Organisation

UNCHS: United Nations Human Settlement

UNDP: United Nations Development Programme

USEA: United States Energy Association

UNEP: United Nations Environmental Programme

OECD: Organisation for Economic Co-operation and Development

ORNL: Oak Ridge National Laboratory

WBDG: Whole Building Design Guide

GW: Gigawatt

HVAC: Heating, Ventilating and Air conditioning

KwH: Kilowatt hour

Kcal/hr: Kilocalorie per hour

L: Insulator thickness (meter)

m^2: Square Metre

m^3/s: Cubic Metre Per Second

R: Thermal Resistance

Twh/year: Terawatt hour per year

w/m^2: Watt/Square Metre

W/mk: Watts per square metre of surface area for a temperature gradient of one Kelvin per metre

W/m^2C: Watt per square metre Per degree Celcius

Kcal/h: Kilocalorie per hour

λ: Lambda (Thermal conductivity)

Abnama: Fountain

Badgir: Wind catcher

Ghel: Mud

Godal baghche: Greenery area/Garden in the middle of the courtyard

Hayat: Courtyard

Khak-e ros: Clay

Khesht: Adobe

Makhzan ab: Cistern/Water storage

Moshabak Rangi: The Nodes designs on wooden windows cause small pieces of colored glass

Norgir: Skylight

Saabaat: curvy pathways and covered alleys

Tighe: The blade of Wind catcher

Yakhchal: Icehouse

CHAPTER ONE: INTRODUCTION AND MOTIVATION

1.1 Statement of the problem

The growing world population today combined with other problems emerging from urbanisation and industrial development have affected our demand and use of fossil fuels as non-renewable energy resources (Vallero and Brasier, 2008). Today we face different types of pollution, and water and soil resources face serious limitations. The Earth's natural resources are at enormous risk because of heavy utilisation resulting from population growth (Billatos and Basaly, 1997). Since the early twentieth century when human societies underwent profound transformations, traditional architecture compatible with the regions' climate has gradually slid into obscurity (Brian, 2010). This lack of congruence of architecture with its environment has become a major issue.

With continuing population growth, the excessive consumption of fossil fuels in buildings is reaching a critical stage (Jenkins, 1989; BP, 2008). Figure 1 reveals the global patterns of energy consumption from 1860 to 2008. This clearly shows every decade that traditional renewable energy has decreased, but also the use of fossil fuels as non-renewable energy resources which has increased.

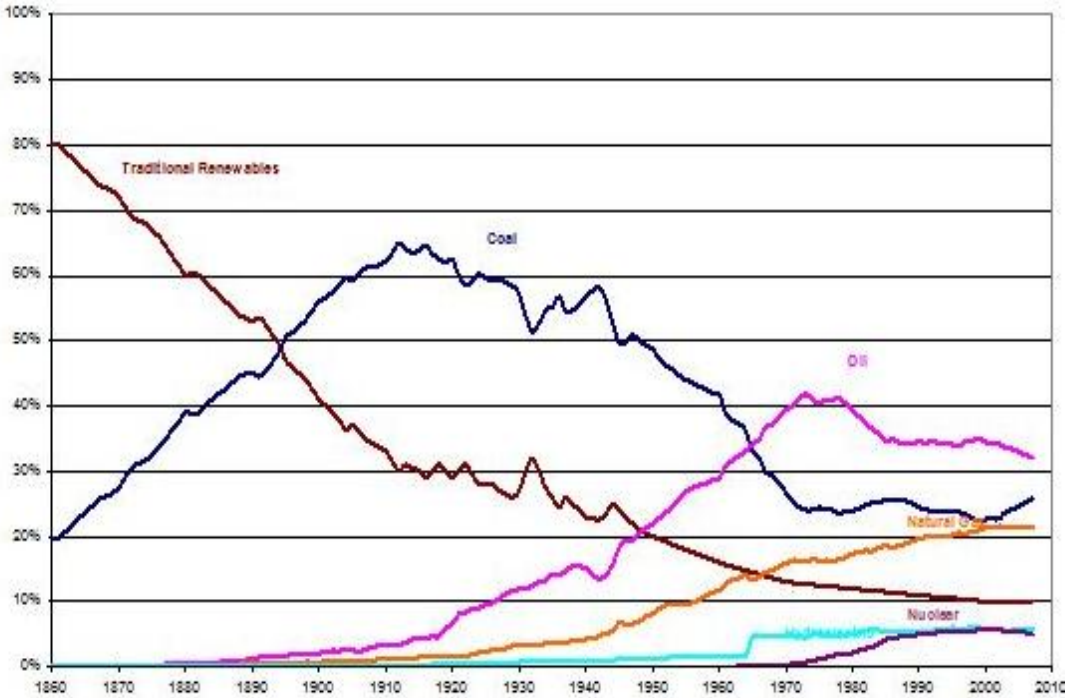
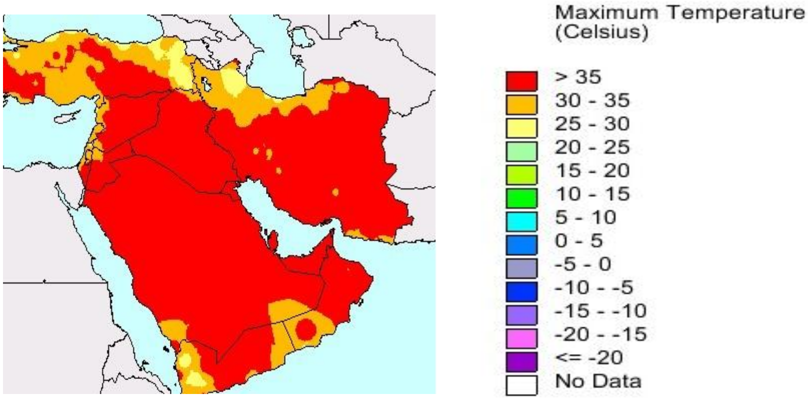


Figure 1: Yearly consumption contributed by each energy source

The construction and operation of buildings contributes significantly both directly and indirectly to most of our environmental challenges. Buildings are enormous consumers of resources and generators of waste (Mendler et al., 2006). This causes problems such as limited availability of fossil fuel sources for future use, increase in heating and cooling expenses, and increased psychological distress owing to detachment from nature (UNDP, 2000). According to BP (2012) the wind energy accounted for nearly 60 per cent of all renewable energy growth and solar output also saw a dramatic increase. However, despite rapid growth, renewable resources account for 2 per cent of global energy consumption. In addition, the consumption of oil, coal and natural gas has accounted for more than 87 per cent of energy consumption. The world's hot arid regions such as the Middle East are particularly sensitive in this regard. According to the World Energy Council Report (2013), energy consumption in the Middle East is expected to rise by as much as 114 per cent from 2010 to 2050. Because of the long term economic growth (IEO,2013) and severe limitation of renewable water resources in these regions, as well as the vulnerability of the ecosystem, the consequences of urban and industrial development are much more detrimental than in other regions of the world (Shaterian, 2007).

1.2 Rationale of the research

Vernacular architecture techniques are known for their ingenuity, as early dwellers used these methods to protect themselves from the diverse weather conditions to which they were subjected (Haj Soghta, 2011). Examples of vernacular architecture are located in the Middle East and North Africa where a hot and arid climate zone prevails. The study of such climates with hot and extreme weather conditions may provide excellent examples to explore the architectural techniques that have allowed the creation of independent microclimates in these regions. Figure 2 shows the extreme hot and arid climate zones in the Middle East, and shows that the maximum temperature is above 35 degrees Celsius.



Source: US department of agriculture, 2013

Figure 2: The extreme weather condition in the Middle East

In Iran, with a history dating back several thousand years, creative people have left behind important valuable achievements in compatibility and harmony with nature and the environment, particularly in arid regions and deserts. Iranian traditional architectural heritage are amongst these achievements bringing about comfort for inhabitants with maximum use of renewable resources and consuming the lowest amount of fossil fuels (Parsi, 2004). In the past, builders invented and implemented construction solutions and plans on the basis of their experience in order to arrive at comfort in buildings without mechanical systems.

Despite its deep-rooted history of architecture compatible with climate, nature, and the environment, Iran has unfortunately fallen away from its past in the previous few decades. That is why we witness construction that neglects traditional techniques for optimising energy consumption (Moghaddam and Rajabi, 2006).

1.3 The research question

In today's world, one may see the unpleasant design of buildings, whether residential or non-residential, which are severed from the surrounding environment and have no connection with it (USEA, 2006). As a developing country and with an area of over 1650000 km^2 (Zanjani, 2012), Iran has witnessed an increasing trend in domestic energy consumption during the past few decades, enjoying extensive energy resources such as oil and gas. According to a report by Kreft and Eckstein in 2013, among 61 major producers of greenhouse gases in the world, Iran ranks 60^{th} in the effectiveness of policies and strategies for dealing with climate change. Buildings account for a major part of domestic energy consumption, accounting for 20 to 40 per cent of Iran's total energy consumption (Ayatollahi, 2003). The major problem in Iran is heat; during the summer, the temperature reaches 40 degree Celsius during the day. Water is scarce and so is the vegetation. These harsh conditions have been the major reasons why occupants have tried to overcome climate conditions by using air conditioning systems (Hamouche, 2003). Due to improper design and construction, nonstandard materials and equipment used in buildings, and inappropriate choice of building facades such as windows and insulation systems, Iranian buildings consume the largest amount of energy among other sectors (Iranian Ministry Energy, 2013). The thermal performance of Iranian modern buildings is very low. Energy is subsidised by the government and this is the reason architects and building designers consider it as a minor factor in terms of planning and design. Contrasting with the standards recommended for thermal insulation that could save up to 50 per cent of energy (Numan et al., 1999), most private houses are constructed with low thermal performance building materials and have no consideration of the climate. Currently, vernacular architectural principles appear to have been forgotten (Naseri, 2013). This is the result of sudden urban development in Iran and the replacement of old architectural values with western values and methods (Debache and Benzagouta, 2014).

According to Washington and Cook (2011), reliance on technology and using mechanical systems to make a comfortable zone for occupants has led humans to not consider themselves as belonging to nature; rather, humans believe themselves to be an external force that has to dominate nature (Stone et al., 2007; Huber and Knutti, 2011). In the past, climate considerations were very important in building and urban designs. However, with the emerging of modern architecture and building services systems, the process of climatic design is now often overlooked (Givoni, 1998). People have acted in harmony with environmental conditions and nature in the past when population was much more limited and they established their constructions along with natural conditions and with minimum damage to nature.

The overall motivation of this study is to identify, organise, interpret, and express these ancient principles in an understandable way and in particular to explore how extract some of these principles that can be employed in light of today's requirements. As Mozayeni (1997), an international architect stated, there is dependence in industrialised countries on technology on the one hand, and the blind imitation by the third world countries of such technology and ignorance of indigenous know-how on the other hand. Therefore, the following question is of interest now:

What are the real benefits of vernacular architecture principles in today's modern architecture and if such energy efficiency benefits do exist, why haven't Iranian vernacular principles been integrated with the design of new buildings in Iran?

1.4 Aim and objectives of the research

The key interest of this research is to assess how energy use in modern buildings can become more sustainable, and how related greenhouse gas emissions can be minimised, by using vernacular architecture principles in modern buildings. There is also a gap in the research addressing the opportunities and values of traditional methods and technologies. Furthermore, there is a lack of comprehensive studies on Iranian traditional building design examining in depth how they provide a 'comfortable zone' for residents during the extremely hot summer temperatures sometimes exceeding more than 40 degrees Celsius. This study will identify key principles of Iranian vernacular architecture that are cheap, simple, logical (Eiraji and Namdar, 2011) and consider how the paradigm of modern architecture can be updated to make it feasible to include such Iranian vernacular architecture design strategy in contemporary buildings in Tehran and other similar climate conditions.

The aim of this particular research is to explore and prove the feasibility of the concept of the application of Iranian vernacular architecture in designing contemporary buildings which offer improved energy consumption while achieving further goals of a sustainable agenda such as using local materials and traditions to preserve cultural values.

To achieve the aim of the research, the objectives are to:

1. Identify the sustainable architecture, sustainable design methods, and assess characteristics of vernacular architecture; (Chapter two)
2. Analyse and assess the feasibility of using the principles of vernacular architecture as part of the design of modern residential buildings in Iran; (Chapter four, Chapter five)
3. Establish the key principles of Iranian vernacular architecture that contribute to energy efficiency and the principles and of sustainability; (Chapter five, Chapter six)
4. Develop a process which helps to evaluate energy consumption in modern design using vernacular principles; (Chapter six)
5. Use the identified principles in the design of a prototype building, and test their validity and reliability through scientific testing and user response; (Chapter six)
6. Identify factors that have contributed to the abandonment of such systems in recent decades in Iran (Also see figure 3). (Chapter seven)

1.5 Thesis contribution

The current thesis explores the potential principles behind the Iranian vernacular architecture. The thesis does not propose imitation and repetition of the past; rather, it seeks to identify and comprehend architectural principles which can be incorporated into modern architecture. Using secondary and primary methods, the thesis identifies, verifies, evaluates and concludes Iranian vernacular architecture principles (IVAP), and using modern technology, it offers methodologies to integrate such lessons into feasible solutions to reduce energy consumption in modern buildings. The ecological simulated building designs presented in the following chapters will offer alternative design options, as means to reduce energy consumption in buildings in hot arid zones. In recent times, most buildings rely on mechanical services to provide a comfort zone for their occupants. The proposed approach in this thesis relies on IVAP which use natural and locally sourced resources to reduce the energy consumption and make an environmentally friendly building. This thesis builds upon previous research but makes a clear and significant contribution on the use of a selected range of principles such as the wind catcher, locally sourced materials, and the principle of courtyards. The analysis offered in this thesis constitutes of a comparison of the energy performance of an IVAP designed building with a building designed using conventional building principles. By identifying main building elements in terms of structure, substructure and superstructure, it is shown how reliance on passive systems can reduce energy consumption, lower carbon emission and conserve fossil fuels. Using locally sourced materials which was identified as a key principle in architecture is reconsidered in this thesis via an analysis of a novel application of ‘mud/adobe’ as an insulating material. Furthermore, the study explores and tests the impact of different building elements such as shading, orientation, canopies, and planting in different location of the building. These case studies offered here can help guide and inform architects and designers in pursuit of energy reduction in buildings.

With reliance on passive design principles of IVA, this study promotes architectural design which is in harmony with its natural and social environments. In conclusion, the following contributions can be identified:

- Establishment of key principles of Iranian vernacular architecture by comparing and synthesising literature using desk based analysis of documentary evidence supplemented by observation;

- Proof of concept of IVAP as feasible alternative to architectural design to enhance energy performance (energy in use) by offering case studies of two simulated buildings where a conventionally designed building is compared and contrasted to an alternatively designed building using IVAP;

- Critical evaluation of different factors contributing to reducing energy consumption in a IVAP designed building;
- Creating a novel approach to the use of mud/adobe as an insulating material by evaluation, design, measurement and analysis of a wall construction in a laboratory environment;
- Identification of the key contributing factors to the lack of integration of IVAP into the architectural curricula of Iranian higher education and university.

1.6 The structure of the thesis

Following this introductory Chapter which set out the scope and limitations of the research the rest of this thesis is structured as follows:

Chapter 2: (**Literature review on environmental challenges and emergence of sustainable development)** deals with the sustainability and sustainable architecture. The methods and principles of sustainable architecture explored. The main objective in this chapter is to link it to architecture, while interpreting the concept of sustainable architecture. This chapter will highlight the fundamental principles of sustainable/passive design in the literature and evaluate their contribution to sustainable architectural design. The chapter will specify principles to achieve a passive design. Each principle is divided into different categories, and explains how to achieve a sustainable design.

Chapter 3: **(Research methodology)** This chapter will offer an overview of the methodology, research strategy and philosophical standpoint behind the study.

Chapter 4: **(Renewable energy resources for designing sustainable buildings**) The scope of this chapter will review: i) the renewable sources of energy commonly used in buildings, and ii) to explains the relationship between the building sector and energy by examining traditional vernacular architecture.

Chapter 5: **(Iranian vernacular principles)** This chapter will review and evaluate principles of Iranian vernacular architecture. The chapter will first review the literature on vernacular architecture and then will focus on specific aspects of Iranian vernacular architecture.

Chapter 6: **(Calculation and analysis of virtual modern and vernacular buildings**) This chapter presents an energy performance comparison between both modern and Iranian vernacular architecture, which enables the identification of performance problems based on a comparison of simulated performance data.

Chapter 7: **(Barriers of using Iranian vernacular architecture)** The purpose of this chapter is to describe and discuss the barriers to the application of Iranian vernacular architecture principles in residential buildings in Tehran.

Chapter 8: (**Conclusion and recommendation)** This chapter contains a summary of all the chapters such as the findings from the literature review, principles of sustainability, the energy usage of modern and vernacular building, principles of Iranian vernacular buildings, awareness and usage of an Iranian vernacular principles based on survey from architects and designers. The conclusion chapter contains research findings and research recommendations for future research .

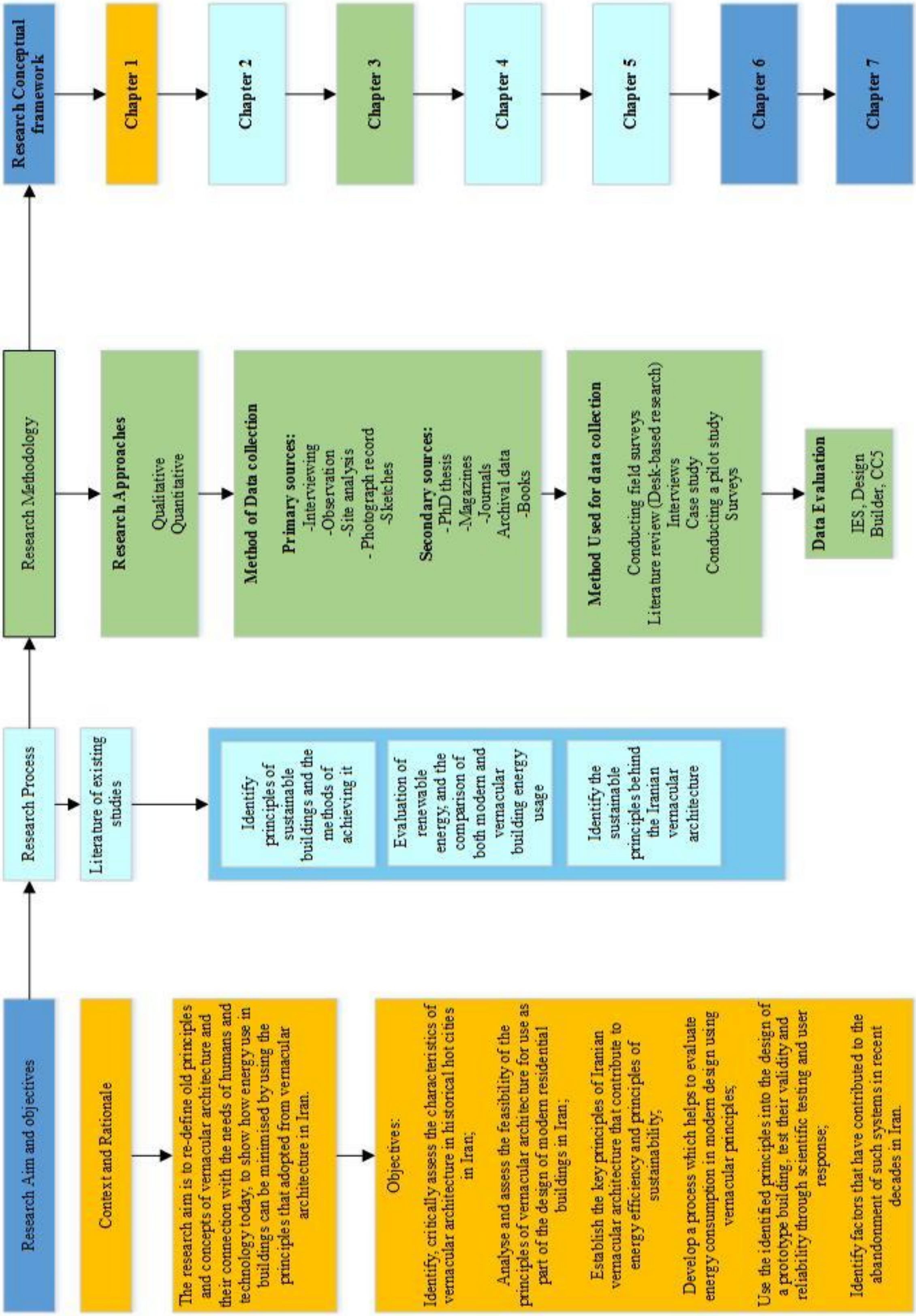


Figure 3: Research steps

CHAPTER TWO: ARCHITECTURAL DESIGN AS AN INTEGRAL COMPONENT OF SUSTAINABLE DEVELOPMENT

2.1 Scope of the chapter

Chapter one offered an overview of the thesis and elaborated on the aim and objectives and research questions. This chapter focuses on the concept of ‘sustainable development’. One of the integral components of sustainable development is considered to be architectural design and how it can help minimise energy use in buildings. The interpretation of sustainable development into the language of architecture (i.e. passive design) has a relatively young tradition which is nevertheless critical to our understanding of how buildings can become more sustainable. The rest of this chapter will highlight the fundamental principles of sustainable/passive design in the literature and evaluate their contribution to sustainable architectural design. Each principle is divided into different categories, and explains how to achieve a sustainable design. This chapter through identifying those principles will introduce the way that each principle can help achieve a sustainable design.

2.2 Sustainable development

In the past few decades, scientists and researchers have become increasingly concerned with environmental issues, alternative development models, and the implications of consumption of natural resources. As a result many have advocated that people and countries must show commitment to changing their behaviour (Morris et al., 2012), and in so doing the management and consumption of natural resources have turned into a joint problem (Jones and Wigley, 1990; Pearce and Atkinson, 1998; Rogers et al., 2008).

The term "sustainable development" was first coined in the 1970s and was formally introduced to the development literature in journals of global protection strategy in the 1980s, which led to more attention from the viewpoint of global environment and development of societies (Elliott, 2006; Vallero and Brasier 2008). The concept of sustainability developed in reaction to increasing global pollution, depletion and the irrational depletion of non renewable resources (Barrow 1995, P.372). Sustainable development is not a fixed state of harmony but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are made consistent with future as well present needs (United Nations Centre for Human Settlements, 1991). Thus, Mendler et al. (2006) states that, sustainable development fulfils the needs of society, without compromising the power of future generations for addressing their needs.

2.2.1 Sustainable architecture: definitions and concepts

Sustainable construction and the environment are pivotal to maintaining the permanence of the ecosystem equilibrium. Consequently, the human's assuming moral "custodianship" role and responsibility regarding ecological resources demands a conscious wise action in regard to adjusting the relationship between the human environment and the natural environment (Bahreini and Maknon, 2003). In order to gain knowledge of sustainable architecture, the gradual development process of this architectural approach needs to be investigated and factors influencing it should be expressed. Of course, the roots of this concept are not limited to the twentieth century; rather, just as the relationship between human, nature, and the physical environment is as old as the history of human architecture, the root of environmental considerations in architecture dates back to a time much earlier than when the concept of sustainable architecture was introduced. In recent time, the term sustainable architecture is used for a wide range of environment-sensitive approaches and encompasses traditional native architecture, which is always regarded as architecture tending to ecological and social sustainability (Jodat, 2001). As well as that, a small number of architects lead architecture towards meeting the needs of internal and external environment conditions. Whilst difficult to come up with a comprehensive definition of the sustainable architecture approach that can serve as a reference. Charles Kibert’s (1994, quoted in Abdul Azis et al., 2012: 630) definition of sustainable architecture, which was put forward in the first international conference on sustainable construction, is as follows: "Creation of a healthy built environment achieved by using resource efficient methods and ecologically based principles".

These principles are the following: minimising the consumption of non-renewable resources, enhancing the conditions of the natural environment, and minimising ecological damage to the environment (Stubbs, 2008; Newman, 2008).

Susan Hagan (2001) defines sustainable architecture according to a moderate viewpoint of environmental morality, in which establishing ecological balance with the pillars of the environmental system is emphasised. She states that achieving the aforementioned hinges on whether architecture can fulfil environmental conditions. In this definition, there is a comprehensive holistic outlook on the environment, and the ecological aspect of which is taken into consideration as well as its cultural, socioeconomic, and political identity. The sustainable architecture concept implicitly embraces balance and interaction among three main areas, namely social, economic, and environmental (Dabidiyan and Farhodi, 2003) (Appendix A).

Many in this field argue that separating the word “sustainable” from architecture and placing emphasis on it will be a temporary matter, because the course of development of architecture will tend to a more environment-sensitive and farsighted outlook depending on conditions, as all types of architecture will turn into environmentally sustainable architecture.

Susan Maxman (1993), the president of the American Institute of Architects, has emphasised this claim in the international conference of architects in Chicago. Sustainable architecture is the way to do architecture, it is an outlook and a method of work; hence, it had better be called under no specific term, it should simply be called architecture (Maxman, 1993, quoted in Guy and Farmer 2001:140). Ken Yeang (2006) also defines sustainable architecture as ecological design. In his point of view, sustainable design is indeed a kind of design that is in perfect harmony with the ecological systems of Earth during its life cycle. In sustainable design, materials and energy are used in such a way that the least negative effects are put on the environment and the least waste of resources would follow.

2.2.2 Sustainable modern architecture

Modern life has made people to become less concerned about conservation and more wasteful of its recourses, producing more solid waste, and increasing their dependence on artificial cooling and lighting. However, today, a great deal of effort is placed all over the world in achieving sustainable development in the construction industry with the aim of reducing energy consumption, thus city planners, designers and architects have tried to improve the eco-efficiency in their designs. Cities and regions are moving from linear to circular systems, where substantial amounts of their energy and material needs are provided from waste streams (Newman, Beatley and Boyer, 2009). In terms of architecture, sustainable modern buildings bring together a vast array of techniques to reduce and ultimately eliminate their impact on the environment. Sustainable modern buildings emphasise taking advantage of renewable resources (Mustakeem et al., 2014). For instance, using sunlight as an active solar tools (for example, solar collector and photovoltaic techniques) to generate electricity and hot water. Other key elements of sustainability used by modern architects are plants and trees though green roofs; these can be used through modern materials, for example, using packed gravel or permeable concrete instead of conventional concrete to enhance replenishment of ground water (Esmaeili & Pimplikar, 2012).

2.3 Sustainable and passive design

The environmental impact of construction, minimising the carbon emission, recycling and eco buildings have captured the attention of architects and engineers across the world (Johnson, 1993; Cole, 1998). Sustainable design recognises the interdependence of the built environment; it is a change and moderation in architectural design and a response to the current era's apprehensions concerning harmful effects and consequences of human activities for creating a type of artificial environment; an environment that "fulfils humanities present needs without disturbing next generation's abilities for addressing their own needs" (World Commission on Sustainable Development, 1987). Sustainable design means making buildings that use land, material, energy, and water resources efficiently; that improve the health of ecosystems; and that address health issues relating to the indoor environment. Thus, in line with sustainable development objectives, the effect buildings exert should be examined through different aspects and scales in various stages of construction, from the start of the design until habitation and commissioning stages, so that it is ensured that constructed buildings have the least negative effects on humans and the environment. It is important to adopt a passive design in buildings; the least it will help is to cut the running cost of energy in the long term and hence less energy and earth resource exploitation. Those recommended factors are (Bansal et al., 1994): site selection, shape of buildings, position and size of building and the selection of building materials.

2.4 Sustainable design principles

The roles that buildings play in modern society are as diverse and profound as the people that use them. Putting buildings up, renovating them, taking them down, these construction life cycles have a substantial environmental footprint (Environmental Protection Agency, 2008). Thus, after reviewing 52 sources, for achieving a sustainable design, three fundamental principles for sustainability in architecture have been identified (Schneider, 2012; Lehmann, 2010; Nouri, 2003; McDonough, 1992; Watson, 1983):

1- Economising on the consumption of resources.
2- Design on the basis of life cycle.
3- Interaction of humans with nature.

Meanwhile, for each of these principles, a number of relevant specific strategies are introduced by several scholars and researchers, which create improved indoor environmental quality and reduce energy by respecting the site and making a comfortable zone for the occupants. The challenge of sustainable design is in balancing human needs with nature. The main objectives of sustainable design are to reduce the use of critical resources like energy, water and raw materials; prevent environmental damage during the life cycle; and create liveable, comfortable and productive building for occupants by respecting the nature around. Studying these strategies brings about the possibility for the designer to analyse proper methods architects can employ in order to reduce harmful environmental effects of buildings they design. Table 1 summarises the literature on the principles of sustainable design which are later discussed in the rest of the chapter in more detail.

Sustainable design principles		
Economising on the consumption of resources	Conservation and efficient use of water	Reusing and reducing water consumption
	Conservation of energy	Energy conservation in urban and site planning
		Passive heating and cooling systems
		Daylight and insulation
		Selection of low energy consumption devices and materials with low embodied energy
	Conservation of materials	Efficient use and recycling materials
Design on the basis of life cycle	Pre-construction stage	Using less and recycled materials
		Designing for durability and adaptability
	Construction stage	Minimising effects on site
		Using non-toxic materials
	Post-construction stage	Reusing the building
Interaction of humans with nature.	Preserving natural conditions	
	Urban design and site planning	
	Providing temperature, visual, and aural comfort	
	Providing visual contact with outdoors	
	Using ventilation to provide clean fresh air	

Source: Author's compilation of literatures

Table 1: Principles of sustainable design

2.5 Principle 1: economising on resources

This principle deals with reusing and recycling natural resources used in buildings. In each building, there is a constant input-output flow of natural and artificial resources (Organisation for Economic Co-operation and Development, 2008). This flow begins with the production of construction materials and carries on through the entire life of the building. Buildings may have some undesirable side effects to the planet such as, air and water pollution, depletion of natural resources like deforestation and generation of waste (Canadian Wood Council, 2003). Therefore, with appropriate cautious use of resources, architects can reduce the degree of use of non-renewable resources in construction and operation of buildings. In analysing each building, two branches of resource flow should be taken into account:

a- Resources enter the building-environment interaction system as inputs. These methods reduce the flow of non-renewable energy sources that enter buildings. The degree by which buildings require input sources has a direct relationship with its efficiency in utilising those sources.

b- Resources exit the building-environment interaction system as outputs. By reducing the amount of waste and managing them properly, these methods lessen the environmental pollution level of buildings.

The principle of economising on resources includes three strategies, each of which lays emphasis on a specific type of resources required in construction: conserving water, conserving energy, conserving materials (Global Reporting Initiative 2011; Masnavi, 2002). Economising on energy, water and materials are the issues that have been mentioned most often in sustainable architecture designs. This principle will introduce the minimal use of energy through reduction of the amount of electricity, water and materials consumed. It will also introduce use of natural resources.

2.5.1 Conservation and efficient use of water

Water stress is a global problem, especially in the Middle East region. The Middle East is the driest region in the world (Appendix B). Renewable fresh water availability is already below 1000 cubic meter per person per year, compared to over 6000 worldwide (Tolba, 2009). Water conservation methods can lead to a decrease in input or output flow or both, because water entering the system of the building for consumption and water exiting from the building as wastewater are typically in connection with urban water treatment equipment. Therefore, decrease in consumption will be followed by reduction of waste.

In each building, large amounts of water are consumed for purposes such as drinking, cooking, washing, cleaning WCs, and watering plants. All of this consumed water requires treatment and transfer that involves energy consumption. In addition, Water efficiency is an indicator of the relationship between the amounts of water required for a particular purpose and the amount of water used or delivered (Vickers, 2002).

Source: Mirata, 2010

Figure 4: Typical water usage in residential buildings

2.5.1.1 Reusing and reducing water consumption

A sustainable design should use water efficiently, and reuse and or recycle water, when it is possible. Drinking water for occupants consumes enormous energy resources, such as pumping, transport and treatment (Cheremisinoff, 2003). Water consumed in buildings may be divided into two categories: Blackwater and Greywater.

The wastewater is effluent consisting of blackwater (Urine and faecal sludge) and greywater (Sally and Jayakody, 2008). The wastewater contaminates fresh water and coastal ecosystem, threatening food security, access to safe drinking and bathing water and providing a major health and environmental challenge (Corcoran et al., 2010). The greywater is collected in ground tanks and generated from utilising rainwater and recovered wastewater for the purpose of supplying non-potable water. The greywater does not require treatment as much as blackwater (Waleed, 2013). The greywater is purified by using pebbles and biological filters, which can be used for the irrigation of gardens or flushing WCs. This is another suggestion that contributes to water conservation.

In order to improve water efficiency in buildings systems and equipment should be adopted in a way to reduce loss and consumption. Technology used to reduce water consumption and modification of existing appliances is becoming more familiar. Inserting a spray nozzle into the outlet of an existing faucet will reduce the flow rate up to 70 per cent compared to a standard tap (Cuong, 2007). Furthermore, using low-volume WC tanks, suction toilets, and bio-compost decreases water consumption considerably.

2.5.2 Conservation of energy

Building energy consumption and increasing demand on the world's fossil fuel resources is now a major interest of professionals in the building industry (Crawley, 1999). Once the construction stage of any building is over, a constant flow of energy is required to enter the building during commissioning. Increasing demand for building services and comfort levels, together with rise in time spent inside buildings, assure the upward trend in energy demand will continue in the future (Lombard, 2008). Energy consumed in buildings for heating, cooling, lighting, and start-up of installations is based on non-renewable energies. Thus, it is essential to find different ways to reduce energy use, increase efficiency, and maximise the use of renewable energy sources.

2.5.2.1 Energy conservation in urban and site planning

With the majority of the world's population being urban (Arnstberg, 2005; quoted in Lundqvist, 2007), one of the key factors which can make cities sustainable is to increase efficiency of land use in relation to transportation systems. By using and re-utilising existing sites inside cities and reusing old buildings with applications appropriate to conditions, irregular expansion of cities can be prevented (Pout, 2012).

It is important that architects study the ecology of the site and ensure to design according to the site conditions to get the benefit of using of natural resources (such as: weather condition, site orientation, building location). For instance, in very cold or very hot and arid weather, buildings are placed next to one another to reduce the visible surface. In hot and humid weather conditions, structures with great distances from one another are required to maximise natural ventilation (Soltanzadeh, 1995). This kind of planning makes it possible for designers to maximise the use of natural resources existing in the site, which will help reduce the green house gas emissions (WBDG, 2014).

2.5.2.2 Passive heating and cooling

Designing passively means working with external weather conditions, instead of fighting against them. These incorporate certain elements in buildings to use ambient energy sources to heat and cool an interior space, without using electricity or natural gas; the energies which can be used are daylighting, solar energy, and natural ventilation (Brown and Dekay, 2001). Hence, the amount of energy spent on heating and cooling homes can be reduced. For instance, residential green roof systems can significantly reduce home heating and cooling costs in hot climates. By cultivating plants for shade around buildings, this can be further leveraged through the use of clean and natural energy for shade and ventilation (Daniels, 1994). This subject will be discussed and identified further in the following chapters.

2.5.2.3 Daylight and insulation

Daylighting is the practice of using natural light to provide illumination in interior environments. In the past decades, practically every residential and workplace used daylight as the primary illumination source (Heschong, 2002). Appropriate consideration of daylighting ensures not only visual and thermal comfort in the urban setting, but also contributes to the preservation of the visual identity of the place (Bean, 2014). Designing passive buildings and their windows in a way that they can use natural light leads to economising on electrical energy required for lighting, and a decrease in peak of electrical load (US department of Energy, 2002). In addition, the major factors affecting the daylighting of an interior are depth of the room, the size and location of windows and roof lights (Marks and Woodwell, 2010). Insulating will ensure energy efficiency in every part of the building envelope. The insulation will reduce the energy loss of a building.

2.5.2.4 Selecting low energy consumption devices and materials with low embodied energy

Accurate selection of low-consumption heating, cooling, and ventilation systems is absolutely crucial (Burdick, 2011). The primary price of such equipment may be higher than that of low-quality ones; however, this additional expense will be compensated through future savings (Procura, 2012; BRE, 2003).

The embodied energy of the construction material shows the total amount of energy that is spent during its entire life cycle (Daniels, 1994). Low embodied materials are those that use less energy and resources to make, transport and build. Building regulations should lead the way in the use of green materials, which are composed of renewable resources, and do not deplete limited natural resources. Green materials are environmentally responsible because impacts are considered over the life of the product (Spiegel, 2012). Selecting materials with low embodied energy reduces the overall effect of buildings on the environment during their life (Khasreen et al., 2009).

2.5.3 Conservation of materials

Buildings all around the world consume 3 billion tons of raw materials each year or 40 percent of total global use (Roodman, 1995). Buildings and materials are in constant use as long as there are economic and population growth. However, short cycle of material use and less use of energy will help in the broader sense in the direction of sustainable environment and sustainable development. Buildings can be constructed using a wide range of materials, and producing and using construction materials has various effects on local and global environments. The amount of waste resulting from the construction and equipment installation processes is remarkable. After construction, a slow flow of materials continues to enter the building for maintenance, replacement, and renovation. Finally, all these materials will be recycled or heaped in dumping grounds. A number of methods are employed to achieve better usage of materials such as: designing for standard sizes, reusing or refurbishing an existing building, and using products with high recycled content (Jefferson, 2005).

2.5.3.1 Efficient use and recycling materials

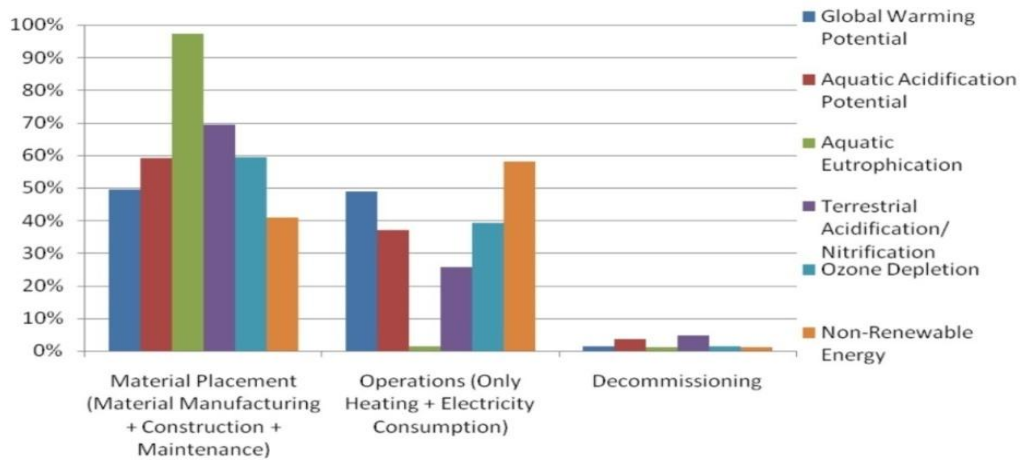
Extracting, processing, producing, and transporting construction materials are all followed by environmental damage to some extent (Hagan, 2001). Efficient use of materials involves constructing buildings with a low rate of harmful gas emissions by using materials and tools that minimise the consumption of resources and help to preserve the environment. It also includes recycling, using materials produced through sustainable processes and mainly using local building materials. Therefore, one of the most direct and most effective methods of economisation materials is to use resources that are already in the form of buildings (Vallero and Brasier, 2008) such as, bricks or windows which can be used in their original form in new buildings. Recycling is the separation of recoverable waste materials generated during construction and remodelling (Jethoo, 2012). Demolished buildings should be used for more than one purpose in a manner that befits other buildings, as resources for new buildings.

2.6 Principle 2: design on the basis of life cycle

The second principle of sustainable architecture presents a method for analysing the construction process of buildings and its effects on the environment. The Environmental Protection Agency (1995) defined environmental life cycle assessment as

> *"a process aimed at identifying, evaluating and minimising environmental impacts associated with products, manufacturing, processes or systems".*

Figure five shows that buildings goes through various stages in its life and the impact of each stages of the building life cycle. Each stage is composed of a number of activities, and are more defined as pre-construction; the use of material manufacturing and the construction period, and post-construction; the use and maintenance, and the end of life. In this section, the building's life cycle is shown in three different categories, and on each category the building stages will be discussed.



Source: Krogmann, 2008

Figure 5: Distribution of impacts among different life cycle phases

2.6.1 Pre-construction stage

The early stages of a construction project are often the most important ones, as the decisions made during this phase will determine many important aspects of the overall plan. At this stage, the selection of materials used in a building is a major factor in building life-cycle environmental impact, as producing and processing materials can have effects on a global scale and leave behind long-term results and consequences. Under the sustainable design strategy, environmental consequences of design, orientation of the building and its effects on the scenery, and the materials used are examined (Guinee, 2001).

2.6.1.1 Using less and recycled materials

Lessening the amount of material and elements used makes a building's design less complicated, and requires less labour to deconstruct it in the future. Additionally, if construction professionals consider using the least amount of materials in the most efficient manner, they will help move the project towards the goal of generating near-zero waste (Korber and Guy, 2006). In addition, using recyclable materials causes the embodied energy of their primary form, which would have been wasted if they were disposed, to be conserved (Hastoe, 2009; Jackson, 2005). Architects should incorporate reused materials in the construction of new buildings. Besides minimising waste from disposal of materials from existing buildings, as well as decreasing resource use and pollution associated with the creation of new materials, incorporating reused materials will help preserve the materials' embodied energy, which is the amount of energy consumed to produce the materials (Berge, 2009).

2.6.1.2 Designing for durability and adaptability

Durability is one of the aspects of sustainable development (Dabidiyan and Farhodi, 2003). A part of this compatibility is the ability to cater for the needs of people with different ages and physical conditions. It is important that greener materials perform the same as standard products over their awaited life-cycle. Therefore, it is valuable to develop a durability plan. Designing a building for disassembly includes designing it for adaptability, which can reduce the generation of significant construction waste during building renovation (Shell, 2006).

2.6.2 Construction stage

Manufacturing construction materials affects the environment in a range of different ways and different times during their life cycles. For instance, transportation and manufacturing of raw material to the site can be a highly pollutant activity, depending on weight and distance to the respective site (Allen and Shonnard, 2006). This also includes the use of power equipments during construction and the energy used for site work. For a sustainable design strategy, construction processes of the building need to be evaluated in order to find solutions to reduce environmental effects of consumption of resources.

2.6.2.1 Minimising effects on the site

All construction sites impact the environment, whether they are in an urban or rural settings. There is a great potential for negative impacts like the direct loss of species and fragmentation of their habitats. The sudden rush of heavy equipment and machinery into the site and the resulting ecological damages may be prevented via precise planning . Removal of topsoil due to excavation will lead to high water requirements for future landscape purposes and will prevent the growth of native plant species (Mhaskar, 2005). Adhering to lifecycle construction principles whenever possible can provide meaningful benefits by reducing the energy and resource consumption required to produce the necessary building materials and systems and by reducing solid waste (Kozlovska and Spisakova, 2013). With respect to sites, materials that are transportable to the site via human workforce will reduce the need for additional construction of roads and using heavy vehicles.

2.6.2.2 Using non-toxic materials

Throughout the 20th century, the construction industry has changed both in methods and materials used in buildings. At the beginning of the 20th century, about 50 materials were used in buildings; currently about 55,000 building materials are available, and over half of them are manmade (Spiegel, 2012). Growth in the use of modern building materials, decreased ventilation levels and fluctuating moisture levels have introduced increased levels of allergens in the indoor environment (Liddell, 2008). Hence, making use of non-toxic materials in order to enhance the health of building users, three fourths the time of whom is normally spent indoors, is essential (Brian, 2010).

2.6.3 Post-construction stage

This stage begins when the useful life of the building is over. At this stage, energy will be consumed and environmental waste will be produced due to building demolition and disposal of materials to landfills (Arena, 2002). Recycling and reuse activities related to demolition waste can also be included in this stage. Deconstruction of building materials is the careful disassembling and reclaiming of the structure's reusable finished materials. It also saves energy and reduces greenhouse gas emissions by reducing the need to extract and process raw materials and transfer new materials a long distance, conserves natural resources, and reduces the environmental impact of waste disposal (Environmental Protection Agency, 2013; Lennon, 2005).

2.6.3.1 Reusing the building

This minimises the need to produce new materials due to saving more natural resources and reducing impacts of production such as emissions (Billatos and Basaly, 1997). Reusing and recycling construction products avoid or reduce waste and saves primary resources (Milford, 2010). Reusing or adapting an existing building has a number of tangible environmental benefits. Reusing existing buildings reduces the need for new materials and lower the environmental impact and CO^2 emissions connected to their production (Orbasli, 2009).

2.7 Principle 3: Interaction of humans with nature

This principle focuses on the interaction between humans and the natural world. While economising on consumption of resources and design on the basis of the life cycle deals with efficiency and maintenance, this principle addresses the ability to live for all components of the global system of life, such as plants and wildlife.

In modern societies, more than 70 per cent of each person's life is spent indoors (UNEP, 2008), and most activities are conducted within built spaces (Farshchi and Fisher, 2000). Furthermore, Wilson (1998) identified some factors that affect the quality of the indoor environment such as the selection of building materials and finishes, combustion of gas or wood, high moisture levels, and the amount and quality of fresh air circulated through ventilation systems, and these bad indoor environments can affect human health. Hence, the most essential contribution of architecture is creating constructed environments that provide their inhabitants with security, health, physical comfort, psychological health, and efficiency.

The design team should minimise the effects buildings exert on local ecological conditions (such as existing topography, plants, etc.). Sustainable design should improve the quality of workplaces and residential areas. This leads to an increase in efficiency and decrease in psychological stress and will positively influence health and comfort for the residents (Clements, 2014; Heerwagen, 2000).

This principle consists of five strategies:

<u>2.7.1 Preserving natural conditions</u>

Building on the land surface, makes the natural groundwater recharge difficult (Dexter, 2011; Winter et al., 1998). Altering contour lines affects water absorption and expulsion methods as well as the way wind moves within the site (Mitcham, 2000). Soils are often compacted, slowing or preventing the downward movement of water. Most building materials effectively seal off the land surface, which are called impervious surfaces (Dexter, 2011). Impervious surfaces not only reduce the rate of ground water recharge (New Jersey Stormwater, 2004), and therefore can limit water supply, but also increase the damage from rain that falls on impervious surfaces and becomes storm water runoff.

Construction sites and plans should be selected in a way that excavations lower than the local aquifer level are not required, as placing a huge obstacle such as a building in an aquifer damages the natural hydraulic process (Brown, 2001).

2.7.2 Urban design and site planning

Creating sustainable buildings starts with site selection, including consideration of the reuse of existing buildings. On the urban scale, sustainable architecture is designed for enhancing public transportation, the location, orientation, and the landscaping of a building which affects local ecosystems, transportation methods, energy use.

Urban development should be guided by sustainable planning that promotes interconnected green space and a multi-modal transportation system (Parsad and Bansal, 2015; Hegazy, 2015). Integrating transportation planning with natural systems analysis and land use planning is essential for creating communities in a sustainable environment (Deakin 2003, Williams, 2000). Streets and highways should enhance interconnected transportation options, particularly for pedestrians and cyclists; these provide mobility options and help reduce pollution by reducing vehicle trips.

2.7.3 Providing temperature, visual, and aural comfort

The way humans consider energy is based on their experience of motion, sound, light, and heat (Brown, 2001). However, it should be noted that energy is saved inside construction materials surrounding people. The thermal performance of the building depends on the energy transfer between a building and its surroundings. The location, form, and orientation of a building will have a major effect on the ability to light, ventilate and heat the space naturally and passively. Temperature is the most significant component to the experience of comfort in a space. Knowledge of heat exchange principles and basics is essential in order to design buildings that have efficiency in terms of using solar energy (MacKay, 2009). Heat is a form of energy that flows from a point at one temperature to another point at a lower temperature (Emery, 2014). Heat is transferred into or out of the building through different ways such as walls, roofs, windows, floors, and convection and radiation. Heat is also added to the space due to the presence of human occupants and the use of lights and equipments (Indian Ministry of New and Renewable Energy, 2012). Human bodies perform within an internal temperature range much narrower than external temperatures (Boduch, 2009). People cannot function well in environments that are either too hot or too cold. The human body’s thermal comfort is provided when the skin temperature is 37 degrees centigrade (Emery, 2014).

Sound is created by waves of compressed air that humans perceive with his/her ears. The noises of the building installations or people can disturb concentration and harm the building users’ sense of hearing.

2.7.4 Providing visual contact with outdoors

Daylight not only creates a link with the outside environment, which can have a positive effect on occupants' health, it is also a key factor in the reduction of energy use. From a psychological standpoint, windows and skylights are considered as very necessary tools in correctly regulating the human biological clock (Edwards and Torcellini, 2002). Adjustable windows are highly important and crucial, because they enable the buildings inhabitants to control the temperature and ventilation of their workplace to a certain degree.

2.7.5 Using ventilation to provide clean fresh air

There are two important methods for controlling comfort in buildings via ventilation, each of which is used depending on the region is humidity (SUNA, 2009). The primary purpose of ventilation is to moderate indoor air quality. The secondary purpose is to prevent summer overheating; this is achievable by bringing outdoor air through the room to remove unwanted heat gains, thus preventing an increase in room temperature (Scottish Executive, 2007). In hot sultry regions, achieving comfort using natural tools is merely possible by creating constant motion of air along the building shell. The most important useful factor in design is to employ light shells for buildings that rapidly cool off at night, such as sunshade with no structure that absorbs heat. Furthermore, the volume of airflow that passes through a structure is governed by the size of the openings; the greatest numbers of air changes are obtained when both inlets and outlets are as large as possible (Smith, 2011; Nakanishi et al., 2007; Van der Maas, 1992). The velocity of air movement through the structure is maximised, creating the greatest cooling, when the area of outlets is greater than the area of inlet openings. In arid regions, humidity of air is very low and during the day, the situation is far from being comfortable. A clear sky engenders extremely cold nights. That is why buildings with thick roofs and walls are useful by keeping internal air temperature stable during a day (Brown, 2001).

2.8 Summary

The aim of this chapter was to summarise and synthesise the literature on sustainable design. The principles were divided into three categories and each category was divided into other sub-categories. In summary, the chapter reviewed methods of achieving sustainable design and offered solutions to save more energy, reduce carbon emission by relying on conserving materials, energy, and water, and creating design on the basis of the life cycle and action and reaction of human with nature. The aim to minimise the use of resources is also fuelled by the fact that the world's growing population together with the increase in per capita use of natural resources have caused imminent threat to the question of sustainability. The principles of sustainable architecture are demonstrated and summarised through the chapter encourage the shifting of dependence on non-renewable resources to valuable renewable resources. The following chapters will indicate the Iranian vernacular principles and manifest a practical application of the fundamentals of sustainable architecture.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 The conceptual framework of the research

This chapter will offer an overview of the methodology, research strategy and philosophical standpoint behind the study. The aim, objectives and questions proposed in this study rely both on physical performance of buildings and their components as well as on the interaction of human beings with such physical environments. In such context the research will rely on factual data and simulated measurements as far as the physical and natural environments are concerned, but will seek to explore attitudinal and behavioural aspects of human interaction using interpretation and opinion based studies.

As stated in earlier chapters the aim and motivation for this study has been to identify and scientifically measure and compare the performance of simulated buildings in terms of energy consumption with a view to further exploring the impact of changes in design through the application of IVAP. In other words, the research is motivated by exploring, comparing and analysing factual and measurable data on performance of simulated buildings. In this endeavour it can be suggested that the research may have a tendency towards observing and measuring the 'objective' reality (i.e., independent from the observer/researcher) which is commonly associated with the 'positivist' philosophical standpoint. The data that form the foundation of such study, therefore, would need to rely on the scientific information available on different components as well as the whole building. However, measurements and data collection on existing buildings (i.e., vernacular architecture in Iran) faces challenges that may lend themselves to other philosophical standpoints such as the realist approach. For example, the evidence of the performance of such buildings may not necessarily be based on scientific and objective data, and in many cases the benefits of such architecture can been observed in the personal and subjective experience of the building users. It is argued that the 'subjective' experience of the people is less prone to measurements and require interpretation and hence an Interpretivist approach. Therefore to achieve the goals of this study a mixed approach to research has been adopted as discussed in the rest of this chapter.

3.2 The Research Methods

The combination of qualitative and quantitative methods enable the researcher to overcome the difficulties in measuring both facts and opinions and/or personal experiences of individuals. According to Habib et al. (2012), the study that involves both quality and quantity analyses need both qualitative and quantitative research methods. There are also substantial advantages when both quantitative and qualitative methods are used, such as literary and statistical data which can be researched and analysed to draw conclusions (Isiadinso et al., 2011; Osmani and Reilly 2009). To successfully achieve each objective, it was necessary to apply appropriate methods to each given task. For example, the extraction of principles of Iranian vernacular architecture relied on a mixed approach by initial observations, sketches, informal interviews, which were later supplemented by a desk-based investigation of secondary sources. This involved the review, summary and synthesis of literature on vernacular architecture and creating summary tables.

To explore the feasibility of the implementation of IVAP in contemporary architecture, the research sought the virtual environment of a simulation software. Alterative models were created and tested and data for each type of building were compared in terms of energy consumption.

To create a novel approach in wall construction using adobe/mud as an insulating material, the research relied on a real scale construction and subsequent testing of the energy performance in the laboratory.

Finally, the experiences of the design teams and their perceptions of the barriers to the successful implementation of IVAP required the exploration of opinions which was achieved using a questionnaire survey. In the following section, general discussions of various research approaches have been provided and the selected approaches for the research has been justified and elaborated.

3.3 The Research approach and procedure

<u>3.3.1 Qualitative research approach</u>

Qualitative research is based on an inquiry method of research, and has been employed in various academic disciplines. Specifically, qualitative research contributes to knowledge by interviewing and generating personal opinions, and has the ability to seek and gain substantial insights to be able to understand people's perceptions. According to Creswell (2003), qualitative research is explanatory in nature with the aim of trying to answer (how and why) type of questions. As Mmari (2006) states, "Qualitative methods permit the evaluator to study selected issues in depth and detail". In this thesis, qualitative methods such as in-depth interviews and participant observation were vital because they enhanced the understanding of the vernacular building's function and analysis without an observation. Therefore, the various methods of collecting qualitative data includes interviews, which is the direct observation (Manase, 2008), and a case study, which has been taken into consideration in this thesis.

There are various benefits of using a qualitative research approach. Qualitative research is open to any possible results by developing explanations and theories from the observation of the empirical world. Hence, this study initially relied on site visits and conduct of informal and in-depth interviews in a number of cities in Iran with the tradition of vernacular architecture. Through site observations and in-depth interviews, relevant examples of vernacular architecture were collated. The findings from these visits and interviews helped the researcher to understand how vernacular architecture has been able to protect buildings from harsh climates, especially dust storms, and create a comfort zone for the occupant in extreme temperatures. These observations further strengthened the view that traditional builders had designed buildings to be climate-responsive and sustainable (Merriam, 2009). In addition, site visits and observations provided this research with a holistic description of issues and concepts (Merriam, 2009). However, qualitative research method described above are inherently 'subjective' experiences of the researcher and may introduce biases and errors which can cast some doubt in the reliability of the findings. As stated earlier this problem was overcome by triangulation through application of alternative modes of data collections.

3.3.2 Quantitative approach

Quantitative research approaches refer to the kind of research requiring given measurements to be objective, statistically valid and quantitative (Bowerman, 2014). Quantitative approach is a systematic and objective approach used to obtain information through testing relationships and also examining the cause and the effect relationships of a given study (Blumberg et al., 2011). The Quantitative research is objective unlike qualitative research which is subjective, hence the quantitative method involves deductive reasoning. Subsequently, this method is usually used to test existing theories. The samples collected from the given population can be used to obtain proper data (Blumberg et al., 2011). More often than not, researchers seek the sample sizes that yield results that have at least a 95 percent Confidence Interval hence the error margin is reduced (Collis & Hussey, 2013). Notably, quantitative research is an accurate form of data collection, which collects numerical data that are analysed using mathematical based methods to determine whether the predictive generalisation of the theory is true (Aliaga and Gunderson, 2000).

The two most common types of quantitative approach to research are experimental and survey (Olayemi, 2013). Quantitative research needs to gather factual and genuine evidence about an idea and a question. Consequently, this study identified a case study whereby quantitative analysis was applied to make generalisation about the findings. This approach contains elements of the empirical-analytical scientific approach, with an in-depth investigation of the potential effects that have made Iranian vernacular buildings sustainable and well adapted to the environment and climate. Importantly, this approach was not only used for analysing data from modern and contemporary simulated buildings in Tehran but it was also used for analysing a virtual building that had used selected principles of Iranian vernacular architecture.

Qualitative research was also applied in recording and measuring factual aspects of buildings in order to identify and establish key principles behind Iranian vernacular architecture. Elaboration and examination of these principles together with the conduct of preliminary analysis, evaluation and comparison of vernacular and modern virtual buildings enabled this study to offer proof of concept and feasibility study of the selected IVAP in the later stages of the study. The deductive approach was also employed to analyse the literature to provide the context of the research, and also in identifying the gaps between existing evidence by collecting data through analysis of the findings. Therefore, the research provides a concluding design of a prototype, which will introduce new methods in building designs, inspired by the Iranian vernacular architecture. Notably, the research simulated and calculated designs via different software packages such as Energyplus, IES, and Design Builder to evaluate the research prototype and current existing buildings in Tehran.

3.3.3 Research philosophy

The literature survey that was conducted to find out the appropriateness of the approaches to research showed that there are two significant methodologies for theory building. According to Collis and Hussey (2003), there are two methodologies that can be used, which include the positivist and the phenomenologist. The positivist approach involves quantitative, experimental or scientific techniques; whereas, the phenomenological approach is described as the humanistic, qualitative, and subjectivist (Collis & Hussey 2003). Importantly, there are various assumptions that are categorised under five headings; epistemological, rhetorical, axiological, methodological, and ontological (Collis & Hussey 2003). Specifically, the ontological perspective requires that the quantitative researcher perceives the research objective as concrete and independent of themselves, and can be measured by the use of a questionnaire. Therefore, the qualitative study not only considers the actors being investigated but also gives special consideration to those charged with interpreting the study. In addition, the researcher is also required to minimise the distance between him or her and the respondents (Creswell 1998). Moreover, there was the need to consider that impersonal language and various facts are explicitly reported from the study.

The other consideration is the rhetorical and language concept that was used in the research approach. In a quantitative study, the language must be formal and impersonal, and should contain a well defined definition of various concepts and words (Collis & Hussey, 2003). This research also involved quantitative study and the language was framed to exemplify the study in a more formal perspective. In addition, this thesis has been written in line with the writing styles that are sympathetic to the position made.

The other aspects that were considered include both deduction and induction to describe the logic that is attributed to the study. This was due to the adoption of both qualitative and quantitative research approaches. This implies that the ideas and variables that were chosen in this research were selected before the beginning of the study (Leedy & Ormrod 2001). Importantly, such theories remained fixed throughout the research process. In addition, induction was also considered, especially in describing the processes that were related to the testing theory and the developing theory.

3.4 The Research Strategy and Design

3.4.1 The research design

The research strategy provides the logic or a set of procedures for generating new knowledge (Blaikie, 2010). According to Chandler (2014), research methodology refers to a major step in a thesis and outlines the research process, which is a way of presenting the logic to achieve the objectives of the research. Consequently, this section provides details of the stages of the research and how data collection was carried out, including the calculations to answer the research questions so as to achieve the precise and detailed expression of knowledge.

Notably, the study adopted the following chart for data collection:

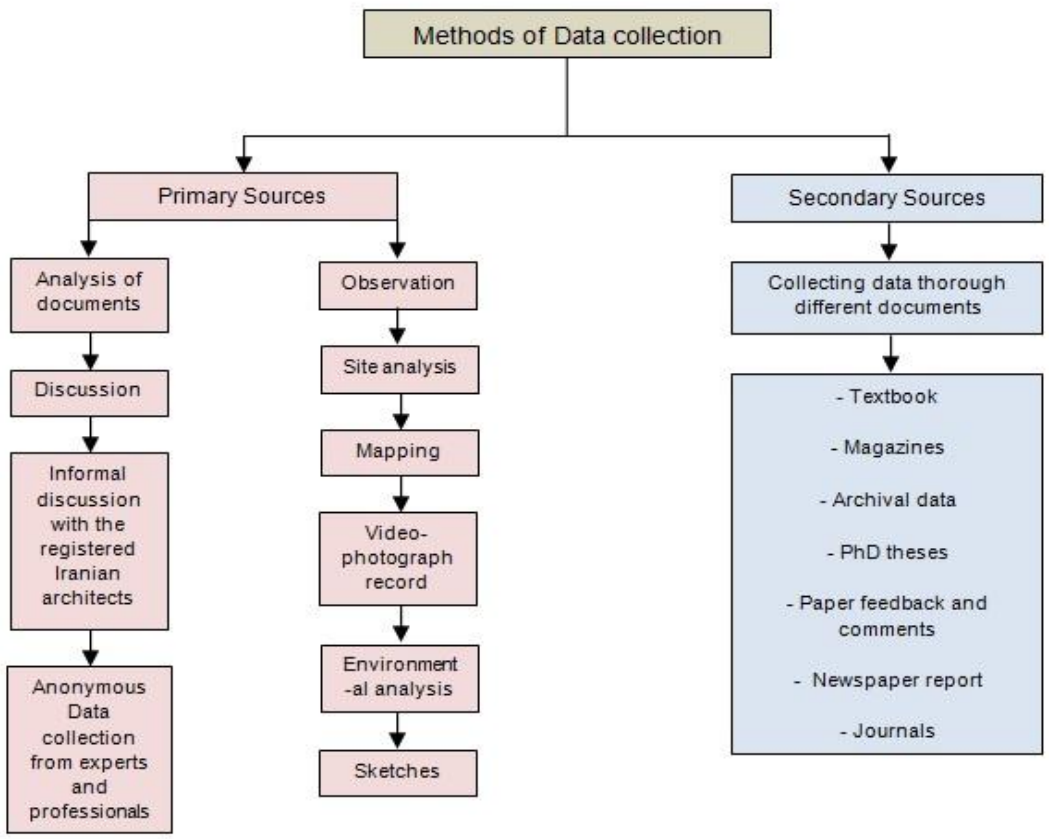


Figure 6: Methods of data collection

Therefore, the above chart was used to provide the reference to all activities that were conducted during the entire data collection process.

3.4.2 The research strategy

The strategy for conducting the research followed logical steps in collecting data and information compilation using both induction and deduction. Documentary analysis, field trips and surveys, interviews (informal, structured and unstructured) helped this study to capture a holistic and contextual understanding of the principles of Iranian vernacular architecture. Whereas methods of achieving sustainable construction, passive design, and the principles behind the Iranian vernacular architecture and their usage and their functionality in the past required desk based and comparative analysis which was planned through studying different literature in English and Farsi to explore the depth and breadth of concepts. This helped to identify variables that are relevant to the principles of sustainability, in order to distinguish what has been undertaken by Iranian traditional architects and how principles of Iranian vernacular architecture can be incorporated into modern design. This part explained how renewable energy resources can help to design sustainable buildings to consume less fossil fuel and reduce carbon emissions. Following that, the research plan was to collect data from different vernacular architecture in Iran, which was extremely important in establishing an initial knowledge base about the function of the buildings. The data collection concentrated on the usage IVAP in the past and current climate, comparing and gathering case studies and information on successful and unsuccessful projects.

Data were collected through visiting Iranian vernacular architecture and having informal in depth- interviews with some of the Iranian scholars and architects. The principles behind the Iranian vernacular architecture were described, including their usage and their functionality in the past (Tahbaz and Djalilian, 2008; Ahmadkhani, 2011; Hosseini and Namazian, 2012; Vaezizadeh and Kazemzade, 2013). Furthermore, site observations highlighted the existing buildings that have followed the same methods and pointed out their weaknesses.

3.5 Data Collection

A combination of personal informal interviews and administered questionnaires were used for the present study. This was because of the advantages derivable from both methods. Interviews allow respondents to express their views in a broader sense. In addition, interviews authorise the explanation of issues in the questionnaire by the interviewer in areas where respondents may not be fully knowledgeable. With regard to the questionnaire surveys, this method permits the researcher to analyse and compare the outcome and result of the respondents.

The study was aimed at constructors, city planners, and qualified architects in Iran, to obtain the relevant data in the context of the research. The following methods of data collection were used to obtain data from the study participants as well as secondary research.

3.5.1 Methods used for data collection

The following research strategies were adopted to collect relevant data that are in line with the formulated objectives:

i. Literature review (Desk-based research)
ii. Interviews
iii. Case study
iv. Conducting a pilot study
v. Survey

All these methods were extensively used to obtain effective and flawless data. The subsequent sections show the discussion and justification for the data collection methods employed in this study.

3.5.1.1 Survey

In this study, site visits and observation were adopted as qualitative methods. Notably, personal experience of the researcher enhanced the identification of the study sites. During the visits, the rules of the design, the types of materials used and the orientation and environmental performance were assessed, and further inquiries were made from the several architects and Iranian scholars. In order to collect the data using the field survey strategy, the study adopted various approaches. Particularly, the researcher travelled to different locations in Iran to conduct the study involving the examination of traditional buildings and vernacular architecture. The main task was to record, measure, analyse, evaluate and compare various aspects of vernacular architecture in Iran. This was conducted through informal interviews and questionnaire to establish the notion of sustainability of the vernacular buildings during the actual surveys. The data collected using such strategies provided an opportunity to seek and gain substantial insights to be able to understand the professional perceptions. This is because the benefits of the surveys are numerous. The first benefit is that it provides an opportunity for the researcher to be in touch directly with the local people; specifically the town planner, to document their visions about the vernacular buildings. Secondly, it also provided new research and supporting evidence based upon the aims and objectives. During such visits to the study sites, the research focused on identifying the key elements and principles behind Iranian vernacular architecture which made them sustainable. This enhanced the understanding of the rules in design, types of materials, site orientation and environmental performance at various sites. Therefore, the intended information was gathered through direct observation, which is primarily a quantitative technique in which the observer is explicitly mapping the action of a particular scene (Robinson, 1988). Such methods like sketching, site analysis, drawing the plans and characteristics of the buildings were also used to collect data (Appendix C). Importantly, drawings and sketches assisted in capturing the spatial concept of Iranian vernacular buildings. Studies show that the order of a drawing is highly revealing of the drawers understanding (Jee et al., 2009). Smith (1998) states that visually depicted ideas are more able to inspire new ones. Hence, the sketches enhanced the generation of the idea techniques, such as brainstorming which helped him to come up with an idea for the final design.

Site observation was carried out to reflect the effective functioning of various principles. This method is a technique of data collection in which the situation of research subjects are watched and recorded (Bryman, 2015). This method was used in this study to find out the site layout, construction materials, forms and connections between spaces. The actual activities that were carried out included taking photographs to identify the physical environment such as light, ventilation, building forms, floor plans, building materials, site plans, and types of roofs. The photographs that were taken were later used to do the comparison between the observed data and the data provided by other scholars and researchers. Site observation was used beside interviews to review and provided a basis for the discussion. The buildings that were observed were recorded in the form of notes.

These notes contained the personal impression of the researcher, plans, and sketches elevation of those buildings.

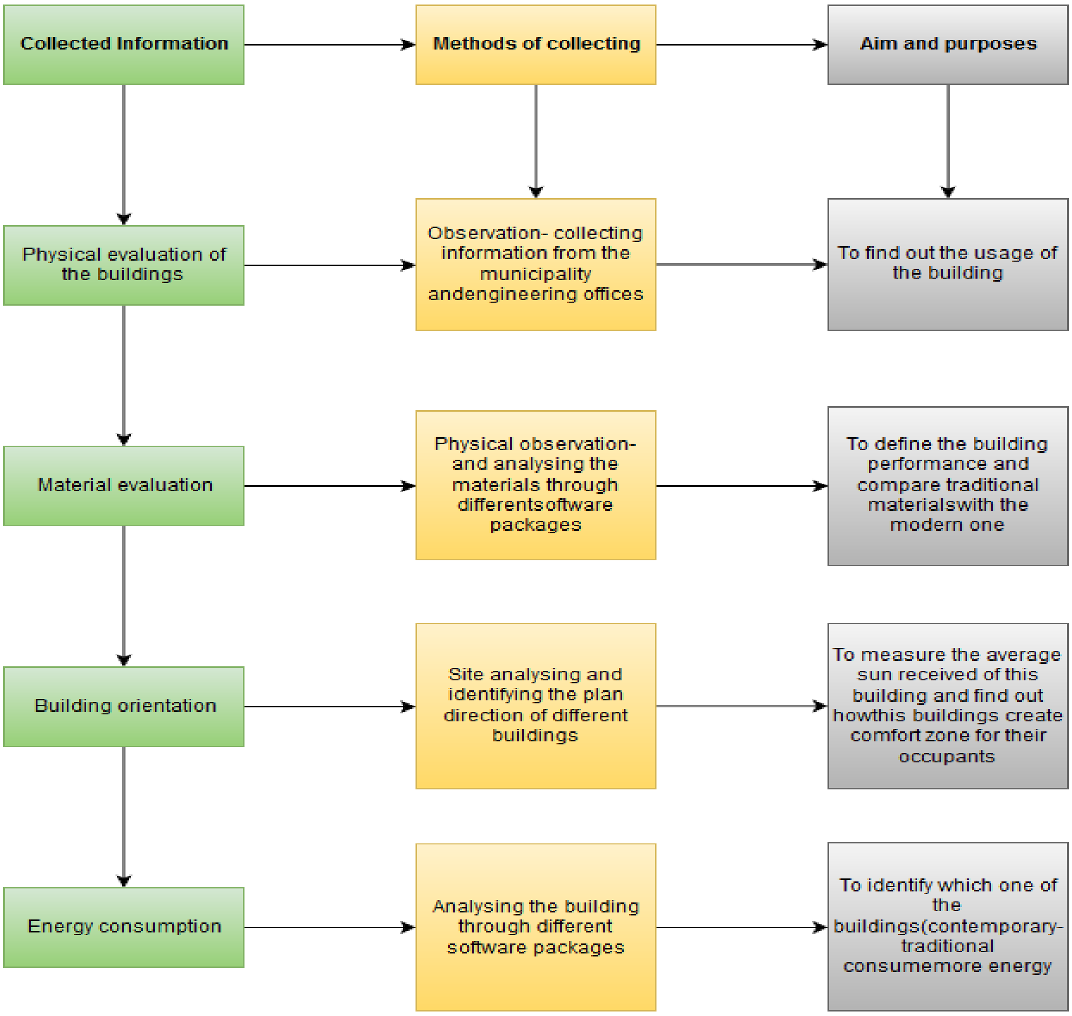


Figure 7: Collecting data through observation

The specific vernacular building that was visited is in the city of Yazd. Yazd was chosen because it has the densest Iranian vernacular buildings (Monshizade, 2008). In Yazd city the actual places that were visited included Dolat abad garden, Lari House, the Water reservoir of six wind catchers, Jame mosque, Malakol tojar house, the Water museum, Rasolian house, Amir chaghmagh, Eskandar prison, mirror museum, and Kolahdozha house. The information that was obtained from such visits is presented in chapter five.

The rationale for the selection of the cities and sites that were visited was rooted in the fact that these sites offered the most historic and viable cases. The aim of these site observations was to study vernacular buildings and to analyse them with the aim of gaining insight into this style of building. The study of buildings was in accordance with the main features of the vernacular architecture. Therefore, it was concentrated on the materials, orientation, design (such as; floor plans, elevation, site plans), spatial organisation, openings and circulation between the spaces with special emphasis on the courtyard. Importantly, gaining the understanding of the governing principles of Iranian vernacular architecture, and defining optimal strategies for their use in today's residential buildings was also one of the objectives.

3.5.1.2 Desk-Based Research: The Review of Literature

Desk-based research methods also known as secondary research, are categorised into two distinct sources; external and internal secondary data. Examples of secondary resources that are commonly used include city information, internet sources and directories, among others. These sources of information are already established information that most researchers gather their data from. Otherwise, desk-research is the most commonly employed data collection method.

The researcher used several related literature sources including works of notable authors (Hejazi and Mehdizadeh, 2014; Saeidian 2014; Memarian, 2012; Roaf, 2004; Bakhshi and Mofidi, 2001; Farshad, 1997) for better understanding of the vernacular buildings and sustainability. A broad literature review was preferred since it helped to cast a spotlight on ideas and information concerning vernacular architecture, eco-building and green development. Importantly, the literature review is considered a body of text that aims to review the critical points of current knowledge (Blaikie, 2010). Furthermore, it was established that the literature review is an evaluative report of studies and an introduction to the work which is obtained from other academic sources, such as the review of books, related past journals and theses (Hewitt, 2009; Marrelli, 2005). The study of literature reviewed in this thesis covered published and peer reviewed journals and conference proceedings. In addition, this thesis used a variety of web-based search engines and extensive databases, and various scientific and specialist articles and journals.

Moreover, previous studies have not treated attributes of principles of sustainable buildings for developing countries in detail (Zabihi,2012; Ahmadkhani, 2011). Therefore, the analysis of the relevant documents included books, journals, magazines, Ph.D. theses and archival data, to identify and evaluate principles behind the Iranian vernacular architecture, which can be used in the modern context. Consequently, there was necessary to register as a member of the biggest library in the Middle East (Iranian national library), and also to obtain letters from the Iranian authorities to be able to enter and use the facilities of all Iranian universities. The search was mainly for archives, theses, literature and plans about the Iranian vernacular buildings. Documentary analysis was also used in several of the reviewed studies, mainly to supplement data collected from other sources. Therefore, this research picked two of the primary types of document analysis:

1- Public records which analyse the official documents such as policy, guidance and strategic plans (Appendix D).
2- Personal documents which have been collected by the researcher, email communications, analysing different journals, magazines and attending cyber forums.

The use of desk-based research methods in qualitative research poses various strengths and weaknesses. The strengths of desk-based research include:

i. There is ease of access to many secondary sources of data; whereby, the availability of the online sources makes research easily accessible (Neale, 2009). Specifically, it is simpler and easier to search through various sources of data and finally obtain the most relevant material especially on the online platform.
ii. The use of secondary sources offers clarification of primary research questions. According to Neale (2009), the use of desk-based research is able to indicate some of the difficulties experienced while conducting primary research.
iii. Importantly, the use of desk-based research is characterised by low costs that are incurred whilst acquiring data. Most researchers obtain relevant information from the secondary sources at cheaper costs and sometimes incur no charges in their acquisition (Neale, 2009).

The associated limitations of desk-based research include:

i. There is usually incomplete information; this is the case where researchers may obtain valuable information. However, such sources do not always avail full version of their results (Neale, 2009). This implies that for one to get the full version of the research, various costs are demanded by the research owners.
ii. The use of secondary sources requires one to be very cautious. In addition, the information that a given source may have in a particular period, may be irrelevant over a certain period, since new researches are carried out to challenge previous results (Neale, 2009).

From the above illustrations on the desk-based research methods limitations and benefits, it is evident why secondary sources were preferred for the study. The use of the desk-based research sources provided several significant advantages that enabled the research to realise its objectives. The study considered all the disadvantages and the advantages of the desk-based research. The outlined disadvantages make the data that was obtained questionable over their validity and relevance in line with the topic of research. The results from the previous researches that were searched were also subjected to many questions, for example, the authenticity test on the results that were used in this study.

3.5.1.3 In-depth interviews

Depending on the nature of the research, it was necessary to conduct interviews so as to obtain a comprehensive data on the relevant information needed. Therefore, informal interviews were conducted with 28 local people (male and female) to evaluate the impression and intuitive approaches of interviewees. The interviews were carried out with people who were still living in Iranian vernacular buildings. This involved asking people about the buildings, and whether these old buildings were still working in the current climate and environmental conditions. Face to face interviews were also undertaken to gain qualitative understanding of the environmental impacts on the design phase of the vernacular houses in central Iran.

While in Iran, registered Iranian architects were involved in an in-depth interview so as to gain understanding of the design phase of buildings that can considerably affect their environmental impact. As Yin (1994) states, interviewing which has a high level of flexibility is the most widely used data collection technique to produce data of great depth. A page summary after each interview was produced to outline the key points and thoughts. As recommended by Robson (2011) the summary of the interview has to be undertaken after the interviews as the researcher's memory is fresh. These were chosen because of the potential richness and validity of the data obtained.

There are various types of interviews: structured, semi-structured and unstructured. These provide varying extents of depth and flexibility in regards to the responses (Mathers et al., 2002). Unstructured informal interviews are commonly used in qualitative research. Mackinder and Marvin (1982) used interviews with architects to specify the role of information and influences on the design process. Furthermore, Ko and Fenner (2007) used interviews to identify barriers relating to their willingness, motivation and capacity for change in introducing energy efficient measures into new build housing. In line with Lowe et al. (2004), the current research has used semi-structured and unstructured interviews. Semi-structured interviews were conducted on a one to one basis with official key figures of the city, and town planners, as this approach offered the opportunity for the researcher to find out more about the framework of the Iranian Buildings Rules and Regulations. During the site analysis and observation, the unstructured interviews were carried out with ordinary Yazd inhabitants and other official people in designing the city layout. This type of interview was mainly employed to gather information at the time of discussions, in order to find out the advantages and disadvantages of the vernacular buildings in Iran.

Notably, the questions of the interviews were designed with analysis from some of the reviewed publication and reports. Prior to the interview, interviewees were first informed about the aim and objective of the study. The details of the interviews as well as the questions are in Appendix E.

The questions in the interview focused on three main issues, which are:

A. Identifying the framework of the Iranian Buildings Rules and Regulations
B. Investigating and identifying the Iranian vernacular architecture

3.5.1.4 In-depth Case Studies

According to Ler Eng (2006) the case study as a research approach is considered the best approach employed to gain a deeper understanding of selected buildings in respect of the plan and elevation. Therefore, an in-depth analysis of the buildings and their functionality was undertaken, with the aim of understanding the sustainability of the buildings. Case studies were adopted because they allow for an in depth examination of the problems (Feagin et al., 1991; Yin, 2009). Similar to Dabaieh research (2011) the current thesis in regards to the case study methodology applies an explanatory phase. This phase focused on:

A. A site visit and observation to determine sustainably of Iranian vernacular buildings and results. (Presented in Chapter five).
B. Identification of the research problem, in which literature analysis was carried out to establish the energy consumption of modern and vernacular buildings (Chapter six).
C. Analysis and evaluation of vernacular buildings (Chapter six).

The study developed Energy Performance Comparison Methodology in line with recommendations by Maile (2010). Therefore, it was necessary to present an energy performance comparison between both modern and Iranian vernacular architecture. This enables the identification of performance problems based on a comparison of simulated performance data representing design goals. The perspectives of the energy consumption assessment of a whole building were presented based on a feasibility study of both a modern and vernacular building. The steps in the development of analysis of both buildings were presented and discussed. The purpose of analysis was to gather and quantify information for incorporating principles of Iranian vernacular architecture into modern designs. In the assessment stage, the differences between the energy consumption in both buildings on a statistical basis were identified. Based on these differences, the study identified performance problems with the help of measurement assumptions and simulation approximations. Therefore, during the study, the building energy analysis simulation as it pertains to the work done with the software such as (IES) and Climate Consultant 5 (CC5) were adopted. Furthermore, the aim of the case studies was to find out the consumption of energy in both Iranian vernacular architecture and modern construction in

Tehran. Based on Mohammad and Shea (2013) research at Bath University, the thesis selected Integrated Environmental Solution software package for this section. The software was employed since it is able to simulate the performance of a building with real climate data (Crawley, 2008). Following that, the research investigated how to practice climatic design and employ the Iranian vernacular principles into modern housing in hot climates. This was necessary so as to understand the need for climatic design and the underlying principles. Alongside this, the climatic design takes into account the local environmental conditions, such as the speed and direction of wind and the number of sunlight hours.

In designing the respective buildings, efforts were made to prepare the conceptual context for design by taking a glance at the past and understanding methods, values and concepts ruling peoples' lifestyles and paying special attention to the principles employed by traditional architects. On the other hand, by having a look at the current technological advancements, employing technology rationally and wisely can pave the way for the development of creativity in design and in a fashion that future architects can also follow. Therefore, this research method demonstrates that by utilising modern dynamic thermal simulation it is possible to establish a more logical relationship between the environment and internal conditions, through the changing seasons.

In order to carry out a comprehensive case study that is not biased, there was the use of software packages such as Design Builder, which are capable of calculating the amount of daylight hours and modelling various aspects such as heating, cooling and lighting systems (Zamani et al., 2012). The software is able to calculate thermal comfort in indoor environments, energy consumption and the amount of energy gain and loss from different parts of the building. This software is used to predict energy flows in buildings. This includes temperatures, system performance, and electrical loads. By having a detailed and measured data, a more detailed performance assessment is possible. Thus, in designing buildings, efforts are made to bring about desirable conditions inside the building by means of architecture compatible with nature via utilising the potentials of the local climate and controlling natural energies instead of excessive consumption of non-renewable energies. Succeeding in coming up with such design entails a real understanding of the local climate and adopting appropriate strategies by the designer in order to create acceptable conditions together with minimum energy consumption.

The virtual buildings were intended to be representative as well as to allow finding out which of them is much more energy efficient and produces less carbon. The building model was created as a 4 storey building. The building had multi thermal zones. Both buildings are located in Tehran climate condition and are similar in terms of general shape; however, the first building is one of the conventional constructed samples in the city (base building), while some changes are made to the second building through the use of passive solar and wind designs (optimal building), which has always been considered in the Iranian traditional architecture. Overall, in conducting the case study, Tehran was chosen because it is densest in terms of buildings and population. This was in order to set up a challenge where research can try to address the sustainability issues, since the goal of the study was to simulate both buildings and compare their energy consumption.

3.5.1.5 Collecting data through questionnaire

A questionnaire survey is a research tool, through which respondents are asked to respond to the same set of questions (Gray, 2009). The questionnaire was used to collect data in quantitative ways, in order to analyse and gain the views of the professional and specialised people in the field (Robson, 2002). The questionnaire can be used for descriptive and analytical purposes within the research to find out facts and views of the respondent (Naoum, 1998). The questionnaire in this study was designed with a combination of the aim and objectives of the research and literature reviews.

Balnaves and Cupti (2001) describe questionnaires as a method of collecting data from respondents about who they are (job roles), how they think (motivation, ideas). In order to evaluate relationships in a research survey and to draw broad conclusions, it requires the researcher to generate large amounts of data. Therefore, the data collected from questionnaires were used to identify the research question. Consequently, the study participants were divided into three different categories to cover the knowledge of architects, constructors and engineers. Their selection was based on job title and experience. Such a strategy was supported by Pedrini and Szokolay (2005), who showed three different stages; pre-design, schematic design and detail design stage of the RIBA Plan of Work, by targeting different groups of architects to examine their approach to the project of energy efficient office buildings in warm climates at different stage of design. The review of the profession in this research were targeted as the qualified professionals in Iran that have specialised knowledge regarding the information sought and possible shared interest in the study. The survey covered why professionals have forgotten some of the Iranian vernacular principles and why they are not allocating these principles into new designs, and secondly whether universities incorporate modules regarding Iranian vernacular architecture. The questionnaire was designed in two sections. Part A explores whether the respondents are familiar with sustainable and vernacular architecture. Part B explores the reasons for the apparent lack of use of traditional principle in modern Iranian architecture. The aim of the questionnaire was to gauge the idea of the aforementioned authority about the integration of Iranian vernacular principles with modern buildings. The ambition was to identify if people are interested in these types of designs or not, and to identify factors that have contributed to the determent of such approaches in recent decades in Iran.

Overall, the main objective of adopting the questionnaires was to collect and analyse data, and to find out about the perception of the Iranian vernacular principles in new design (The details of the questionnaires are in Appendix F). Therefore, the key elements and main reasons behind this study were to:

- Identify and test the feasibility of using principles of Iranian vernacular architecture, and introduce new methods according to those principles into modern buildings
- Determine the factors that deter professionals from using Iranian vernacular principles in modern designs.

3.5.1.6 The Pilot study

In order to evaluate the clarity, comprehensiveness and to examine the validity of the questionnaire, a small-scale preliminary study called "pilot survey" was conducted before the main research. The aim of the pilot study was to check the feasibility and improve the design of the research to set the contents as well as the translation of the questionnaire (Haralambos and Holborn, 2008). The pilot study ensures that respondents in the main survey do not have trouble in completing it (Ahadzie, 2007). Therefore, before the survey was carried out, the researcher piloted 10 per cent of the actual surveys. In order to ensure efficiency, five copies of the survey were distributed amongst professionals and engineers. The purpose of the pilot study was to test the questionnaire to identify errors, and to make sure that everyone understands the questions. This involved suggestions, comments and revision to the questions.

3.5.1.7 Design of the questionnaire

After finalising the questionnaire, 78 qualified people among the aforementioned three categories in the field of architecture were selected to investigate the following:

- Identify their perception of Iranian vernacular building's principles;
- Identify factors that have contributed to the determent of such systems in recent decades in Iran;
- To gauge their idea about the integration of Iranian vernacular principles with modern buildings;
- Identify which one of the Iranian vernacular principles is well known and the authorities rely upon.

In addition, the chosen category of the questionnaire involved a combination of both open-ended and closed questions. The reason behind the selection of open-ended questions was to let the respondent obtain the detailed answer in cases where their experience could be easily articulated. Additional questions were asked in the event the researcher required more information on a particular question and answer from a particular participant of interest. The final questionnaire was rigorously tested in different drafts for validation flexibility, easiness and consistency of scaling. There are five strategies that the quantitative researcher can adopt to administer questionnaires (Nesbary, 1999). These are the fax, phone, web based, mail and face to face interviews. All those approaches were applicable for this study. However, the study employed the face to face interview. This was based on the advantage of face to face interviews; whereby it enhanced getting more results and detailed answers. However, the disadvantage of this method is that it is costly and hard to organise a study within a wider area.

Otherwise, to attract better responses, the questionnaire contains ticking boxes and descriptive questions that let the respondents complete it easily and give as much information as possible.

3.6 Ethics, reliability, validity, and limitations of the study

The current research complies with the University's Research Ethics guidelines. This has been compiled from British Psychological Association's prescription (The British Psychological Society, 2009). The current research targets were identified to be architects, engineers and the constructors. The research conducted professional survey, where as the respondent information will be anonymous and they would not be personally identified. However, it was necessary to clarify to respondents that the questionnaire detail and summary would be available upon their request, in order for them to remove any part of the questionnaire that they do not want to be included in the analysis. The main challenges for this study were the rarity of data, creating original forms of calculation and examination of Iranian vernacular buildings in both the English and the Persian language. A lack of architectural and metric data on Iranian vernacular architecture in cities which have been visited has delayed the scope of the research analysis and was an obstacle in finding accurate measurements. The information that this thesis provides will help in filling the gap between the Iranian vernacular buildings and modern architecture and it could be the base and starting point for future work.

CHAPTER FOUR: RENEWABLE ENERGY RESOURCES FOR DESIGNING SUSTAINABLE BUILDINGS

4.1 Scope of the chapter

The scope of this chapter is to review: i) the renewable sources of energy commonly used in buildings, and ii) to explains the relationship between the building sector and energy by examining traditional vernacular architecture.

Renewable sources are not harmful to the environment and its supply is unlimited. Utilisation of such sources of energy will not only reduce greenhouse gas emissions and reduce dependency on oil, but have the potential to also create and introduce economic savings for occupants via domestic energy bills or generation of income through the feed in tariff. Here vernacular architecture or passive design is shown to provide internal environments which occupant can utilise renewable resources in order to create comfort zone.

4.2 Renewable energy resources and advantages of using them

Renewable energy is heat and electricity that is generated from natural resources such as waves, sun, and wind which are sustainable and never run out. In contrast, burning fossil fuels such as oil, coal, and natural gas, which will not only run out one day, but releases stored carbon into atmosphere as carbon dioxide, causing global warming which will have a serious impact on the environment (Solomon et al., 2009).

As Action with Communities in Rural England (ACRE) in 2013 states, in the last two decades the use of renewable energy sources globally has increased, as it leads to a more sustainable energy, reduces greenhouse gas emissions and a lower dependency from oil on one hand, and increases in energy prices which are translated into higher prices for transport services on the other hand, it will have a huge impact on the economy. Renewable sources can save money on domestic energy bills, and generate income through the feed-in tariff; therefore, this can be invested in energy saving, which will offer further economic savings.

The climatic conditions of Iran are such that architects are able to make use of natural resources such as wind and the sun for supplying energy, particularly in buildings.

Renewable energies fall into six groups.

4.2.1 Solar energy

The sun is the most powerful source of energy. The energy which can be exploited from the sun is categorised as active or passive. Active technologies convert solar energy into electrical or thermal energy for the occupants, such as photovoltaic cells that convert sunlight directly into electrical energy or solar concentrators that use mirrors to focus solar irradiation and generate intense heat, turning water into steam and generating electricity (Jayarama, 2012).

Passive technology refers to the orientation towards the sun or the use of special materials and architectural designs to exploit solar energy. The earth receives solar energy in the form of solar radiation, the amount of which is far more than what is required. The amount of energy that reaches the earth's upper atmosphere is about 1,350 W/m^2 the solar constant (Robertson and Athienitis, 2010). Solar radiation reaching a building surface may be direct or reflective (Watson, 1983). Direct radiation is rays shining in parallel penetrating the earth's atmosphere which provides the most usable heat. Indirect radiation represents the short wave energy of solar origin scattered downwards by gas molecules, water vapour and clouds in the atmosphere (Bhattacharya, 1996). Buildings absorb substantial amounts of solar energy radiated by other surfaces (such as the ground, walls, and building surroundings) and reflected from them. Iran is a very sunny country and numbers among the best countries in terms of solar energy reception, with about 300 clear sunny days a year and an average of 2,200 KwH solar radiations per square meter (Zawya, 2010).

The Iranian vernacular architecture is indicative of the fact that proper effective use of solar energy was of particular interest to Iranians in previous centuries. In spite of this, the present use of solar energy through employing new science and technology is negligible (Haj Soghta, 2011). Yazd, a historical city in the centre of Iran, offers a good case for investigation as there are many vernacular buildings in this part of Iran.

Direct sunlight in Yazd generates 70 to 80 kilowatt hours of energy per square meter in horizontal surfaces. As the reflected beams from surfaces or from under the ground increase in intensity, energy intensity also increases (Moghaddam and Rajabi, 2006). Low humidity and lack of clouds in the sky causes large temperature variations in these regions. In summer, solar radiation during the day increases the temperature to 55 degrees centigrade, whereas at night time, the temperature falls rapidly reaching 15 degrees centigrade or lower (Kasayi, 2000).

Given the fact that Yazd is situated in a region with substantial amounts of solar radiation (Appendix G), the town has great potential for utilising natural solar energy whether actively or passively (Yazd Statistical Annals, 2003). The following table shows solar radiation amounts as well as sunny hours compiled by Ayatollahi (2003).

Index	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual total**
Sun/H	185	205	211	240	296	341	345	343	314	283	221	198	3182
S/radiation kW/h	3.29	3.24	3.16	5.06	5.62	5.7	6.1	5.5	4.6	4.2	3.8	3.34	53.61

Source: Ayatollahi, 2003

Table 2: Annual sunny hours and solar radiation in Yazd

4.2.1.1 The use of sun as the main source of energy in building in Iranian architecture

In vernacular architecture in Iran the position of the building in relation to the sun and shade influences all aspects of design, from the primary selection of building site and dividing up land pieces to the final selection of plant types and yard construction details. Due to the high sun angles the degree of solar radiations onto the ground during the months of summer is approximately twice as much that on east and west facing walls (Haj Soghta, 2011), secondary reflection of solar radiation from the ground, windows, and walls can considerably add to the degree of cooling that a building requires. The simplest ways to limit heat absorption from the eastern and western windows of the building are solutions modifying conditions outside the building. The irregular rough surface of planted bushes helps prevent solar re-radiation and causes less reflection, even compared with a vegetation surface such as grass. Analysing building in different conditions and orientations in CC5 software packages illustrates that, by placing the building on the eastern side of trees or slopes of the ground, the solar heat intensity radiating onto the building in the afternoon may be reduced. The space under trees should be kept free of objects so that air flow for ventilation is not blocked. Tall trees are appropriate for the southern part of the building in order to provide shade on the walls and roof. Evergreen trees on the western and north-western side can often be a barrier against winter wind (Appendix H). Some delicate points should be noted in implementing such solutions. For instance, if the goal is to build a two-stories building, two types of trees should be used with different heights, so that the first type can cover the windows of the second floor (the trunk of this tree on the first floor should have little or no leaves), and the second type should have low height to cover the windows of the first floor (Prowler, 2014).

The amount of solar heat absorbed by building surfaces may be minimised through different methods:

4.2.1.2 Plan shape, orientation and building height

The amount of solar heat received by the surfaces of a house can be minimised for any period of the year through manipulation of the shape and orientation of the building with respect to the sun (Kamal, 2010; Ling et al., 2007). The building height factor has a dramatic effect on absorbing solar heat, because the outer surface area of the building increases as the building height does, and consequently a larger area is exposed to the sun (Walker, 2014; Huffer, 2009).

4.2.1.3 Roof shape and slope

As Jayakumar (2009) states that, the effect of solar heat on the shape and slope of the roof depends on the angle at which the sun shines and the time the sun shines. At a wide angle, all different types of roofs with equal areas absorb the same amount of heat. If the radiation angle is smaller, roofs with greater slopes absorb more heat. If the roof surface has a bright colour or it is cooled via evaporation or there is a proper thermal insulation underneath the roof, the shape of the roof will take on less importance (Appendix I).

4.2.2 Wind energy

Wind is caused by the sun’s uneven heating and cooling of the earth’s surface (Brown, 2001). Areas of high and low pressure are adjacent to each other in a geographic region, the high pressure areas (areas which are denser and cooler) rush in to fill in the empty spaces of the low pressure areas. This movement of air is wind. Wind variations are instantaneous, hourly, daily, and seasonal and are considerably affected by air and earth topography.

Wind energy was used 2600 years ago in Iran. The remains of old windmills, may still be found in the Khaaf region of Khorasan province (SUNA, 2009, Appendix J). Currently, worldwide, wind energy is one of the fastest growing renewable electricity technologies (Gelman,2013). Wind energy is exploited by using particular blades to capture wind, and engines to transform it to electrical energy. Wind turbines, which exploit wind energy, are installed both on land (onshore) and in sea or fresh water (offshore).

4.2.3 Geothermal energy

Geothermal energy utilises the accessible thermal energy from the earth's interior. Heat is extracted from geothermal reservoirs using wells (Edenhofer, 2011). Geothermal energy can be acquired from deep underground reservoirs through drilling, or from other geothermal reservoirs closer to the surface. Reservoirs that are naturally hot are called hydrothermal reservoirs. Geothermal energy can be harnessed to produce electricity or for heating and cooling purposes.

4.2.4 Biomass energy

Biomass is the fuel that is developed from plants and organic materials. Plant biomass comes from the sun through the photosynthesis process, they are basically the chemical storage of solar energy. Worldwide, biomass is the fourth largest energy resource after coal, oil and natural gas and estimated at about 10 percent of global primary energy (Ladanai and Vinterback, 2009). Globally biomass energy use has been independently estimated about 2 percent of annual biomass production on land (Kurchania, 2012). Biomass includes a wide variety of materials including wood, energy crops, agricultural and forest debris, food waste and organic components from municipal and industrial waste. There are technologies which convert the energy in forms that can be used directly such as heat and electricity, or convert it to liquid biofuel or combustible biogas.

4.2.5 Marine energy

Marine energy refers to the mechanical energy carried by ocean waves and tides, or to the thermal energy of the ocean coming from the Sun. The ocean holds vast energy potential, such as waves, tidal energy and offshore energy and each of them offers different opportunities. Ocean waves produced by winds passing over the surface of the water can be converted into electricity when energy is extracted from the surface motion of the waves or from pressure fluctuations below the surface. The cost of wave energy is estimated by the International Energy agency in the range of $0.20 to $ 0.75 per kWh (Scotia, 2012). Tidal energy is a good renewable energy source as it is more predictable than wind and solar power, and the International Energy Agency report estimated that 800 Twh/year could come from "in stream" tidal energy (Lako, 2010).

4.2.6 Hydro power

Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevation. This is generated from the water being recharged through the cycle of evaporation and precipitation which is driven by solar radiation. Hydropower offers significant potential for carbon emission reductions (Edenhofer, 2011).

The installed capacity of hydropower by the end of 2008 contributed to 16 percent of the worldwide electricity supply, and hydropower remains the largest source of renewable energy in the electricity sector (Kumar, 2012). According to Bloomberg New Energy Finance's estimate, 0.8 GW large Hydro capacity has been installed in Iran in 2012 (McCrone, 2013).

	Principle one: Economising on resources			**Principle two: design on the basis of life cycle**			**Principle three: action and reaction of human with the nature**		
Renewable energy resources	**Conserving and efficiency water**	**Conserving energy**	**Conserving materials**	**Preconstruction stage**	**Construction Stage**	**Post construction**	**Preserving Natural condition**	**Urban design and site planning**	**Design for health and wellbeing of the occupant**
Solar energy		X			X		X	X	X
Wind energy		X			X		X		X
Geothermal energy		X							
Biomass energy			X	X			X		
Marine energy	X			X	X		X		
Hydro power	X				X		X		

Table 3: The link between renewable energy and sustainable architecture

In the table 3, the research illustrates and links the renewable energy resources with the three fundamental principles for sustainability in architecture.

4.3 The relationship between energy and the building sector

One of the most significant environmental pollutants in the world is Co^2, especially in Iran, where it is the consumption of fossil fuel in residential areas for acquiring hot water as well as heating (Sakipour, 2014; Mazria, 1996). With the ever-increasing movement of humans from rural areas to cities, the number of fossil fuel consumers has continuously been on the rise. As a matter of fact, fossil fuels constitute the pillars of the world’s and Iran’s new industry (Rifkin, 2012). This trend of growing pollution due to a higher number of buildings is the result of designers and constructors failing to take into consideration each region’s natural conditions. Environmental and natural phenomena play a particularly significant role in creating the region's interrelated cultural, economic and social infrastructure. According to Wahid (2012) "Vernacular architecture is a consequence of local conditions as it tends to evolve over time to reflect the environmental, cultural and historical context".

Modern buildings are criticised for their incompatibility with their surroundings (Farshchi and Fisher, 2000), and are poorly designed for the prevailing climate conditions leading to extensive use of electrical equipment and energy to maintain desired thermal comfort conditions. As a result, one of the major consumers of energy is the building sector (Abbaspour et al., 2013; Farahmandpour, 2008; Ayatollahi, 2003). In developing countries, the building sector consumes around 40 percent of the proportion of total energy use (Levine et al, 2007), and it is expected that energy consumption will double in the next 25 years, with an annual average growth rate of 2.8 percent (Lombard, 2008). It can be seen that the building sector in a few nations around the globe has been a considerable consumer of energy; for example, UK, India and Iran contribute 46 percent, 39 percent and 36 percent respectively (Forunzanmehr & Nicol, 2008). A large share of energy consumed is wasted due to inefficiencies (Zyga, 2011). In the UK, for example, the energy consumption could be halved with adequate insulation of the existing building stock (Roaf, 2004, p.130).

In contrast to most modern buildings, vernacular buildings tend to be climate-responsive in many ways. Vernacular buildings represent a resource for sustainable design principles because they are made of locally available materials, employ local people, use mainly renewable sources of energy, and adopt construction practices that favour recycling and respect for nature (Halicioglu 2012; Heal et al., 2006; Yilmaz, 2006). It is essential to learn from vernacular architecture because it is naturally sustainable, as vernacular architecture uses natural resources in a way to make a comfort zone for the occupants in the harsh outdoor environment. Traditionally, builders used the knowledge passed from generation to generation to ensure that their buildings could modify the impact of a hostile outdoor environment. That is one of the reasons behind the pressing need to salvage vernacular principles and use them as a means for developing sustainable architecture.

In the last two decades, with the growth in population in cities, enhancement of building services and comfort levels, together with the rise in time spent inside buildings, tall buildings have become common in all cities and towns regardless of climate. This style of building construction has caused essential use of mechanical heating and cooling systems (Lombard, 2008). Due to the lack of access to modern heating and cooling equipment in ancient times the architects were obliged to rely on natural energies to render the inside condition of the buildings pleasant. In view of the energy crisis and energy saving in residences (cooling and heating), new construction techniques in Iran that do not allow for principles of the past climatic conditions and the use of inappropriate materials consume a lot of energy and are very expensive (Ahmadkhani, 2011). This results in waste of capital incurring heavy costs due to waste of energy.

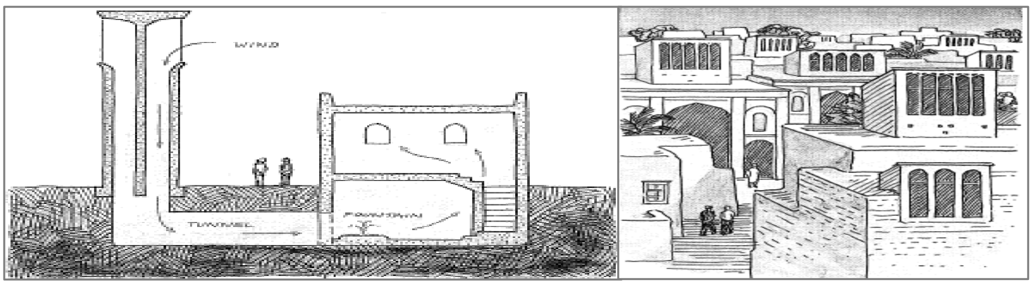
Given the limitation of fossil fuel resources and the imminent energy crisis, it is strictly necessary to focus on sustainable and renewable energy resources in designing buildings (Atkinson, 2009). The sustainable architecture should be inspired by nature and be compatible with the climate by relying on domestic knowledge and being in accordance with Iranian people's behaviours and habits. Furthermore, employing environment-friendly technologies through incorporating and adjusting it with the domestic knowledge of the ancient land of Iran aiming at sustainable development as well as the need for designing buildings with optimal energy consumption is deemed necessary now more than ever.

The transformation of architecture without taking into consideration the geographical condition of each region has imposed a situation upon society, especially in rural societies in which people consume several times as much energy as they used to consume in the past decades, (Debache and Benzagouta, 2014) especially fossil fuels such as oil or electricity (Appendix K). It can be firmly stated that the propagation of incorrect architecture that is incompatible with climatic conditions is one of the most important reasons behind the waste of energy in Iran (Naseri, 2013). This is particularly relevant to Iran, because a major part of Iran's area, almost 90 percent, has an arid and semi-arid climate (Alavipanah, 2006); central and southern parts of Iran are among the sunniest regions of the Earth with more than 3000 sunny hours annually, due to being on the northern hemisphere; thus, they have great potential for supplying solar energy. In Iran, the sun shines an average of 2360 to 3330 hours annually. This amount of energy is equivalent to six million barrels of oil per day (Rahimi, 1997).

4.4 Vernacular versus modern buildings

As the assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) states, it is estimated that buildings contribute to one third of total global greenhouse gas emissions, primarily through the use of fossil fuels. Parameters that depend on energy and fossil fuels such as electricity, air conditioning, in addition to other equipment which consumes high energy, have been unable to adapt to constantly changing climates (Taylor et al., 2008). This is particularly true in the case of modern buildings, where most buildings are reliant on electro-mechanical cooling and heating systems. The modern buildings are responsible for more than 40 per cent of global energy used, and 30 per cent of global annual green house gas emissions (Huovila, 2009).

Vernacular buildings on the other hand have been known to be part of the environment rather than being a self-serving entity (Sundarraja et al., 2009). Often designed and considered in regards to human scale, these buildings consider the building process much more than the result as compared to modern buildings. By researching on cases regarding vernacular buildings, it is evident that these buildings are adapted and constructed keeping the local environment and resources in mind. For instance, buildings in the hot climate usually comprise of thick high walls, wind catchers, an open courtyard design, ponds, and vegetation (Parsi, 2004). Besides being environmentally conscious, these buildings for most of the time include functionality, comfort and beauty with equal consideration. Therefore, such buildings with vernacular resources, forms and technologies are considered to be well adapted to the climatic conditions of the local area and are often an ideal base for environmental design (Memarian, 2012). The figure 8 illustrates a typical example of a vernacular building showing the wind tower direction in the hot climatic area with the natural cooling system through evaporation.



Source: Johnson, 2001

Figure 8: Wind tower direction and the natural cooling system through evaporation

In spite of its importance, traditional architecture and its strategies and methods are found to be undervalued and underused in new constructions. It can be argued that many new architects lack sufficient experience in using the traditional methods. Among the limited number of researchers in this field there are only a few who have engaged in the revival and utilisation of the traditional techniques to find new approaches that can benefit modern buildings and new constructions. Many of these studies have suggested that these solutions are not only for architecture in hot-dry regions, but these can also be applied in all styles and environments. The use and recognition of the traditional knowledge will enhance human thought and culture because as Fathy (1986) has remarked, combining this expertise with modern principles will lead to an architecture more suited to the hot arid regions of the world.

Therefore, when comparing both styles, modern and vernacular, it has been noted that vernacular architecture is more environmentally adaptable according to principles which have evolved over many generations (Forunzanmehr & Nicol, 2008). However, Vellinga (2006) mentions that even though vernacular architecture is environmentally friendly, adapting it to modern buildings will be quite a challenge considering the fact that many of these resources and technologies do not function properly in today's culture and ecological situations. The Broujerdi's house as a vernacular building in Kashan is an example of this (Hashemi and Mahdavinejad, 2015). Due to insufficient difference between the outdoor and indoor temperature, it can be clearly observed that the wind catcher as the main element does not operate properly.

Figure 9: The Boroujerdi's house, Iran

4.5 Summary

The chapter set out to explore the concept of renewable energies and identified how they can be used through reduction of carbon emissions. The chapter has also sought to understand the relationship between the energy and building sector, and in this section it has been noted that fossil fuels constitute the pillars of the current industry. Alongside this, it is evident that the building sector contributes a large amount of energy consumption and half of the energy is being wasted. Furthermore, the chapter elaborated the reason behind the vernacular buildings, identifying how they are much more climate responsive and environmentally friendly. In addition, it has been explained that the new construction in Iran, besides having good potential use of natural resources and availability of vernacular buildings as a symbol which are climate responsive, are still not sustainable. In the next chapter the research will identify the sustainable background of the principles of Iranian vernacular architecture. The next chapter will describe how traditional Iranian builders tried to use natural resources in a way to make a comfort zone for the occupants in the harsh outdoor environment.

CHAPTER FIVE: IRANIAN VERNACULAR PRINCIPLES

5.1 Scope of the chapter

Chapter four gave an overview of the renewable energy resources in order to use them in a way to reduce the carbon emission. The previous chapter elaborated on the relationship between buildings and energy. In addition, the chapter explained and compared the vernacular and modern architecture in terms of being environmental friendly.

The main objective of this chapter is to review and evaluate principles of Iranian vernacular architecture. The chapter will first review the literature on vernacular architecture and then will focus on specific aspects of Iranian vernacular architecture. To derive principles of Iranian vernacular architecture a mixed methodology has been adopted where the first guiding principles have been identified by direct observation. The following steps have been to assimilate the literature on principles identified by numerous authors. A desk based evaluation of these principles has been confirmed by identifying the relationships between different principles and energy saving outcomes.

The philosophy behind Iranian vernacular architecture can be seen by direct observation of such architecture in central and southern Iran where the unavailability of modern sources of energy such as electricity (i.e., fossil based energies) and the extreme climatic conditions in different regions, had led local designers (whether architects/builders or ‘Memars’) to use natural solutions to deal with heating and cooling in buildings. In this section, the strategies used in hot arid climates and their application in today’s constructions will be discussed.

5.2 Iranian vernacular architecture styles

In Iran today, a great deal of energy is consumed by the residential sector. Buildings account for approximately 36 per cent of the energy consumption of the country as a whole (Iran Energy and Electricity Planning Committee, 2013). Energy consumption in the Iranian building sector is 2.5 times more than the global average, and this sector has accounted for 26.4 per cent of the CO^2 emission (Nasrolahi, 2012), which ranks second in the world with the per capita production of 1411 kg carbon dioxide in the residential sector. According to the energy balance sheet in 2011, the social cost of the emission of pollutants in the household sector is estimated to be 12726 billion Rials (£340 million). This is a sharp contrast to patterns observed in industrialised countries, where the major part of pollutants is produced by industries, and the household sector makes a relatively smaller contribution. It can therefore be argued that Iran's CO^2 emission problems are due to excessive energy consumption in the residential sector, and any policy toward energy reduction should be aimed at this sector.

Cities like Yazd with extreme hot weather conditions are more dependent on electricity based air-conditioning systems rather than traditional passive cooling system.

In contrast, it is clear that vernacular architecture symbolises the cultural values of the Iranian society, by embedding the architecture with its surrounding environment. The architectural characteristic of Iranian vernacular architecture reflects the society's identity, cultural values, and beliefs. Furthermore, Bakhshi and Mofidi (2001) argues that the Iranian vernacular architecture has lost its identity in recent years since the methods and strategies are undervalued and unused in the design and construction of modern buildings. Accordingly, vernacular architecture is drawing its last breaths as the contemporary buildings demonstrate little understanding of the natural energy resources and how design can help reduce the levels of energy consumption in buildings. Some authors have argued that the deterioration of vernacular styles is mainly due to the implementation of technological solutions and designs that are not suitable for climatic conditions in a developing country such as Iran. El Kafrawi (1998) states that construction technologies and design of modern (based on western styles) buildings are foreign to this region since such technologies have been applied without the philosophy which underlies it.

Over many centuries, Iranian vernacular architecture has found ways to adapt and respond to the natural environment in which it has been built and as a result has attained principles and methods that impose no destruction of, or loss to, the environment (Tahbaz and Djalilian, 2008). All over the vast land of Iran, which embraces various types of climate (mountainous, forest, tropical, desert) as well as varied environmental conditions, Iranian native architecture features one most important factor, adaptation to different weather conditions. The passage of time clarifies the importance and efficiency of this factor more than before.

All over the country vernacular buildings show a high level of adaptability to the natural and extreme environments through principles which moderate the effects of the external environment on the spaces created within the buildings. The design of different elements of such as roofs, external surfaces, sunshades, wind catchers, basements, central spaces, windows as well as sensitive selection of building materials together with the widespread use of water reservoirs is a manifest of how vernacular architecture has respected its surrounding environment. Sarami (1997) shows that vernacular architecture brings about the best level of internal space comfort without using complicated energy generation machines that cause pollution.

5.3 Principles of Iranian vernacular architecture

Iranian vernacular architecture has shown an intimate connection with nature, whilst also being responsive to the climate and the occupants requirements. In the hot arid zone of Iran, lower levels of humidity and the lack of clouds results in extreme temperature fluctuations during day and night. Thus, ancient designers were using natural climate approaches in their design in order to adapt to the harsh conditions (Iranmanesh and Bigdeli, 2009). Relying on a wealth of experience obtained in the course of centuries, Iranian traditional architects put forward logical solutions and methods of dealing with the surrounding environment by means of architecture which is compatible with the climate (Eiraji and Namdar, 2011). They provided humans with comfort in difficult situations such as in deserts (Ahmadkhani, 2011). The Iranian vernacular architecture can offer sustainable patterns for solving today’s problems of design and construction. Upon designing building plans in traditional textures of arid regions, daily activities within spaces of the building are separated according to the path of the sun. This has brought about economisation in energy consumption in a way that buildings save energy in hot and cold weather using the direction of the sun's path and absorbing heat (Ghaffari, 2002). This chapter will explain all two levels (Macro, Micro) that Taleghani, et al. (2010) refer to as climate responsive design strategies in hot and dry area of Iran.

The current research reviewed 132 pieces of literature for the current chapter and scrutinised each one (see Appendix L). Figure 10 illustrates the types of resources and the percentage of using each source that has been used in current chapter.

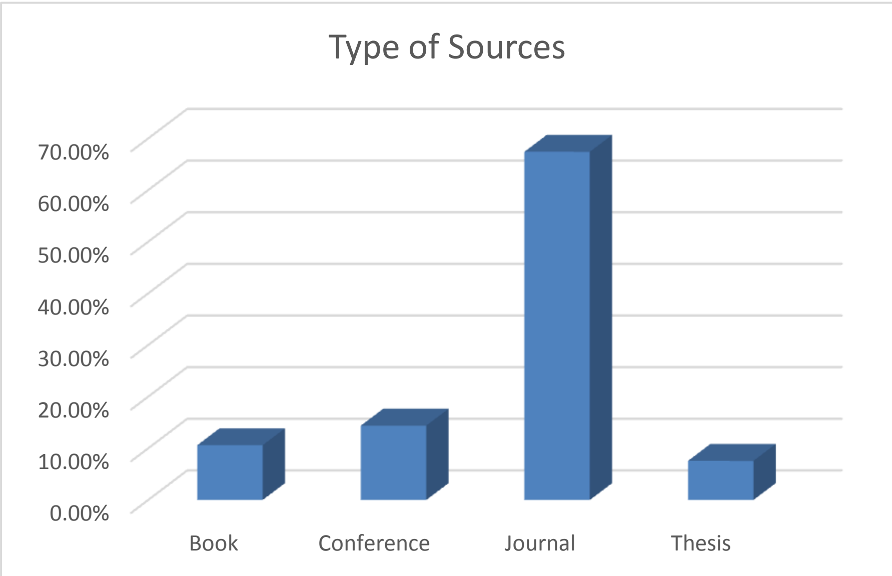


Figure 10: Type of sources

Following the identification of each source, the research defined the year of each literature to make sure the other researches in regards to Iranian vernacular architecture are up to date and the researches were worth investigating. The main purpose behind this was to find out what the current principles are and the key points of interest for other scholars. The below chart clarifies the date of current chapter literature review.

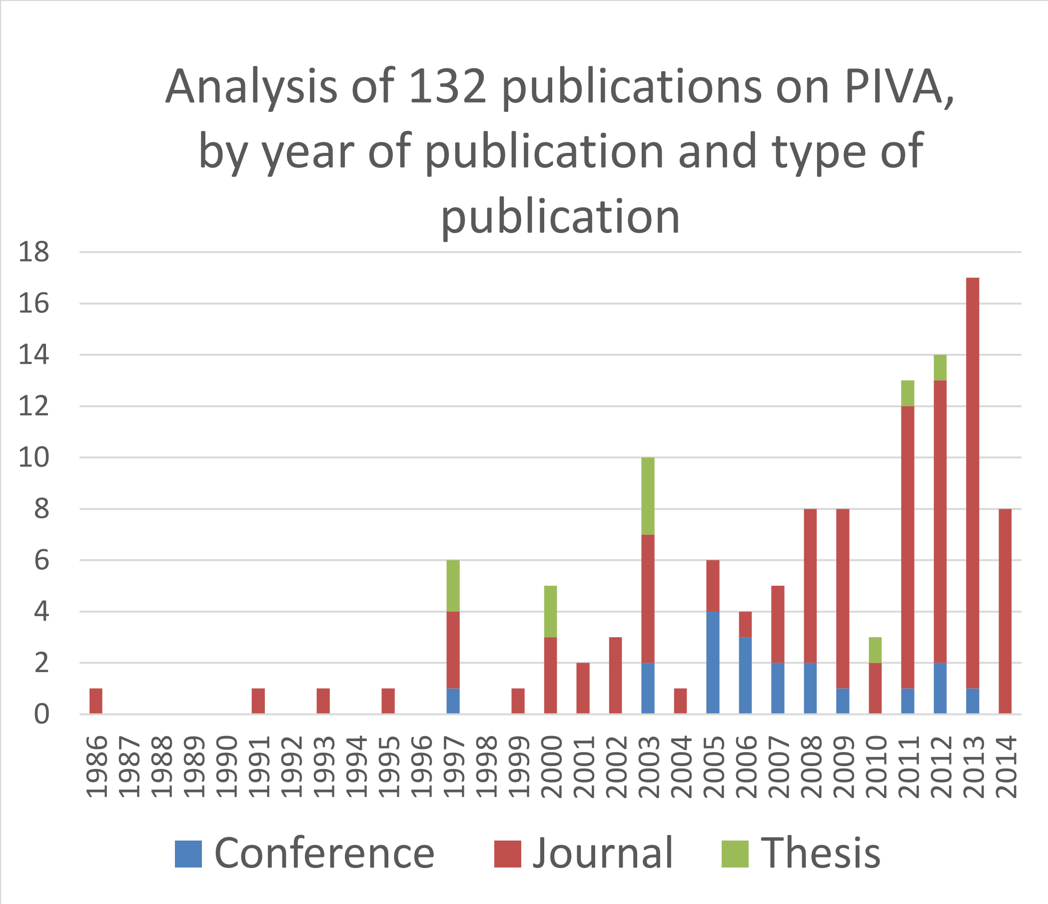


Figure 11: Categorising the sources by year

From figure 11 it can be noted that most of the research literature was reviewed after 2009, this means the research literature review is up to date and these sources are relevant and vital in explaining key points of Iranian vernacular architecture.

After extracting the sources , the research tried to identify and sort out principles next to each other. Following the previous charts, the below chart shows which principles were discussed by other researchers and scholars. Figure 12 evaluates those different principles and arranges them in order of popularity. This explanation indicates which principles are important elements when researching or discussing Iranian vernacular architecture.

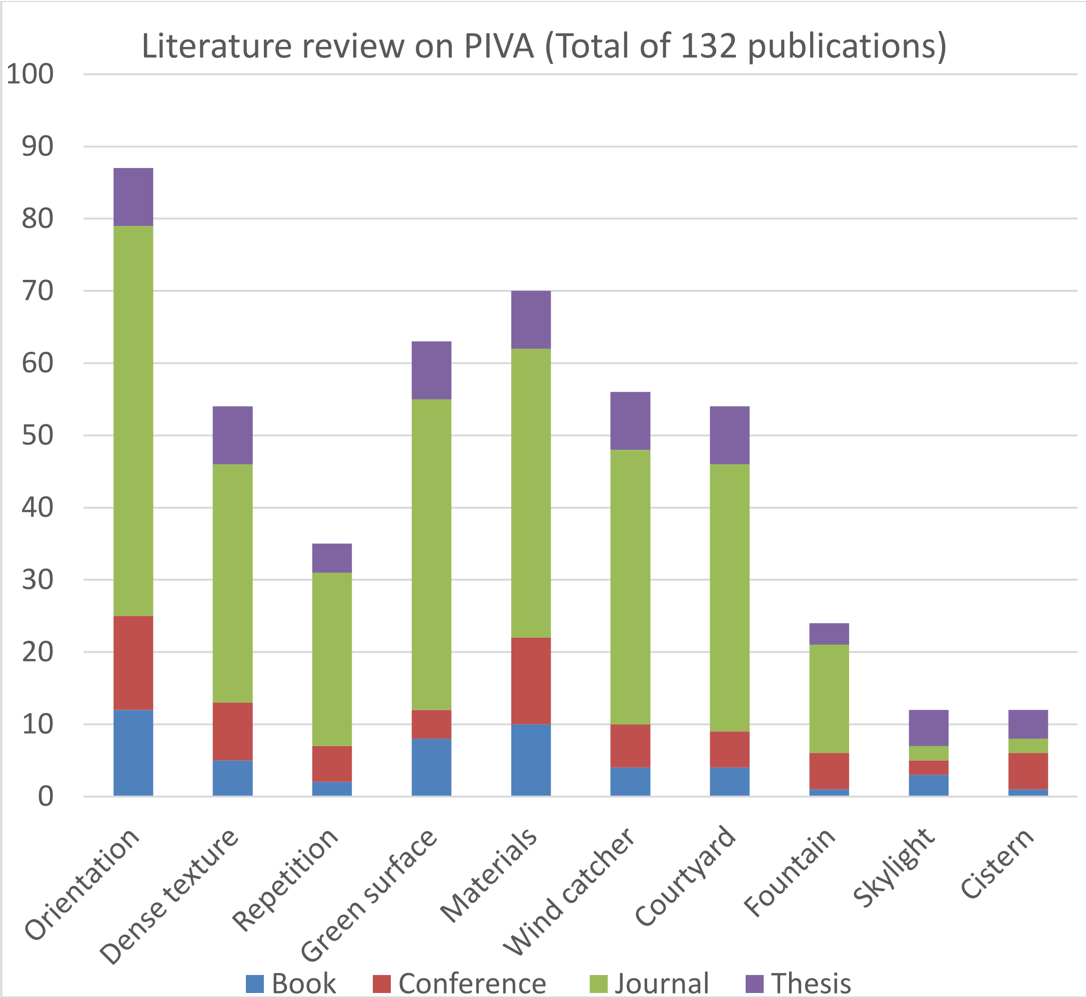


Figure 12: Classification of the Iranian vernacular principles

It is evident that most researchers and scholars were concerned about orientation, materials, wind catchers, and green surfaces. Therefore, the research needs to consider and prioritise these principles for designing upcoming buildings in the next chapter. Furthermore, the source of each principles has been identified and can be seen in Appendix M.

5.3.1 Density, positioning and orientation

Traditional towns of Iranian deserts are in general constructed on high density of built forms in urban areas (Naghizadeh, 2000). Richardson (2004) identified that there are significant relationships between the "sustainable city" concept and "density and compression" concepts, because providing climatic comfort and economising on energy may be done by means of reducing building surfaces exposed to solar radiations and creating density (Golkar, 2001). Density and arrangement in hot arid cities is in a way that minimising sunlight reception allows buildings to cast shadows on each other creating external shaded spaces (Bahreini and Maknon, 2003). The height of buildings is the same so that wind would not be distributed in an unbalanced manner. The positioning of environments is done under the effect of multiple factors among which soil type, soil resistance, fertility and water absorbability, vegetation type, access to water resources and finally the climatic features of the region may be mentioned (Ghobadian, 1997). It can be stated that wherever there was sufficient water available, and as a result there was appropriate soil, a habitation is also formed. Even though many deserts of Iran enjoyed apparent climatic conditions such as precipitation and a permanent river for establishing cities and settlement, water was brought to the surface from distances as much as 20-40 kilometres (Appendix N) through the invention of qanat by Iranians playing its role as the factor that allowed life to carry on in cities and villages (Esfandiari, 2007). Independence and self-sufficiency, lack of need for fossil fuel, moderate utilisation of underground water, and protection of the environment may be mentioned as the characteristics and advantages of qanat in line with sustainable development (Ward, 1997).

The orientation of buildings is one of the most influencing factors in determining the characteristics of Iranian vernacular architecture. In traditional buildings, employing and using natural resources and energies are among the construction principles (Okhovvat and Farrokhzad, 2014). In ancient times, Iranian architects were aware of the direction of the prevailing winds and they knew that giving enough credit to this factor could significantly affect environmental comfort (Ebrahimi et al., 2013).

The building orientation in desert textures is effective in benefiting natural potencies and resources within reach. This orientation has brought about certain climatic conditions causing summer spaces and winter rooms to find their logical position in the design of residential spaces (Fardpour, 2013). The orientation of a mansion was fashioned so that the northern side of the yard, which receives oblique sunlight in winter more than other parts of the building, was known as the winter habitation. On the other hand, rooms on the southern side of the yard, which are in the shade and are cooler, were known as the summer habitation (Aminzadeh, 2003).

5.3.2 Green belt

The condensed urban texture is often surrounded by a green belt comprising of fruit gardens and farms. Thus, the reflection of the solar heat from the desert's dry burning soil, which leads to considerable increase in temperature is minimised (Monshizade, 2008). The green space around cities plays an important role in protecting the central texture against desert winds, dust, and the aridness of the desert air numbering among important factors in the natural ventilation of cities (Rapoport, 1997).

Iranian vernacular architecture is formed with extreme respect to site and geographical specifications of the earth. The Iranian vernacular architecture emphases are on weather conditions, position, light and tectonic form and human experience (Fardpour, 2013). In desert cities, the networking of routes, division of pieces of land, and organising full and empty spaces are performed via two completely different methods. The network of routes is created in an organic hierarchical order in accordance with the slope and direction of qanat for water, whereas pieces of land are divided irregularly and buildings are built in a geometrical order (Ghaffari, 2002). The meandering pathways and covered alleys (Saabaat) (Appendix O) prevent the entrance of disturbing winds, and they produce the most shade thanks to their great depth. The way Saabaats are established, which is among distinct features of desert urban planning, leads pedestrians on a shaded space along the path.

5.3.3 Interior-oriented

Most of the buildings in Iranian traditional cities are compact and interior-oriented (Moghaddam and Rajabi, 2006) so that the area of surfaces exposed to sunlight would be reduced. The most evident feature of Iranian vernacular architecture is its being interior-oriented; that is, complete separation from the exterior and connecting with the internal space. Thus, buildings have no external visual appeal except for the entrance. In this manner, most of the decorations may be found inside the buildings (Karimi and Hosseini, 2012), and the four sides of the buildings are enclosed with tall walls. Tall walls in such buildings block sunlight, casting shadows over a vast area of internal surfaces as well as the ground of the central yard during the day (Pourvahidi, 2010). Furthermore, the buildings in such a climate envelope the central courtyard and also protect the building from the harsh climate, especially from dust storms. The central yard is the major space of desert houses (Tahbaz and Djalilian, 2008). During the day, the central yard warms up more rapidly compared to the surrounding buildings causing air to move due to temperature and height difference. As hot air moves upward, air is sucked into internal spaces via wind catcher's inlet, thus generating a breeze. On its path towards buildings, this air often passes over water or green space, thus increasing its cooling effect. During the night, the central yard collects the cool air descending from the roof. The cool air is purified via doors and openings facing the central yard.

5.3.4 Repetition of the ordinary shapes

Iranian vernacular architecture emphasises the most elementary geometric shapes; there are regular geometrical centre-oriented shapes in the house plan (Memarian, 2012), because external walls lack flexibility in terms of thickness and no specific visual appeal is intended from the exterior (Amini and Zakeri, 2014). Thus, it could help to maintain comfortable conditions in house. Each space within the house can function independently from others.

The orderly and harmonious repetition of lines is called the shapes of forms. Beams and columns repeat themselves and doors and windows recurrently bore holes in the building surface in order to facilitate the entrance of air, light, and people.

5.3.5 Vegetation to create a cool microclimate

In traditional architecture, a plant and water climatic design technique is used in order to create comfortable cooling conditions desirable for the inhabitants in summer. The green surroundings and water ponds inside courtyards increases the relative moisture and mildness of weather (Zamani et al., 2012). Vegetation influences temperatures, humidity, radiation and it also has an effect on air quality as well as the social and psychological well being of urban dwellers (Arbaoui, 2003). Small gardens and trees that demand little water compensate for the environments lack of humidity along with providing shade and contributing to creating beauty. By absorbing sunbeams, these green surfaces preclude the reflection of light and the heat from increasing undesirably (Ziabakhsh and Ziaolhagh, 2012).

5.3.6 Wind catcher, wind based passive-cooling system

Among other conventional methods in the architecture of desert cities, which helps economise on energy consumption, is to employ natural equipment and systems. Elements and installations such as “wind catchers”, “water reservoirs”, “natural refrigerators”, “windmills”, and “watermills” provided services in desert cities, and the costs that the original architects incurred were lower. As explained in chapter four, wind was created when warm air over land rises, and it can be classified as an important factor for architects in the design of a building (Mahmoudi and Mofidi, 2008) is one of the critical and major elements for studying the climate. Wind based on locations and different geographical directions creates different pressure on the exterior wall that has an effect on natural ventilation and the indoor temperature in the building, and the differences in temperature induce circulation of air from one zone to another (Ashrafian, 2011). Therefore, it is mostly utilised in the hot regions to create thermal comfort. Wind has strongly been taken into consideration in many particular cities with the harsh and extreme weather conditions such as Yazd. The city has the highest number of wind catchers in the country and is well-known as a wind catcher city (Pirhayati et al., 2013). The wind catcher is one of the architectural elements which is established in the vernacular architecture of the warm and dry climate of Iran (Bahramzadeh and Sadeghi, 2013). The effect of wind and its influence on the buildings form can be captured through the use of wind towers which are designed to provide the best use of wind for the comfort of occupants. This architectural feature functions on the basis of sustainability principles and defines the amity of architectural design with the natural environment (Bahadori, 1985). Despite the advantage of the wind catcher in terms of passive cooling design, some academics have argued against the utilisation of the wind catcher, because it is a place that insects and dust may enter easily (Karakatsanis et al., 1986). Hence, Hassan Fathi, the Egyptian architect who made considerable efforts to incorporate traditional architecture into present-day technology, used a water pipe inside the wind catcher channel of his buildings, by creating a fountain on days when the air was hot and dusty, he managed to reduce both heat and dust. Wind catchers have been adapted for many years as ventilation tools for natural cooling in countries with hot weather conditions, particularly in Iran. Wind catchers called "Badgir" are appearing in different type of buildings including mosques, residential and commercial buildings in the central region of Iran.

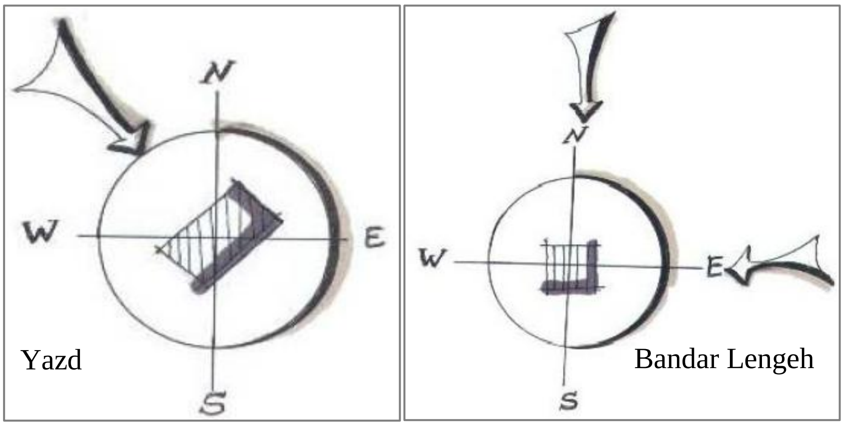
Source: Author, 2013

Figure 13: The wind catcher, Yazd, Iran

The wind catcher comprises of a tower with one end connected to the living area as the main space of the building and the other end rising from the roof (Mahyari, 1997). The wind catcher includes several internal partitions that divide the vertical air passage in the vertical shaft. The wind catcher has two air flow directions, moving up and down. It is a combination of inlet and outlet openings, the windward direction is inlet, and the leeward opening is an outlet and vice versa (Saadatian et al., 2012). Today, the wind catcher can be used in conjunction with the ventilation and cooling system of buildings.

5.3.6.1 Wind catchers function and orientation

In general, the orientation of the wind catcher follows the position of the wind tower flank based on four main geographical directions (North, South, West, East). It is determined in term of function, the desired direction in which the wind blows and use of wind power (Mahmoudi, 2007). The desired wind direction in the city of Yazd with a hot-dry climate is along the north-west. Therefore, to maximise the usage of wind in the buildings for the purpose of cooling, wind catchers are oriented towards the north-west. In the following diagram the wind catchers design in Bandar Lengeh, on the Persian Gulf is depicted for the purpose of contrast.



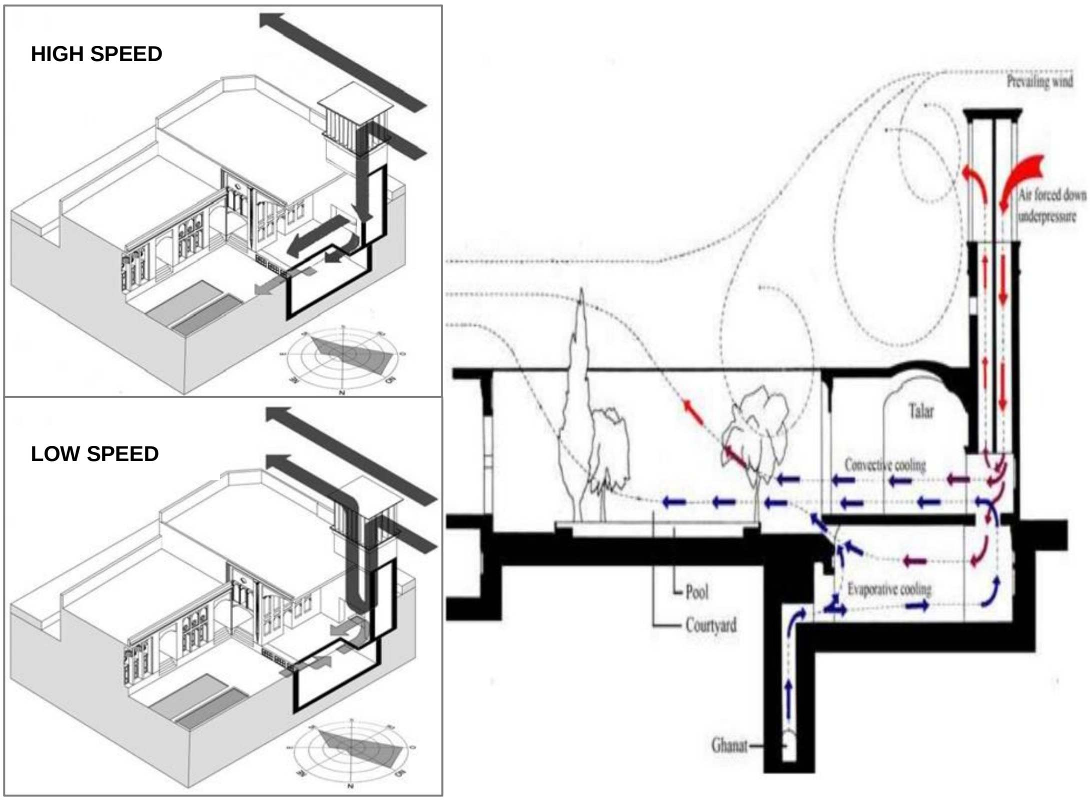
Source: Pirhayati, 2013

Figure 14: Orientation of wind towers in Yazd (hot- dry) Bandar Lengeh (hot- humid)

In order to achieve and provide thermal comfort for the occupiers, Iranian architecture has used wind towers to direct the wind into interior spaces of the building.

Figure 15 illustrates the system of high and low wind speed air circulation through the internal space. When the wind is strong, the air flows toward the courtyard and the basement. The basement is often cooler compared to the ground level. Therefore, the cooler air is directed within the internal space to reduce the temperature. However, during low speed air circulation the wind catcher mainly removes heat from the internal space (Razjoyan, 2000). Karakatsanis (1986) has mentioned that the wind catchers are not very efficient for the areas with low wind speed.

A wind catcher is divided by several internal partitions that create shafts. One of the shafts operates to receive the breeze all the time while the others work as outlet air passages. Based on the principle of the chimney effect, the air density increases, while the temperature increases. The interior and exterior temperature differences of a building cause different pressure and result in air currents (McCarthy, 1999).



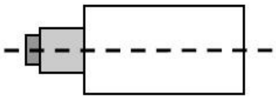
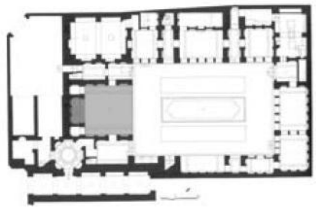
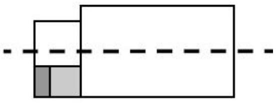
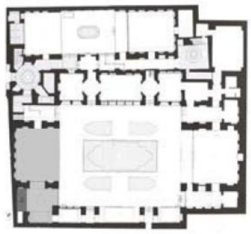
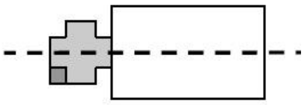
Source: Mahmoudi, 2009 and Mashhadi 2012

Figure 15: Illustration of distributing high/low wind speed through the internal space

5.3.6.2 Wind catcher typology in Yazd based on the plan set up

The wind catchers which are set up on the buildings in Yazd vary according to the building layout. However, this is probably due to the cooling operation of the wind tower. One of the main sections of an Iranian house built in hot climates is the wind catcher.

Studies show that previously wind catchers were connected directly to the hall but from time to time this connection has changed. Based on their set up on sites, on the roofs in different buildings and their interactions with original spaces, wind towers can be divided into three types (Mahmoudi, 2007).Table 4 indicates the three types of wind catchers, and it illustrates the position and the way it has been linked to internal spaces.

TYPE	MODEL	PLAN
1		
2		
3		

Source: Mahmoudi, 2009

Table 4: Three main types of wind catchers in Yazd

1) The wind catcher is placed and connected behind the main interior space (living room). The living room and courtyard are symmetrically extended along the axis in this type of wind catcher.

2) The wind catcher is placed on a corner: it is required that the wind catcher be connected to the main interior space through the medium space but not directly related to it.

3) The wind catcher is placed on one of the northern corners of the main interior space (living room).

All types of wind catchers reviewed above show that only certain spaces within a building can be ventilated by wind catchers. Therefore, positioning the wind catcher connected to the prominent interior space is critical and should be taken into consideration (Montazeri, 2011).

5.3.6.3 Wind catcher typologies in plan

The wind catchers in Iran have been recognised in varied forms and plans such as circle, square, polygon and oblong (El-Shorbagy, 2010). A wind catcher with a circular plan or form is exceedingly rare compared with other forms. A significant problem with the circular wind catcher is its aerodynamic efficiency, an undesirable property for a wind catcher (Parker, 2004).

The wind catcher height is normally between 5 and 33 meters (Montazeri and Azizian, 2008), and is usually divided into four quadrants. This makes the wind catcher system less vulnerable to periodic wind changes (Liu and Mak, 2007). Wind catchers are internally arranged in the form of blades. These blades are divided in two sections, the main blade and the side blades. The main blade plays the crucial role and influences the operation of the wind catcher. The main blade rises from the ground floor reaching 2.2 meters high and is extended to the ceiling of a wind catcher and further develops smaller ducts (Jazayeri, 2011). Side blades are placed within the gap of the wind catcher and exactly resemble the blades in contemporary coolers. Side blades are considered as the structural elements of the wind catchers, but besides that, well-known architects in Iran believe that the structural element side blades perform is a thermal role in wind catchers as well. From the external view of wind catchers, except side blades which can be clearly sighted, the main blades are not visible.

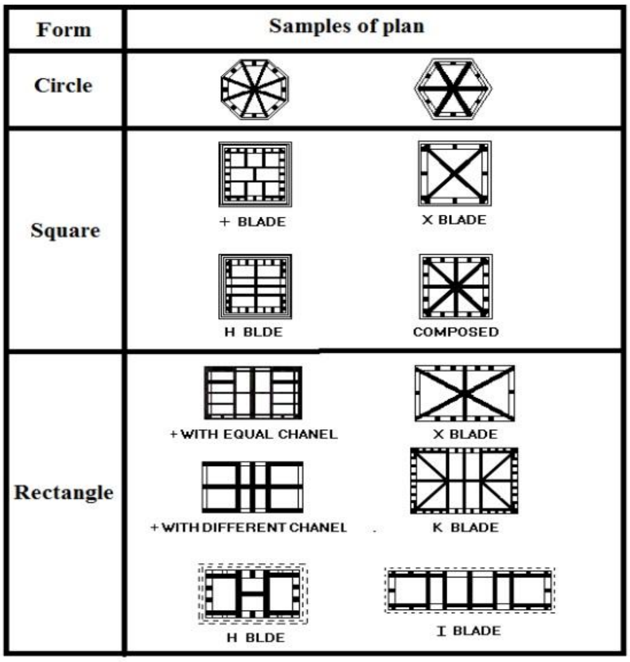
Source: Author, 2013

Figure 16: Main blades rise from a floor

According to the Bernoulli Effect, blades divide the tower into small shafts to increase air velocity. As a result, the air rate will be increased when the air passes from the narrow section. Such an arrangement provides more surfaces in contact with the flowing air, so that the air can interact thermally with the heat stored in the mass of these partitions (Ahmadkhani, 2011).They work as fins of the cooler window or fins of the radiator because mud brick partitions give back stored heat during the night and they are prepared to absorb the heat. Warm wind contacts mud brick partitions, and therefore its heat transfers to partitions (Ghaemmaghi, 2005).

5.3.6.4 Wind catcher with oblong plan

Among the 53 types of wind catchers that have been recognised, the oblong plan wind catchers are the most common built wind catchers in Yazd (Amirkhani et al., 2010). Arrangements of varied main blades that create a wind catcher provide different types of oblong shape.



Source: Dehnavi et al., 2012

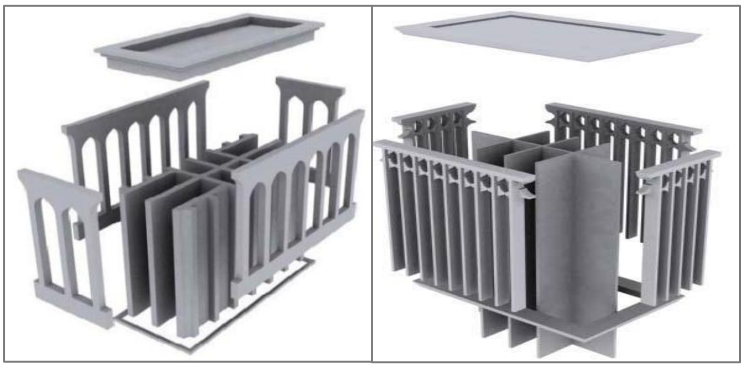
Figure 17: Wind catchers with different forms and blades

A) 'x' form blades wind catcher

This is the rarest type of wind catchers and small numbers of them exist in Yazd. From the 53 type of wind catcher studied in Yazd only two of the wind catchers were recognised with an oblong plan and 'x' form blades.

B) '+' shaped blades wind catcher

This type of wind catcher is the most common shape of wind catcher in Yazd with perpendicular blades to one another (Hossein Ghadiri et al., 2014). The latitudinal depth is ½ of the depth of its canal in linear front. The depth of the canal depends on overall length and number as well as the form of separating blades in the latitudinal front (Hossein Ghaderi et al., 2012). This type of wind catcher can be divided into two more categories, the equal canal and different canal wind catcher. In equal canals wind catchers which are the most dominant ones in Yazd, the blades are equally spaced, and as a result some small canals with equal spaces and dimensions are created which increases more air flow from all faces (Amirkhani et al., 2010). In the different canals wind catcher, the canals of longitudinal form are larger, and the oblong plan is directed toward the prominent wind.



Source: Mahmoudi and Mofidi, 2008

Figure 18: Wind catcher with different canals (Left) Equal canals (Right)

5.3.7 Cisterns and Ice-houses, water based passive cooling system

Vernacular buildings in Iran have employed some ingenious passive techniques which are still little known in the west in order to restore thermal comfort and coordinate with the local environment and climate (Dadfar, 2014). Meanwhile, there is much to be gained from the knowledge of a highly developed technology which makes such ingenious use of natural resources without the consumption of additional power (Kazemi, 2011). As Soltani (2012) states, among different Iranian vernacular constructions, cisterns and ice-houses are two other examples which motivate cultural values and instructive skills in which the Iranians excel:

- Firstly, the design and execution of domes and vaults in mud-brick, which result in beautiful buildings, often constructed for mundane purposes.
- Secondly, the Persian imagination and ingenuity, which is unrivalled in making the best use of water in a hostile desert environment.
- Thirdly, an Iranian traditional building technique which explores the ingenious ways of applying natural resources without energy consumption using additional power (electricity and air conditioners).
- Finally, applying local materials in construction and repair work has many advantages which make the original materials available and close to the site.

Buildings built in Iranian hot arid zones are constructed and designed based on the local climatic conditions and the principles applied differ from those built in other areas with different climates. In the past, due to limited access to modern cooling and heating equipment, architects were supposed to rely on natural sources to create pleasant internal conditions (Najafi, 2013). Buildings were designed significantly to circulate cool air through the building and could even keep water cold and ice frozen from the winter until the height of the long, hot summer of the country's arid central and eastern plains. Such buildings were characterised by passive cooling systems that functioned through the natural environment and without any energy input. Some of the systems which will be described in turn are the wind based system (wind tower) and water based system (cistern and ice maker).

5.3.8 Cistern / water storage

Water storage is a traditional reservoir of drinking water in Persian antiquity (Okhovat et al., 2011). A cistern is a reservoir of about 10 to 20 meters deep, sunk into the ground, covered by a domed roof and surrounded by several wind towers. In some areas on the arid plains of Iran, water is brought by a system called qanat. The qanat, or underground water channel, is designed so that water is carried by gravity from a water-bearing stratum at a higher level (usually near the base of mountains) to a village or oasis on the plateau (Ward, 1997). The purpose of the cistern is to hold the water at a reasonably low temperature during the hot summer months. The design of the cisterns takes advantage of the annual temperature changes in the desert and the insulating properties of the ground.

In the arid zones of Iran, the winter nights are extremely cold. In winter, cold water is admitted to cisterns, partly filling them. In summer, the domed roof which is the protection of the cistern from the sun is warmed, and so is the air and the top layer of water in cisterns. The water in the top layer evaporates and the water vapour is carried away by a draft across the surface, maintained by the wind towers. In this way, the water is kept cold (Memarian, 2009). A cistern cooling system operates in one of two ways. Firstly, if it has a domed roof with an air vent in it, the air flows down the wind tower, across the water and up through the vent. This airflow entrains the mixture of air and water vapour under the roof. Secondly, if the cistern has an air vent, dust, insects and other matter can fall into it and foul the water, and so some cisterns are constructed without vents. In these cisterns, the flow of air from the tower is short-circuited: the air flows down through the passages on one side of the tower and back up through the passages on the other side, entraining the mixture of air and water vapour in the cisterns and inducing it to flow out through the openings on the leeward side of the tower. The cisterns were incorporated with wind catchers, which provided ventilation and cooling to prevent air stagnation and humidity. The accumulation of air thereby preserves the integrity of the water and a year round supply of pure, clean and cool water (Saeidian, 2013). A cistern system effectively operates by storing energy from one season to another. Many passive cooling systems operate on this principle.

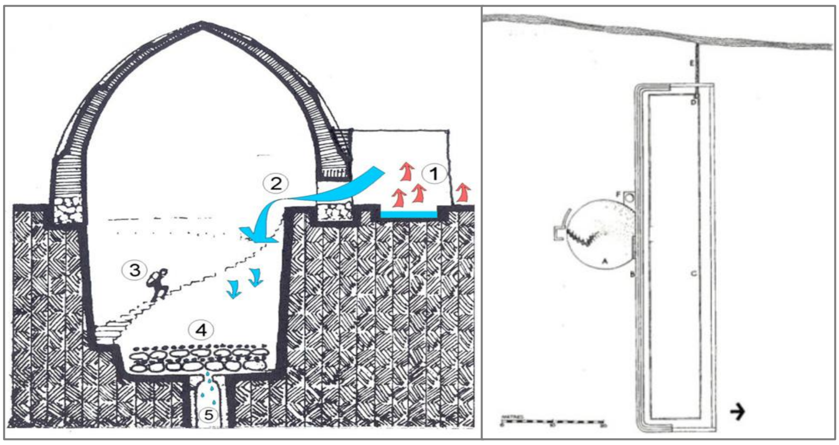
Source: Kazemi and Shirvani, 2011

Figure 19: Cistern roof plan and wind catcher detailed plans (Right)

5.3.9 Ice-houses

Another example of a passive cooling system is the traditional ice making system of Iran. In Iran's arid regions, the night-time temperature of the air in winter is usually only a few degrees above freezing. With an icemaker, ice can be produced in winter and stored for the summer (Eiraji and Namdar, 2011). The ice maker consists of a large storage pit with the depth of 10 to 12 meters and one or more shallow rectangular ponds (Amirkhani et al., 2009).

On cloudless winter nights, each pond is filled with water. Water in such a pond loses heat to the sky by radiation; it loses heat from the air by convection and from the ground by conduction (Hosseini and Namazian, 2012). The walls along the pond shield the pond from the wind and thus reduce the heat gain by convection (When there are several ponds, their parallel walls contribute to the overall shielding effect). Under these circumstances, the heat loss by radiation from the night sky is sufficient to freeze the water in the pond (Pouya, 2000). Sometimes the pond is filled a few centimetres at a time during the night, which increases the rate of ice formation. On the following day, the ice is cut up and placed in the storage pit. While that is being done the walls of the pond help to keep the ice from melting in the heat of the daytime sun (Okhovat et al., 2011). On the other hand, conduction from the ground tends to melt the bottom of the ice, so that it can be more easily removed.



Source: Kazemi and Shirvani, 2011

Figure 20: Ice-house at Yazd: plan and section

Figure 20 describes an ice house where: 1) Water in the pond loses heat, 2) The opening allows cold air flow down the ice house, 3) The southern staircase is to let ice set in the deeper part of earth, 4) Ice cube layers are covered by hay to avoid them sticking and 5) A small well discharges melt water.

A passive cooling system exploits the exact features of the climate it seeks to overcome. The passive cooling and ventilating systems of Iran could work well in climates similar to the climate of Iran. For instance, although the cistern and ice-making systems have been abandoned for public-health reasons in Iran, they could be employed in Iran and elsewhere to supply cold water and ice for purposes other than direct human consumption. In climates where the passive cooling systems of Iran cannot be applied they should still be of interest. They demonstrate the possibilities of working with rather than against the external environment. In the future architects and engineers will need to take the climate more in to account and might well examine the possibilities it affords for passive cooling and ventilating systems. With this information, they should be able to design buildings that have modern amenities and yet consume minimal amounts of energy.

5.3.10 Construction materials

The type of construction materials used in Iranian vernacular buildings are predominantly brick and mud generally obtained from soil resulting from excavations and diggings at the construction site (Tehran Times, 2011). The heat insulation of buildings is affected by the nature of the construction materials. All passive heating and cooling systems are based on the ability to gather and store energy within a material for a period of time. Mud and brick will hold heat until it is needed for heating. This characteristic is called thermal mass. Thermal mass is used to store heat from the sun during the day and re-release it when required (Hejazi and Mehdizadeh, 2014). Maintaining the coolness of the internal air in summer and its heat in winter in difficult desert conditions is a very significant principle put into practice using the thermal capacity of the materials. Thick curved walls approximately 60 cm and ceilings made of brick, which is the only material available in the desert, play the role of a capacitor for preserving the heat or cold of the internal space (Mortezaiemanesh and Latifian, 2014). Curved ceilings cause sunbeams to have their most vertical form at only one point. Therefore, less heat is produced, but also provides light without direct penetration of the sun's rays. The double-skin dome roof design, besides a having structural advantage, casts a shadow on the main part of the roof for most of the day and reduces sunlight absorption of the roof wall in the summer. The double-skin structure of the roof causes the air layer between the skins to act as a thermal insulator. The height of rooms, which is a result of the ceiling curve, will improve the air circulation and can contain a large volume of air preventing the room from warming up or cooling off rapidly (Foudazi, 2010).

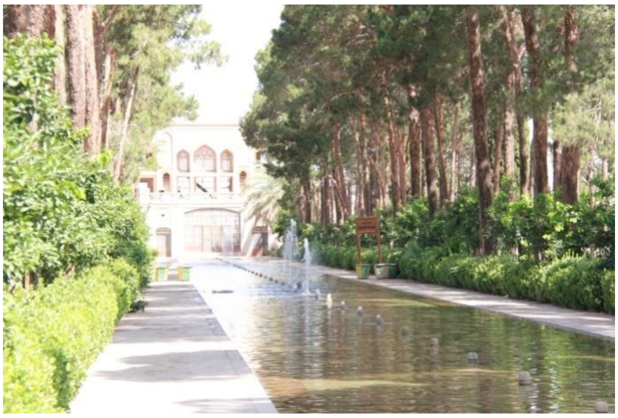
The materials used in traditional and local architecture in Iran have a compatibility with the environment. Hence, the use of such materials in buildings, not only brought no destruction to the environment, but also their wastes and materials from buildings after their useful life is over do not damage the environment and are easily absorbed by nature (Zarghami et al., 2012).

5.3.11 Courtyard with neutral flooring and fountain

The courtyard is internally oriented to the surrounding house, but is also exposed to the external environment, and is a place for daily activities of people in the house. As Ghorbani Nia (2013) states, the courtyard is important with regard to the climate as well, in the way that sunshine and wind circulation will be possible and it has a huge influence on repelling moisture from construction and making a comfort zone for the occupants. Neutral flooring causes delay in the transfer of heat or cold to humans in the yard, and while water is spread all over the yard in summer afternoons, water penetrates into the depth of the flooring and the gradual evaporation cools the air for a longer period of time. They save sunlight heat in winter and as the air gets chilly after sunset, they slowly give off heat to the environment. Traditional courtyard buildings with central ponds provide comfortable weather conditions within the house. Ponds in the middle of the yard keep the air humid in summer by evaporating to decrease the temperature and reflect sunlight to the enclosed air in winter. The amount of heat needed to create water vapour is taken from the surrounding air within the yards, hence the air itself becomes cooler. Moreover, by decreasing the temperature and the moisture of the air, the humidity of the air increases, and hence, will create comfortable conditions for the occupants (Lavafpour and Surat, 2011). Using ponds alongside trees humidifies the air since ponds contain water, in addition to creating shade and protecting buildings from direct sunbeams. In traditional houses that were built in the northern-southern direction, one part of the building was always in the shade and another part in the sunlight. The temperature difference between the two constructed fronts of the yard is the cause of air flow within the yard. The air flow passes through the branches and leaves of trees and also from over the pond; thus, it cools off and blows into the space.

5.3.12 Fountain

In a hot arid climate, the water from courtyard pools and fountains cools the area as well as acting as a decoration. As the most beautiful visual appeal of water, not only keeping cool and ventilating the summer quarters, (Safarzadeh and Bahadori), fountains have a particular place in an Iranian garden and house adding to the beauty of the environment, but also it has a very satisfying performance and it serves as a means of emphasising the visual axes and creates a microclimate (Moradi, 2008). The fountain paired with the vegetation around the pond plays an important role in. The dry and warm wind will pass over a pond with a fountain and gets cool and wet through evaporation (Ahmadkhani, 2011; Foudazi, 2010).



Source: Author, 2013

Figure 21: Fountain as one of the main elements in Iranian vernacular architecture

5.3.13 Skylight and opening on walls

Daylight was an important natural element in Iranian vernacular architecture, due to its spiritual and decorative aspects. Daylight was integrated with other elements of architecture, and remains inseparable from it (Nabavi, Ahmad and Tee Goh, 2013). In a hot arid region, the angle and direction of the sun in winter and summer to receive the daylight and heat is controlled by the design of the window. Windows are designed to keep southern light the summer and in the winter to allow the construction of optimal skylight (Yousefi et al., 2013)**.** Most of the building roofs are constructed in the form of an arc or dome. Walls have bright colours and small windows are installed at the upper parts of walls. These skylights may be found as holes in the domes of public baths, bazaars and houses. They are used in places where windows on walls cannot provide the space with lighting and there is little light, thus necessitating light from the roof. Natural light can indirectly enter the spaces through a skylight. The warm air in warm days can also exit from the open skylights; therefore, fresh cool air is provided (Vaezizadeh and Kazemzade, 2013). Given the climate and environmental factors, the windows on the walls have specific dimensions and proportions. They are decorated in accordance with the building application. Nodes and designs on wooden windows cause small pieces of coloured glass (Appendix P) to sit next to each other in a gorgeous setting so that they would shelter the eye in addition to playing an ornamental role under the harsh and at times blazing sunlight (Sattari, 2013).

Figure 22 indicates the relationship between the main principles, the sub-elements and further subsections, thereby demonstrating mutual dependence. For instance, the courtyard's connectivity with orientation, interior orientation, green surfaces, wind catchers and fountains are a reflection of not only an efficient use of renewable resources of energy, but also establishes the interdependence of the aforementioned principles.

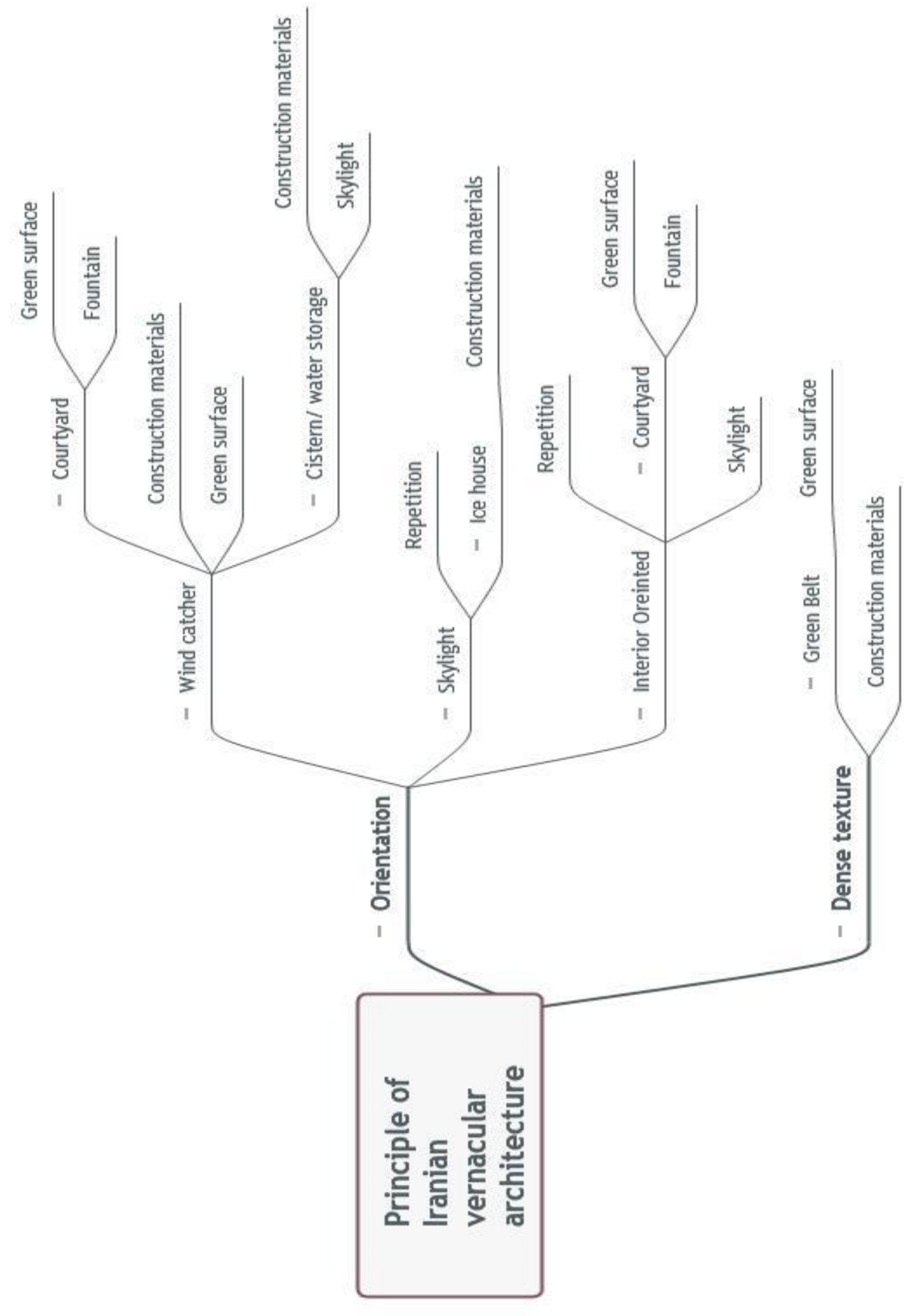


Figure 22: The connection detailed of Iranian vernacular architecture

5.4 Basic concepts governing the design of Iranian vernacular architecture

In designing buildings, Iranian traditional builders tried to bring about desirable conditions inside the building by means of architecture compatible with nature by utilising the potentials of the local climate and controlling natural energies instead (Kamalipour and Zaroudi, 2014). Various strategies have been taken into consideration by the traditional designer when designing the building in order to save natural energies in the building and employ them properly and in a timely manner so that the users comfort would be provided (Shohouhian and Soflaee, 2005). The following are a number of these strategies:

- Employing architectural elements that are compatible with the climate, such as wind catchers
- Employing appropriate materials compatible with the climate as well as using water and plants
- Passive methods of using solar energy (increasing the surfaces of southern windows)
- Proper orientation of the building in order to receive the most heat at cold times and least heat at hot times and to use desirable winds
- Using solar energy directly (for natural reception of light in certain parts of the central building)
- Using proper material to insulate the walls such as adobe and clay
- Using proper vegetation as the complement to the environment
- Considering the relationship between the building, the site and the surroundings
- The effect of climatic factors on designing plans, views and sections

5.4.1 Design philosophy

A square plan was the most stable form of Iranian vernacular architecture (Moradchelleh, 2011) and was considered as the basis of the main structure of the building. Iranian traditional builders used squares in their plans to receive indirect light and create interior orientation (Heidari, 2000). According to the researcher observation, the Iranian traditional architect tried to divide each side of the square into three parts, the reason for the divide was to create the courtyard in the middle of the house. Furthermore, each section of vernacular buildings in Iran are selfdetermining, as by eliminating one section, it would not effect to other part of the house.

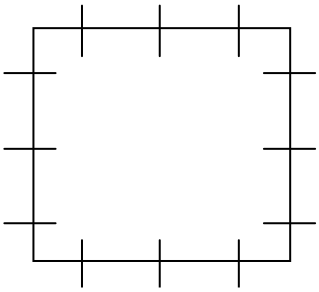


Figure 23: Layout of Iranian vernacular architecture divided into sixteen parts

The one-third points were connected to each other correspondingly. By this method, a square was created within the original square which was smaller and rotated as much as 45 degrees compared with the original square. These four parts become distant from each other and constitute the four entrances to the building. These paths are in northwestern-southeastern and also northeastern-southwestern directions.

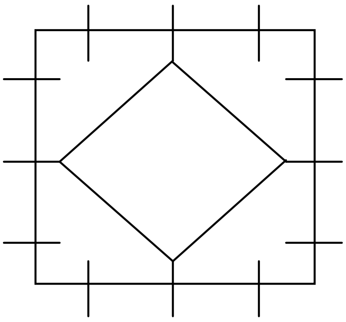


Figure 24: Connecting the points in different directions

The two directions facilitate the ventilation of the central yard in terms of the climate in addition to the entrance directions, particularly in the southeastern-northwestern direction, which was aimed at dominant summer winds. In this fashion, the flow of desirable wind throughout warm months of the year was directed into the structure and by passing over water and plants, which were located within the central yard, a pleasant environment was created for occupants.

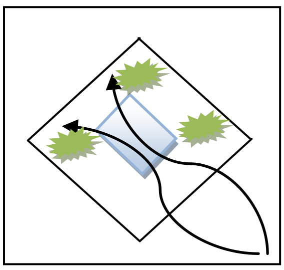


Figure 25: Wind passing over water and plants

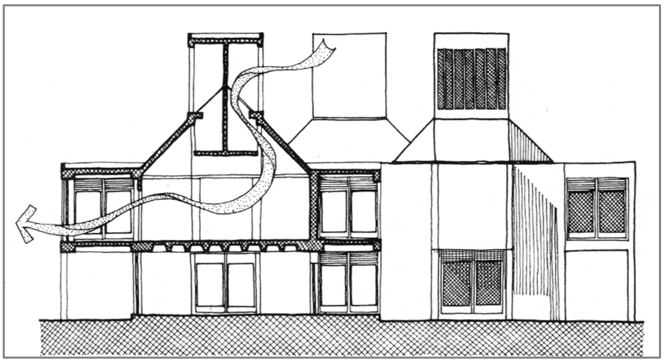
5.5 Qatar University a modern building with decorative wind towers

The University of Qatar, built in the Persian Gulf area with hot and extreme weather conditions, is selected as the modern building case study in our field. The climate, except being humid, has similar weather conditions to Yazd. Investigating the description of the architecture of Qatar University Campus reveals that one of the initial intentions in the design of the campus was to integrate the vernacular principles into the modern context. Therefore, the design included natural ventilation throughout the university and for this reason the idea was developed by introducing a series of wind towers (Saadatian et al., 2012).

Source:Salama, 2008

Figure 26: Wind towers in Qatar University

El Kafrawi, an Egyptian architect, had a number of desirable intentions in terms of trying to respond to climatic conditions and addressing the dialectic relationship between modern technology and local character. However, expectations have not been met, especially when relating his main concern to current reality; the air conditioning system is used almost throughout the year because the wind towers are not utilised any more (Salama, 2009). This was based on a decision of the University administration to close them all due to the amount of dust entering all the spaces through them. The positioning of wind catchers for every single space of the campus all facing each other with not enough gaps between them increases air circulation in that specific area and allows more dust entering through wind catchers during a storm (Salama, 2009). On the other hand, designing in a humid climate but neglecting to place a water basin below the wind catcher canal that helps in preventing dust entering in space can lead to this problem. By not sufficiently reviewing vernacular architecture, and not having a good understanding of the way wind towers should be designed, to prevent issues like dust entering this building, has resulted in a decorative wind tower rather than a functional one.



Source: (ARCHNET, 2013)

Figure 27: Section/elevation of Qatar University

5.6 New approaches using passive-cooling techniques for modern buildings in hot–dry climates

Clearly, the architecture and construction materials of the buildings also play a significant part in the success of a wind catcher based ventilation strategy in Yazd, but the sheer longevity of the wind catcher combined with the time, money, and energy put into their construction, and the "artistry of their subsequent beautification", must represent a successful ventilation strategy that could have a role to play in a modern building. The noted Egyptian architect Hassan Fathy (1986, p.37) is quoted as saying:"Before inventing or proposing new mechanical solutions, traditional solutions in vernacular architecture should be evaluated and then adopted or modified and developed to make them compatible with modern requirements."

As mentioned before, in the hot climates of Iran and neighbouring countries, wind catchers have been used as natural ventilation and passive cooling systems in buildings. However, as Salama (2009) states, the conventional wind catchers such as Qatar University mentioned in the case study have some disadvantages that could be categorised as follows:

- Insects and dust can enter the building with inlet air.
- The wind catchers with more than one opening with no internal partitions cause air entering a portion from the opening and exiting through other openings.

- In general, the amount of stored coolness in the tower mass is limited due to small mass and low specific heat of the energy-storing material which can hinder fulfilling cooling needs during hot summer days.
- The evaporative cooling potential of the air is not used efficiently.
- They are not applicable in areas where wind speeds are extremely low.

Refer to Farshchi publications (2011, 1998), the following table categorised the principles from the literature reviews and site observations into different groups. By individually categorising each component into a table format, it becomes evident how vital each principle is in contributing to the overall sustainability when used in architecture.

		Principles	Function
Micro	Substructure	Water storage	Hold the water at a reasonably low temperature during the hot summer months
		Ice house	
	Superstructure	Wind catcher	Adapted as ventilation tools for natural cooling in cities with hot weather conditions
		Courtyard	Traditional courtyard buildings with central ponds provide comfortable weather conditions within the house. Ponds in the middle of the yard keep the air humid in summer by evaporating to decrease the temperature and reflect sunlight to the enclosed air in winter.
		Fountain	The fountain paired with the vegetation around the pond plays an important role in. The dry and warm wind will pass over a pond with a fountain and gets cool and wet through evaporation.
		Skylight	They are used in places where skylights on walls cannot provide the space with lighting and there is little light, thus necessitating light from the roof. Natural light can indirectly enter the spaces through a skylight. The warm air can also exit from the open skylights; therefore, fresh cool air is provided.
			The orientation of a Iranian vernacular buildings was designed in a way that

Macro	Orientation	the northern side of the yard, received sunlight in winter more than other parts of the building. On the other hand, rooms on the southern side of the yard were in the shade and were cooler used for summer times.
	Dense texture	Density and arrangement in hot arid cities is in a way that minimising sunlight reception allows buildings to cast shadows on each other creating external shaded spaces.
	Repetition	Height of buildings is the same so that wind would not be distributed in an unbalanced manner. The square holes repeated on the surface of the building, in order to facilitate the entrance of air, light, and people.
	Green surface	The green space around cities plays an important role in protecting the central texture against desert winds, dust, and the aridness of the desert air numbering among important factors in the natural ventilation of cities
	Materials	The type of construction materials used in Iranian vernacular buildings are predominantly brick and mud generally obtained from soil. Mud and brick will hold heat until it is needed for heating. These materials used to store heat from the sun during the day and re-release it when required

Source: (Author, 2016)

Table 5: The connection of Iranian vernacular principles with sustainability

The site observation and literature reviews indicates the micro and macro conditions of the principles. In addition, the structure types have been identified through both methods of data collection. The function of each principle has been reviewed following personal evidences such as site observation, testing and simulating, which confirmed the functionality of each principle. Table 5 illustrated how the Iranian vernacular principles contribute to the sustainability of architecture.

The following are the vernacular principles in hot and arid regions that research suggests could be used in modern architecture:

- Using ventilation to have more fresh air
- Daylight penetration
- Using much more space as green areas
- Using water to humidify the interior air
- Reconciliation between humans and nature and a close interface with nature
- Symmetrical design
- Using mud as a insulator
- Use of large pools as a mirror and a beautiful landscape in front of a pavilion (using reflection as beauty)
- Saving more natural elements and prevention of waste of energy
- Naturalism and enjoying the view

Table 5 opens the research to introduce the hypotheses that there is a positive link between orientation and reducing heating and cooling loads. Furthermore, mud/clay acts as an insulator in order to reduce the heating and cooling loads as well. Chapter 6 will test and validate these hypotheses.

5.7 Summary

The current chapter was a key of the following chapter, as it has explained about the main reason of the thesis. The Iranian vernacular principles have been investigated and elaborated. The chapter set out to explore the concept behind Iranian vernacular architecture and has identified the elements and principles which assist the building to be sustainable and energy efficient. Following that, the chapter gave an example of a case study which has followed the Iranian vernacular architecture principles. However, the case study used the features but failed to achieve the main purpose of creating sustainability.

The following chapter has been divided to two sections, firstly the research will compare and analyse two buildings (modern and vernacular) in the same location, with the same weather conditions, through different software evaluations, to find out which building consumes more energy. Following that, the chapter will calculate and analyse two modern buildings, which one of them is regular building and other optimised by Iranian vernacular architecture principles.

CHAPTER SIX: CALCULATION AND ANALYSIS OF VIRTUAL MODERN AND VERNACULAR BUILDINGS

6.1 Scope of the chapter

Buildings have a very long life-cycle so their effect on the environment is long-lasting, and their energy performance is often inadequate given design goals. The entire production process of the built environment comprises of material utilisation and energy consumption which cause environmental problems. To reduce the damage to the environment, it is of vital importance to realise how the building production process, including the design, construction and operation influences the environment, and to evaluate the significance among a variety of factors. When it comes to sustainable development there have been a variety of studies which examine the life-cycle of green buildings and sustainable products. It has been determined that, generally, the earlier green building features are incorporated into the design process, the lower the cost will be. In return, sustainably designed buildings provide financial benefits that conventional buildings do not. These benefits include energy and water savings, reduced waste, improved indoor environmental quality, greater occupant comfort/productivity (Acuff et al., 2005). Typically, there are a few major elements that bring down the costs of running buildings such as windows, lights and water fixtures, and boilers. For instance, windows could be used for ventilation, natural cooling and lighting purposes in order to eliminate the mechanical system. The intent here is to explore and find the elements of Iranian vernacular buildings, which help make it easier to reduce the energy consumption in modern buildings.

This chapter presents the energy performance comparison of two buildings, one design is the basis of current architectural practices in Iran, and the other is designed using principles of vernacular architecture identified in chapter 5 (see table 5 for details). In addition, the aim of this chapter is test and validate the hypotheses identified in chapter 5.

According to Scofield (2002) several studies show that heating, ventilation and air conditioning (HVAC) systems in buildings do not operate as predicted during the design because of performance gap. The following research and analysis will indicate an untapped potential to reduce the energy consumption of buildings and highlight the gap between modern buildings and vernacular buildings.

In this chapter, the energy consumption assessment of a whole building are presented, based on a feasibility study on performance analysis on both modern and vernacular buildings. The purpose of the analysis is to gather and report information for incorporating principles of Iranian vernacular architecture into modern design. The aim of the current thesis was to explore how to reduce the energy consumption during building use. In order to test this, two simulated models (contemporary and vernacular buildings) were presented to identify the gaps between these two type of buildings.

Due to the significant share of final energy consumption in the residential sector in Iran, accurate calculation of heating and cooling loads of a building, analysing the loads, and trying to reduce energy consumption in buildings are among the effective ways for reducing energy consumption of heating and cooling systems in buildings. To asses and compare energy consumption in vernacular and modern buildings, energy simulation software is one of the tools necessary for studying energy use in buildings and we needed accurate software that allowed the observation of performance problems in practice. Using energy consumption optimisation software in buildings helps designers and building owners, without the need for complex calculations, to select the best equipment and apply optimisation techniques of energy consumption and estimate the resulting economic savings.

Today, there are numerous software tools for optimum analysis and design of solar energy systems and especially passive solar designs such as Energy Plus, Design Builder and Integrated Environmental Solutions (IES). An energy consumption analysis attempts to articulate all of the energy needs and usage in buildings. In order to determine how to analyse the energy consumption of the buildings a realistic graph and chart must be created and presented for the particular climate condition.

6.2 Simulation methods

Building energy analysis simulations are used to predict energy flows in buildings. This includes temperatures, system performance, and electrical loads. By having more detailed and measured data, a more detailed performance assessment is possible. However, the increased number of measured data points requires a structure to organise these data results. The buildings in question are an existing modern structure and vernacular buildings in the location and weather conditions of Tehran city. The data taken from the buildings were real measurements of the two aforementioned buildings in different locations. This study intends to create an advanced modern building sustainability rating tool. The analysis aims to cope with the mentioned problems and look towards the real implementation of vernacular principles into modern buildings. This can be seen as a fruitful area for future research.

6.3 Case study 1

This study sets out to test a design. Therefore, the research compared two different building typologies, a regular modern building design with modest modern materials located in Tehran, and a vernacular building with traditional design and materials to assess and simulate which of the aforementioned buildings consumes more energy.

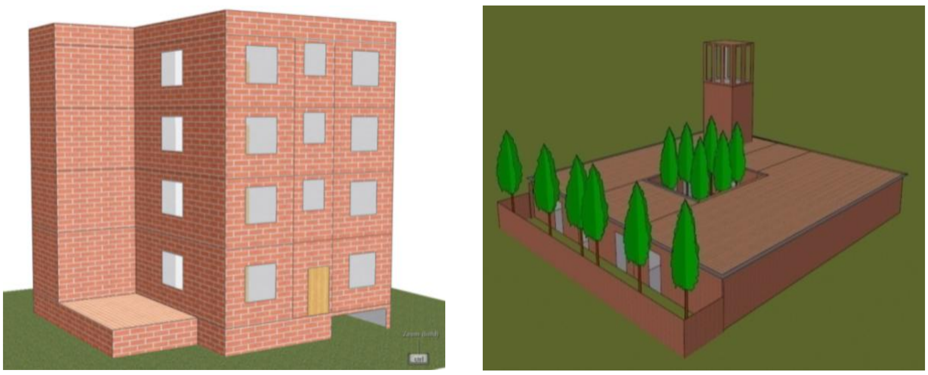


Figure 28: Virtual modern (left) and vernacular (right) buildings

Building Type	Apartment
Area (m²)	712
Peak Cooling Load (W)	20334
Peak Heating Load (W)	22912
Cooling Load Density (W/m²)	56.24
Heating Load Density (W/m²)	64.83

Table 6: Energy consumption of vernacular building

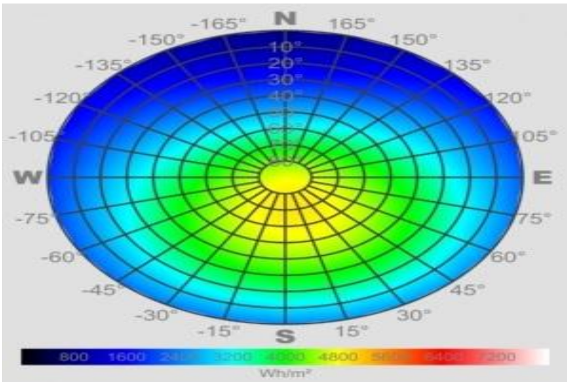
Building Type	Apartment
Area (m²)	657
Peak Cooling Load (W)	35726
Peak Heating Load (W)	40648
Cooling Load Density (W/m²)	78.77
Heating Load Density (W/m²)	89.35

Table 7: Energy consumption of modern building

The research has created two buildings with similar areas to identify the energy consumption of both buildings while been in used. Both building has been analysed in the same location with same climate conditions. From tables 6 and 7 can be noted that not also contemporary building has smaller area (55 m² less than vernacular one) but it consumed more energy compared to vernacular one.

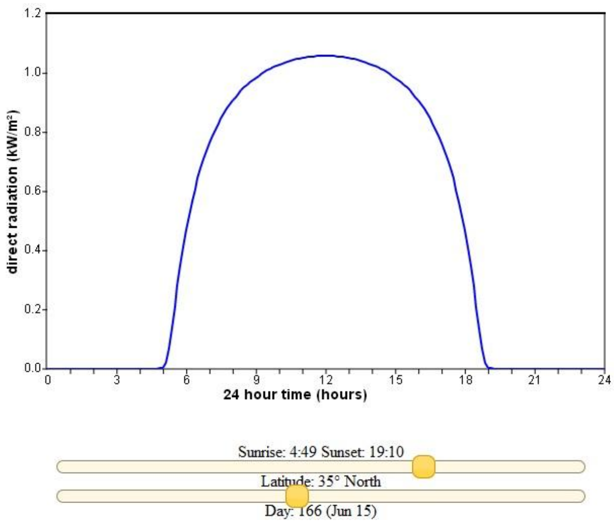
6.4 Description of the location

Figure 29 which has been provided by the US department of Energy (DOE) illustrates the solar angle during the whole year in Tehran. Furthermore, Figure 30 shows the intensity of direct radiation in W/m² throughout the 15th of June in Tehran (31 December can be found on appendix Q). It is the amount of power that would be received by tracking radiation concentration in the absence of cloud. The time is the local solar time.



Source: DOE,2013

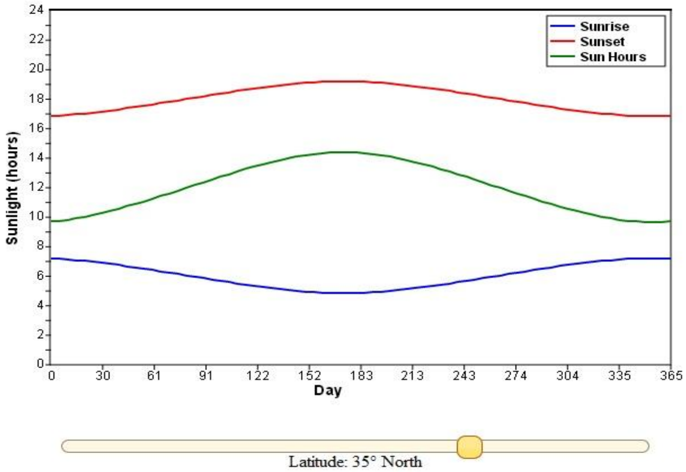
Figure 29: Position and angles of the sun in latitude



Source: Honsberg and Bowden, 2006

Figure 30: Tehran's solar irradiance on 15 June

Tehran is located on a 35º latitude, hence the number of hours between sunrise and sunset is high, which is a positive option to have and uses renewable energy to create sustainable house.



Source: Honsberg and Bowden, 2006

Figure 31: The number of hours the sun is shining each day

Table 8 illustrates the information about the wind speed, temperature and total hours of sunshine in Tehran in 2013. The information below is provided by an online weather organisation.

Index	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature	11	14	18	23	28	34	38	35	33	24	16	9	23.5
Total hours of sunshine	171	193	200	236	263	324	374	329	314	264	114	192	2974
Prevailing wind speed(kph)	10	11	14	13	16	14	12	12	11	10	8	10	11.75

Source: (www.worldweather.org)

Table 8: Wind speed and monthly temperature/ hours of sunshine in Tehran

6.5 Description of the applied software

The research reviewed several energy simulation software packages, to identify which one is more suitable to be used in the current thesis. After careful consideration alongside with the ability of the researcher, two software packages (IES, Design Builder) have been selected. The reason was to reduce bias and errors of the results. Therefore, for the first analysis, the Integrated Environmental Solutions (IES) software was selected. This software permits the measurement of energy consumption whether in an existing building or an un-constructed building. IES software quantifies the modelled energy consumption under certain conditions. This software will identify the heating loads, cooling loads and energy used in the buildings.

The weather data available in IES software is real data which has been collected for different years. The software used is generally able to predict hourly temperature variations. However, the studies below tried to show the energy consumption on a yearly basis. Furthermore, the behaviour of occupants can introduce large discrepancies between actual and predicted building performance.

The IES software is able to take into account many factors in evaluating the buildings such as:

- The energy flow through the buildings envelope, including the surfaces;
- The performance of the air-conditioning and ventilation systems;
- The control strategies, sequencing of plants and equipment, controlled settings;
- The design relative humidity range;
- The different energy types, e.g. electricity.

6.6 Description of the evaluated project

In the assessment stage, the researcher identifies differences between the energy consumption in both buildings, on a statistical basis. Based on these differences, the researcher identifies performance problems with the help of measurement assumptions and simulation approximations. This section outlines the building energy analysis simulation as it pertains to the work done with the software such as (IES) and Climate Consultant 5(CC5). Furthermore, the aim was to find out the consumption of energy in both Iranian vernacular architecture and modern construction in Tehran.

Calculating the impact of a wide variety of energy consumption on total building loads will help us to find out, not only which building consumes more energy, but will also help us to identify the elements in vernacular architecture which help to reduce consumption of energy.

For the simulation the buildings were divided into distinct blocks. To state the source of the discrepancies, we need to define a few charts and graphs. A building consists of components (walls, windows, HVAC, ground, etc.) that together form a system driven by the environment and internal loads. Each of the two buildings demand a set of building energy services (i.e., heating, cooling, water heating, cooking, lighting, appliances, and equipment). The following charts show the results after assessment by IES. Below in the comparative graphs are statistical quantities calculated as the difference between modern and vernacular buildings. In addition, the charts will compare the energy consumption between these two buildings.

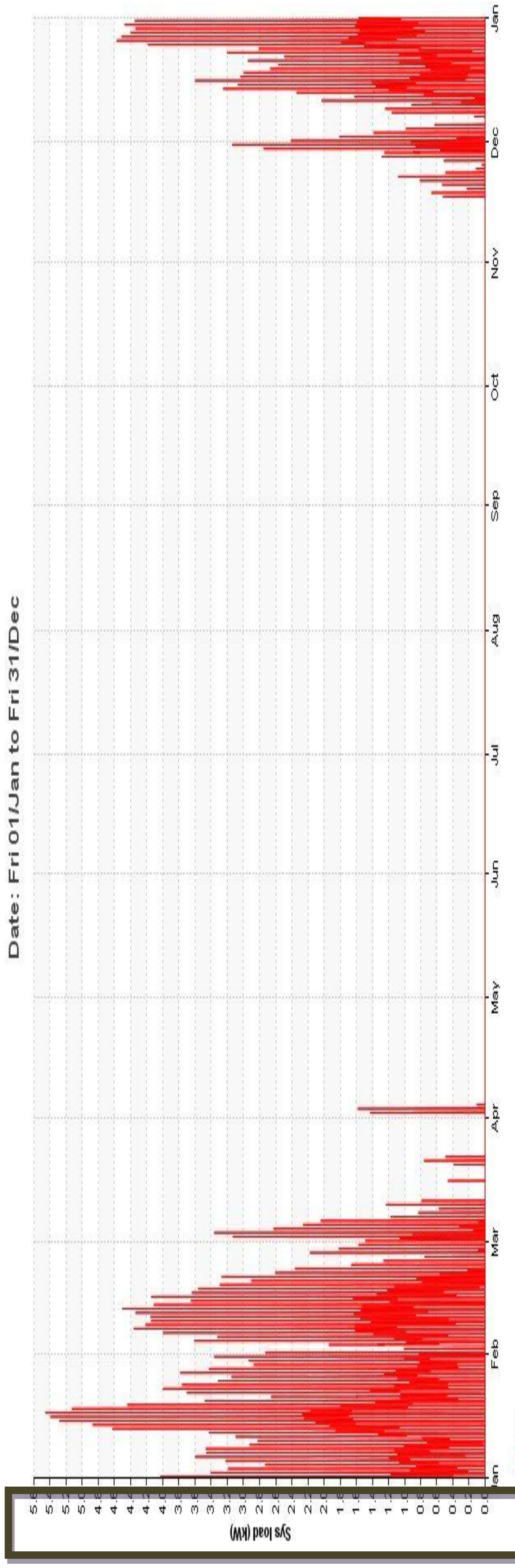


Figure 32: Various heat loads in a vernacular building in a real environment

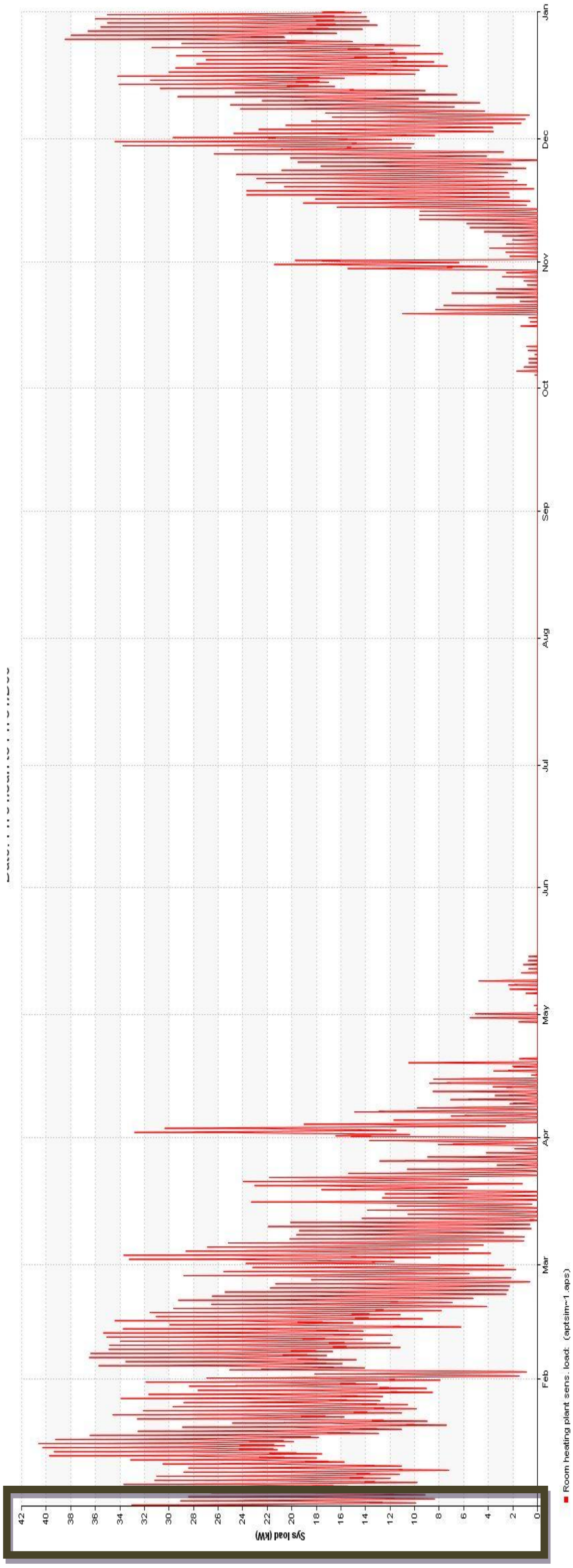


Figure 33: Various heat loads in a modern building in a real environment

As the graph shows, this modern building needs 41 kW/m² to consume energy on the 15th January to make a comfort zone for their occupants, but in contrast to modern buildings vernacular constructions need 5.5 kW/m² energy to prepare a comfort zone.

As discussed in chapter 5, vernacular buildings in hot dry climates use high mass construction with small well shaded openings operable for night ventilation to cool the mass. The mass acts as a thermal battery (McGowan, 2008). During summer it absorbs heat, keeping the house comfortable. In winter the same thermal mass can store the heat from the sun or heaters to release it at night, helping the home stay warm. The mass will absorb heat during the day from direct sunlight or from radiant heaters. It will re-radiate this warmth back into the home throughout the night.

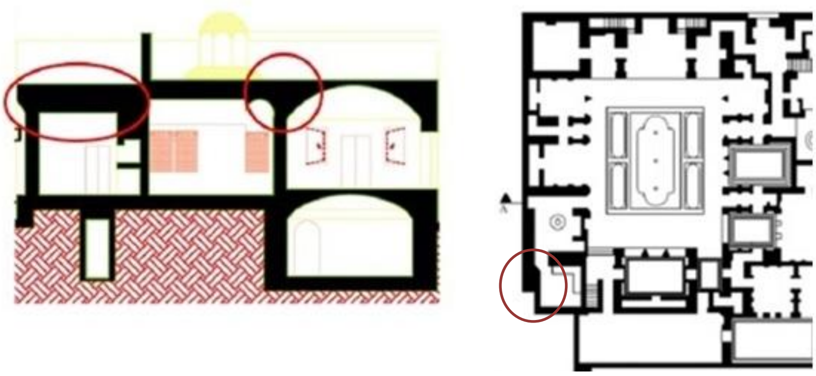


Figure 34: Thick clay wall in Iranian traditional architecture

Window overhangs or operable sunshade to provide solar gain and flat roofs in vernacular buildings work well in hot/mild dry climates (especially if they are light coloured to reflect solar radiation). Furthermore, this can reduce or eliminate the air conditioning systems, which indicates that vernacular buildings are much more environmentally friendly and are not relying on high tech energy consuming systems (Soultandost, 2013) (Appendix R).

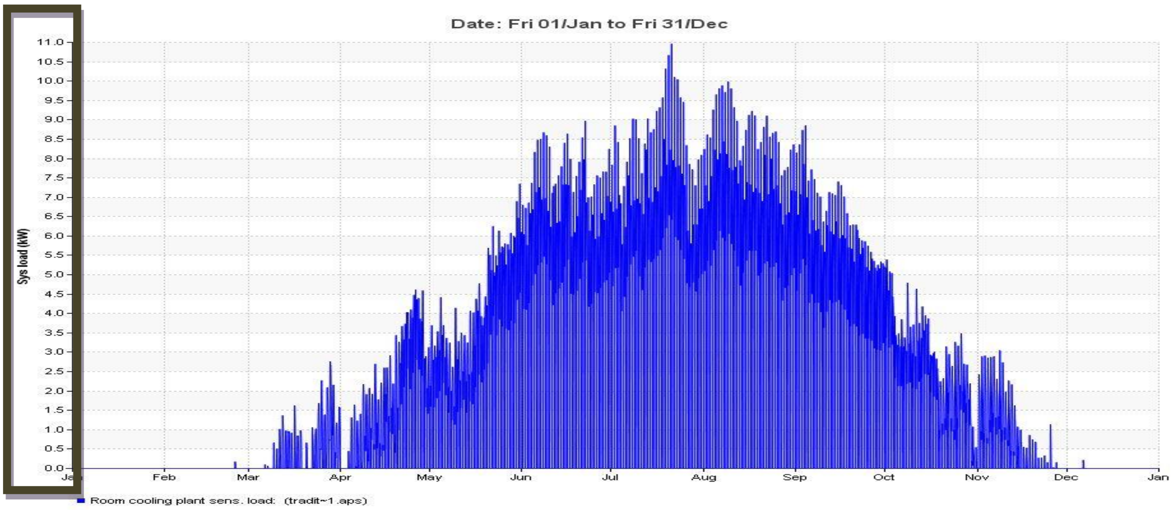


Figure 35: Various cooling loads in a vernacular building in a real environment

Using a fountain or the pond makes the air cool by water mist and evaporation is drawn through the building by the natural ventilation set up by the building's form. Taleb (2014) stated that water and fountain can remove dust or other contaminants which are found in air; these both refresh the air and create a fresher and more pleasant environment. Effective evaporation requires a continuous flow of air which was easily available in open courts over the central pool and fountains.

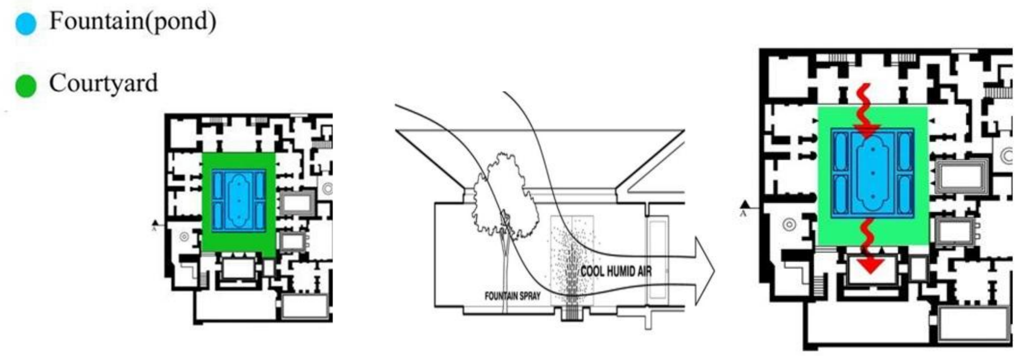


Figure 36: Wind circulation in Iranian vernacular courtyards

Courtyards, according to research findings, offer another type of climatic advantage. In order to encourage circulation of air the home during warm weather, the orientation of the rooms guarantee cross ventilation. Consequently, the walls and the floor keep a low temperature until the evening, because the daylight penetrates the courtyards only in the afternoon, after the sun reaches its highest point. As a result, a convection current is created by the loss of the cool air.

In order to create a comfortable space, the courtyards combine direct gain, cross ventilation and passive cooling. Vernacular buildings in hot, windy, dry climates use enclosed, well-shaded courtyards, with a small fountain to provide wind-protected microclimates. Hot dry air is humidified before it enters the building from enclosed outdoor spaces, with spray-like fountains, misters, wet pavements, or cooling towers.

As Farshad (1997) states, the first climatic advantage of these courtyards is that they allow daylight into the house. This daylight penetrates all the rooms, since they are all arranged around this atrium. The second climatic advantage is the ventilation and passive cooling. The orientation of the rooms towards the patio creates good cross ventilation during the warm season. During the night-time, the courtyard loses heat by irradiation, and the floor, walls and furniture offer coolness that lasts until late afternoon. The sun itself does not penetrate the courtyard until it is noon, when the sun is at the highest point (Naciri, 2007). This actually has its own advantages. As the cool air dissipates from the floor and adjacent rooms, a convection current is created and this therefore adds to the comfort within the house.

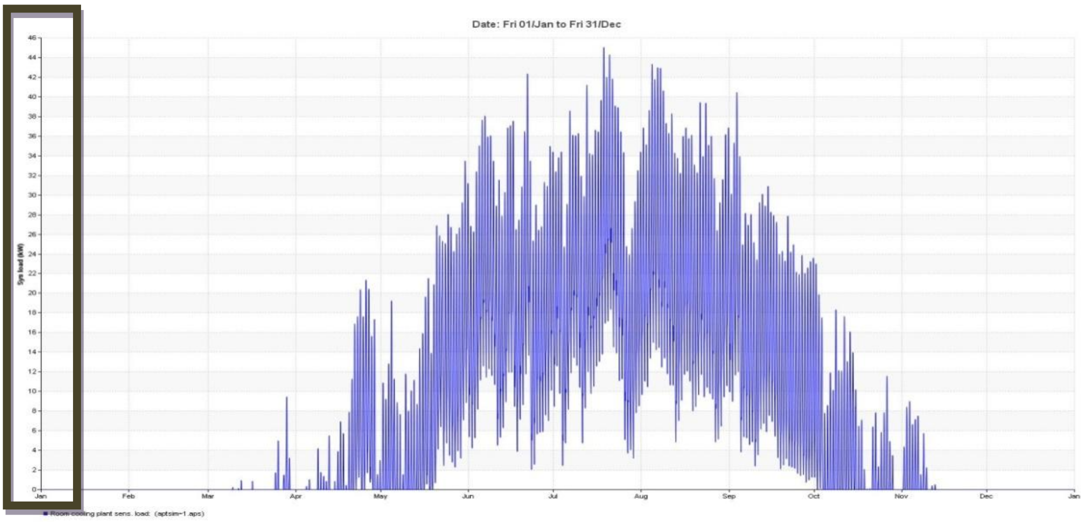


Figure 37: Various cooling loads in a modern building in a real environment

By observing the figures 35 and 37, it is interesting to note that on average the energy consumption of the modern building's cooling load systems was 34 kW/m² higher than vernacular buildings.

The vernacular building has a lower cooling energy requirement. The reason is that firstly Tehran has a mild climate; in mild climates the weather changes rapidly during day and night. Secondly, the vernacular building has huge mass (thick walls, floors and roofs) and stores a lot more energy and requires more energy to heat the huge mass to increase temperature. During the cold nights it heats the interior and exterior as it is getting cooler (releasing the stored energy). In addition to that, a courtyard with a wind catcher will provide a cooling effect. Most of the vernacular buildings are made of clay, adobe and the main material is mud. The material and spaces underground are much cooler compared to the spaces that are closer to the ground level during summer. This means the deeper parts are warmer subsequently compared with the ground surface. Underground during summer is much cooler compared with the surface. In contrast, in the winter time the underground is much warmer than the surface (Appendix S).

The thermal analysis (which includes the heating and cooling) illustrates that the overall energy consumption of the modern building is highly dependent on the type of mechanical systems in contrast to that of vernacular buildings which consume less energy to create a comfort zone for their occupants. For instance, in mid-July the vernacular building consumes 11kW/m^2 energy while the modern building consumes 45 kW/m^2 energy to maintain comfortable conditions.

The analysis showed that the majority of the systems in modern buildings compared to vernacular buildings generally had twice the capacity required for the actual loads served over the monitoring period.

The figures 38 and 39 summarises the yearly energy consumption of the two building types. The results clearly show that the energy consumption in the modern building is consistently higher than the vernacular one.

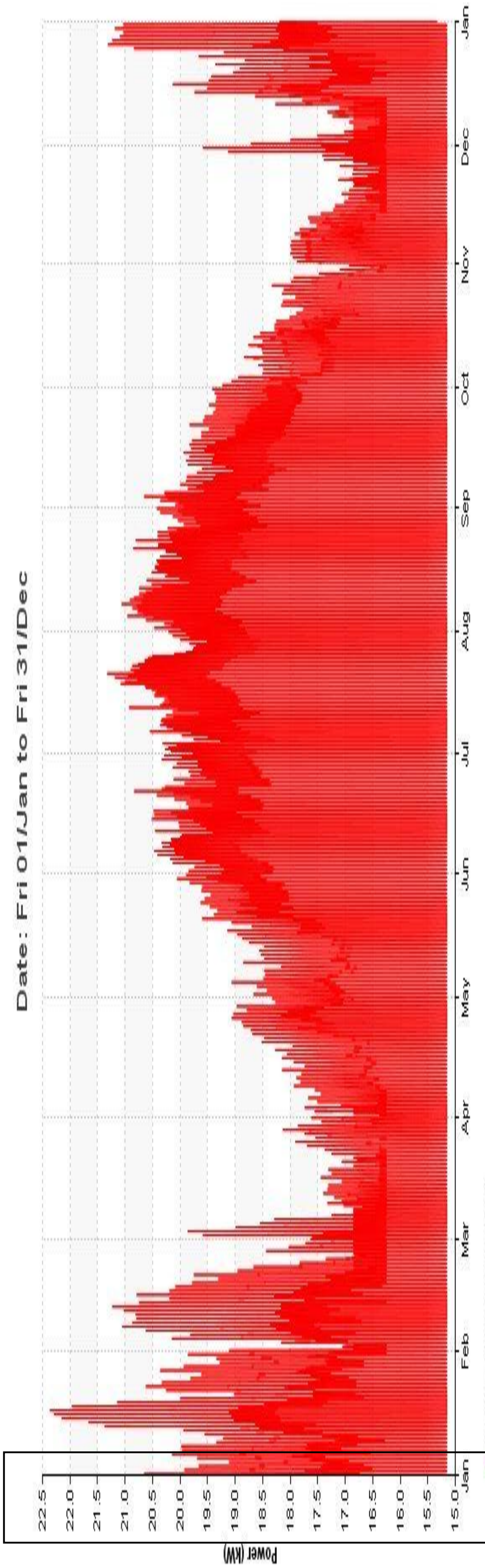


Figure 38: Energy consumption in vernacular building

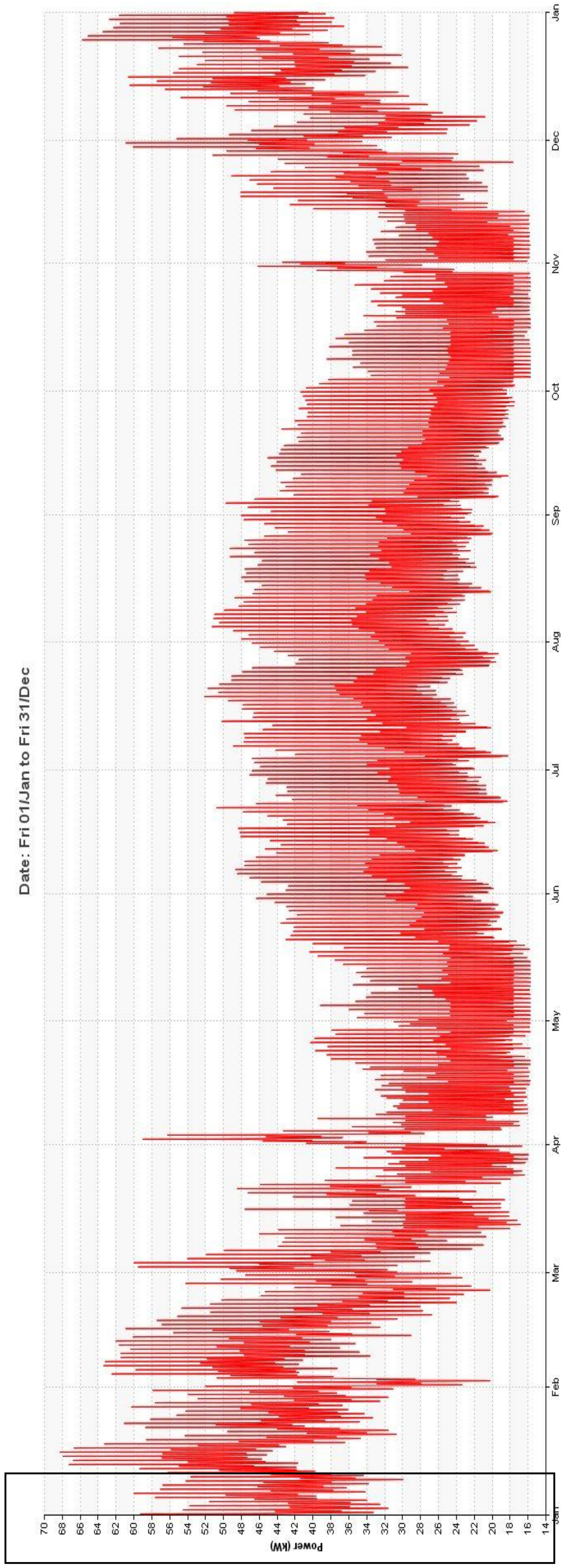


Figure 39: Energy consumption in modern building

The services demanded of the buildings which are lighting, warmth in the winter, cooling in the summer, water heating, electronic entertainment, computing, refrigeration, and cooking, require significant energy use. The growth in the buildings energy consumption comes predominantly from electricity. In addition, the total annual energy consumption of the modern building study ranged from 24 kW/m^2 to 68 kW/m^2; these measured values compared to the vernacular building, which was between 16.5 kW/m^2 and 23 kW/m^2, show that modern building consumes much more energy.

Vernacular architecture does not rely on high-tech energy-consuming systems for heating, cooling, ventilation, but on the immediate natural systems in the local environment.

Current energy consumption charts and graphs(figure 32-39) suggests that modern buildings typically use at least two times more energy than vernacular buildings with similar locations and weather conditions. It can be noted that modern buildings will consume more energy, and potentially a lot more energy, in the future than they do today. The reason is that buildings are getting older, and the amortisations of the materials led occupants to consume more energy to create a comfortable zone for themselves (Szuppinger and Csobod, 2011).

The examination and analysis of the modern building indicates insufficient thermal insulation, nonstandard material used, improper orientation, and incorrect ventilation are the key reasons for high energy consumption for heating and cooling loads. Thus, there is the need to consume more energy and burn more fossil fuel, and clearly the charts and figures show that vernacular buildings are much more sustainable and energy efficient compared with modern ones. Based on the identification of the building's performance energy consumption, which was the main focus at this stage of the research, it is possible to specify elements and principles of Iranian vernacular architecture which reduce the energy consumption of the construction.

In this research the comparative studies showed that the modern building, to achieve the comfort zone for its occupants, needs to use mechanical energy, even for very simple and small buildings. On the other hand, vernacular buildings by using natural resources have eliminated the use of mechanical systems. Therefore, to reduce energy consumption and pollution, using clean energy sources such as wind, water and sun, which have no pollution and low cost production, could be an excellent alternative. In the past, fossil fuel was not as available as it is in modern times, and architects were using simple but intelligent methods to use existing natural energy for their designed buildings. The research simulations stated that the vast difference between modern buildings and vernacular ones. The detailed analysis that has been undertaken on these two building types demonstrates that vernacular buildings offer a reduced consumption of energy with a huge gap compared with the modern buildings.

6.7 Comparing two similar buildings base and optimal-added vernacular principles

The following section compares the required heating and cooling capacity as well as the annual energy consumption in two simulated buildings. The virtual buildings were intended to be representative as well as to allow finding out which of them is much more energy efficient and produces less carbon. The building model was created as a 4 storey building. The building had multi thermal zones comprising of bedrooms, living room, kitchen, toilet, shower area, storage, toilet, elevators, and car parking lots. Both buildings simulated in the same location which is Tehran. They are similar in terms of general shape; however, the first building is one of the conventional constructed samples in the city (base building), while some changes are made to the second building through the use of passive solar and wind designs (optimal building), which has always been considered in the Iranian traditional architecture. It was intentional choosing a site in the Iranian city which is densest in terms of buildings and busiest in terms of population. This was in order to set up a challenge where the research can try to address the sustainability issues. The goal was to simulate both buildings and compare their energy consumption through Design Builder software.

6.8 Design Builder software

Design Builder is used for modelling various aspects of the building such as the building physics (building materials), building architecture, heating and cooling systems, lighting systems (Wasilowsky and Reinhart, 2009). Therefore, it is capable of modelling all features of the building. As one of the world's most advanced and up-to-date software packages for modelling buildings, this software, besides modelling the heating and cooling load of the building, can dynamically model various energy uses of the building such as heating, cooling, lighting, appliances, hot water.

This software is also capable of calculating the amount of daylight and can even model Computational Fluid Dynamics (CFD). Design Builder can model natural and mechanical ventilation, and calculate thermal comfort in indoor environments and the amount of received and dissipated energy from different elements of the construction. Modelling results are extractable for the entire year and various months, as well as on a daily or hourly basis. All modelling results are also extractable for the entire building, a given floor of the buildings, or a single area of the construction. Energy Plus is the simulation engine of this software which was developed by the American Department of Energy in 2011 and is unique in its kind as one of the most prestigious energy modelling software. Design Builders energy analysis software is used for calculating the energy consumption of a building. This software enables the user to apply various optimal architectural designs and observe the level of improvement in the energy consumption of the building. The floor plans of the building are depicted below.

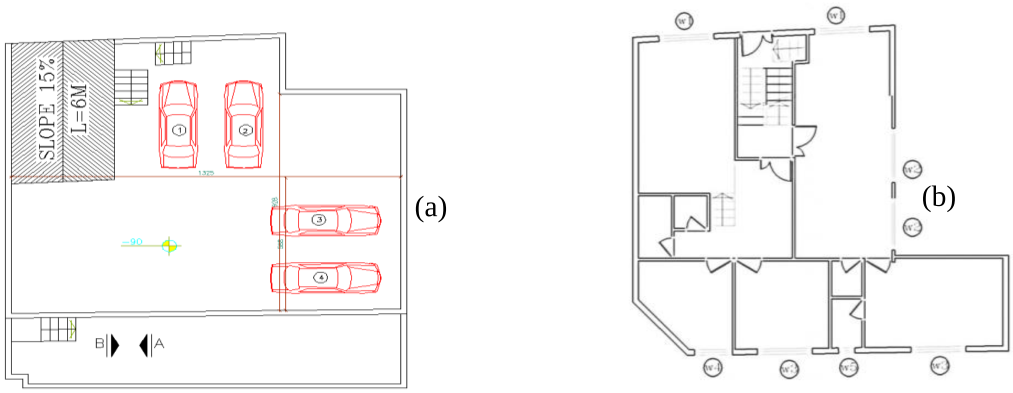


Figure 40: Parking plan (a) and first floor plan (b)

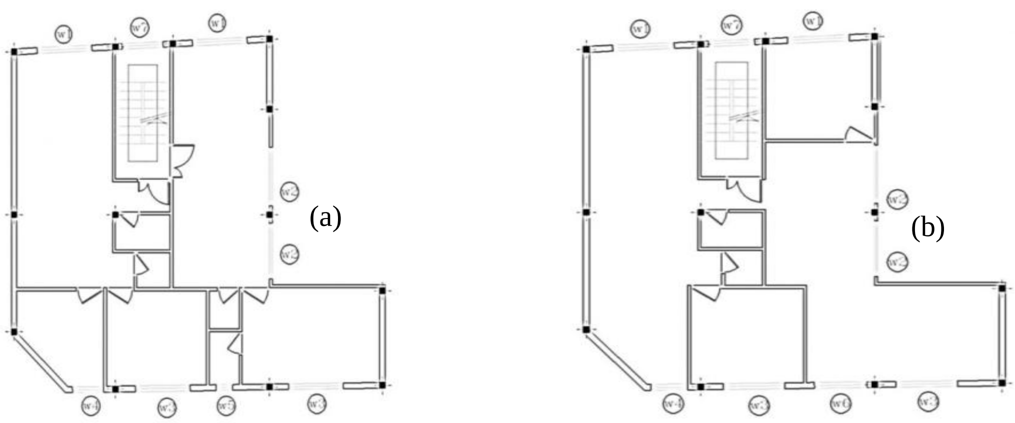


Figure 41: second and third floor plan (a) fourth floor plan (b)

6.9 Specifications of the base building

The base building specifications (non-optimised building) are summarised in the following tables.

Building Name	Building 1(Ordinary)	Usage	Residential
Working Hours	24	Type of Framed windows	Aluminium
Building's Span	East-West	Type of External Doors	Wood
Main Entrance	South	Number of People	18
View of the Exterior Walls	Stone	Plan Shape	L Shape
Roof Shape	Flat	Area	668 m^2
Roofing Materials	Tar Paper	Flooring Materials	Ceramic

Table 8: General specifications of building

- Layers of external walls from outside to inside: 2 cm granite, 1 cm cement and sand mortar, 15 cm bricklaying, 1 cm stucco, 1 cm plaster and paint, with the total heat transfer coefficient of2.11w/m^2c.

- External roof layers from outside to inside: 3 cm insulation (asphalt and fibre glass), 10 cm concrete, 10 cm roof structures, 3 cm plaster and paint, with total heat transfer coefficient of0.99 w/ m^2c.
- Single-glazed windows with aluminium frames with a heat transfer coefficient of 5.4 w/ m^2c.

Row	Window's name	Direction	Number	Length	Height
1	W1	S	8	2	1.6
2	W2	W	8	2	1.6
3	W3	N	8	2	1.6
4	W4	N	4	1.4	1.6
5	W5	N	3	0.6	0.8
6	W6	N	1	1.7	1.6
7	W7	S	4	1.2	1.6

Table 9: Names of the windows are shown in the plan figures

Level	Area (m^2)
Parking	153
First Floor	126
Second Floor	126
Third Floor	126
Fourth Floor	126
Roof	11

Table 10: Measurements of different floors

	Electrical Equipment	Power: W/m²
1	Light	4
2	Computer	1.5
3	Other Equipments	5

Table 11: Power usage of electrical equipment

6.10 Modelling the base building by Design Builder

To compare energy consumption between the two simulated buildings, it is necessary to calculate energy consumption in different parts after modelling the base building. For this purpose, as can be seen in the following figures, the buildings were at first modelled in the software. After physical modelling and inputting the building specifications, the buildings heating and cooling loads, and consequently their monthly and annual consumptions, were calculated. The research used Adiabatic and component block to not transfer heat beyond their outer surface. Furthermore, they have been used to cast shadows and reflect solar radiation and light. The research in line with Bhatia (2012), considers several factors , which determine heating and cooling loads in a building, some of which are as follows:

- ✓ Convective heat transfer from the building skin (walls, ceilings, windows)
- ✓ Heat from electrical equipment, lighting and individuals
- ✓ Heat from solar radiation
- ✓ Heat from leaked or penetrated air
- ✓ Heat lost through ventilation (fresh air supply)

During heating in winter, some aspects such as heat produced by the equipment, individuals, and light are positive and lead to a decrease in the capacity of the heating system (Burdick, 2011), which should be considered in the calculations. In addition, the radiative heat transfer through windows, which is a negative cooling factor in summer, contributes considerably to heating and decreases heating equipment capacity in winter.

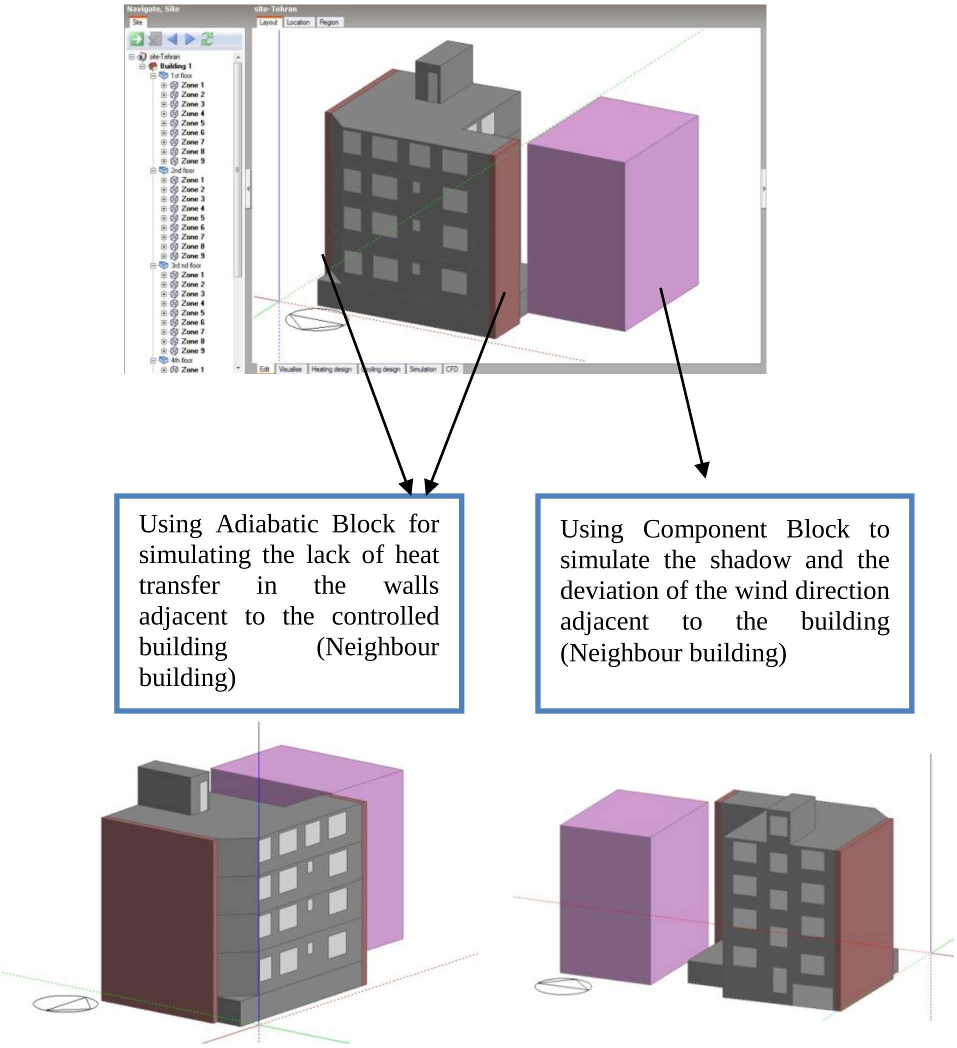


Figure 42: Modelling of base building

6.11 The assumptions used in determining the loads and energy consumptions in buildings

A) **Temperature set point**

Input for the simulation may include space temperature set points. A temperature set point is the desired temperature of the area which should be reached by the cooling system (such as chillers and their equipment) and the heating system (such as the boiler and its equipment) (Katipamula et al., 2003). For instance, if the set point temperature in summer is 24°C, the cooling system will use less energy compared to the case when the temperature set point is 22°C. The initial update includes external boundary conditions, which are outside air temperature, solar radiation, wind speed and direction, as well as wet bulb temperature or relative humidity.

In this study, the heating and cooling set points in both buildings were considered to be the same, because the purpose was to compare the consumption level by changing the design specification of the building. In both buildings, the cooling set point of 24℃ and heating set point of 19℃ were selected.

B) Heating and cooling systems

In both simulated buildings, heating and cooling were provided through the split air conditioner. In splits (gas coolers), a very important factor in energy consumption is the Coefficient Of Performance or the system COP. Cooling COP is defined as follows:

$$\text{COP} = (\text{cooling load required}) / (\text{power consumption})$$

The better the performance coefficient, the lower the energy consumption, or in other words, the higher the system performance. The system used was the split air conditioner with the cooling COP of 1.83, and the heating COP of 2.53.

C) Adjacency

The building was assumed to have neighbours on both right and left sides (it is closer to reality in a city like Tehran), so that the shadowing degree and the deviation of wind direction in energy calculations could be considered.

D) Equipment

Since the effects of architecture on cooling and heating loads were to be examined, the equipment (electric, gas) was assumed to be the same in both buildings. While outside weather data are obvious boundary conditions, simulation input can also consist of other additional measurements. These other measurements include occupancy, plug loads and electric lighting.

E) Occupancy

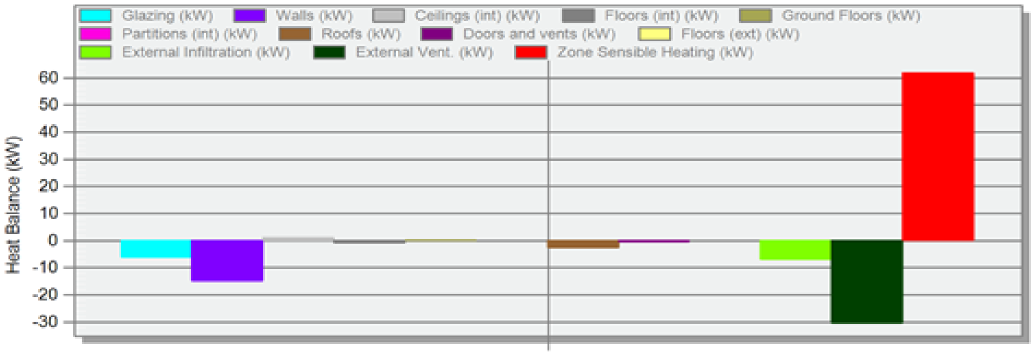
Buildings were calculated on the basis of 24 hour/seven days a week residential occupancy. Furthermore, the calculation defines the individual presence and use of equipment.

6.12 Results of energy consumption and load in the base building

After modelling and inputting the same building specifications and assumptions for both buildings, the building was simulated. Table 12 illustrates the result of the calculated data points and points out the energy consumption of each space with a different volume for the total cooling load. The numbers and data given in the table will identify the differences and performances while comparing with next section of the building simulation. Part of the results is given below.

Building	Block	Zone	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Floor Area (m2)	Volume (m3)
Building 1	1st floor	Zone 4	0.19	1.8	16	49.6
Building 1	1st floor	Zone 3	0.32	3.13	29	89.8
Building 1	1st floor	Zone 9	0.27	2.9	31.7	98.2
Building 1	1st floor	Zone 6	0.12	1.16	9.8	30.5
Building 1	1st floor	Zone 1	0.13	1.25	12	37.3
Building 1	1st floor	Zone 5	0.04	0.37	2.2	6.7
Building 1	1st floor	Zone 2	0.02	0.23	1.8	5.6
Building 1	1st floor	Zone 7	0.04	0.34	3	9.3
Building 1	1st floor	Zone 8	0.03	0.23	1.7	5.2
Building 1	parking	Zone 1	0.18	2.56	134.1	241.3
Building 1	2nd floor	Zone 8	0.24	2.53	31.7	85.7
Building 1	2nd floor	Zone 9	0.34	3.28	29	78.2
Building 1	2nd floor	Zone 5	0.11	1.04	9.3	25.2
Building 1	2nd floor	Zone 6	0.12	1.19	12.5	33.8
Building 1	2nd floor	Zone 3	0.04	0.33	2.2	5.8
Building 1	2nd floor	Zone 1	0.18	1.72	16	43.2
Building 1	2nd floor	Zone 4	0.03	0.24	1.8	4.9
Building 1	2nd floor	Zone 2	0.04	0.31	3	8.2
Building 1	2nd floor	Zone 7	0.02	0.21	1.6	4.4
Building 1	3rd floor	Zone 8	0.25	2.62	31.7	85.7
Building 1	3rd floor	Zone 9	0.38	3.65	29	78.2
Building 1	3rd floor	Zone 5	0.11	1.06	9.3	25.2
Building 1	3rd floor	Zone 6	0.13	1.24	12.5	33.8
Building 1	3rd floor	Zone 3	0.04	0.37	2.2	5.8
Building 1	3rd floor	Zone 1	0.2	1.95	16	43.2
Building 1	3rd floor	Zone 4	0.03	0.29	1.8	4.9
Building 1	3rd floor	Zone 2	0.04	0.32	3	8.2
Building 1	3rd floor	Zone 7	0.02	0.21	1.6	4.4
Building 1	4th floor	Zone 6	0.56	5.44	37.2	100.6
Building 1	4th floor	Zone 3	0.18	1.71	11.7	31.6
Building 1	4th floor	Zone 5	0.4	3.91	41.1	110.9
Building 1	4th floor	Zone 1	0.16	1.51	12.5	33.8
Building 1	4th floor	Zone 4	0.03	0.28	1.6	4.4
Building 1	4th floor	Zone 2	0.05	0.41	3	8.1
Building 1	stair box	Zone 1	0.34	3.8	16.9	133.1
	Total		**5.38**	**53.59**	**579.5**	**1574.8**

Table 12: Cooling load in different location of the building on 15th July



16.78	Air Temperature (°C)
13.49	Radiant Temperature (°C)
15.14	Operative Temperature (°C)
-3.10	Outside Dry-Bulb Temperature (°C)
-6.22	Glazing (kW)
-14.99	Walls (kW)
0.99	Ceilings (int) (kW)
-0.99	Floors (int) (kW)
0.15	Ground Floors (kW)
0.00	Partitions (int) (kW)
-2.67	Roofs (kW)
-0.41	Doors and vents (kW)
-0.00	Floors (ext) (kW)
-7.13	External Infiltration (kW)
-30.56	External Vent. (kW)
61.79	Zone Sensible Heating (kW)

Figure 43: Heat losses in winter of base building

Figure 43 illustrates each element of the base building which loses heat during the winter time. It indicates components of buildings envelope such as walls and roof are losing more heat during the winter, compared to the other parts of the building. Therefore, one of the key elements which need to be considered for designing optimal buildings is defining the layers of each components and considering to use other materials that have low thermal conductivity.

Building	Block	Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)
Building 1	1st floor	Zone 4	15.73	2.64	3.17
Building 1	1st floor	Zone 3	16.08	4.31	5.18
Building 1	1st floor	Zone 9	17.26	3.66	4.39
Building 1	1st floor	Zone 6	16.51	1.48	1.78
Building 1	1st floor	Zone 1	16.76	1.68	2.01
Building 1	1st floor	Zone 5	16.14	0.36	0.43
Building 1	1st floor	Zone 2	16.92	0.21	0.25
Building 1	1st floor	Zone 7	17.19	0.29	0.35
Building 1	1st floor	Zone 8	17.27	0.17	0.2
Building 1	parking	Zone 1	9.92	4.09	4.91
Building 1	2nd floor	Zone 8	17.83	2.92	3.5
Building 1	2nd floor	Zone 9	16.55	3.63	4.35
Building 1	2nd floor	Zone 5	16.97	1.17	1.4
Building 1	2nd floor	Zone 6	17.24	1.43	1.71
Building 1	2nd floor	Zone 3	16.45	0.29	0.35

Building 1	2nd floor	Zone 1	16.13	2.22	2.67
Building 1	2nd floor	Zone 4	17.28	0.16	0.19
Building 1	2nd floor	Zone 2	17.6	0.22	0.27
Building 1	2nd floor	Zone 7	17.54	0.13	0.16
Building 1	3rd floor	Zone 8	17.79	2.96	3.55
Building 1	3rd floor	Zone 9	16.54	3.65	4.38
Building 1	3rd floor	Zone 5	17.01	1.16	1.39
Building 1	3rd floor	Zone 6	17.23	1.43	1.72
Building 1	3rd floor	Zone 3	16.42	0.29	0.35
Building 1	3rd floor	Zone 1	16.16	2.21	2.66
Building 1	3rd floor	Zone 4	17.21	0.16	0.2
Building 1	3rd floor	Zone 2	17.6	0.23	0.27
Building 1	3rd floor	Zone 7	17.53	0.13	0.16
Building 1	4th floor	Zone 6	16.08	5.18	6.22
Building 1	4th floor	Zone 3	15.9	1.8	2.16
Building 1	4th floor	Zone 5	16.96	4.61	5.53
Building 1	4th floor	Zone 1	16.74	1.61	1.93
Building 1	4th floor	Zone 4	17.08	0.16	0.2
Building 1	4th floor	Zone 2	17.07	0.28	0.34
Building 1	stair box	Zone 1	14.41	4.88	5.85
	Total			**61.8**	**74.18**

Table 13: Heating load in different locations of the building

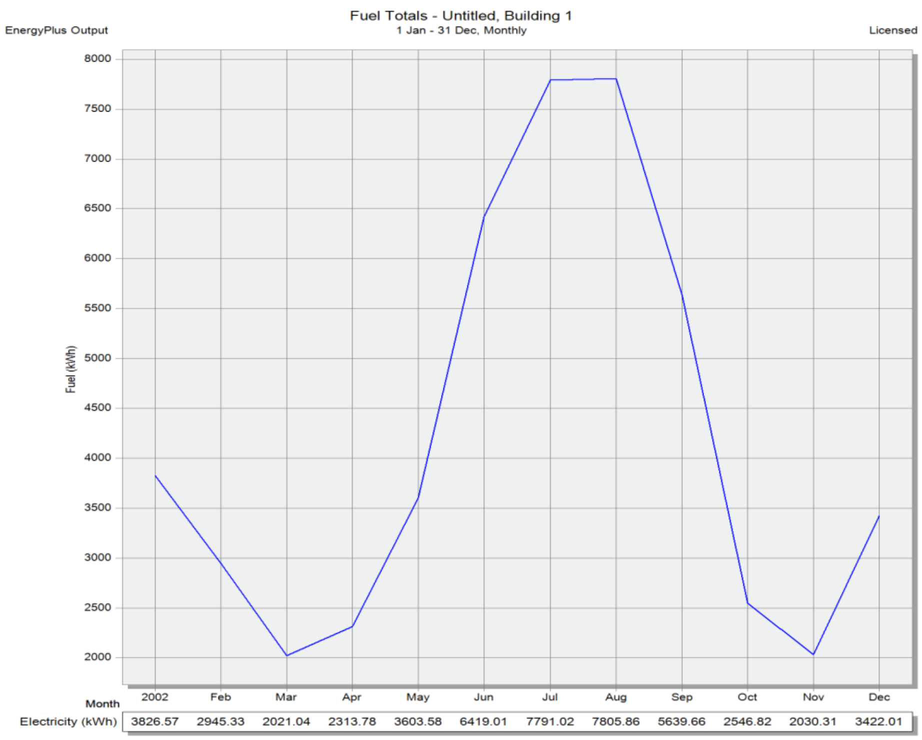


Figure 44: Monthly simulation electricity consumption

Figure 44 and table 13 demonstrates the annual electrical consumption which includes the heating, cooling loads and power for appliances of the base building. For instance, they are indicating that electricity consumption in the base building in July is 7791 kWh. The minimum energy consumption of the building simulated in March and November time, which the chart has marked as 2000 kWh.

6.13 Using IVAP in designing the investigated sample building

Most modern buildings that are getting increasingly complex, greatly depend on mechanical systems for controlling the internal air, desirable temperature, light. These mechanical systems that consume non-renewable energies not only are normally very costly, but also produce Co^2 (Palmer and Cooper, 2011), which can especially lead to undesirable consequences for living in these regions that have difficult climatic conditions and encounter numerous natural limitations. Due to the population increase and the rising price of land and materials in cities, it is less feasible to design the buildings similar to the past. Therefore, older constructions are replaced by apartments. However, by using architectural principles stated in the previous chapter, it is possible to design buildings with lower energy consumption and more compatibility with the climate. In this section, the intended solutions are discussed with regard to the Iranian vernacular architecture. In designing the respective buildings, efforts were made to prepare the conceptual context for design by taking a glance at the past and understanding methods, values and concepts ruling people’s lifestyles and paying special attention to the principles employed by traditional architects. On the other hand, by having a look at the current technological advancements, which are caused by changes in human life style as well as intellectual evolution of humans, and in view of the degree and method of using it for achieving future styles of architecture, employing technology rationally and wisely can pave the way for the development of creativity in design, in a fashion that future architects can also follow this path. Therefore, the experiences of predecessors as well as new ones in architectural design can put forward valuable solutions for solving today’s architectural problems and also arriving at architectural design which fulfils current needs.

Succeeding in coming up with such a design entails a real understanding of the local climate and adopting appropriate strategies by the designer in order to create acceptable conditions together with minimum energy consumption. The design’s success will of course be completed when the building’s users help control the desirable conditions inside the building. For instance, this may be achieved by controlling the times when it is necessary for the windows to be open or closed in order to create natural ventilation or proper lighting and also by controlling other climatic factors.

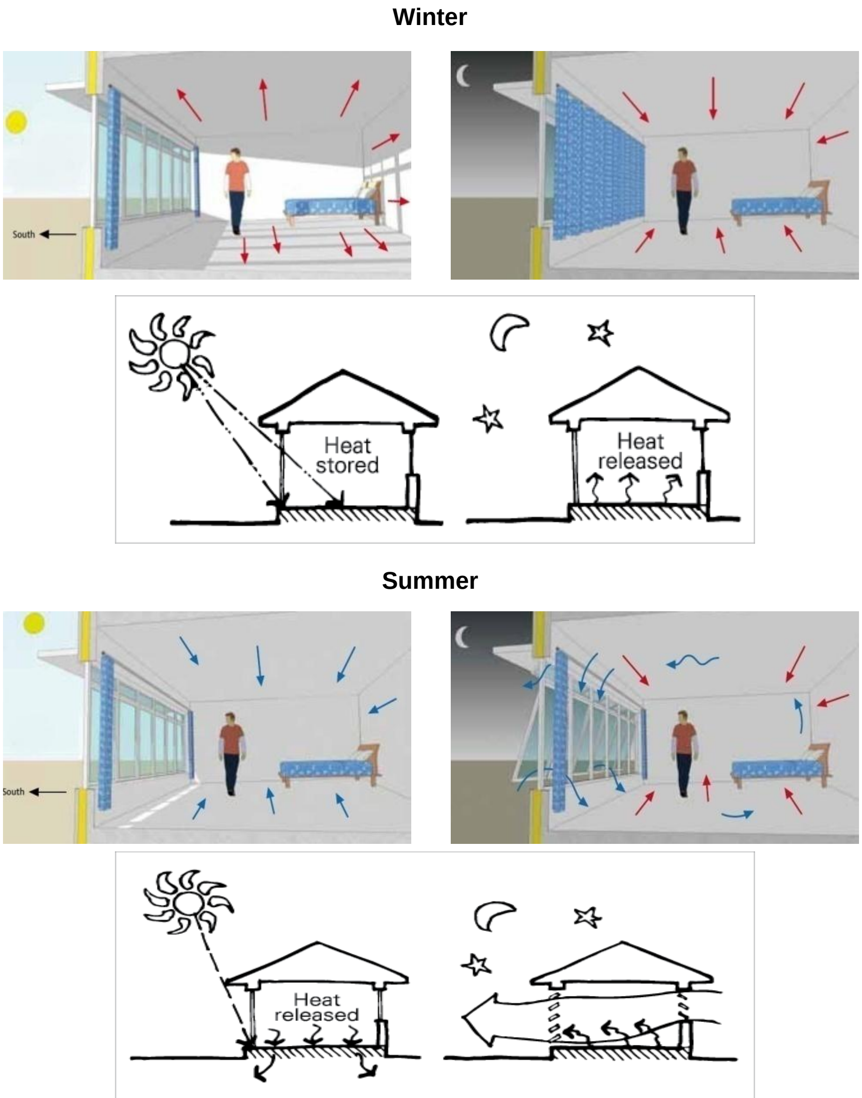
This design is based on compatibility with the environment. In order to attain this compatibility in designing buildings, strategies to employ natural forces as renewable energies for fulfilling human needs should be adopted. In this manner, environmental forces are converted into usable energies for buildings and on the other hand, the building should become a component of the natural environment cycle, in a way that it should inflict the least damage upon nature at construction and usage stages, and it should be able to play its role as an environmental element. In order to arrive at the above goals, the designed building makes maximum use of renewable resources. The design of the building should make use of natural cooling, heating and ventilation systems through maximum utilisation of renewable resources and regional potentials.

In this section, a sustainable building is designed using the theoretical background obtained from previous chapters and the conducted studies take an architectural shape. At first, the way the idea and concept of the project was formed is discussed and afterwards, the subsequent stages are introduced step by step until the final designs are developed.

The following are a number of conceptual basics that contributed to attaining Iranian vernacular principles:

- ✓ Orientation and rotation of the building from the south up to 15 degrees according to the movement of the sun, which leads to accelerated energy absorption in winter and reduces its effect on the southern wall of the building in summer.
- ✓ The use of materials with a high thermal capacity in the floor as a thermal mass to absorb solar energy and transfer it to the interior space during the night in winter. During the summer allowing the cool night breeze to pass over thermal mass, drawing out all the stored heat. The figure 45 illustrates the function of thermal mass in different seasons. For instance, during the winter the low angle sun can shine and penetrate into the room and the heat will be absorbed by thermal mass in the floor and walls.

Therefore, in the evening when the sun sets the temperature drops, in that time the heat flow is reversed and passes back into the room.



Source: De saulles, 2012

Figure 45: Using heat absorb by thermal mass in different seasons

- ✓ The use of canopies of proper depth on southern windows brings in the sunlight in winter and prevents it in summer. Boxwell (2012) states that, the winter sun path is much shorter and lower than the summer sun path. On the 21st December, the sun will rise 73º east of due south and set 73º west of due south. However, on the 21 June, the sun will rise 110 º east of due south and set 110 º west of due south. Therefore, canopies and sunshades have to be adjustable, to have maximum sun penetration into the building during the winter and minimum heat from the sun during the summer.

- ✓ The use of thermal insulation in the buildings walls reduces heat exchange within the building environment.
- ✓ The use of plants in the patio (increasing moisture and creating a micro-climate)
- ✓ The use of thermal insulation on the roof (to reduce heat exchange on the roof)
- ✓ Using more windows in the building’s southern wall and near the building floor to absorb sunlight energy in winter and less window on western and northern walls to reduce energy loss from the building’s internal spaces.
- ✓ Use of wind catcher leads the fresh air into the building and the solar chimney directs the internal warm air to the exterior and natural ventilation occurs in this way.

6.14 Principles of passive solar design

Passive solar design is the balance between components resulting in more efficient energy performance of the building throughout the year (Charron et al., 2005). Attention to the sun’s movement and radiation angle and exploiting it is clearly seen in the design of old houses of Yazd and today, not only sunlight, but also solar energy is used to heat water and supply some part of the electricity required and consumed by the building. Taking advantage of the wind motion for cooling the spaces of the house using the wind catchers system was another instance of adaption with the climate in the past.

Thermal mass plays an effective role in the comfort cycle from day to night, which is only possible through its correct design and proper distribution throughout different components of the building. If the thermal mass amount is considered low in the initial estimation, the temperature of the building will fluctuate sharply during the day and no positive effect will be achieved after sunset. In fact, proper design is a balance between the window area and thermal mass, proper shadowing and natural ventilation, which allows a building to perform as a system.

The orientation of the building due south has caused the greatest amount of required heating energy during winter to enter the building via two direct and indirect solar energy absorption methods. The southern glass surface, which is employed in order to make maximum use of solar energy and natural heating in winter, is controllable in summer via natural and artificial sunshades. Northern and eastern front windows are used for ventilation, natural cooling and lighting purposes (Robertson and Athienitis, 2010).

6.14.1 Insulation of building

The thesis didn't just focus and concentrate on researches and books but it also looked into invention too. For instance, the USA patent office has been explored to identify the usage of clay/mud on the walls. The workability and thermal performance of mud/clay has been passed from generation to generation. The summary of the exploration is as below:

Author	Patent number	Date	Country	Contribution
Przybylowicz	21890534	1998	USA	Mud pan for use in dry wall construction
Zacher	2234790	1941	USA	Mud wall disintegrator
Morey, Ogletree	38163636	2006	USA	Adobe building construction system and associated methods
Hopman	22430397	1980	USA	Method and form for mechanically pouring adobe structures
Nelson	22332611	1980	USA	Poured adobe building construction and method of forming same
Janopaul	22473011	1998	USA	Energy conserving wall unit and method of forming same
Chervenak, Holstein, Paxton	27016869	1991	USA	Sprayable wall sealant
Otsuka	11798172	1989	JAPAN	A wall material, and method of preparing a wall material of soils and vegetable materials

Mechkovsky	39536520	2007	RUSSIA	General-purpose method for producing large-sized ceramic products such as houses or rooms from clay, large-sized blocks, bricks, and ceiling slabs
Di Modica	8196501	1986	ITALY	Modular mirror on clay support
Vadala	11266346	1986	ITALY	Highly sound insulating hollow clay tile for the construction of floors
Schultz	25287964	1977	USA	Adobe wall construction
Swallow	25388554	1997	USA	Non-cracking, smooth, and flat patch for wall cracks
Tommie, Shelton	43464457	2009	USA	Method for repairing aberrations along a drill bore wall

Table 14: Inventions registered in USA patent office

The above inventions have been refined out of 2824 inventions in regards to adobe/clay wall inventions. From the top selection, the inventions of Hopman (1980), Janopaul (1998), Morey (2006), Otsuka (1989),and Schultz (1977) have similar ideas in regards to saving labour, energy conservation and local materials. However, the current research not only discusses why this material will reduce energy consumption but also compares the regular wall with the proposed design through testing both physical and calculation methods.

One of the key issues for passive solar design is the use of super-insulators and preventing infiltration of the air of the building. Based on the Carbon Trust report (2012), the lower the rate of heating and cooling loads required by the building, the less solar energy is required to provide comfort for most parts of the year. In the heat flow between the external and internal air of the building, there is always a very thin layer of air on both sides of building walls, which sticks to the surface and acts as a thermal resistance against heat flow. Conductive heat transfer through building layers such as walls, ceilings, floors, doors, windows, and glass can be calculated from the following equation (Holman, 2002):

$$Q = AU (t^{l}-t^{2})$$

Q- Heat transferred from the wall (Kcal/h)

A- The wall area (m^2)

U- The overall coefficient of heat conductivity (Kca1/m^2.h°c)

t^{l}- Warmer temperature(C°)

t^{2}- Colder temperature (C°)

Walls, as one of the key elements of the building skin, are either load bearing or non-load bearing (Mehta et al., 2011). In both cases, they act as a protection against environmental factors such as heat exchange, humidity, sound transmission, and vulnerability. The most common walls in Iran are made of brick, blocks, cement, and concrete.

There are two general methods for insulating such walls (whether load bearing or non-load bearing). The first is to put the thermal layer inside the cavity of the wall, and the second is to place a mud/thatch like insulator. One of the principles of the Iranian vernacular architecture is to use materials such as concrete, brick, clay, or stone, which have high heat capacity on one side of the walls, inside or outside, and finish the surface with plaster. Thatch walls are thermally insulated, prevent heat and cold penetration and make possible savings in fuel consumption.

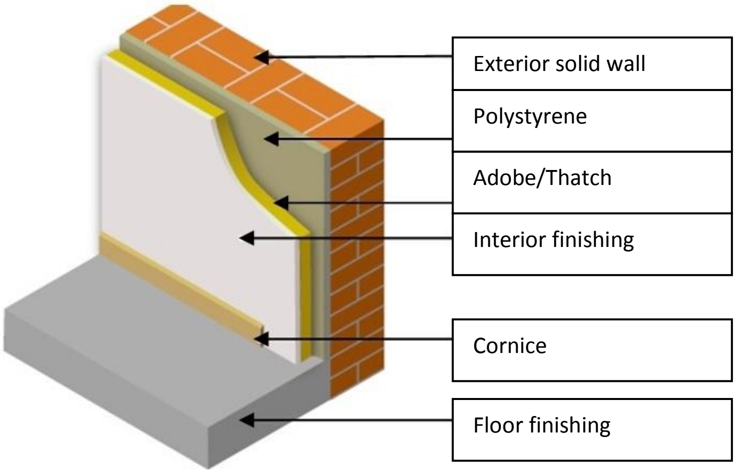


Figure 46: Wall layers as an insulation

Thatch is one of the Iranian vernacular principles in terms of material and has low thermal conductivity (0.06). According to Araghchian (2009), the thermal resistance (R) of an insulating layer is calculated from the following equation. To compare insulators with various thicknesses and thermal conductivities, the R value of insulators is calculated and any insulator with a higher R will have a higher level of performance.

$$R = L / \lambda$$

L = Insulator thickness (meter)

λ = Thermal conductivity (W/mk)

Due to the low flow of heat through mud walls, internal spaces will have a significant temperature difference with the outside temperature, which is not so with other building materials. To prevent the cold thermal bridge between the floor and the wall the polystyrene has been suggested, which also need to be airtight. Due to low heat transfer, the interior of mud buildings is much cooler than the exterior. During the night, the internal heat is not quickly transferred through the mud walls and hence, the interior temperature is much higher than that of the exterior.

6.14.2 Testing the wall

In this part of the thesis a new application of mud/adobe as an insulating material is prepared for the optimal wall as a opposed to the regular wall, which does not contain this component. The thermal performance of adobe as an insulation is tested by creating a real size wall in laboratory. Firstly, for the researcher to identify the possible solution for this test, he had decided to test both walls in an industrial fridge. The theory was to place the wall into a box made of polystyrene, which acted as a thermal insulator and was fitted in the fridge. One side of the wall acts as an interior section which is located in the box, whilst the other surface faced towards the fridge, as the researcher planned to change the temperature to find out the temperature difference. For the second step, the researcher collected the materials he needed such as: brick, plaster, multi finishes, mud, cement, mortar and insulation box.

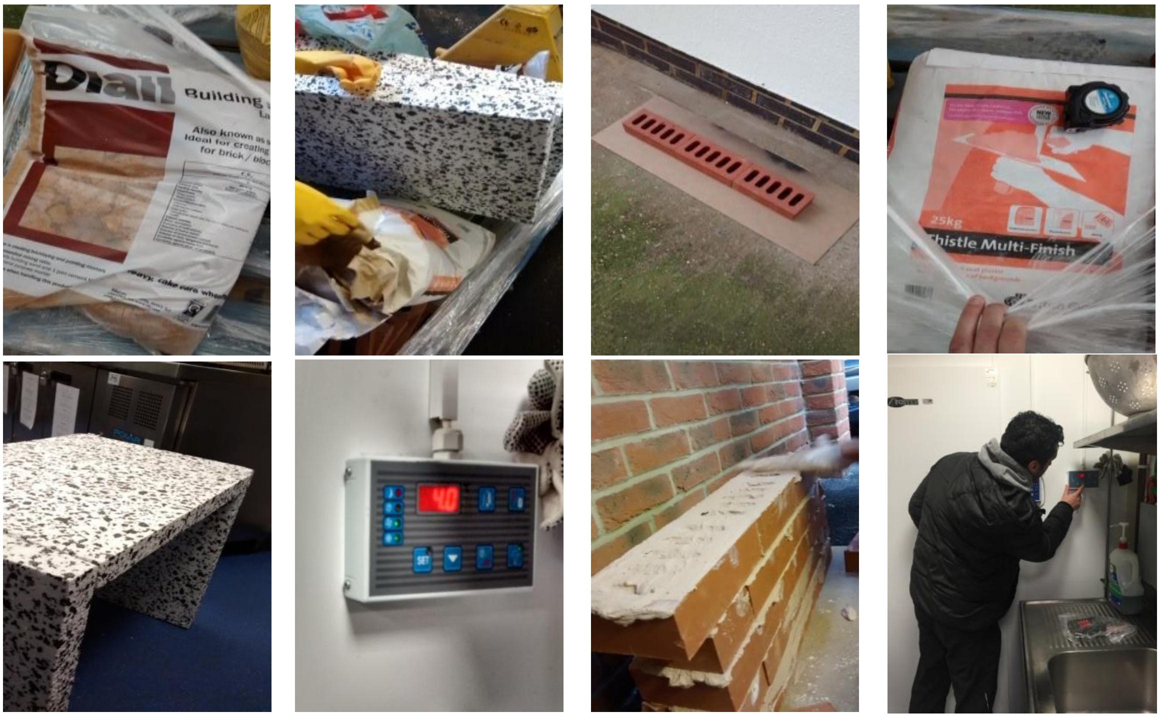


Figure 47: Frame by frame of creating the examined wall

For the third step, after establishing the walls and the insulation box, the researcher placed them into the fridge. The researcher had tested the wall in 28 different temperatures between 0-14 Celsius over the period of 18 hours in total.

The result of the test is below:

Temperature (´c)	Regular wall	Optimum wall	Difference
0	6.2	9.2	3
0.5	6.9	9.5	2.6
1	7.3	9.9	2.6
1.5	7.7	10.3	2.6
2	8.1	10.8	2.7
2.5	8.6	11.2	2.6
3	8.9	11.7	2.8

3.5	9.4	12.1	2.7
4	9.7	12.4	2.7
4.5	10.2	12.7	2.5
5	10.7	12.9	2.2
5.5	11	13.3	2.3
6	11.7	13.9	2.2
6.5	12.1	14.2	2.1
7	12.5	14.5	2
7.5	13.1	14.9	1.8
8	13.9	15.6	1.7
8.5	14.2	15.9	1.7
9	14.7	16.9	2.2
9.5	14.9	17.1	2.2
10	15.3	17.7	2.4
10.5	15.7	18.2	2.5
11	16.1	18.8	2.7
11.5	16.5	19.4	2.9
12	16.9	20.1	3.2
12.5	17.2	21.1	3.9
13	17.8	22.3	4.5
13.5	18.6	23.6	5
14	19.2	24.4	5.2

Table 15: Result of the test in different temperatures

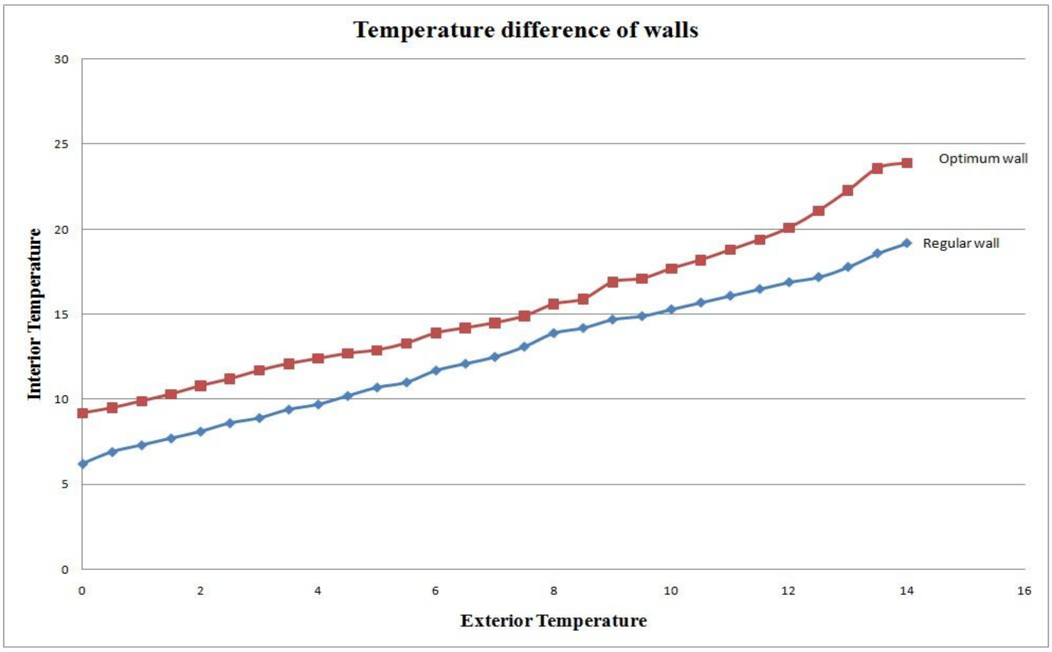


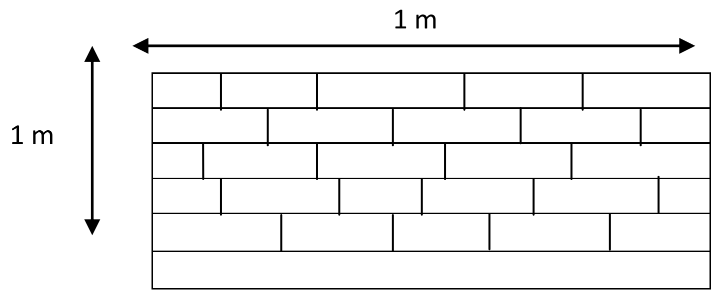
Figure 48: Comparison of optimum versus regular wall

By reviewing the above chart and table, it can be seen that the optimum (offered design) wall is well insulated compared to the regular wall and is more efficient and keeps the interior warmer. However, during the collection of data and numbers, the researcher noticed that in the middle temperature the gap was not that different but by reducing the temperature the difference between temperatures increased. The reason behind this is that mud can store the heat from the sun or heaters to release it at the time exterior surface gets cold. The mass in a time that temperature was high absorbed the heat, and it released the warmth back into the interior throughout the temperature reduction. It can be stated that, using the optimum wall could be a beneficial in terms of reduce the energy consumption.

After testing the wall, the researcher decided to calculate the wall as part the strength of the wall, which is the mechanic's side and considered the weight of the building that the wall would need to support. Therefore, to calculate the strength of the wall following formula was used. Step one was to calculate the mass (m) of the building. Hence, F=m.a where (a) is acceleration due to gravity (=10m/s^2).

$$\left.\begin{array}{l} W=m.g \text{ (g=gravity, m=mass)} \\ \text{Force (F)} = m.a \end{array}\right\} \quad W=F$$

The next step was to calculate the cross sectional area (A) of the load bearing parts, which was the exterior wall.



Materials	Thickness (m)	Special weight (g)	Weight per meter square
Brick wall	0.2	850	170
Mud	0.025	1600	40
Cement and sand	0.02	2100	42
			Total : 252 Kg

w= m.g

g= acceleration of gravity, which is 9.8~ 10

m= mass

Therefore, 252=m.10 m= 252/10 m=25.2

6.14.3 Reducing the northern, eastern, and western windows and preparing the conditions of natural ventilation (creating air current and chimney effect)

As discussed in chapter 5, Iranian vernacular principles suggests that the southern windows should differ from other windows (there should be use of windows with low-emissivity glass in the east and west). Eastern and western windows dissipate energy equal to the amount they absorb (especially in areas with hot summers). Due to the low angle of the sunlight, they receive direct radiation in the morning and afternoon. Also, as shown in Figure 49, eastern and western windows can be used for natural ventilation (typically using multi-condition windows).

Screens on windows and doors should be installed and they should be left open whenever possible to let fresh outdoor air inside. Greater amounts of oxygen will then enter the home, and carbon dioxide will circulate out (Martin, 2012). There are three primary types of whole house systems: exhaust ventilation draws indoor air outdoors, supply ventilation forces outdoor air indoors and balanced ventilation a combination of both methods. A balanced system is effective in most climates. In this system, one duct system channels air into the house, and another duct system channels air out of the home, with vents that channel air in and out of each room (Oak Ridge National Laboratory, 2002). The two general rules for internal stack outlet design are the: 1- the outlet should be located as high as possible in the interior spaces, 2- the geometry of the outlet should offer minimum resistance to upward air flow (Watson, 1983).

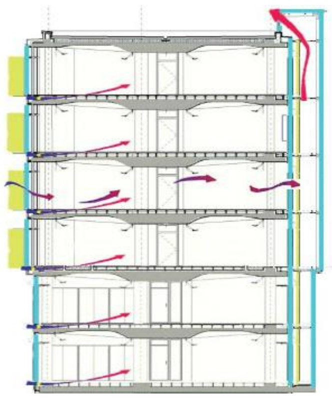


Figure 49: Natural ventilation cross section

6.15 Modelling the optimal building

With regard to the former discussions in respect to the vernacular architecture and by applying principles of passive solar and wind architecture, the optimal building was modelled by performing some changes to the basic construction. Changes to the basic building are as follows:

1. Increasing the thickness of the external walls to 40cm and using materials of high thermal resistance and 5cm insulation of mud and polystyrene (heat transfer coefficient of 0.69 w/m^{2}c)
2. Rotation of the buildings towards dominant wind to have proper ventilation.
3. The use of thermal mass (paving) in controlled spaces adjacent to external windows
4. Using vertical and horizontal canopies commensurate to the construction location and the size of windows (canopies were adjustable and used mostly during summer time)
5. Use of wind catcher (natural ventilation) contributing to cooling in summer, and also aim to achieve reasonable temperatures and also to moderate the relative humidity in hot-dry climates.
6. Replacing single-glazed windows with double-glazed

Memarian (2012) mentioned that wind catchers with a wider cross section can allow more air with a suitable speed to flow through the building. To achieve this goal, it is necessary to consider the wind tower geometry facing towards the dominant wind. Furthermore, Calautit and Hughes (2012), investigated and studied the performance of the wind tower incorporated into a row of houses to replace the traditional ventilation devices through computational fluid dynamics. However, the current research examined that a wind catcher with more height (distance of air entrance to the discharge point) has more pressure difference and therefore efficiency will improve. On the other hand, the Bernoulli Effect describes how the airflow speed will increase if the air flows through a smaller cross section. Therefore, increasing the height of the total area of the wind tower will increase the wind flow speed. The canal therefore provides cool air in the building and acts as a conduit through which the stuffiness within the space is conveyed through the shaft.

Recent days in growing cities we often see fewer single storey buildings as most have been changed to multi-level buildings. Therefore, designing a single wind tower having the same traditional version openings on top to ventilate all levels is not reasonable. Introducing new openings on the wind catcher for each level to allow air to flow separately in each single space combined can be a new contribution to this field. In the larger scale buildings, the number of wind catchers built can depend on the number of spaces that are prominent. For such a design to ventilate and achieve thermal comfort, one wind catcher can provide cool air within the spaces and design while another wind catcher with different openings can act to discharge the internal heat from the building.

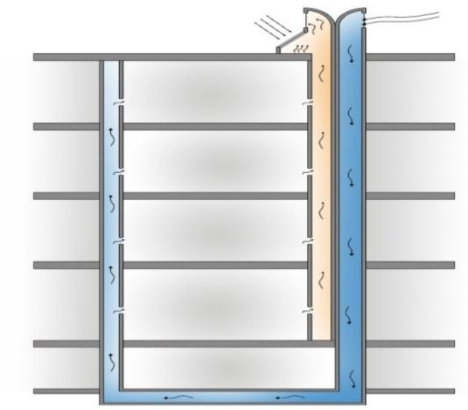


Figure 50: Modelling conducted for the ventilator

Changes in the layout, area, and shape of the windows are given according to the orientation to receive more light and ventilation to eliminate the appliances power. For instance, southern windows length and height increased by 40 cm. In the following table and plan figures.

	Window's Name	Direction	Number	Length	Height
1	W1	S	8	1.6	1.7
2	W2	W	8	1.9	1.2
3	W3	N	4	1.8	1.2
4	W4	N	4	1.3	1.2
5	W5	N	3	0.6	0.6
6	W6	N	4	1.5	1.2
7	W7	S	4	1.2	1.2

Table 16: Changing the windows dimensions

Given the above, the optimal building was modelled in Design Builder, and some figures are shown below:

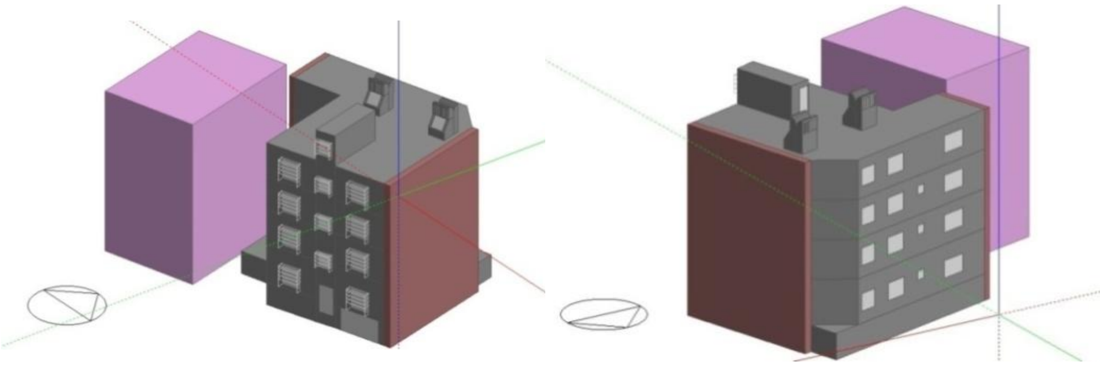


Figure 51: Three dimensional model of optimised building

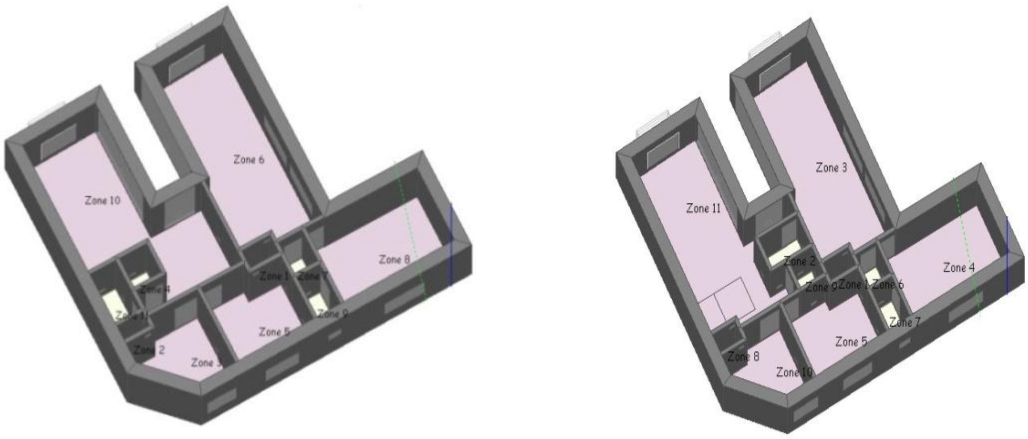


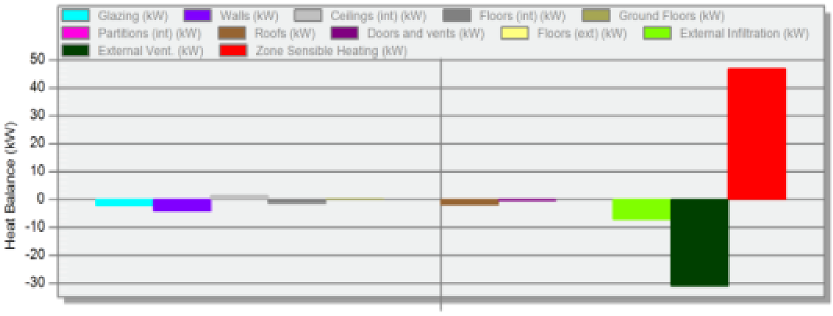
Figure 52: Interior design of optimum building

6.16 The results of load and energy consumption in the optimal building

After modelling and inputting the same building specifications and assumptions for both buildings, the construction was simulated. A part of the results is given below:

Building	Block	Zone	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Floor Area (m2)	Volume (m3)
Building 2	1st floor	Zone 8	0.11	1.07	16	49.6
Building 2	1st floor	Zone 6	0.18	1.73	29.4	91.1
Building 2	1st floor	Zone 10	0.16	1.55	32.6	101
Building 2	1st floor	Zone 3	0.07	0.64	9.2	28.5
Building 2	1st floor	Zone 5	0.07	0.7	10.8	33.3
Building 2	1st floor	Zone 9	0.02	0.22	2.2	6.7
Building 2	1st floor	Zone 7	0.02	0.16	1.8	5.6
Building 2	1st floor	Zone 1	0.01	0.06	1.3	4
Building 2	1st floor	Zone 2	0	0.03	0.9	2.9
Building 2	1st floor	Zone 11	0.02	0.18	2.8	8.6
Building 2	1st floor	Zone 4	0.02	0.15	1.9	6
Building 2	2nd floor	Zone 11	0.13	1.29	32.4	87.6
Building 2	2nd floor	Zone 3	0.17	1.67	29.4	79.3
Building 2	2nd floor	Zone 10	0.06	0.54	8.4	22.6
Building 2	2nd floor	Zone 5	0.07	0.65	11.6	31.2
Building 2	2nd floor	Zone 7	0.02	0.19	2.2	5.8
Building 2	2nd floor	Zone 4	0.1	0.98	16	43.2
Building 2	2nd floor	Zone 1	0	0.04	0	3.5
Building 2	2nd floor	Zone 6	0.02	0.13	1.8	4.9
Building 2	2nd floor	Zone 9	0.01	0.12	1.7	4.6
Building 2	2nd floor	Zone 2	0.02	0.17	2.9	7.9
Building 2	2nd floor	Zone 8	0	0.03	0.2	3
Building 2	4th floor	Zone 7	0.57	5.55	78	210.5
Building 2	4th floor	Zone 1	0.09	0.91	12.3	33.3
Building 2	4th floor	Zone 6	0.09	0.89	11.6	31.2
Building 2	4th floor	Zone 4	0.01	0.09	1.3	3.5
Building 2	4th floor	Zone 3	0.02	0.17	1.7	4.6
Building 2	4th floor	Zone 2	0.03	0.26	2.9	7.9
Building 2	4th floor	Zone 5	0.01	0.07	1	2.6
Building 2	Parking	Zone 1	0.01	0.12	135.6	244.2
Building 2	3rd floor	Zone 11	0.15	1.48	32.4	87.6
Building 2	3rd floor	Zone 3	0.19	1.79	29.4	79.3
Building 2	3rd floor	Zone 10	0.06	0.58	8.4	22.6
Building 2	3rd floor	Zone 5	0.07	0.69	11.6	31.2
Building 2	3rd floor	Zone 7	0.02	0.21	2.2	5.8
Building 2	3rd floor	Zone 4	0.11	1.05	16	43.2
Building 2	3rd floor	Zone 1	0	0.04	0	3.5
Building 2	3rd floor	Zone 6	0.02	0.15	1.8	4.9
Building 2	3rd floor	Zone 9	0.01	0.12	1.7	4.6
Building 2	3rd floor	Zone 2	0.02	0.18	2.9	7.9
Building 2	3rd floor	Zone 8	0	0.03	0.2	3
Building 2	Stairbox	Zone 1	0.13	1.32	9.4	113.2
	Total		**3.01**	**29.35**	**579.5**	**1581.9**

Table 17: Cooling load in different location of the optimise building on 15th July



Air Temperature (°C)	16.79
Radiant Temperature (°C)	15.49
Operative Temperature (°C)	16.14
Outside Dry-Bulb Temperature (°C)	-3.10
Glazing (kW)	-2.28
Walls (kW)	-4.13
Ceilings (int) (kW)	1.35
Floors (int) (kW)	-1.35
Ground Floors (kW)	0.09
Partitions (int) (kW)	0.00
Roofs (kW)	-1.87
Doors and vents (kW)	-0.44
Floors (ext) (kW)	-0.00
External Infiltration (kW)	-7.22
External Vent. (kW)	-30.93
Zone Sensible Heating (kW)	46.68

Figure 53: Temperature and heat losses in winter

The above figure illustrated that, after insulating the wall, the research reduced the heat loss by almost 10 kW per hour. The adobe and thatch which have been used in the walls of the building have reduced the heat loss. Therefore, it can be noted that the principles which have been selected not only saved energy throughout by reducing the heat loss, but also that the material is easy to find and produce and is economical. Due to the good insulation with both new and vernacular materials of the optimised building and other methods such as adding large windows and thatch (thermal conductivity), the proposed improvements of thermal insulation and design contributed to the reduction of heating load. For instance in January, which is the coldest time in Tehran, the difference between the base building and the optimised one was about 1700 kWh, which identifies how much energy can be saved.

As in most hot climate regions, cooling is an important factor, and the use and extensive amount of energy to cool the building creates a reasonable and comfortable temperature. The research, by creating the optimised building, tried to eliminate the need for air conditioning by introducing a passive solar chimney to extract hot air from rooms and vernacular thermal mass principles. The calculated data and the tests that the research carried out on the three dimensional models of the virtual building indicate that it is possible to merge Iranian vernacular principles with modern techniques. One of the key factors which reduced the cooling load was adding the wind catcher. As shown on figure 50, the inlet was orientated towards dominant wind to have higher wind pressure in order to cool all the floor, and the living room space by extracting hot air towards the outlet.

Building	Block	Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)
Building 2	1st floor	Zone 8	17.34	1.78	2.13
Building 2	1st floor	Zone 6	17.38	3.15	3.77
Building 2	1st floor	Zone 10	17.84	3.22	3.87
Building 2	1st floor	Zone 3	17.63	1	1.21
Building 2	1st floor	Zone 5	17.68	1.14	1.37
Building 2	1st floor	Zone 9	17.12	0.23	0.28
Building 2	1st floor	Zone 7	17.37	0.17	0.21
Building 2	1st floor	Zone 1	17.44	0.12	0.15
Building 2	1st floor	Zone 2	17.52	0.09	0.1
Building 2	1st floor	Zone 11	17.47	0.25	0.3
Building 2	1st floor	Zone 4	17.5	0.17	0.21
Building 2	2nd floor	Zone 11	18.36	2.54	3.05
Building 2	2nd floor	Zone 3	17.85	2.55	3.06
Building 2	2nd floor	Zone 10	18.09	0.73	0.88
Building 2	2nd floor	Zone 5	18.15	0.97	1.16
Building 2	2nd floor	Zone 7	17.46	0.18	0.21
Building 2	2nd floor	Zone 4	17.81	1.43	1.71
Building 2	2nd floor	Zone 1	17.8	0.09	0.11
Building 2	2nd floor	Zone 6	17.74	0.13	0.16
Building 2	2nd floor	Zone 9	17.87	0.12	0.14
Building 2	2nd floor	Zone 2	17.88	0.2	0.24
Building 2	2nd floor	Zone 8	17.88	0.08	0.09
Building 2	4th floor	Zone 7	17.7	7.17	8.61
Building 2	4th floor	Zone 1	17.52	1.21	1.46
Building 2	4th floor	Zone 6	17.77	1.08	1.3
Building 2	4th floor	Zone 4	17.6	0.1	0.12
Building 2	4th floor	Zone 3	17.5	0.14	0.17
Building 2	4th floor	Zone 2	17.46	0.24	0.28
Building 2	4th floor	Zone 5	17.61	0.08	0.09
Building 2	Parking	Zone 1	10.79	2.92	3.5
Building 2	3rd floor	Zone 11	18.35	2.56	3.07
Building 2	3rd floor	Zone 3	17.89	2.54	3.05
Building 2	3rd floor	Zone 10	18.1	0.73	0.88
Building 2	3rd floor	Zone 5	18.16	0.97	1.17
Building 2	3rd floor	Zone 7	17.48	0.18	0.21
Building 2	3rd floor	Zone 4	17.86	1.42	1.7
Building 2	3rd floor	Zone 1	17.82	0.09	0.11
Building 2	3rd floor	Zone 6	17.75	0.13	0.16
Building 2	3rd floor	Zone 9	17.86	0.12	0.14
Building 2	3rd floor	Zone 2	17.87	0.2	0.24
Building 2	3rd floor	Zone 8	17.89	0.08	0.09
Building 2	Stairbox	Zone 1	16.85	3.71	4.45
		Total		**46.67**	**56.01**

Table 18: Heating load in different locations of the optimised building

The optimised building was designed with the goal of incorporating vernacular and modern principles allowing the use of renewable energies such as natural ventilation, having more daylight and using materials that has low thermal conductivity for reducing the cooling and heating load.

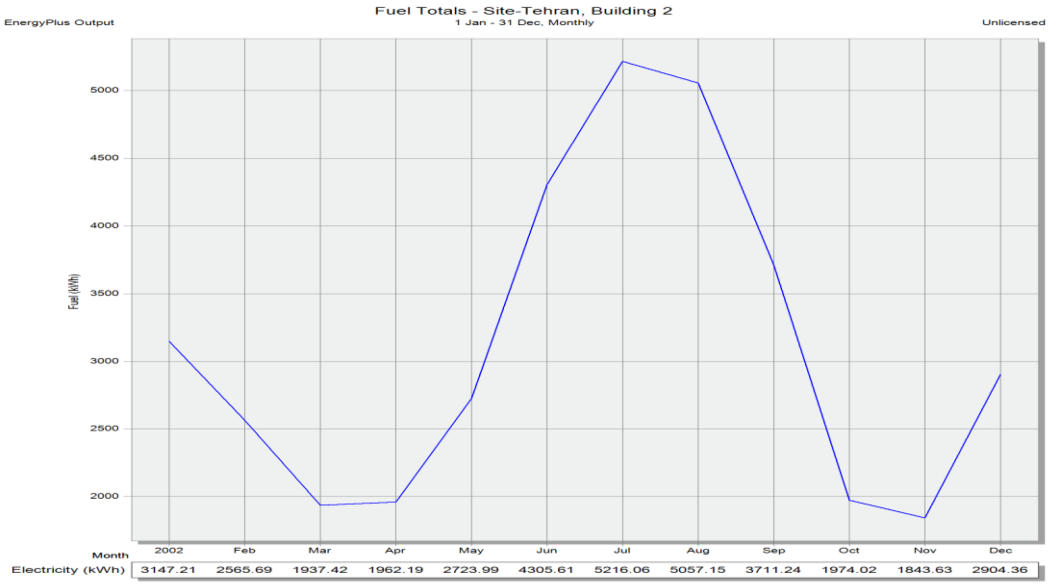


Figure 54: Monthly simulation electricity consumption of optimised building

The figure 54 and table 20 demonstrated the annual cooling and heating loads of the optimised building. For instance, it is indicating that electricity consumption in the optimised building in July is 5216 kWh, which consumes 2575 kWh less than base building that has been calculated earlier on. According to the equation from UK Department of Energy and Climate Change (2011):

$$\text{Energy Source (kWh)} \times \text{Conversion Factor (Kg CO}^2\text{/ kWh)}$$

$$=$$

$$\text{Carbon Produce (Kg CO}^2\text{)}$$

Therefore, the energy source currently under investigation is 2575 kWh and the conversion factor according to the Iran ministry of energy is 0.631 kg CO^2/kWh which will be located in the equation, hence, the research result will be as below:

$$\mathbf{2400\ kWh \times 0.631\ kg\ CO^2/kWh = 1514\ Kg\ CO^2}$$

It can be noted in one particular month the optimised building is not only able to reduce the energy consumption but it also has less carbon footprint. In addition, the production of a smaller amount of carbon has a less impact on environment.

For instance, base building produce 1514 Kg CO² more compare to optimised building in July.

6.17 Comparing monthly energy consumption in two buildings

The evaluation of each data pair started with a comparison graph. The goal of the comparison is to provide feedback on the building design and operation. This feedback is based on performance problems and the subsequent estimation of their impact on thermal comfort and energy consumption. Some of the results obtained by comparing the energy consumption of the two buildings are summarised below. Obviously, all computations can be seen in single calculations of the buildings in previous sections.

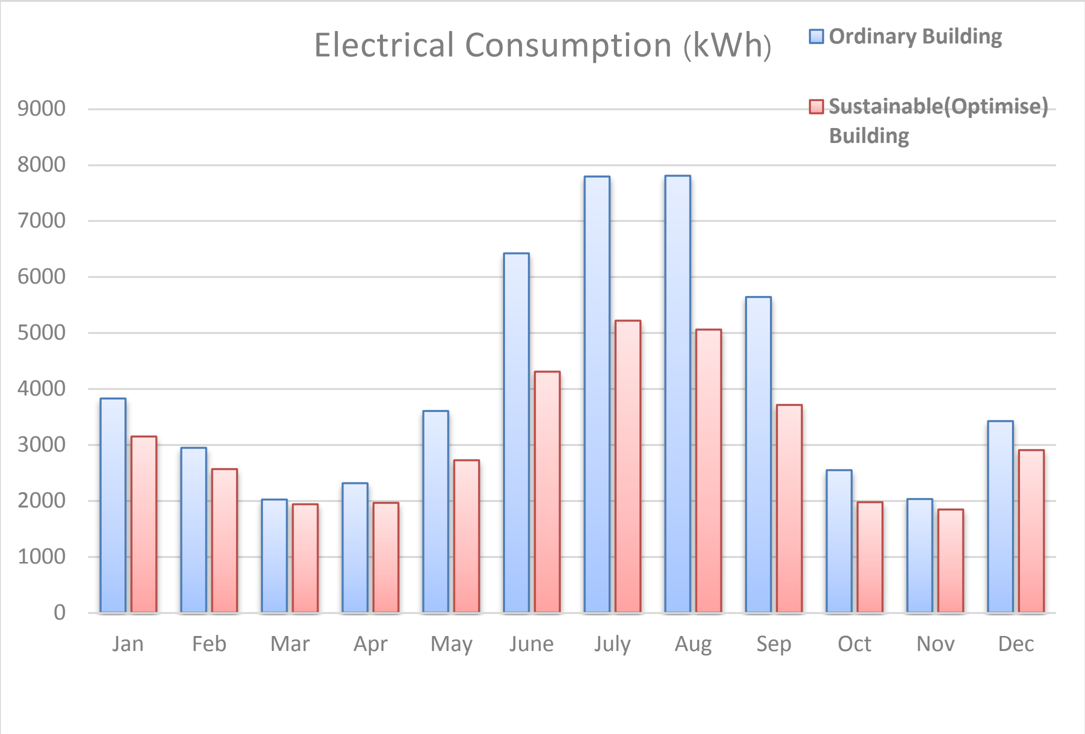
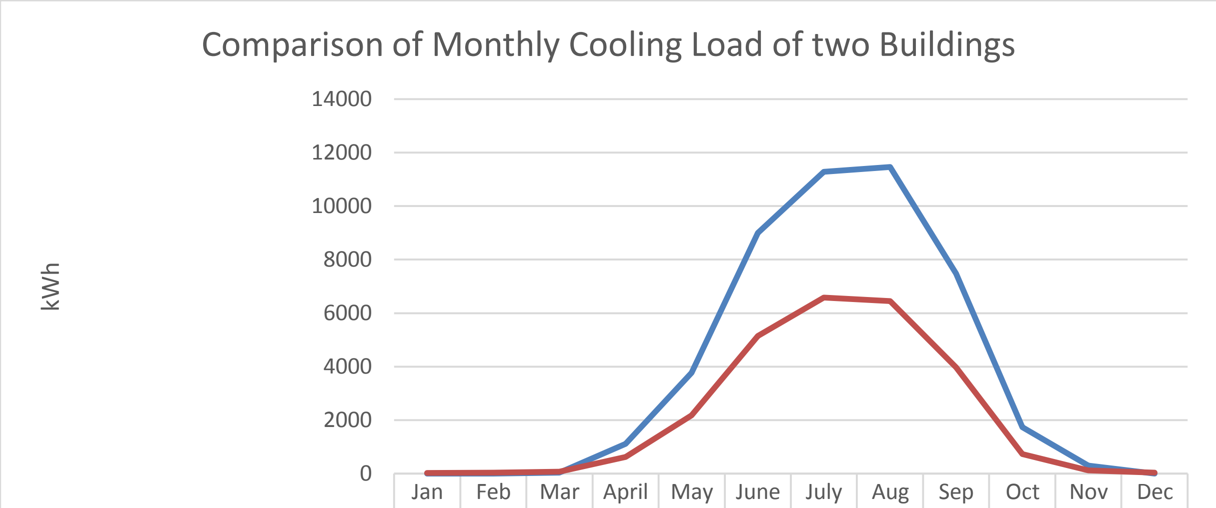


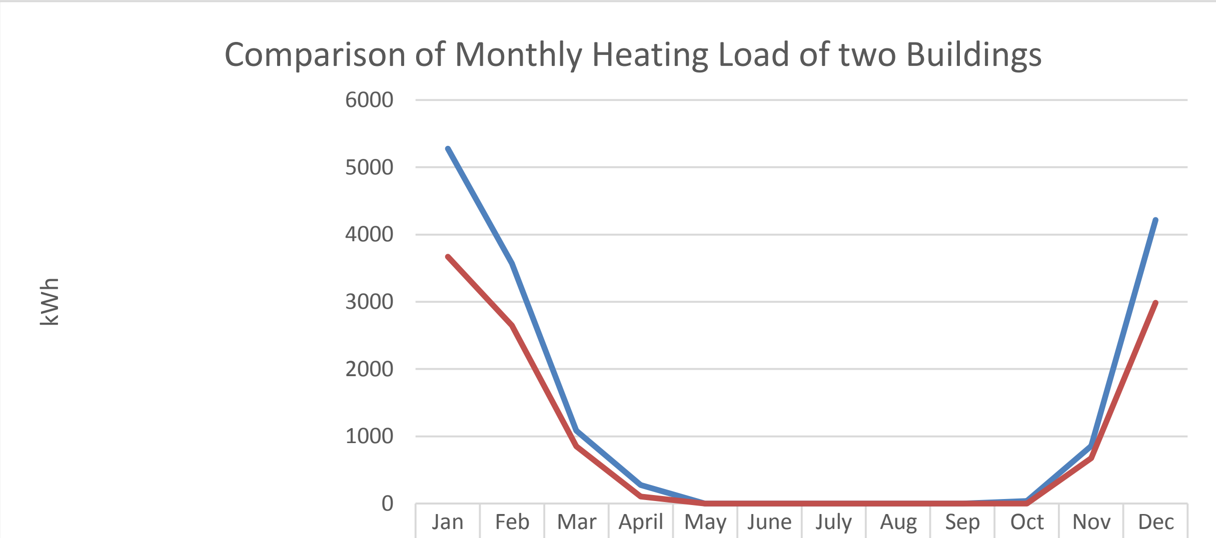
Figure 55: Comparison of electrical consumption in both base/optimised buildings

Figure 55 illustrates that the ordinary building consumes more than 7500 kW of electricity per hour in July, but the maximum electricity consumption of the optimised building is 5100 kW per hour.



	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Cooling Load of the ordinary building	0	0	33	1113	3772	8995	11280	11462	7484	1738	296	0
Cooling Load of Sustainable (optimise) Building	23	39	75	620	2177	5142	6584	6447	3970	733	113	30

Figure 56: Comparison of monthly cooling load in both base and optimise buildings



	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Heating Load of the Ordinary Building	5278	3571	1083	276	0	0	0	0	0	39	858	4218
Heating Load of Sustainable(Optimise) Building	3672	2647	851	103	0	0	0	0	0	2	673	2984

Figure 57: Comparison of monthly heating load in both base/optimise buildings

Figure 56 shows the optimised building's cooling load in the first three months and the last month of the year consumes slightly more electricity to make a comfort zone for the occupants, but within other months it can be seen that there is a huge gap of electricity consumption. For example, in August, the ordinary building consumes around 11462 kW per hour, twice more than the optimised building. Therefore, this can lead the optimised building to be more sustainable. According to the aforementioned equation from the UK Department of Energy and Climate Change, for the cooling load the base building produces 2963 Kg CO^2 more than the optimised building.

$$\mathbf{4696\ kWh \times 0.631\ kg\ CO^2/kWh = 2963\ Kg\ CO^2}$$

The simulation results of the energy consumption calculated by Design builder and compared by Excel for both the base and optimise building are presented and shown in the above figures. It can be seen that the heating load shows in all months that the optimised building was much more energy efficient by consuming less electricity. In terms of carbon emission, Design Builder software has identified the base building has270 Kg creation of CO^2 per day. In contrast to the base building the maximum carbon emission of the optimised building is 190 Kg per day. Therefore, the optimised building has given a positive result in all terms. The spatial arrangement of the base building was to reflect some of the vernacular principles, and use some new and existing techniques to regain the spirit of living comfortably with forces and sources of nature. The optimised building provides a vision for a sustainable future in a period that will face two of the greatest challenges to be faced yet by man, climate change and the end of the fossil fuel age.

6.18 Summary

This chapter has offered an evaluative and calculative perspective on virtual buildings located in Tehran with similar weather conditions. The chapter tried to identify the missing link between the buildings and renewable energies. At the beginning of the chapter two virtual buildings (regular modern and regular vernacular) have been set out and evaluated. It has been identified that the modern building consumes more energy in contrast to the vernacular building and produces tonnes more carbon dioxide according to the UK department of energy equation. The presented graphs and calculated tables showed the vast gap between these two buildings.

As has been mentioned earlier on, the research did not rely on one particular software package. Therefore, the research has created two virtual buildings with similar locations and specifications. However, one of those buildings followed some of the Iranian principles (the optimised building). The calculated and evaluated data identified the huge gap between these two buildings. The regular building (base) produced big amount of carbon dioxide. However, by adding a few principles into the same building (optimised) the research was successful not only in reducing the carbon emission but also in saving much more energy by relying on renewable resources.

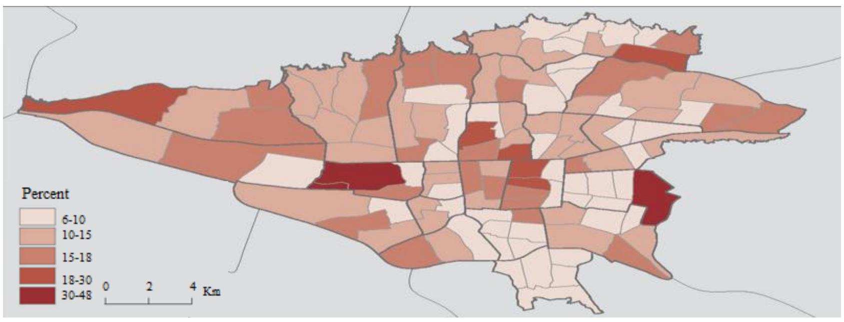
CHAPTER SEVEN: BARRIERS OF USING IRANIAN VERNACULAR ARCHITECTURE

7.1 Scope of the chapter

The purpose of this chapter is to describe and discuss the barriers to the application of Iranian vernacular architecture principles in residential buildings in Tehran. Hence, the background of Tehran city, such as growth in population, urbanisation patterns and energy consumption of residential building will be explained here. The scope of this chapter is to give a critical review of architecture and construction industry in Tehran, review of the educational system for architectural profession. The research questions that were developed were addressed through the use of the questionnaire. The chosen questionnaire was a self-completion questionnaire to collect both quantitative and qualitative information. This study also aimed to compare the results with the previous relevant studies. The questionnaire was adopted since it ensures consistency in data collection and the opportunity to look for statistically significant trends and differences. Furthermore, the objective of developing and using the questionnaire was the need to maximise the proportion of response rate, and to obtain relevant and accurate information from the survey. Therefore, the subsequent sections present the relevant aspects that were considered in the questionnaire.

7.2 Background of Tehran city

According to Tehran Municipality research (2011), a study of population changes in Tehran shows that for over 65 years, the city has an average annual population growth of 7 per cent. Over the past three centuries the main growth population has been in the last fifty years, and city has accounted population growth 6 times higher than 60 years ago. In forty-five years, the area of Tehran expanded 12 times and its population 8.6 times (Shayesteh and Steadman, 2013). The massive migration makes Tehran city hold one-eighth of country's total population(World bank, 2016). Migration is a decision that impacts the welfare of the household and the whole economy in various ways (Azam and Gubert, 2006). The interference of the human activities with the natural environment ends up with universal changes, thus, these changes create new dimensions on the ecological equilibrium of the world (Yilmaz, 2006). Housing is a critical issue in global urbanisation, which has a tremendous impact on the environment (Abu Bakar et al., 2010). During the period 1992-2007, construction permits for residential building represented around 88 per cent of total construction permits (Fereidouni, 2011). Beside this natural demographic development, massive rural-urban migration has led to an explosive urbanisation process (Fahimi and Mederios, 2007). The important factors for migration of people to Tehran in the last few decades were having more job opportunities, better facilities and availability of manufacturing factories and institutes within and surrounding Tehran. Due to the concentration of a wide range of socio-economic opportunities, construction practitioners from all professional areas and from other regions of the country migrate to Tehran in search of work. These are confined by the Ministry of Roads and Urban Development, as around half of construction practitioners in Iran live in Tehran (Hosseini et al., 2016). Tehran's rapid population growth has led to major changes in social environment, traffic and has increased the tension in some specific modes of urban and social life (Abdoli et al., 2014). Traffic in Tehran city is one of the main issues of pollution, as recently the government decided that people should drive on odd or even days of the week according to the last number of their license plate, in order to reduce the traffic, pollution and save time. Due to population growth and increased migration from towns and villages to big cities like Tehran, in order to achieve a higher level in terms quality and quantity of life, uncontrolled growth will be marginalised in big cities. This growth, along with bringing serious damages, and destruction to the environment and environmental pollution, can lead to consumption of substantial amount of energy (Shomali,2015). The biggest problem in large cities such as Tehran is air pollution and the lack of green spaces, which with increasing population and increasing demand for housing, makes it necessary to construct high rise buildings to fulfil and accommodate the residents.



Source: Tehran statistic centre (2009)

Figure 58: Immigrant population in Tehran city

Air pollution has a direct relationship to the population growth. Moreover, the concentration of populations in specific areas adds to the severity of pollution. Building sectors contribute up to 30 per cent of global annual greenhouse gas emission and consumes up to 40 per cent of all energy. In regards to Iran, the building sector contributes 30 per cent of energy consumption in 2009 (Seelig, 2011) and this number has been increased to nearly forty percent in 2014 (Falahatian, 2014). According to Tehran Statistics Centre (2009) the average consumption per subscriber in building residential sector was equivalent to 2613 kWh, which is 37/1 per cent of total Tehran energy consumption. Mansouri (2014) described, Tehran's density as one-third of European cities, however, when the government demolishes one storey buildings and make ten storey buildings, the density of Tehran city becomes 200 times more than European cities. This causes more air pollution.

Nowadays, the air pollution in Tehran has been one of the main discussions of the Government. Many conferences have been organised to discuss this problem.

The lack of an overall plan for building facades, as well as the absence of coordinated developments in the demolition of single or multiple family terraced houses, has left many residential streets in Tehran with very chaotic skylines (Shayesteh and Steadman, 2013). According to Motesadi (2016), one of the main sectors, which has a direct relationship with the pollution in Tehran, is the construction of high-rise buildings to accommodate the population, which was caused through massive migration. However, Navaei (2015) argues that vertical expansion (high-rise buildings) can save cultivable land to supply needed food for an increasing population. This in turn is reducing environmental destruction due to reduced construction on natural land, as well as reducing transportation and urban traffic. Furthermore, it is also causing a reduce in energy consumption and air pollution caused by horizontal expansion of cities.

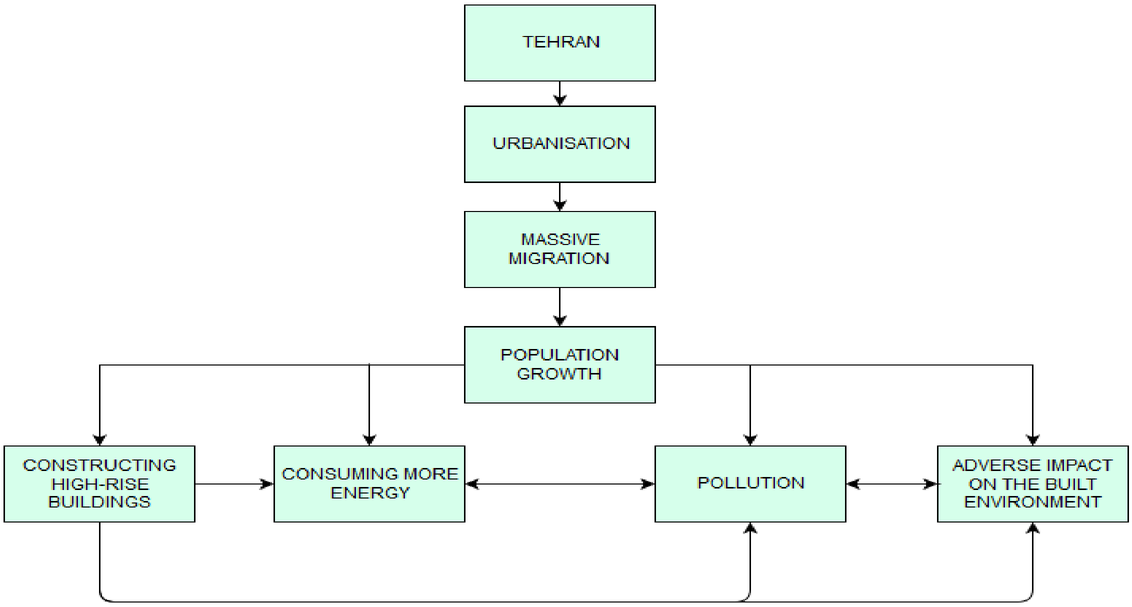


Figure 59: Side effects of massive migration

Tehran has a semi-arid continental climate, with the towering Alborz mountain to its north and the central desert to the south. The great geographical location makes Tehran have pleasant winds throughout most of the year. However, Hosseini the manager of Tehran air quality control company (2016), mentioned that the high rise buildings are not letting the wind cross city and clean the air. Another main issue in Tehran's buildings is that not only builders follow passive rules and regulations, but there is also a lack of accurate supervision of the construction process. For instance, based on the building rules and regulation comprehensive plan, the construction of a building which contains more than twelve floors is prohibited, however, it is common throughout the city to see most high rise buildings with at least twenty floors. These buildings following the modern architecture, which are steel and glass boxes, short on fresh air and natural lights and their internal ecosystem separated from their surrounding (Gissen, 2003).

7.3 Sustainability in architectural education

Over the second half of the twentieth century, energy problems have been the main point of sustainable development worldwide. Buildings play one of the most important roles in the current climate crisis. Environmental degradation can occur during and after construction process. The generation of solid waste during construction leads to the production of carbon dioxide by the occupants (Usman and Gidado, 2015). Construction waste can account for up to 15% of the embodied carbon of the building (WRAP,2012). Hence, due to the accumulation of users in a limited area, who are enjoying a lot of energy in buildings, the need for sustainability in the design process and utilisation should be considered (Kolvir and Domola, 2015). There is an urgent need to promote and enhance sustainable practices in the built environment (Langston and Ding, 2001), as such buildings would have minimum adverse impact on the built and natural environments, in terms of the buildings themselves and their immediate surroundings (Hasegawa, 2003). A sustainable house is cost-efficient over time, comfortable, cheap to maintain and complements our unique environment (Abu Bakar et al., 2010; AIA, 2006). In addition, sustainable buildings are known as high performance buildings (BEAM, 2004). The performance relates to five attributes: appearance; quality; function; durability and maintenance (Ashworth, 2004). The ongoing development in the building industry also had its influence upon architectural education (Ceylan, 2014). There is a division between academic fields and professional practices in architecture around the world (Moradi and Akhtarkavan, 2008). Therefore, several new approaches have emerged in regards to the renewable energy education system, which seek to address the needs for sustainable energy supply systems all around the world. Lack of education is often cited as a major barrier for implementing green design (Carlisle et al., 2004; Shafii, 2005), as education and experience informs a designers understanding and values towards sustainable design (Hankinson and Breytenbach, 2012). One of the major barriers is the lack of green design knowledge that internal and external decision-makers exhibit throughout the construction process (Grund, 2005). The professional market claims sustainable design as a key element of their approach to architecture (Altomonte, 2009)**.** Over the past ten years it has been noted that sustainability has been embraced as a core precept in both the architectural profession and in schools (Stewart ,2008).

Architectural education prepares future professionals for the field of architectural practice in the industry as well as the attitudes of future professionals towards nature and humans (Benkari, 2013). Graduate students from architectural courses mostly employ solutions rather than methodology to apply for their designs, and this derives from their educational process as they learn through a series of different designs that are solution focused rather than problem focused (Rutherford and Wilson, 2006). Adegbile (2012), identified factors such as natural resource depletion, climate change and ecological damage supports the implementation of consideration of sustainability in architectural education. The role of education in creating a more environmentally sustainable life is irrefutable (Shari et al., 2006). However, information about sustainability and the method of sustainable design is generally not given and explained in detail to the students in architectural courses in Iran's universities curricula. In Taleghani et al, research (2011), the sustainability in the architectural education system between Iran and Australia has been compared. Their research identified academic obstacles such as; ambiguous definitions of sustainable architecture, confusion over the meaning of sustainability, and lack of experts in this field that are impeding the development of sustainable architecture education. Following that, as explained in earlier chapters, rich socio-cultural interactions, hospitality, privacy and its levels, ecological and architectural considerations, social and cultural systems that are highly considered in Iranian traditional culture, are not widely discussed (Osivand et al., 2013; Shahamat, 2014; Shohouhian and Soflaee, 2005). After reviewing the curricula of a few universities in Tehran, it was noted that the curriculum in universities did not only lack in having specific topics related to sustainability but they also had very little discussion about historical buildings. The vernacular architecture is an example of past building design approaches that must be studied (Fernandes and Mateus, 2012). Danaci (2013) developed a questionnaire for architectural students in different countries to identify their willingness to learn about vernacular architecture. The result showed that 48% stated that vernacular architecture education is few while 34% of them said that it is insufficient. The interesting fact about the survey is that 73% of the students gave the answer that the course of the vernacular architecture should be compulsory on university curriculums. This indicates the willingness and interest of the students to study vernacular architecture.

Vernacular architecture is one of the most significant and remarkable aspects of human intervention in the landscape, which is a model of wisdom in the use of natural resources and adaptation of buildings to the surrounding natural environment (Oliveira and Galhano, 1992). Therefore, in line with Haghir and Shohanizad (2012), the current research argues that studying vernacular architecture is necessary in order to reduce the impact of buildings on the natural environment, which requires the universities architecture curriculum in Iran to be rearranged, and the Iranian Ministry of Education should make it compulsory for universities to add more credits on both sustainable and vernacular principles modules.

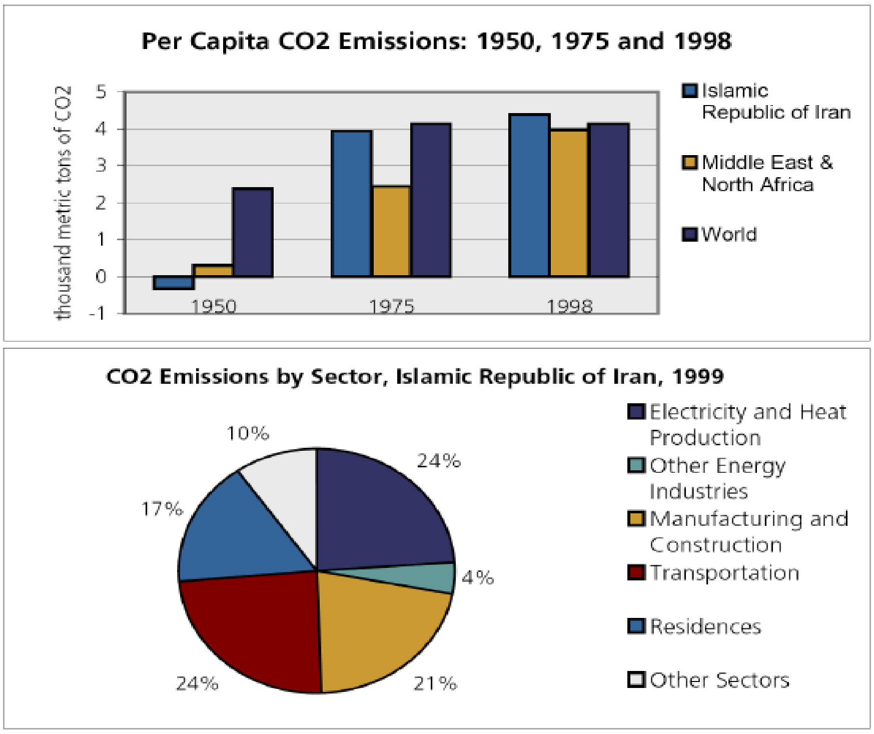
This trend will allow students to learn more about the benefit of sustainability and vernacular principles, to have a passive design for reduction of energy consumption on their future construction.

7.4 The quality of building design and construction in Tehran

According to the United Nations Development Programme (2014) until 2030, 5 billion people will live in urban areas throughout the world which means a projected rise to 60 per cent. Whereas in 1950, 30 per cent of the world population lived in urban areas, and in 2000 the proportion of the urban dwellers climbed to 47 percent. Residential building sectors have been documented to be responsible for approximately 7.9 per cent of carbon dioxide emissions globally in 2004 (IPCC, 2007). For instance, the pollution resulted by warming and cooling of the internal environment of the buildings is more than the pollution resulted by the vehicle exhaust in the United States of America (Hikmat and Alfalah, 2010). Therefore, green and sustainable design has been a societal and governmental demand in the US for nearly four decades (Molenaar and Sobin, 2009). In addition, The Building Research Establishment's Environmental Assessment Method (BREEAM) has been established to ensure that a number of environmental and resources efficiency standards are used in constructing new homes in the UK. However, Aye (2003), identified a number of barriers to incorporate sustainable design into practice, such as perceived cost, time to source materials, client needs, education and training.

Buildings have a substantial energy impact on the environment, the negative environmental effects caused by buildings through energy consumption, carbon emission, raw material use and waste are well known (Pedini and Ashuri, 2010; CSDT, 2001), and having a better design can minimise these impacts (Elforghani and Rahmat, 2010). The design has a significant impact on sustainability, and architects are responsible for fundamental designs in the earliest days of a project (Sefaira, 2013),as architects have the skills to understand the process and outcome of the design (McCamant et al., 1994). Thus, designers are becoming more aware of their role in the current problems of which society faces (Kuijer and De jong, 2011). The design of architects can affect people's health through building design. Sick building syndrome is the result of architects lack of knowledge about heating, ventilation and air conditioning system (Brkovic and Milosevic, 2012). Furthermore, Volker's research (2011) identified that sufficient knowledge of the current sustainability within project teams, which involves in design, built operated, improve employee productivity, maintained to protect occupant health, use wisely natural resources and reduce environmental impact has direct impact to successful green building design. Yadollahi (2014), also identified the team such as civil, mechanical, electrical engineers and architects have important role in this process, as during the building design process hundreds of decisions are made (choosing alternative materials, components assemblies, systems, building shape) at different stages (Arroyo, 2014).

The construction sector such as residential , commercial and administrative buildings are one of the main sector in Iran's economy (Sohaili and Almasi, 2012). The construction industry in Iran, with an annual turnover of USD 38 billion, is one of the most profitable sectors in the country (Asnaashari, 2011). According to a report from World Bank (2004), Tehran has the highest share in the world of private sector investment in urban housing (Shayesteh and Steadman, 2013). In the thirty-year period 1971-2000, on average 33 per cent of the total investment was in housing (Sepehrdoust and Berjisian, 2011). Statistics provided by Global Market Information Databases (GMID, 2011) indicates that construction and the real estate sector contributed about 17 per cent of Iranian GDP over the period of 1995-2009. However, Zakeri et al. (1996) stated that the construction industry in Iran suffers from poor productivity and increasing construction costs. Energy consumption in the Iranian building sector is more than double the global average (Mohammad and Shea, 2013), and there is a need for 800,000 units every year for the residential sector (MHUD, 2009).

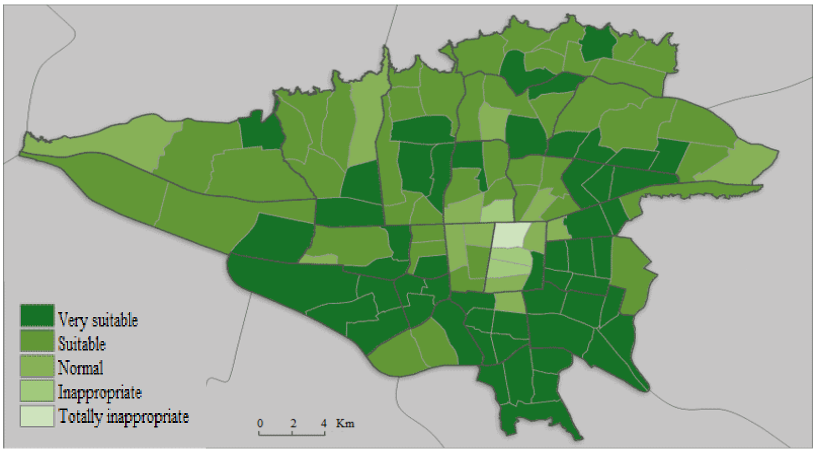


Source: Earth Trends (2003)

Figure 60: CO2 emissions by different sectors in Iran

Non-compliance with building regulations is one of the major shortcoming in Tehran, of which its effects are visible in different aspects and levels (Sarkheyli et al., 2012). The Ministry of Housing and Urban Development (MHUD) is the most influential institution in the building sector. Some of its responsibilities are regulating the housing market, designing, executing and supervising urban development/redevelopment schemes, establishing general strategies in building sector, preparing required regulations, codes, and standards associated with buildings, (MHUD, 2011). The Iranian building rules and regulations, which is prepared by MHUD, is the most comprehensive data centre. MHUD has a direct role in forming urban patterns in Iran (Talen, 2012), but some researchers argue that this needs to be amended and updated. For instance, one of the most important factors, which affects the efficiency of construction projects in Iran, is information and communication technology (ICT), and that some regulations should be revised to facilitate ICT development in construction (Alaghbandrad et al., 2011). Building rules and regulations have been developed to guarantee and play an important role in achieving the higher goals of safety, health and economy of the individual and society. However, there is a direct link between non-compliance with the law and the costs of compliance with the law (Cason and Gangadharan, 2005). Therefore, many builders are trying not to follow the rules and regulations in order to make more money (Shahrara, 2010). This has led to an increase in poor quality houses in Tehran. This vicious cycle applies to architects, builders, civil engineers, and even labours, which causes the downgrade of constructed buildings (Mazaherian, 2015). According to Beigli and Lenci (2016), the amount of energy consumed in buildings in Iran is equal to 30% of its annual oil income (equivalent to USD15 Billion in 2005), with 50% of this being wasted. Lack of both proper building materials and the government plans reduces the life of buildings in Tehran to less than 30 years (Naieni, 2015). Furthermore, the lack of practical understanding of sustainability has hampered the effective enforcement of legislation for sustainable construction (Lam et al., 2008).

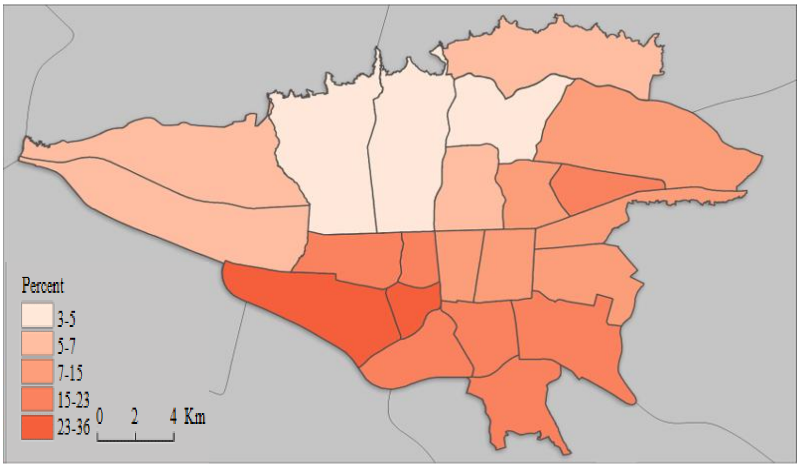
The quality index of residential buildings in Tehran is based and evaluated on the type of building materials and structures used. According to this index, which has been prepared by the Town Planning Centre of Tehran, residential buildings are placed in three different groups (durable- semi-durable and low durable). Most of the population of Tehran is located in the south and south-west of the city. According to Tehran's Statistic Centre, these locations have the highest quality of buildings in the city, although these areas are known as places that poor people tend to live in.



Source: Tehran statistic centre (2014)

Figure 61: Suitable locations in Tehran

Buildings in these location are made mostly from brick, and according to Tehran town planning centre, buildings that were made from brick are considered as the semi durable category.



Source: Tehran statistic centre (2014)

Figure 62: Usage of brick in buildings in Tehran

7.5 The Structure and design of the questionnaire

The purpose of the questionnaire was to identify respondent answers in regards to their knowledge about Iranian vernacular architecture, and to establish factors that have contributed to the determent of such approaches in recent decades in Iran. In forming the layout of the questionnaire, the order of the questions were taken into consideration. First of all, to make it easier for the respondent to understand the general questions it is important to classify the questions into logically coherent sections. This will make the questionnaire more readable and easy to observe. In addition, grouping similar questions together will make them easy for the respondent to complete the questionnaire. Furthermore, transitions between questions should be smooth. Such points will have a great impact on response rate (Walonick, 2013). It has been taken into account that some aspects could affect the arrangement of the questions, such as bringing the difficult and more specific questions to the top of the questionnaire might drop the response rate. Therefore, an attempt has been made to go through the questions from general to specific and from easy to difficult. Considering the points above, the questions were arranged with divided sections and sub-headings, starting from general to specific. The most general question was in the context of the purpose of the survey. The questions were also grouped according to their content, a strategy that helped the respondents to organise their thoughts and reactions and eventually led to more accurate responses to the questions. Furthermore, the response format that was chosen is the structured response formats, which also allowed the respondents to answer questions in a more efficient and easier manner as previously indicated (Nesbary, 1999). In addition, the questionnaire comprised of closed-ended questions and was also constructed using the standardised Likert scale. Moreover, the Likert scale was easier to construct and the respondents easily understood. Berdie et al. (1992) established that the Likert Scale is easier to contemplate than other scales when answering questions.

It was important to develop a questionnaire indicating the areas where the architects, engineers, constructors, and professionals' comments or views are sought, as part of validation process. The validity and reliability in the survey was established, and reliability of the questionnaire was ensured through designing questions that elicited similar information. This assured that the survey related to the consistency of the developed questions and the statements of the questionnaire. The sampling validity of the questionnaire was also required to reduce the biasness of the research. Similarly, the responses were used to assess the population validity as well as the inter-coder reliability. After finalising the questionnaire, most of the questionnaires were distributed amongst 78 construction companies and professionals. The sample size has been selected according to equation below, which illustrates the number of registered construction companies in Tehran, therefore determining how many respondents would be suitable to take part in the survey:

$$n = \frac{N}{1+(N)(e)^2}$$

$$n = \frac{96}{1+(96)(0.05)^2}$$

N= 96 registered construction company in Tehran

e= 95% confidence level therefore the error would be 0.05

The questionnaire focused on four main issues, which are:

- To identify their perception of Iranian vernacular building's principles;

- To identify factors that have contributed to the abandonment of such systems in recent decades in Iran;
- To gauge their idea about the integration of Iranian vernacular principles with modern buildings;
- To identify which one of the Iranian vernacular principles are well known which the authorities actually put into use.

In addition, the chosen category of the questionnaire involved a combination of both open-ended and closed questions. The reason behind the selection of open-ended questions was to allow the respondent to give a detailed answer in cases where their experience could be easily articulated.

There are five strategies that the quantitative researcher can adopt to administer questionnaires (Nesbary, 1999). These are the fax, phone, web based, mail and face to face interviews. All those approaches were applicable for this study. However, the study employed the face to face interview. This was based on the advantage of face to face interviews; whereby it enhanced getting more results and detailed answers. The disadvantage of this method is that is costly and hard to organise a study within a wider area. To attract better responses, the questionnaire contains ticking boxes and descriptive questions that allow the respondent to complete it easily and give as much information as possible. To make it easier for the respondent to understand the general questions is to classify the questions into a logically coherent section. This will make the questionnaire more readable. Therefore, survey participants were asked a range of questions including their suggestions of barriers may deter using Iranian vernacular principles.

7.6 Translation of questionnaires into Farsi

As the questionnaire administered in Iran where Persian (Farsi) is the native language, translation of the questionnaire from English to Persian was an important issue. The translation was conducted considering cultural differences and was sensitive to the meanings and terminologies used in English and Farsi. Therefore, translation of the questionnaires into the Persian language was done after the source questionnaire has been finalised in format and content. There were not any issues on the meaning of the translation and it did not affect the understanding. A research in order to measure the validity of the questionnaire has followed two procedures:

- A draft version of the questionnaire was submitted to the supervisor's team for their comments, in order to modify the questionnaire layout.
- The translation was given to a professional translator to translate back into English, in order to ensure that the questionnaire had not lost any of the original meaning.

7.7 Pilot study

In order to evaluate the clarity and comprehensiveness, and to examine the validity of the questionnaire, a small-scale preliminary study called "pilot survey", was conducted before the main research. Oppenheim, (2000) supported the idea of “A pilot study gives a chance to practice administering the tests.

The aim of the pilot study was to check the feasibility of the survey and to improve the design of the contents as well as the translation of the questionnaire (Haralambos and Holborn, 2008). The pilot study ensures that respondents in the main survey do not have trouble in completing it (Ahadzie, 2007). Therefore, before the survey was carried out, the researcher piloted 10% of the actual survey samples. Five copies of the questionnaire were distributed amongst professionals and engineers. The purpose of the pilot study was to test the questionnaire to identify errors, and to make sure that everyone understood the questions. This involved suggestions, comments and revision to the questions. Prior to the actual assessment process, a questionnaire was designed and tested for clarity and applicability through a pilot study conducted with some engineers and architects. Kidder (1981) has pointed out; "every instrument must pass the validity test either formally or informally. Every researcher who has decided on the instrument must judge whether the test measures the construct he or she wishes to study". Bell, (2010) indicated that "All data gathering instruments should be piloted to test how long it takes recipients to complete them, to check that all questions and instructions are clear and to enable you to removal of any items which do not yield usable data".

Number	Contents	Reviewers	Comments
Draft 1	9 questions	Research team (supervisors)	- Irrelevant questions - Too few questions - Identify the participants -Unstructured questions
Draft 2	15 questions	-Research team (supervisors) - PhD colleagues	- Too long questions - Unconnected questions - Limited and narrow questions - Aim of the questions
Draft 3	20 questions	-Research team (supervisors) - Registered architects	- Change the layout of the question, adding up open ended questions - Include space to gauge the respondent opinions

Table 19: Illustration of questionnaire design process

The comments received from the reviewers were useful for modifying the design of final questionnaire. The following amendments were made to the questionnaire:

- Adding some descriptive questions, to gain an idea how architects and professionals are using the Iranian vernacular principles
- Try to link the principles to the Iranian plan of work
- Change the structure and the order of the questions
- The length of some questions were found to be undesirable.

Importantly, based on the findings of this pilot study, the survey instrument was developed.

7.8 The development and validation of the questionnaire

There are many perspectives regarding the importance of validation in research, its definition, terms to describe it and the techniques for establishing it (Creswell, 2003). The validity and reliability in the survey was established, and the reliability of the questionnaire was ensured through designing questions that elicited similar information. To keep the balance and degree of scoring stability across multiple respondents, the inter coder reliability technique was used. This technique was used in the questions so that all the respondents have same scale of answers, this will allow professionals and architects to have a common formula and argument. However, to reduce the affect of inter coder reliability, the research took the following items into the consideration:

* Leniency/stringency error (lack of knowledge); the researcher picked professional architects who all have many years of experience in this field.

* Reduce the objectively perceiving- perception difference; questions were designed in a way that respondents don't have different ideas of scaling when answering questions.

* Reduce stereotyping; to reduce the affect of other people, the questionnaire was given to people to answer in their office (anonymously) so that other participants cannot influence the answers given by respondents.

The research picked external and sampling validity as a major part for validating the questionnaire. The external validity is divided into two sections:

Population validity: sample of Tehran architect is representing the whole of Iran.

Ecological validity: to increase ecological validity the questions were passed to the respondents to answer without any pressure, this will lead to minimise their anxiety.

To reduce the biasness of the thesis, the researcher was in touch with professionals and architects who are in this field for many years as sampling validity.

The respondents (i.e, professionals, architects, etc) were all residents in Tehran who often encounter various principles and concepts of the vernacular architecture. The sampled architects had varied knowledge concerning the vernacular architecture. Consequently, the respondents were required to provide their views on the definition of the Iranian vernacular principles and the idea about the integration of Iranian vernacular principles with the modern buildings by answering the close ended questions.

Importantly, the questionnaires were self-administered. It was necessary that the validation generates effective and suitable comments from architects and constructors. This could only be achieved by involving the targeted architects and constructors who had the required experience. In regards to this, the selection of respondents were based on three different categories: their experience, expertise and their academic qualifications. In the process, detailed instructions on how to complete the questionnaires were provided at the beginning. Each of the questionnaires sent to the respondents was accompanied by a cover letter (Appendix T), which introduced the theme and objectives of the present research. Thus, the complete survey package contained the information sheet and the questionnaire. The respondents were required to return the completed questionnaire as early as possible; however, no deadline was provided.

7.9 The data processing for the questionnaire survey

The collection of the information from the study participants was conducted using a self-administered survey. The response rate was good since the researcher visited the respondents and collected the responses from the intended participants, a strategy that also increased the response rate. After the answered survey forms had been recovered from the respondents, the responses were edited to ensure completeness, readability and consistency. Upon checking the data, they were neatly arranged in a form that enabled easy analysis. Specifically, descriptive statistics were employed as the tools of evaluation in the analysis of data.

The purpose of the survey was to explore the awareness of Iranian vernacular principles and sustainable architecture in Iran. Professionals in Tehran city were questioned, and data regarding their perceptions of sustainable design and barriers which deter using Iranian vernacular principles were collected. Descriptive analysis of data was collected from 78 architects, constructors, engineers and drafters from major zones and areas in Tehran. During the sample selection, it was observed that all of the participants belonged to major institutions in the country. The demographics of the participants are as indicated in Table 22. The vast majority of the participants were male architects.

Gender	Year in Practice
Male (n=67) 85.9%	< 5 (n=11) 14.1%
Female (n=11) 14.1%	5-10 (n=19) 24.4%
	10-15 (n=31) 39.7%
	15-20 (n=10) 12.8%
	>20 (n=7) 9%

Table 20: Identifying repondent and duration of their experiences

7.10 Analysis of the survey

In total, 78 professionals completed the survey. The average response rate was 100%. The professional's response to the survey was in general acceptable. Table 23 illustrates the results of the field survey.

	Total	Percentage
Distributed	78	100
Completed	78	100
Architects/Civil eng	61	78.2
Drafter	7	8.9
Constructor	3	3.8

Table 21: Completed and returned questionnaire

Respondents were asked a combination of both open-ended and closed questions. Additional questions were asked in the event the researcher required more information on a particular question and answer from a particular participant of interest.

After reviewing the answer of the respondent, it can be concluded that all of them were aware of Iranian vernacular principles. However, 22 professionals (28.2 percent) didn't know what sustainability means and they were not familiar with it.

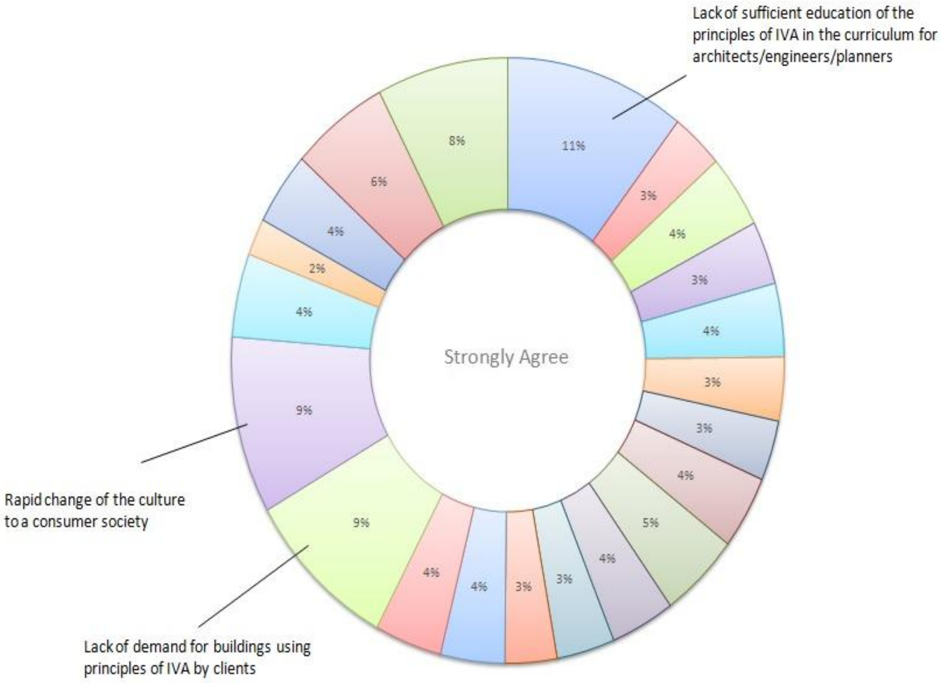


Figure 63: Illustration of respondent that strongly agreeing with the factors

Data indicated from the figure 63 illustrates that 76.9% of the professionals strongly agreed that the lack of sufficient education of the principles of Iranian vernacular architecture in the curriculum for architects/engineers/planners is the most important factor to be considered for using Iranian vernacular principles in modern design. A rapid change of culture and lack of demand for buildings using Iranian vernacular principles took second and third place in the importance factor. According to Shafii (2005), lack of education is cited as a major barrier for implementing green design and the role of education in creating a more environmentally sustainable life is irrefutable (Shari et al., 2006). From the above response, it could be noted that studying principle of vernacular architecture is a need, and therefore should be added to the general curriculum of Architecture courses. Hence, this trend will allow future buildings to benefit from using Iranian vernacular principles.

The second and third factors that professionals were concerned about was the rapid change of culture and lack of demand for buildings using Iranian vernacular principles. In previous chapters it has been mentioned that thermal performance of Iranian modern buildings is very low. Saving energy is subsidised by the government and this is the reason architects and building designers consider it as a minor factor in terms of planning and design. This is opposite to the standards recommended for thermal insulation that could save up to 50% of energy (Numan et al., 1999), most private houses are constructed with low thermal profile building materials and have no consideration for the climate. According to Washington and Cook (2011), reliance on technology and using mechanical systems to make a comfortable zone for occupants has led humans to not consider themselves as belonging to nature; rather, humans know themselves to be an external force that has to dominate nature (Stone et al., 2007; Huber and Knutti, 2011). This is the result of sudden urban development in Iran and the replacement of old architectural values with western values and methods (Debache and Benzagouta, 2014). With the emerging of modern architecture and building services systems, the process of climatic design is often overlooked (Givoni, 1998).

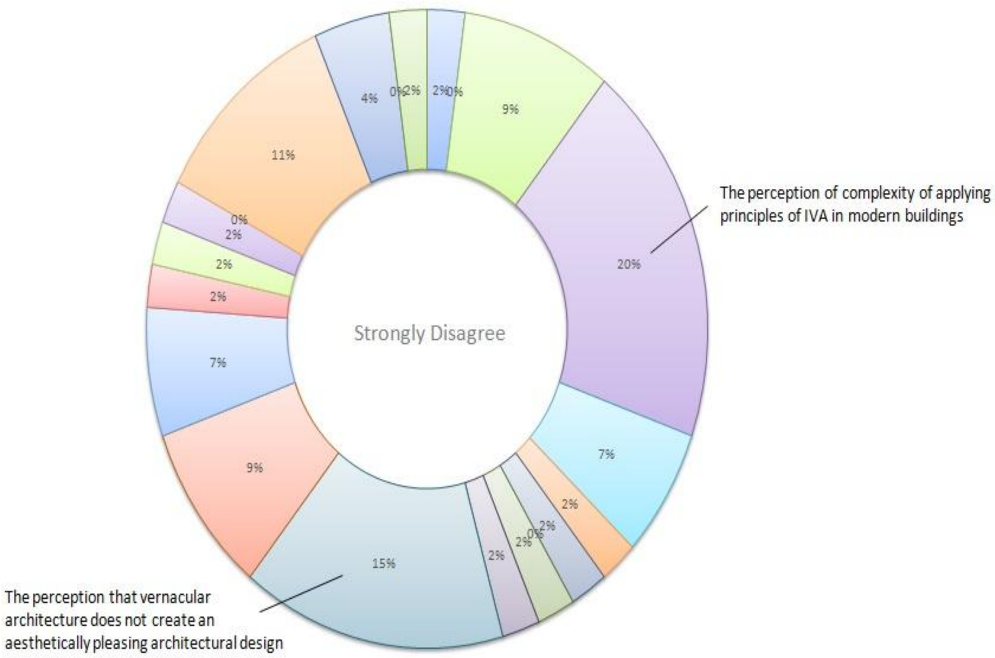


Figure 64: Illustration of respondent that strongly disagreeing with the factors

The figure 64 illustrates that 20% of the professionals (the majority) strongly disagree that applying principles of Iranian vernacular principles in modern buildings is complex, and following that the second stage of strongly disagree was the 15 % of professionls who didnt accept that vernacular architecture does not create an aesthetically pleasing architectural design.

7.11 Significance testing

From various statistical tools useful to assess underlying hypotheses, this thesis makes use of T-test. According to Winter research (2013) William Sealy Gosset in 1908 introduced that the test is only applied in case of unknown variances in two normal distributions or when the sample size is very small. The T-test is assessing whether there is a linear relationship between two variables. Therefore, the research compiled all the responds in a table to facilitate T-test examining.

Which factors may deter the use of IVA principles in the design of new buildings in Tehran	Strongly agree(%)	Agree(%)	Disagree(%)	Strongly disagree(%)
Lack of sufficient education of the principles of IVA in the curriculum for architects/engineers/planners	**76.9**	**16.7**	**5.1**	**1.3**
Lack of sufficient practical training for architects/engineers/builders	**21.8**	**62.8**	**15.4**	**0**
The perception of excessive cost of applying principles of IVA in modern buildings	**29.5**	**3.3**	**32.1**	**5.1**
The perception of complexity of applying principles of IVA in modern buildings	**24.4**	**42.3**	**23.1**	**10.3**
The perception that client’s needs cannot be fully captured using principles of IVA in modern buildings	**25.6**	**48.7**	**21.8**	**3.8**
Lack of transparency in the planning process and ignoring what is good for the environment	**24.4**	**47.4**	**26.9**	**1.3**
Lack of integration of principles of IVA in the Iranian Building Regulations chart	**23.1**	**48.7**	**26.9**	**1.3**
Transition of the value system in society to living for today and ignoring tomorrow	**28.2**	**53.8**	**17.9**	**0**
Lack of an effective planning system	**33.3**	**46.2**	**19.2**	**1.3**
Lack of commitment to the environmental agenda at the national level	**26.9**	**52.6**	**19.2**	**1.3**
The perception that vernacular architecture does not create an aesthetically pleasing architectural design	**24.4**	**38.8**	**29.5**	**7.7**
The practical issues of incorporating principles of IVA into design	**21.8**	**42.3**	**30.8**	**5.1**

The perception of potential liability issues due to the incorporation of "untested" integration of principles of IVA into design	**26.9**	**41**	**28.2**	**3.8**
The perception that integration of principles of IVA into design may add extra time to the process of design and construction	**28.2**	**42.3**	**28.2**	**1.3**
Lack of demand for buildings using principles of IVA by clients	**66.7**	**28.2**	**5.1**	**0**
Rapid change of the culture to a consumer society	**70.5**	**26.9**	**2.6**	**0**
The loss of knowledge about local materials and their use	**32.1**	**23.1**	**44.9**	**0**
Lack of a sense of responsibility and pride in using principles of IVA	**14.1**	**30.8**	**48.7**	**6.4**
Loss of traditional skills for construction of traditional buildings	**29.5**	**38.5**	**30.8**	**1.3**
Lack of a clear understanding of the importance of passive design to safeguard the future	**41**	**47.4**	**11.5**	**0**
Lack of a clear understanding of the contribution of buildings to environmental pollution and energy consumption	**57.7**	**33.3**	**9**	**0**

Table 22: Overview of all the responds

The T-Test is further specified between a one-tailed and a two-tailed test. The one-tailed test is allotting the full alpha in order to test the statistical significance of 0.05 in only one direction of interest. By doing so, it completely disregards any possible relationship in the opposite direction. Since the answers are expected to vary from question to question, the significance is tested using a two-tailed test. In this case half of the alpha (.25) is allotted to test the statistical significance in one direction while the other half is allotted to assess the statistical significance in the opposite direction (UCLA, 2008).

7.12 Commenting at the end

In order to comment on the relevance of obtained figures a T-test was conducted. The T-test was two tailed and opposed all possible answers. The results are very clear and reveal with p-values significantly below 0.05 that the model is not just appropriate but also the extraordinary high levels of confidence (>95 %) to which statements can be made (Appendix U).

7. 13 Summary

This chapter has offered and described the barriers of using Iranian vernacular principles in modern design. Firstly, a background on Tehran city as one of the most polluted city in the world was given. The explanation was to identify the sudden urban development and rapid migration to this city. Therefore, this has affected the building quality and shapes, which led to an increase in energy consumption and creation of low quality buildings. Following that, the education system in Iran has been described. The curriculum of the university and lack of proper modules for sustainability has been identified. Furthermore, the research delved in to building qualities and building rules in Tehran. It has been identified which part of Tehran has the densest and best quality houses and what sort of materials they use. However, to support the aforementioned items and to try to identify the barriers which may deter using Iranian vernacular principles, the researcher created questionnaires to gauge the ideas and opinions of professionals and experts on the matter. The results have shown that 76.9% of the respondents strongly agreed that the lack of sufficient education of the principles of IVA in the curriculum for architects/engineers/planners is the most important factor to be considered for using Iranian vernacular principles in modern design. Therefore, the importance of education in creating and designing a building has observed.

CHAPTER EIGHT: CONCLUSION AND DISCUSSION

8.1 Introduction

This chapter presents a summary of the research and has been divided into several stages to discuss and summarise the research findings. It includes the aims and objectives for the research. This chapter contains a summary of all the chapters such as the findings from the literature review, principles of sustainability, the energy usage of modern and vernacular building, principles of Iranian vernacular buildings and awareness and usage of an Iranian vernacular principles survey of architects and designers. The conclusion links and integrates the research findings. The recommendations provide suggestions for future research which have been raised as an outcome of the findings of this research. Lastly, this chapter discusses the limitations which have been faced during the research. The aim of this research was to assess how energy use in modern buildings can become more sustainable, and how related greenhouse gas emissions can be minimised by using Iranian vernacular architecture principles in modern buildings. In addition, the research conducted a survey to maximise the proportion of response rate, and to obtain relevant and accurate information to identify factors that deter the use of Iranian vernacular principles in new designs. Therefore, this research has set six different objectives to achieve the aforementioned aim.

The aim of this research has been to achieve the thesis objectives set out in chapter one (section 1.4); the objectives are repeated in this chapter to which they have been described and methods of achievement along with the research question has been explained.

Objective one: Identify the sustainable architecture, sustainable design methods, and assess characteristics of vernacular architecture.

For having a better understanding of vernacular architecture and connecting it with sustainability, chapter two presented and discussed the concept of sustainable development, the principles of sustainable buildings and the methods of achieving sustainability by reading and researching different books, journals, theses and articles. This chapter helped the research to identify the sustainable principles behind the Iranian vernacular architecture, as it illustrated the sustainable architecture principles into three different categories; conserving energy, conserving materials and conserving water. Furthermore, this finding led the research to illustrate the relationship of the Iranian vernacular principles to sustainable architecture.

Objective two: analyse and assess the feasibility of the principles of vernacular architecture for use as part of the design of modern residential buildings in Iran.
In fulfilling the objective number two, the research discussed renewable sources, and the difference between modern and vernacular buildings in terms of energy consumption in chapter four. Chapter four investigated both modern and vernacular buildings and has illustrated their strengths and weaknesses. In addition, chapter four explained and addressed the values of traditional methods and technologies to fill the gap of comprehensive studies on Iranian vernacular systems of building design to examine how these buildings create a comfort zone for their occupant. The analyse of the principles achieved in chapter five.

Objective three: establish the key principles of Iranian vernacular architecture that contribute to energy efficiency and principles of sustainability.
Chapter five helped support chapter four to establish the principles of Iranian vernacular architecture. In addition, the design philosophy of Iranian vernacular architecture was also reviewed. This process lead to identify the connection detailed of Iranian vernacular architecture's principles to each other. The relationship between energy and building sectors has been explained to create a foundation for chapter six.

Objective four: Develop a process which helps to evaluate energy consumption in modern design using vernacular principles.
This section compared the required heating and cooling capacity, as well as the annual energy consumption between two similar buildings in Tehran. These virtual buildings furthered research into finding out which of them is much more energy efficient and producing less carbon. Both buildings were located in the same site and city with similarity in terms of general shape. However, the first building was one of the conventional constructed samples in the city (base

building), while some changes were made to the second building through the use of passive solar, orientation, vernacular materials usage and wind designs (optimal building). In addition, for validation and reliability of the designed ecological prototype building, one of the recommended methods was examined in real life. The method was tested and compared with the regular method in the laboratory, to identify the facts and results.

Objective five: use the identified principles into the design of a prototype building and test their validity and reliability through scientific testing and user response.

Chapter six covered objective number five . This chapter compared both modern and vernacular building energy usage through the implications of traditional architectural technologies by simulating both of them in the same climate conditions. The comparison between the energy consumption of both modern and Iranian vernacular architecture enabled the researcher to identify and measure the differences. By calculating and comparing both buildings via IES software, it was found that the vernacular building was more energy efficient and environmentally friendly. However, the research has not relied on one particular software package. Chapter six also evaluated and calculated a modern building and estimated the energy used with Design builder software. By doing so, the research redefined old principles and concepts of vernacular architecture and their connection with the needs of human and technology.

The building design is the first line of defence against the stress of the outside climate, the final design was the one approach by which to reduce the energy cost of a building comprehensively. Buildings should be built according to climatic design principles to reduce the need for mechanical heating and cooling by using natural energy available from the climate at the building site. Eliminating mechanical systems will not only reduce the carbon emissions but the long term energy cost savings, which as a result make climatic design techniques the best financial investment for the building owners. Therefore, by adding some of the Iranian vernacular principles which were now practical, the research calculated the final design and compared this with the modern one. The energy consumption tool, electricity consumption timetable and comparison charts were synthesised and summarised to identified the gap between the base and optimised buildings.

The final design of the research tried to understand the principles of heat/cool exchange. Energy flows in and out of buildings through walls, roofs, windows, and floors. This occurs as lost heat energy migrates from spaces or materials of higher temperatures to those of lower temperatures.

The purpose of designing the final design was to minimise the amount of purchased energy required to maintain comfortable conditions in houses which use Iranian vernacular principles. Chapter six also validated the provided design, as the researcher made an actual wall to find out if the wall reduced the energy consumption and acts as an insulation or not. The researcher decided to identify the method of using clay amongst one wall, and decided to test both walls (regular and optimum) in the industrial fridge. The theory was to place the wall into a box which was fitted in the fridge. One side of the wall acted as an interior section which was located in the box, whilst the other surface faced towards the fridge, as the researcher planned to change the temperature to finds out the temperature difference. The results showed that the optimum wall was well insulated compared to the regular wall and was more coefficient and kept the interior warmer. However, during the collection of data and numbers , the researcher noticed that in the middle temperature the gap was not that different but by reducing the temperature the difference between temperatures raised. The reason behind this was because mud can store the heat from the sun or heaters to release it at the time that the exterior surface gets cold. The mass in a time that temperature was high absorbed the heat, and it released the warmth back into the interior throughout the temperature reduction.

Objective six: Identify factors that have contributed to deter the use of Iranian vernacular principles in new designs.

Chapter seven covered the last objective. This chapter described the barriers to the application of Iranian vernacular architecture principles in residential buildings in Tehran. In the same chapter the background of Tehran city, such as growth in population, urbanisation patterns and energy consumption of residential building has been explained. The literature of sustainable architecture in education and building qualities in Tehran has also been reviewed. The research created a questionnaire to gauge an idea and opinion of professionals and experts to identify the barriers that deterred using Iranian vernacular principles. The research conducted a survey to maximise the proportion of response rate, and to obtain relevant and accurate information to identify factors that deter the use of Iranian vernacular principles in new designs. The chosen questionnaire was a self-completion questionnaire to collect both quantitative and qualitative information. The results have shown that 76.9% of the respondents strongly agreed that the lack of sufficient education of the principles of Iranian vernacular principles in the curriculum for architects/engineers/planners was the most important factor to be considered for using Iranian vernacular principles in modern design.

8.2 Contribution to knowledge

The explained research objectives in chapter 8 section 1 represent the original contribution to knowledge made by current thesis. However, the following chart shows the key contributions of the research;

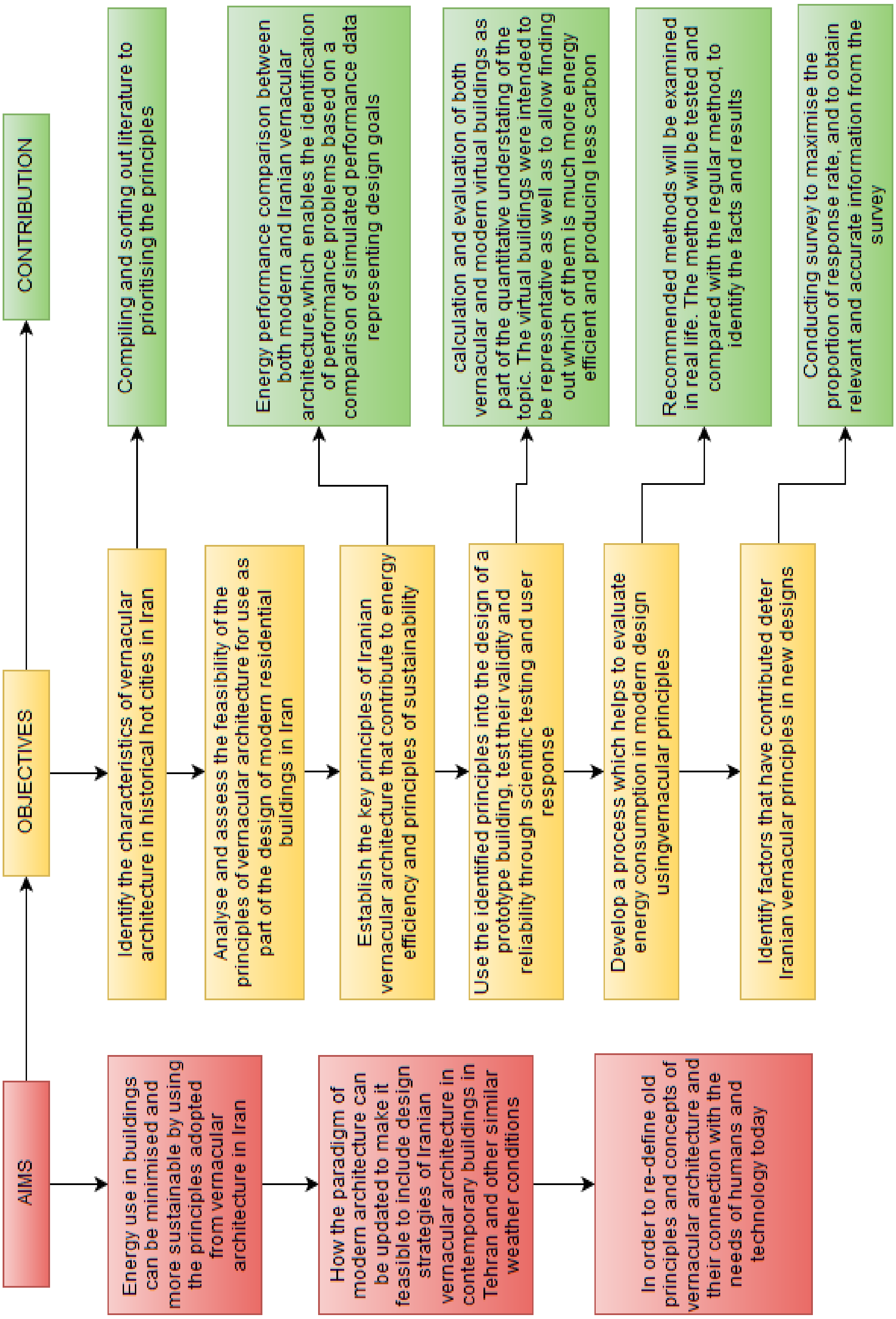


Figure 65: Research contribution chart

8.3 Recommendation and findings

The building sector energy consumption is quite high and is expected to further increase because of changes to modern values and lifestyle besides a growing world population. These issues have increasingly affected the use of electro-mechanical equipment which has penetrated the market for the last few years and significantly contributes to the upsurge of energy consumption. Mechanical ventilation systems not only consume a significant amount of energy but may also cause environmental pollution. Therefore, building energy conservation and sustainable development are the two main designing factors for choosing passive-cooling techniques in the hot climate that Iran faces. Iran has distinct geographical and climatic features conducive to receiving a significant amount of sunshine and wind. These conditions, if used properly, can significantly reduce the energy use and provide proper natural cooling for the buildings. It should be possible to propose a successful future implementation of energy efficiency by investigating factors affecting the success and failure of vernacular building strategies, particularly in Iran. Current research shows that by taking advantage of previous experience, it is then possible to use passive cooling systems alone, or even in combination with simple mechanical systems, to reduce the energy use. The aim of this research was to assess how energy use in modern buildings can become more sustainable by using vernacular architecture principles in modern buildings. The research primary plan was to collect data from different examples of vernacular architecture in Iran, its usage in the past and current climate, and to gather and compare case studies and information on unsuccessful projects which have used some of these principles in their design. The research involved informal interviewing current Iranian architects to obtain qualitative understanding of the design phase that affects the environmental impact of the vernacular houses acquired in central Iran. The researcher identified experts in the field of sustainability by attending different seminars to gauge their ideas about the current research.

According to the findings and results it can be recommended that the current research believes that the government should rearrange the curriculum in regards to architecture, and make it compulsory for universities to add more credits on vernacular principles modules within the universities in Iran. This trend will allow students to learn more about the benefits of Iranian vernacular principles, for the reduction of energy consumption on their future construction.

In conclusion, for many years, Iran has relied on the availability of cheap energy. The country did not have to practice any particular discipline in its consumption of energy. Therefore, people are wasting non-renewable sources, such as fossil fuel, without taking into consideration the fact that these energies are not infinite. Environmental awareness and the ideas of sustainability and energy efficiency have been put back on top of the agenda in regards to building designs in Iran. Most of the modern buildings in Iran have been unable to fully address the sustainable requirements, which can achieve some architectural qualities that can promote and raise the energy efficiency in Iran. Most architects' choice of materials, design and construction is not based on its energy performance or its influence on the environmental comfort of the users.

From the calculations and findings the research points out that the vernacular architecture of Iran could find a solution for its harsh environmental issues without relying on non-renewable energies. Hence, the integration of the vernacular principles and modern technology in buildings can be considered today as one of the most interesting solutions for developing and using renewable energies.

8.4 Limitation

The current thesis like other researches has a number of strengths and limitation. The strengths of the research has been illustrated in section 8.2, in form of contribution to knowledge. This section describes the limitations of our research as well as possible future research directions based on this work. There were a few items which had the effect of delaying the completion of certain chapters;

- A lack of architectural and metric data on Iranian vernacular architecture in cities which have been visited has delayed the scope of the research analysis, and was an obstacle in finding accurate measurements. Investigation and preparing concrete documents about these vernacular buildings can be a part of the future research.
- Having difficulty entering vernacular buildings to explore and compare the buildings to each other.

- Unavailability of enough information regarding Iranian vernacular architecture principles.

8.5 Future research

The IES software and Design Builder allowed the researcher to identify a vast gap between modern architecture and optimised buildings. The building design and building's operating (base and optimised) calculated and indicated annually in the chapter six. However, the estimation of impact and feedback to the environment was not the focus of this research and is an area for future investigation.

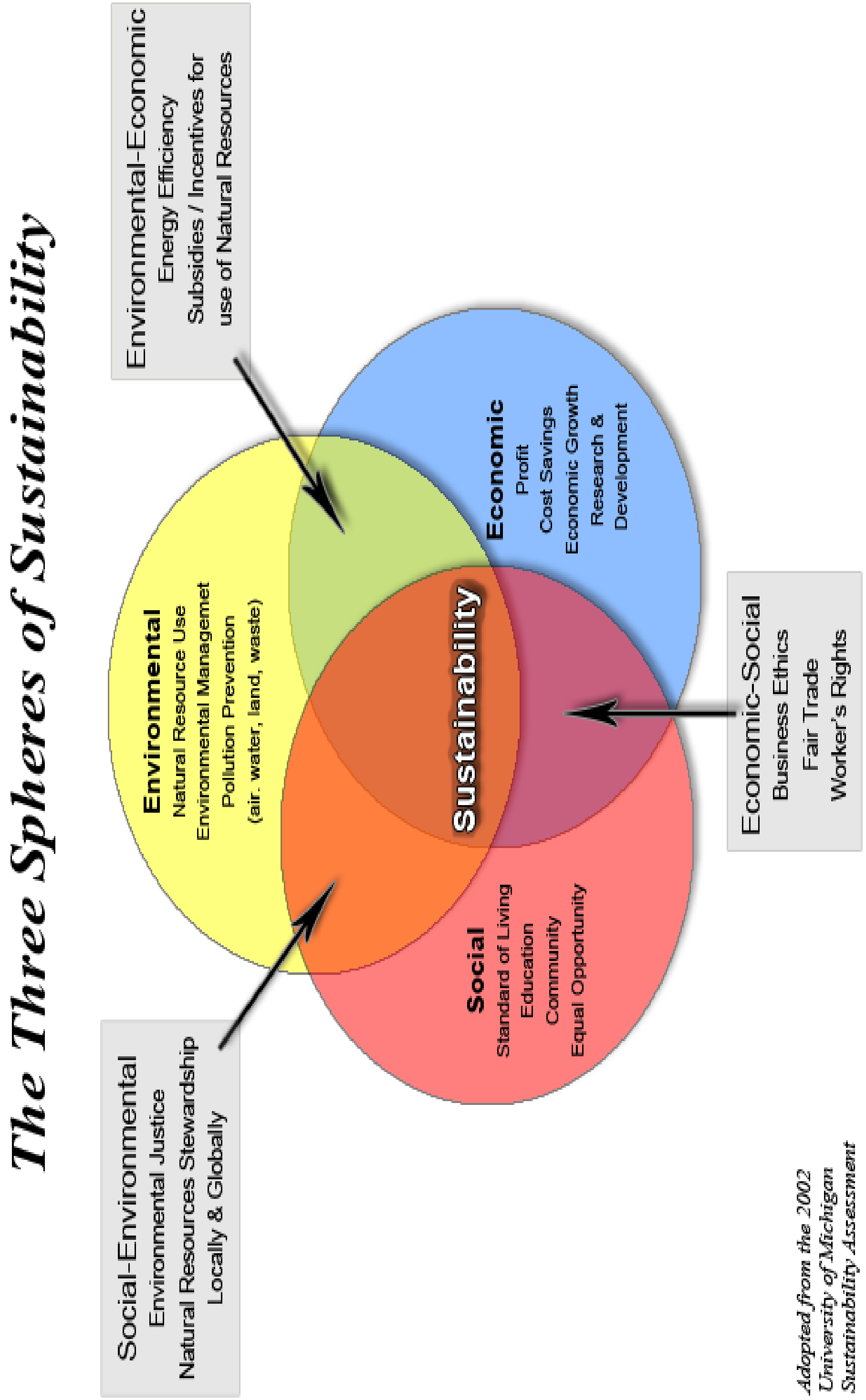
In view of the behaviour of the occupants identified, the researcher feels that the process of implementing these sustainable methods into modern buildings needs to be investigated, in particular through analysing and interviewing the occupants to revise the specific method of gathering data. While some calculation of the tasks to identify performance problems was accomplished during this research, further real-time performance assessment is a next step for future research.

Based on the identification of modern building performance problems, describing a detailed process and energy consumption of each space of the building was outside the scope of this research. The energy consumption of each space and evaluating its impact on the environment and people's health can be part of future research. One major topic for future research is to estimate and calculate the modern building energy consumptions in large quantities in cities like Tehran, to find out how much financial loss the government is facing and what quantity of fossil fuels will be used to prepare the energy required for occupants of those buildings.

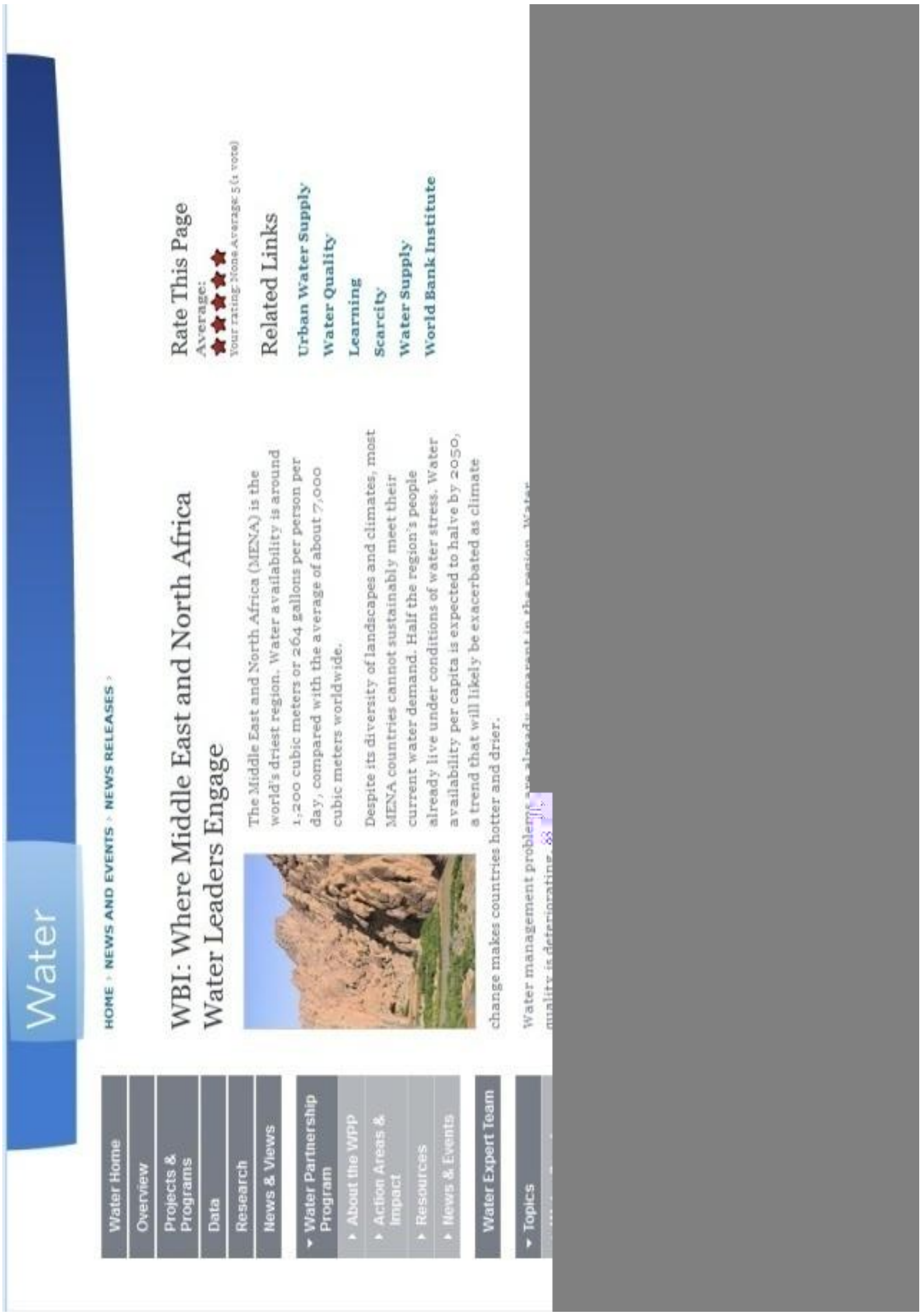
The factors which deter the use of Iranian vernacular principles in new designs which was the research's main focus has been prioritised based on questionnaire responses, it could be recommended that for future research they follow the responses to find out whether is people are using Iranian vernacular principles in their design or not. For instance, the lack of sufficient education of the principles of Iranian vernacular architecture in the curriculum for architects, engineers, planners is the most important factor to be considered for using Iranian vernacular principles in modern design. Therefore, this could be added into their knowledge through different methods to find out it could be a solution or not.

Appendices

Appendix A -The Principles of sustainability



Appendix B- Middle East is the driest region in the world (source of world bank)



Water

Water Home
Overview
Projects & Programs
Data
Research
News & Views
Water Partnership Program
About the WPP
Action Areas & Impact
Resources
News & Events
Water Expert Team
Topics

HOME › NEWS AND EVENTS › NEWS RELEASES ›

WBI: Where Middle East and North Africa Water Leaders Engage

The Middle East and North Africa (MENA) is the world's driest region. Water availability is around 1,200 cubic meters or 264 gallons per person per day, compared with the average of about 7,000 cubic meters worldwide.

Despite its diversity of landscapes and climates, most MENA countries cannot sustainably meet their current water demand. Half the region's people already live under conditions of water stress. Water availability per capita is expected to halve by 2050, a trend that will likely be exacerbated as climate change makes countries hotter and drier.

Water management problems are already apparent in the region. Water quality is deteriorating

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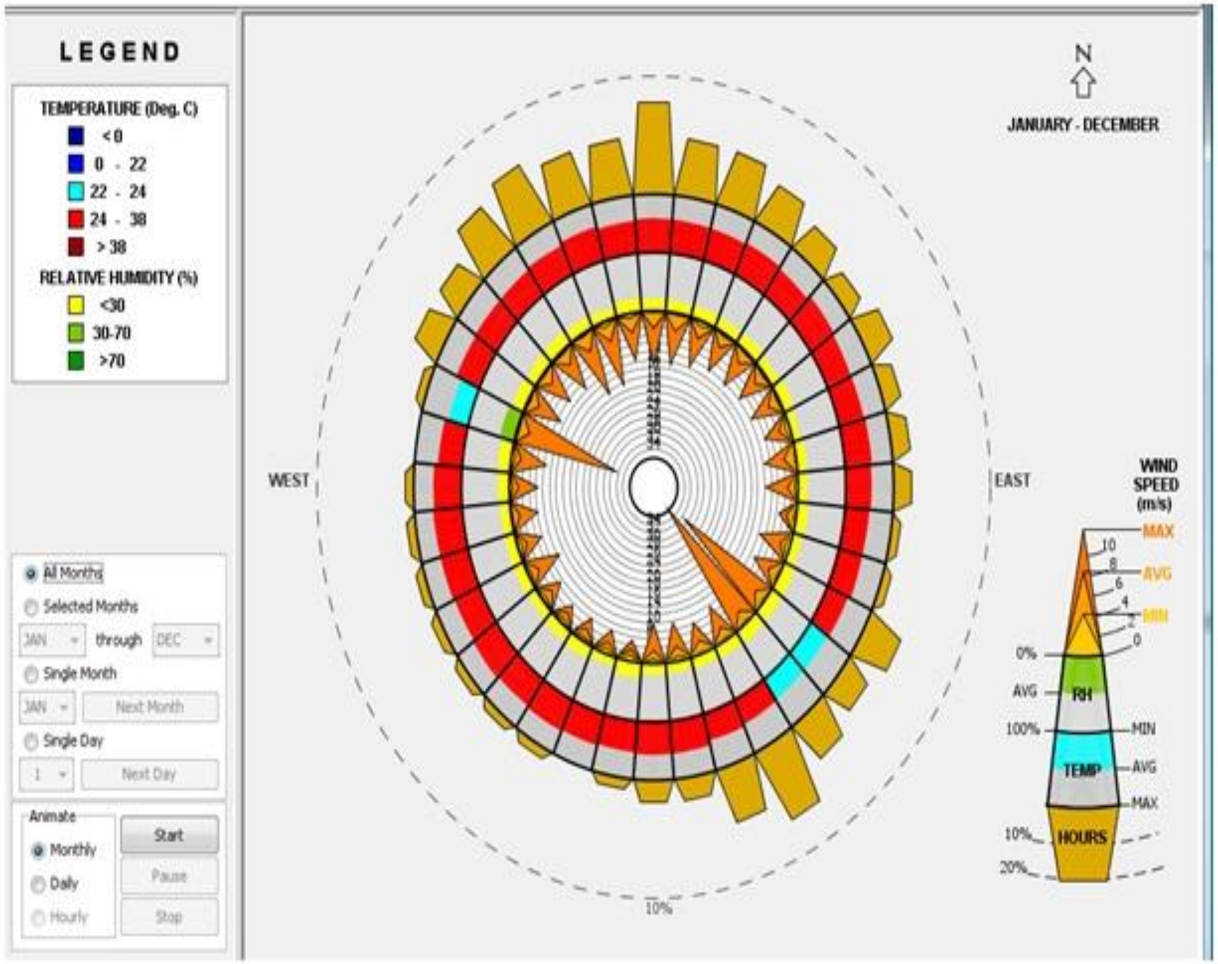
Related Links
Urban Water Supply
Water Quality
Learning
Scarcity
Water Supply
World Bank Institute

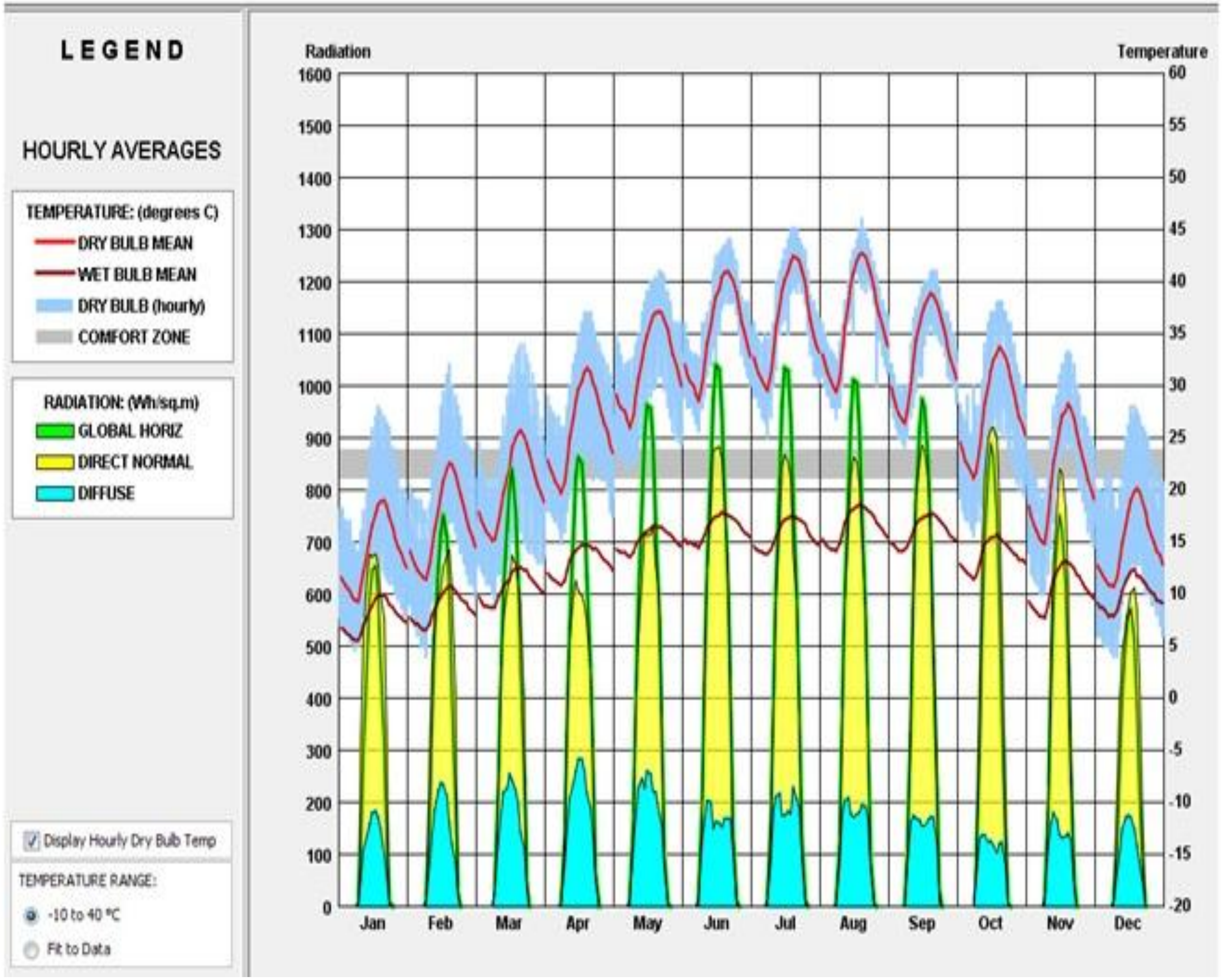
Appendix C- Building analysis and site observation

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	461	541	574	572	650	710	695	664	643	626	500	386	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	591	585	542	479	559	674	622	613	648	749	596	484	Wh/sq.m
Diffuse Radiation (Avg Hourly)	138	177	190	207	203	164	186	174	153	117	135	129	Wh/sq.m
Global Horiz Radiation (Max Hourly)	799	904	1008	1068	1078	1065	1058	1050	1024	949	819	734	Wh/sq.m
Direct Normal Radiation (Max Hourly)	983	1018	988	971	957	949	933	946	954	953	925	969	Wh/sq.m
Diffuse Radiation (Max Hourly)	983	1018	988	971	957	949	933	946	954	953	925	969	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	4275	5061	5769	6411	7336	8033	7815	7432	6888	5991	4705	3596	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	5651	5600	5502	5428	6329	7612	7049	6879	6970	7263	5594	4592	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1313	1710	1981	2362	2378	1962	2163	2017	1719	1248	1357	1235	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	49401	58069	61702	61458	69766	75639	74030	70798	68641	66548	53424	41781	lux
Direct Normal Illumination (Avg Hourly)	57270	57697	53852	47687	55985	67725	62527	61476	64869	74369	58916	46765	lux
Dry Bulb Temperature (Avg Monthly)	14	16	20	25	32	35	36	36	33	27	21	15	degrees C
Dew Point Temperature (Avg Monthly)	0	0	0	0	0	0	-3	0	2	1	0	5	degrees C
Relative Humidity (Avg Monthly)	43	33	30	23	14	11	8	10	15	20	23	56	percent
Wind Direction (Avg Monthly)	159	145	148	183	150	167	255	170	121	107	71	170	degrees
Wind Speed (Avg Monthly)	3	3	3	3	3	3	4	3	2	2	1	2	m/s
Snow Depth (Avg Monthly)													cms
Ground Temperature (Avg Monthly of 3 Depths)	22	19	18	18	21	24	28	31	33	32	30	26	degrees C

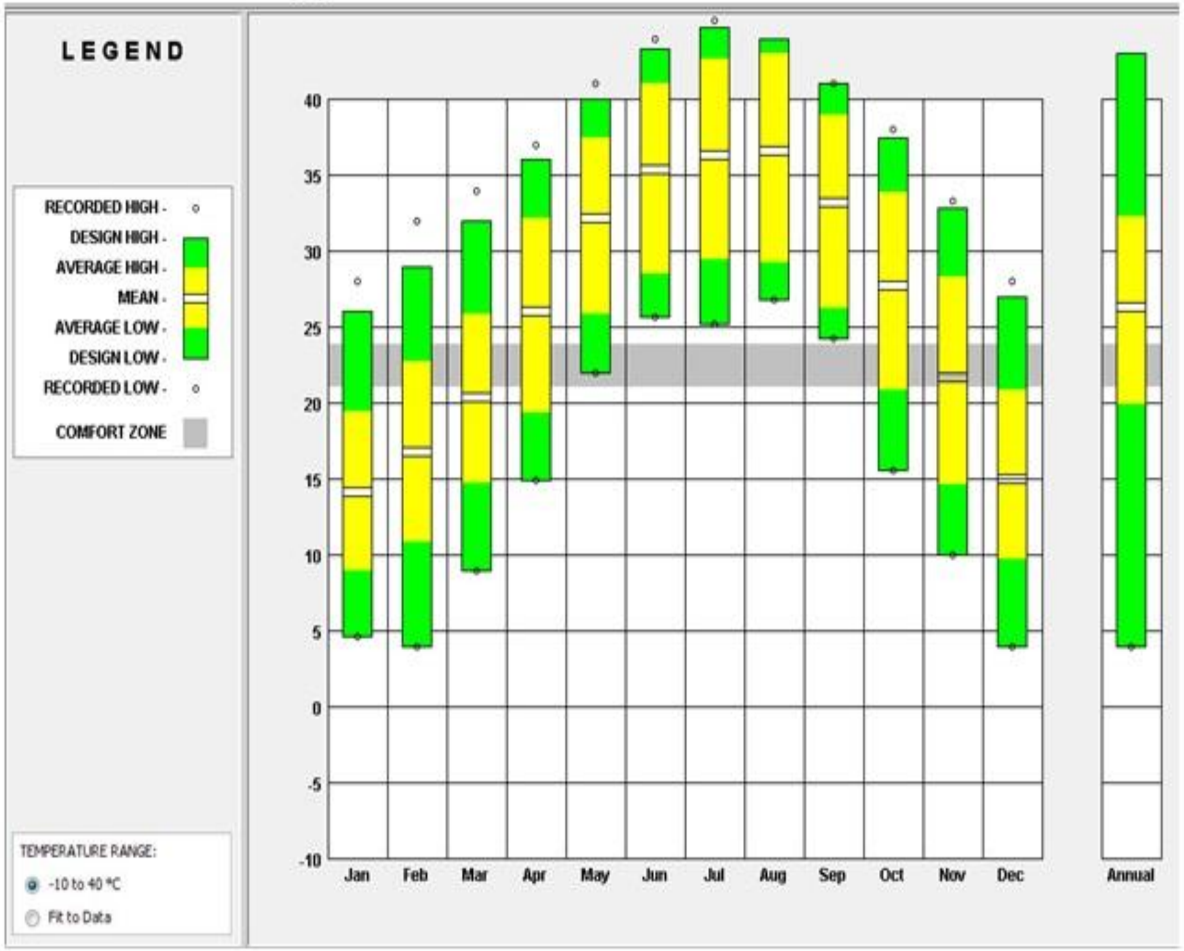
Wind Wheel


LEGEND
TEMPERATURE (Deg. C)
< 0
0 - 22
22 - 24
24 - 38
> 38
RELATIVE HUMIDITY (%)
<30
30-70
>70
All Months
Selected Months
JAN
through
DEC
Single Month
JAN
Next Month
Single Day
1
Next Day
Animate
Monthly
Daily
Hourly
Start
Pause
Stop
N
JANUARY - DECEMBER
WEST
EAST
10%
WIND SPEED (m/s)
MAX
AVG
MIN
10
8
6
4
2
0
0%
AVG
RH
100%
MIN
TEMP
AVG
MAX
10%
HOURS
20%

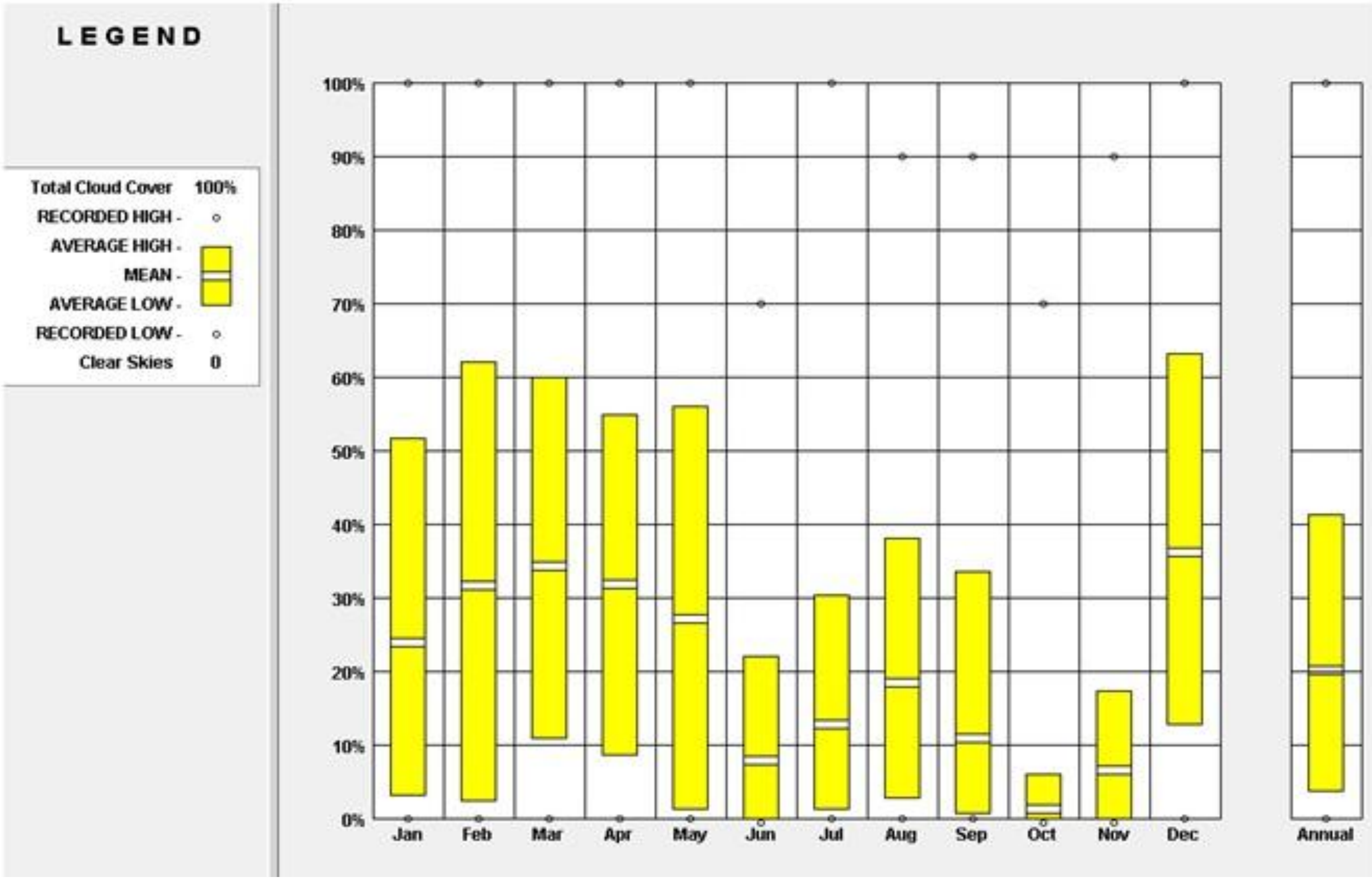
Monthly Diurnal average



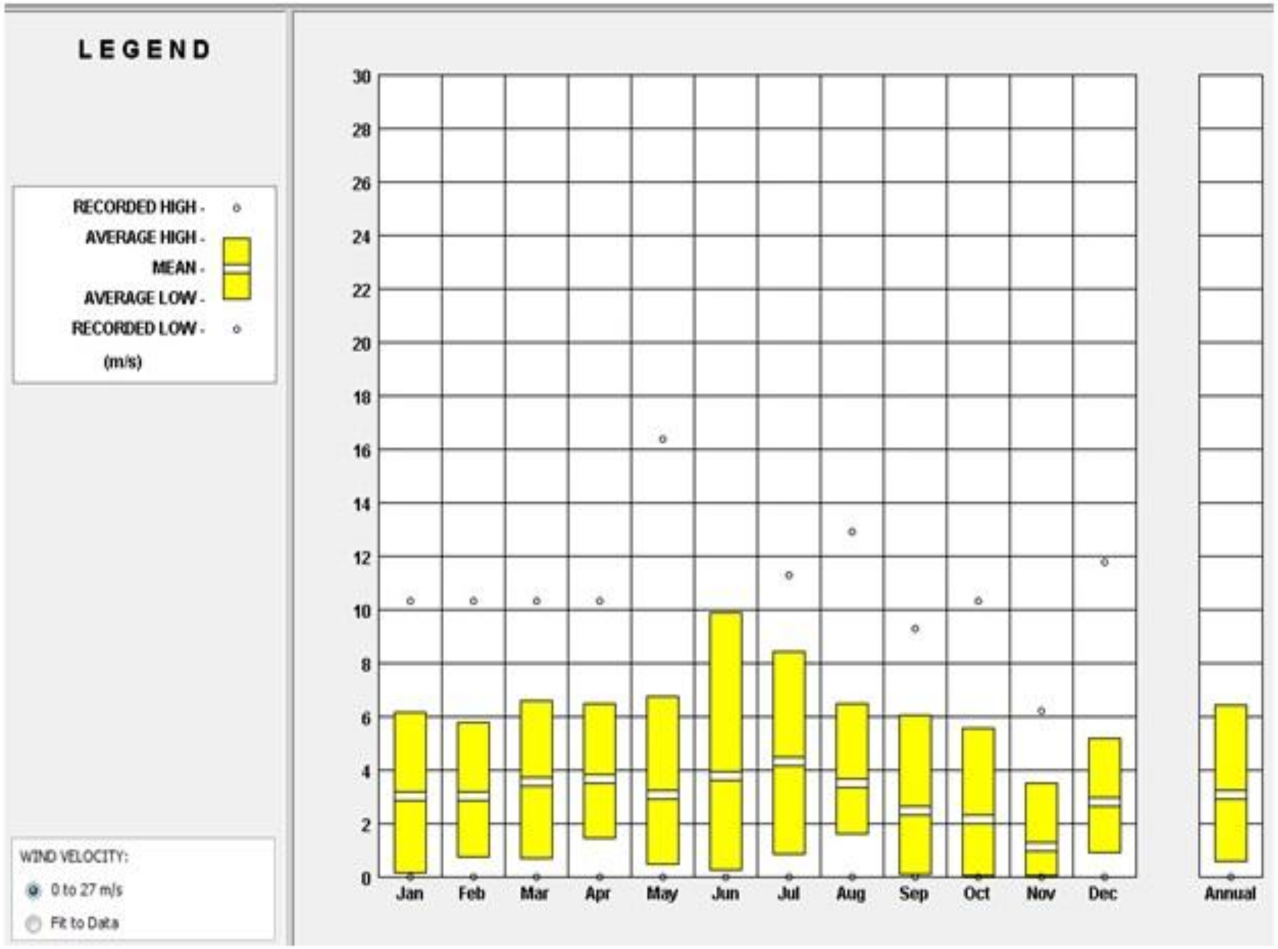
Temperature Range



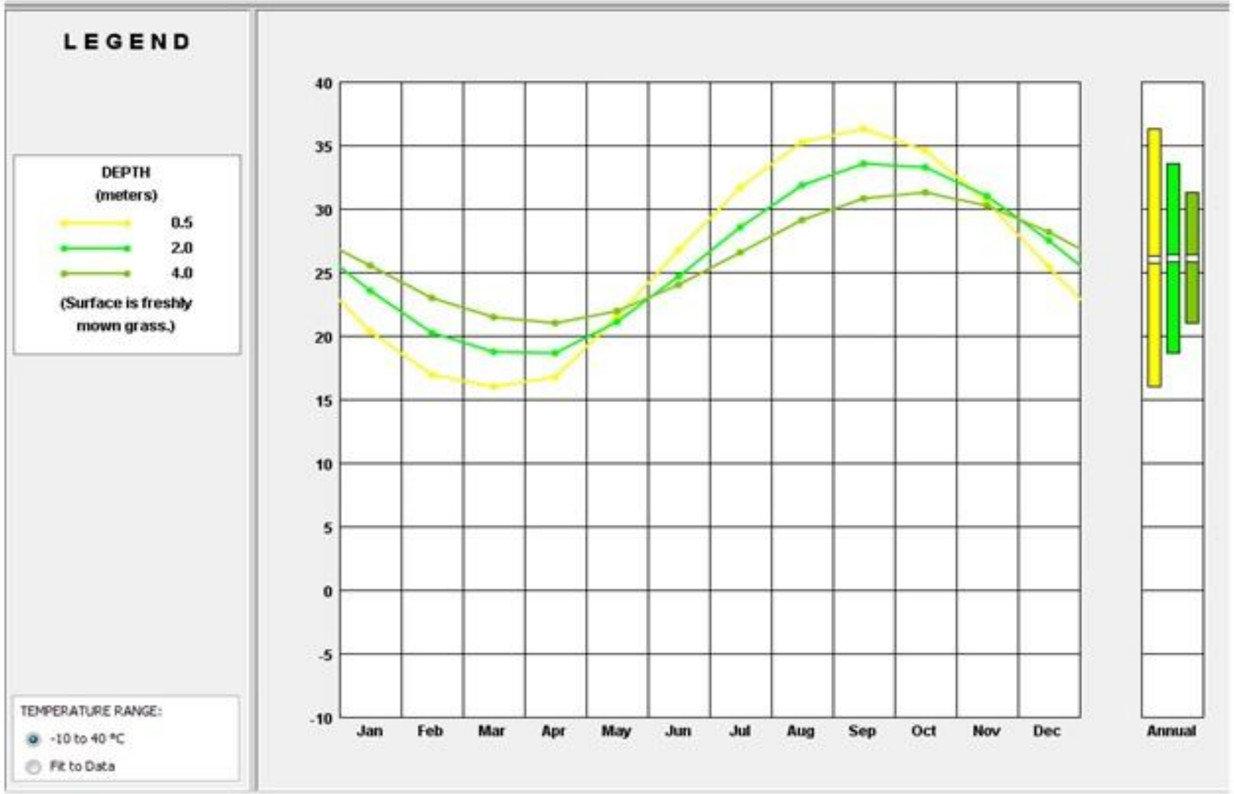
Sky Cover Range

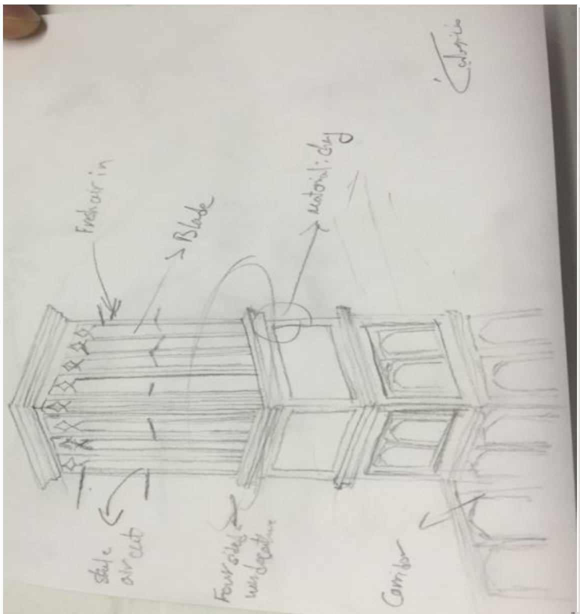


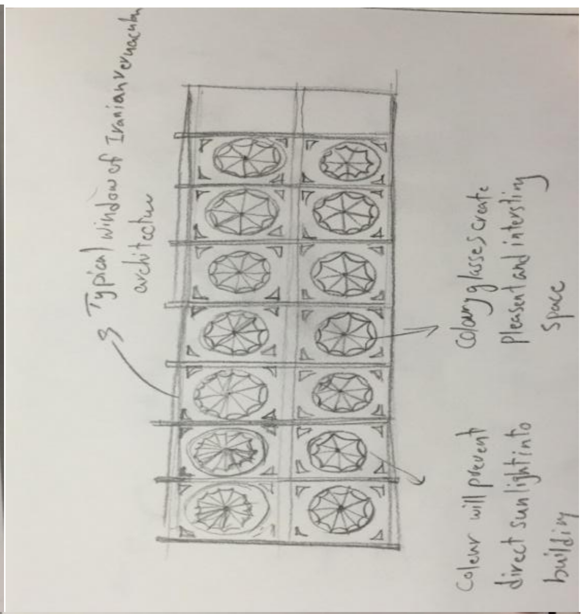
Wind Velocity Range

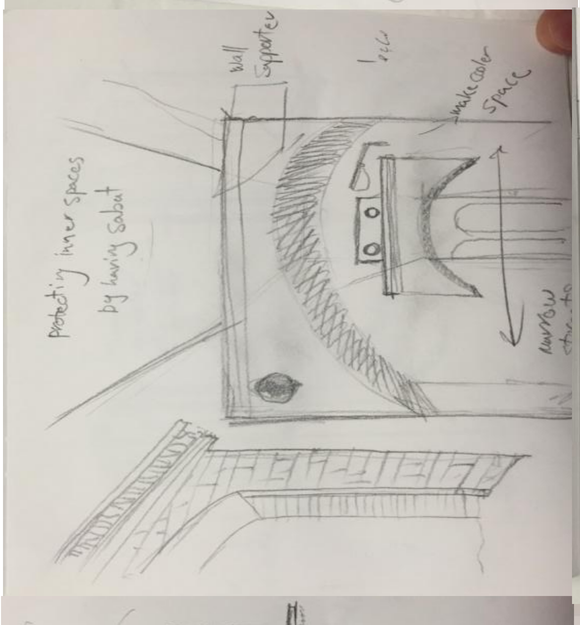


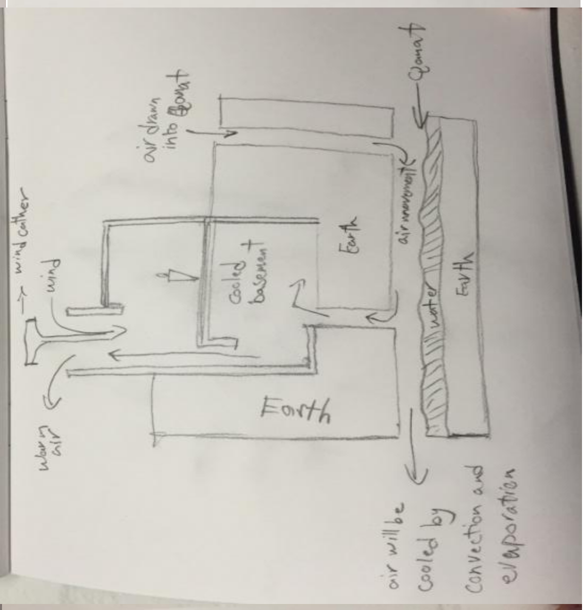
Ground Temperature (Monthly Average)

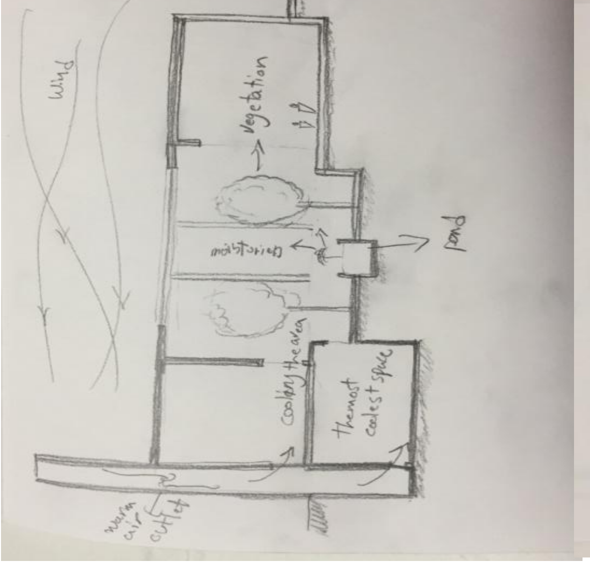


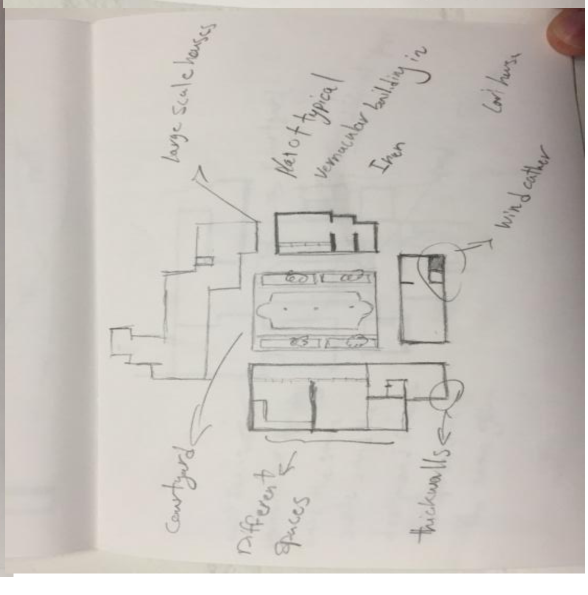

Blade
Four sided
Corridor


Typical window of Iranian vernacular architecture
Colour will prevent direct sunlight into building
Colourful glasses create pleasant and interesting space


protecting inner spaces by having Sabat
make color space
Narrow


wind catcher
wind
warm air
cooled basement
Earth
Earth
air will be cooled by convection and evaporation
water
Earth
Qanat
air drawn into Qanat


Wind
vegetation
pond
cooling the area
the most coolest space
warm air outlet


large scale houses
Plan of typical vernacular building in Iran
wind catcher
Courtyard
Different Spaces
thick walls

Appendix D- Iranian building rules and regulation

Appendix E- Unstructured questions

Response on the Knowledge about Iranian Vernacular Architecture

1. Does the understanding of the Iranian vernacular architecture important in the modern architecture? Yes/No (Explain if possible)
2. Between the modern architecture and the vernacular architecture, which one is useful and efficient in hot climate? (Explain if possible)
3. What are critical aspects or characteristics of the vernacular architecture in the historical hot cities in Iran? (please list them in the space below)
4. What are some of the key principles of the Iranian vernacular architecture that contribute to the energy efficiency and principles of sustainability?
5. What are some of the factors you may consider to have contributed to the abandonment of the vernacular architecture in recent decades in Iran?
6. Do you use the patterns of vernacular architectural elements in your design? Yes/No (explain)

Opinion of respondent

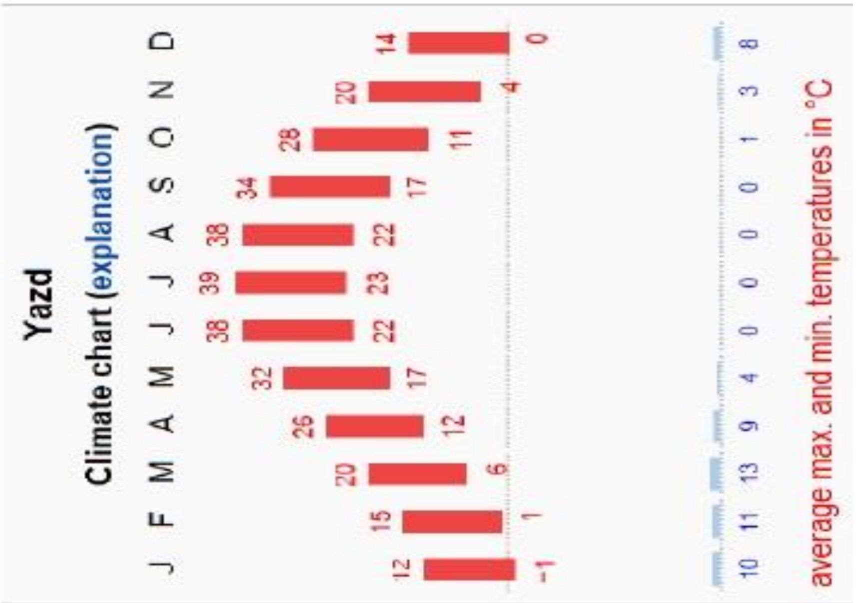
1. Is there any aspect of the indoor environment of the vernacular architecture that you would like to comment on?
2. Please explain, how the overall evolution of the vernacular architecture in Iran Cities, if possible.
3. Please explain your perception of the Iranian Vernacular building's principle?

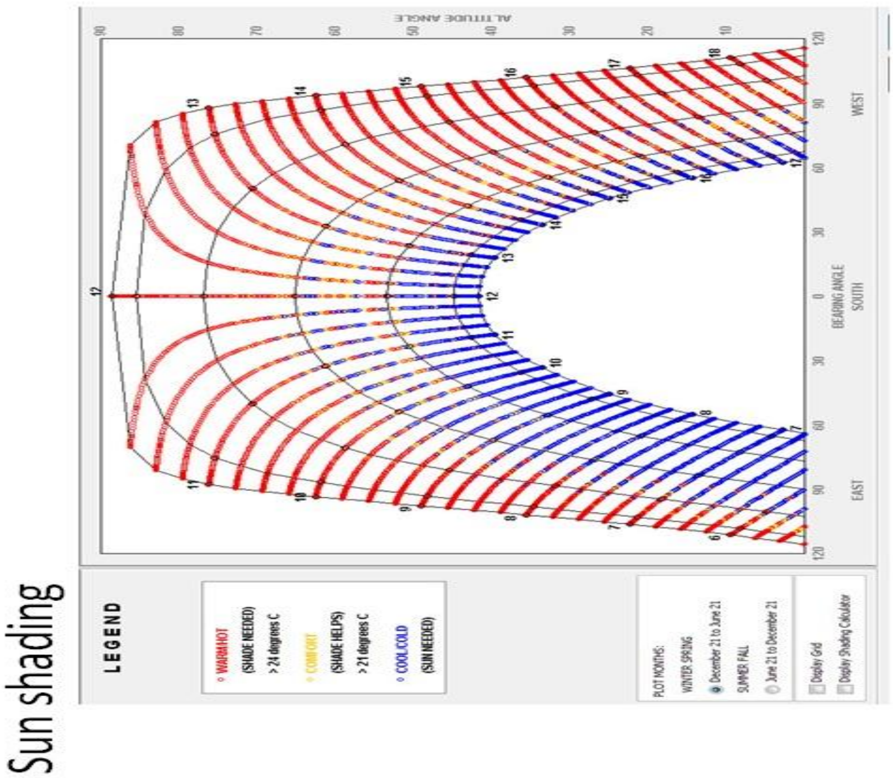
Appendix F- Questionnaire

Section 2: Factors contributing to the use of principles of vernacular architecture in Iran			
Q1	**Are you familiar with Iranian vernacular architecture?**	Yes ☐	No ☐
Q2	**Are you familiar with the passive and sustainable design?**	Yes ☐	No ☐(Go to Q4)
Q3	**How many projects of yours are designed using passive and sustainable principles?**		
Q4	**Which of the principles of IVA do you consider relevant to new buildings in Tehran?**		
	Cross as appropriate Always=① Sometimes=② Never=③		
a)	Use of inner yards	①②③	
b)	Orientation of the building to make the best use of natural lighting	①②③	
c)	Use of local building materials	①②③	
d)	Use of traditional construction methods (such as domes)	①②③	
e)	Use of narrow passages to minimise the exposure to the sun in summer	①②③	
e)	Use of natural ventilation by using the wind catcher principles	①②③	
f)	Use of mud as a heat resistance	①②③	
g)	Use the concept of an Ice house in order to reduce to use of electrical fridges	①②③	
h)	Use of greenery and fountains in order to create a cool area	①②③	
i)	Others:	①②③	

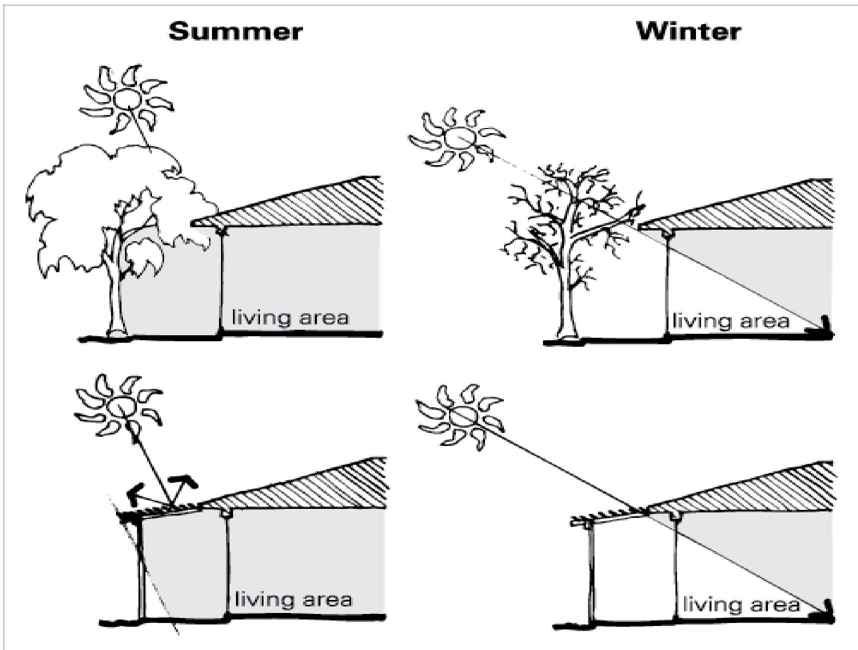
Q5	**Please explain in your opinion which of the following factors may deter the use of IVA principles in the design of new buildings in Tehran**	
	Cross as appropriate Strongly Agree=① Agree=② Disagree=③ Strongly Disagree=④	
a)	Lack of sufficient education of the principles of IVA in the curriculum for architects/engineers/planners	①②③④
b)	Lack of sufficient practical training for architects/engineers/builders	①②③④
c)	The perception of excessive cost of applying principles of IVA in modern buildings	①②③④
d)	The perception of complexity of applying principles of IVA in modern buildings	①②③④
e)	The perception that clients' needs cannot be fully captured using principles of IVA in modern buildings	①②③④
f)	Lack of transparency in the planning process and ignoring what is good for the environment	①②③④
g)	Lack of integration of principles of IVA in the Iranian Building Regulations chart	①②③④
h)	Transition of the value system in society to living for today and ignoring tomorrow	①②③④
i)	Lack of an effective planning system	①②③④
j)	Lack of commitment to the environmental agenda at the national level	①②③④
k)	The perception that vernacular architecture does not create an aesthetically pleasing architectural design	①②③④
l)	The practical issues of incorporating principles of IVA into design	①②③④
m)	The perception of potential liability issues due to the incorporation of "untested" integration of principles of IVA into design	①②③④
n)	The perception that integration of principles of IVA into design may add extra time to the process of design and construction	①②③④
o)	Lack of demand for buildings using principles of IVA by clients	①②③④
p)	Rapid change of the culture to a consumer society	①②③④
q)	The loss of knowledge about local materials and their use	①②③④
r)	Lack of a sense of responsibility and pride in using principles of IVA	①②③④
s)	Loss of traditional skills for construction of traditional buildings	①②③④
t)	Lack of a clear understanding of the importance of passive design to safeguard the future	①②③④
u)	Lack of a clear understanding of the contribution of buildings to environmental pollution and energy consumption	①②③④

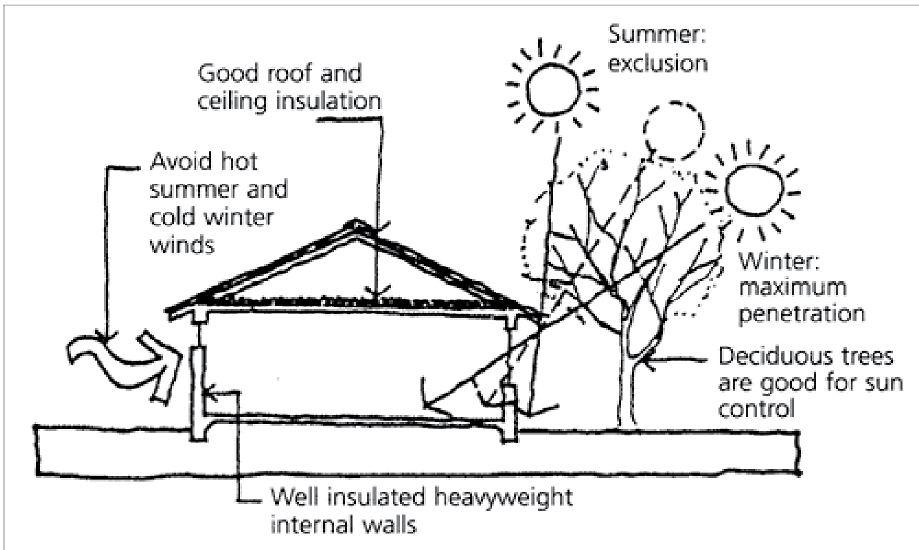
Appendix G- Average temperature and Sun shading in Yazd



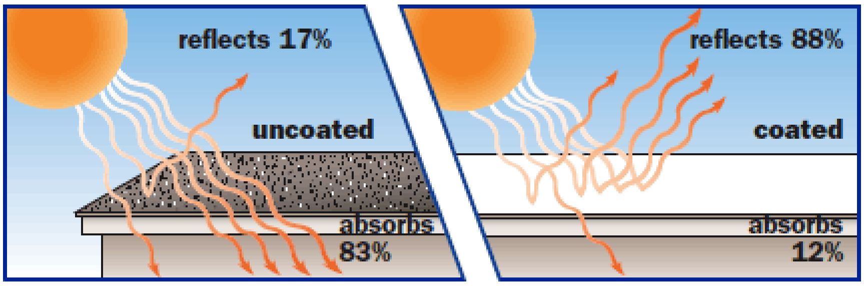


Appendix H- Usage of tree for environmentally sustainable Homes

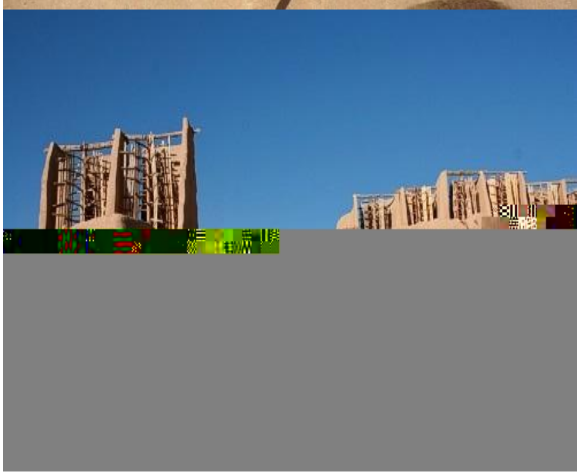




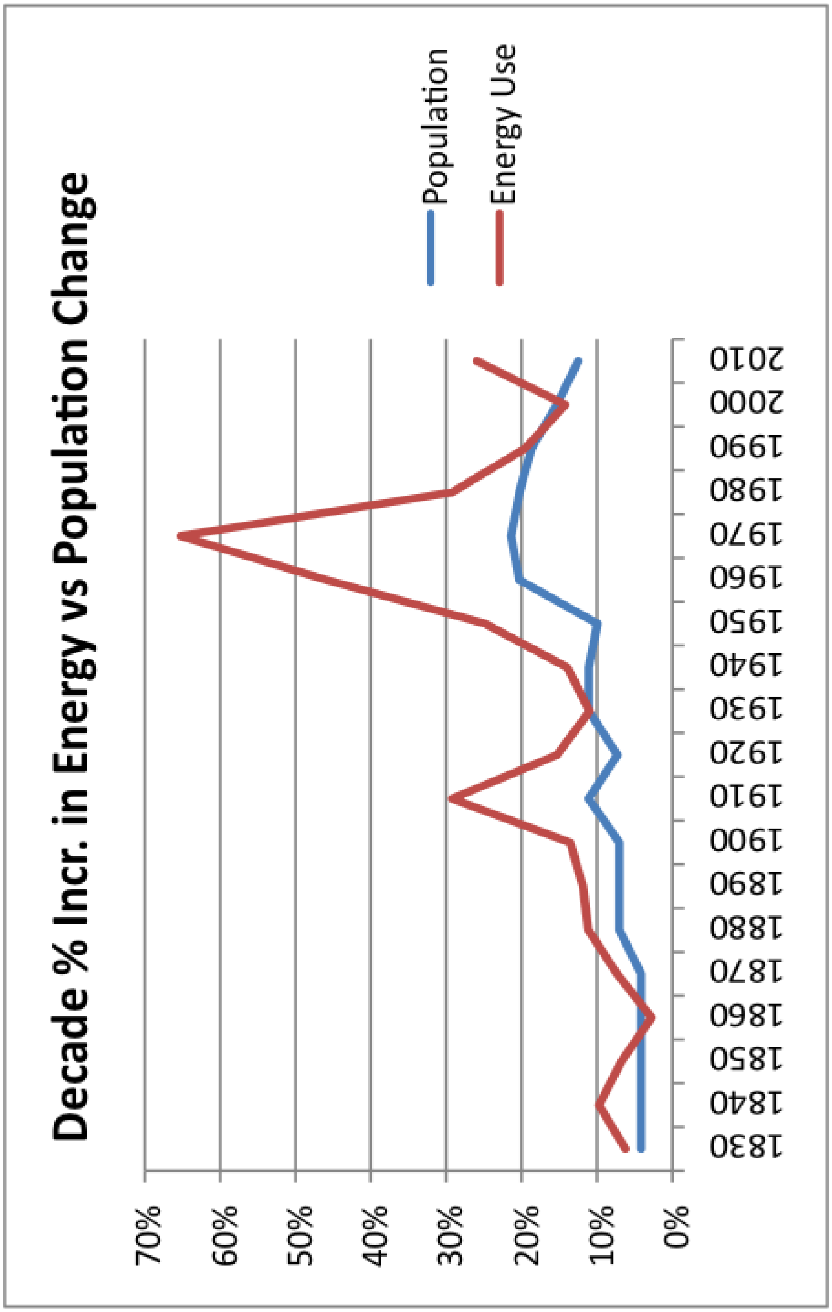
Appendix I- Bright colour on the roof will reflect more heat.



Appendix J-Windmill



Appendix K- Decade percentage increases in energy use compared to population growth



Appendix L- Literature review

Authors	Date	Type of source	Orientation	Dense texture	Repetition	Green surface	Materials	Wind catcher	Courtyard	Fountain	Skylight	Cistern
Fathy and Shearer	1986	Book	Orientation	Dense texture	Not researched	Green surface	Materials	Wind catcher	[illegible]	[illegible]	[illegible]	[illegible]

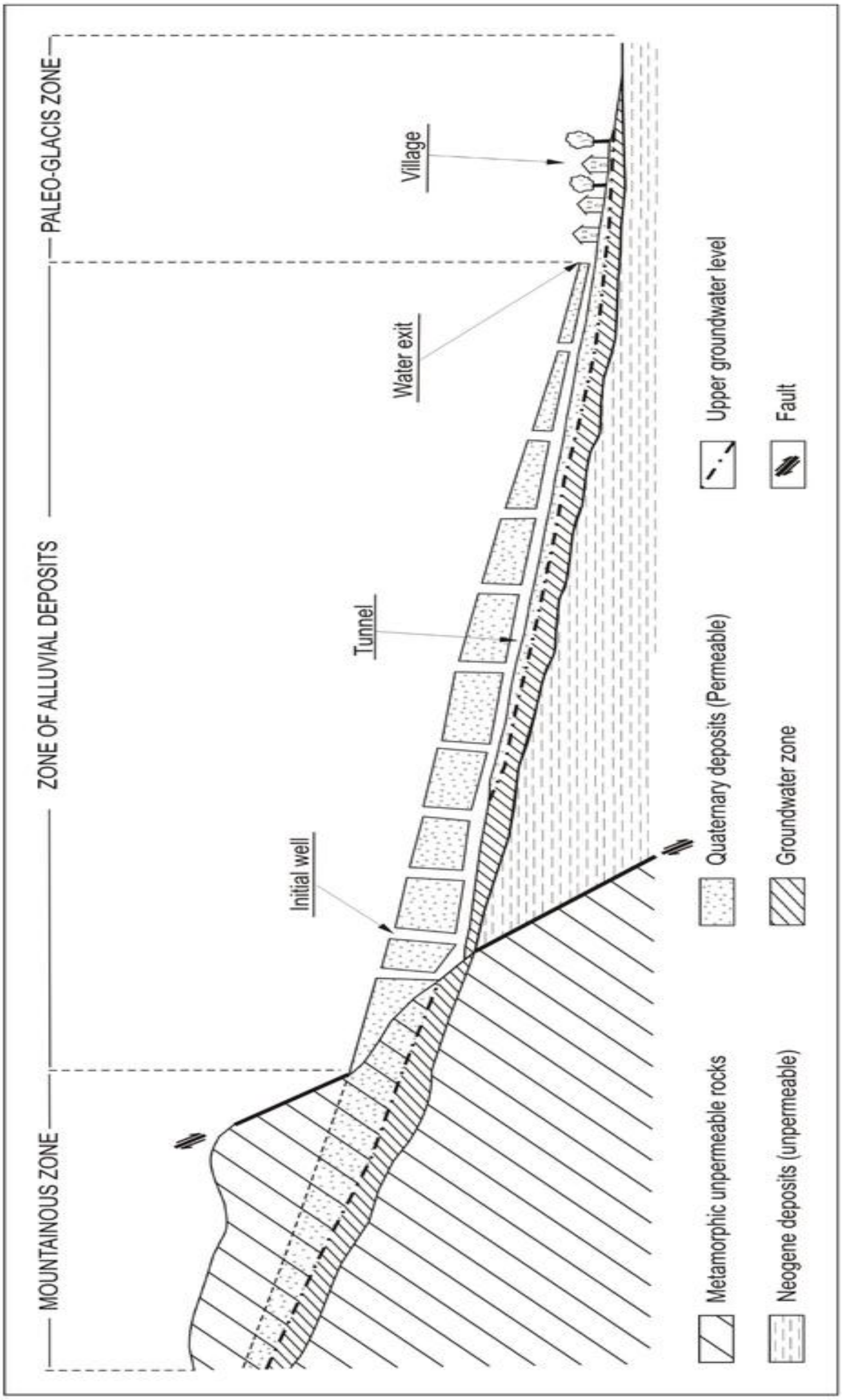
Tahbaz and Djalilian	2008	Journal	Orientation	Dense texture	Not researched	Not researched	Materials	Not researched	Not researched	Not researched	Not researched	Not researched
Araghchian	2009	Journal	Not researched	Dense texture	Not researched	Not researched	Materials	Not researched	Not researched	Not researched	Not researched	Not researched
Bolkhari	2009	Journal	Not researched	Not researched	Repetition	Not researched	Not researched	Not researched	Courtyard	Fountain	Not researched	Not researched
Heidari	2009	Journal	Orientation	Dense texture	Not researched	Not researched	Not researched	Not researched	Not researched	Not researched	Not researched	Not researched
Iranmanesh and Bigdeli	2009	Conference	Orientation	Dense texture	Not researched	Not researched	Not researched	Not researched	Not researched	Not researched	Not researched	Not researched
MacKay	2009	Book	Orientation	Not researched	Not researched	Not researched	Materials	Wind catcher	Not researched	Not researched	Not researched	Not researched
Mahmoudi	2009	Journal	Not researched	Not researched	Not researched	Not researched	Not researched	Wind catcher	Not researched	Not researched	Not researched	Not researched
Memarian	2009	Journal	Not researched	Dense texture	Not researched	Green surface	Not researched	Not researched	Not researched	Not researched	Skylight	Cistern
Salama	2009	Journal	Orientation	Not researched	Not researched	Not researched	Not researched	Wind catcher	Not researched	Not researched	Not researched	Not researched
Sundarraja and Radhakrishnan	2009	Journal	Orientation	Not researched	Not researched	Green surface	Materials	Not researched	Not researched	Not researched	Not researched	Not researched
Amirkhani et al	2010	Journal	Orientation	Not researched	Not researched	Not researched	Not researched	Wind catcher	Not researched	Not researched	Not researched	Cistern
Elshorbaghy	2010	Journal	Orientation	Not researched	Not researched	Not researched	Not researched	Wind catcher	Not researched	Not researched	Not researched	Not researched
Pourvahidi	2010	Thesis	Orientation	Dense texture	Repetition	Green surface	Materials	Wind catcher	Courtyard	Fountain	Skylight	Cistern
Ahmadkhani	2011	Journal	Not researched	Not researched	Not researched	Not researched	Materials	Wind catcher	Courtyard	Fountain	Not researched	Cistern
Ashrafian and Mahdavi	2011	Journal	Orientation	Not researched	Repetition	Green surface	Not researched	Wind catcher	Courtyard	Not researched	Not researched	Cistern
Dabaieh	2011	Thesis	Orientation	Dense texture	Not researched	Green surface	Materials	Wind catcher	Courtyard	Not researched	Skylight	Not researched
Dehnavi et al	2011	Journal	Orientation	Not researched	Not researched	Green surface	Not researched	Wind catcher	Courtyard	Fountain	Not researched	Not researched
Eiraji and Namdar	2011	Conference	Not researched	Not researched	Not researched	Not researched	Not researched	Wind catcher	Not researched	Not researched	Not researched	Cistern
Fereidouni	2011	Journal	Not researched	Not researched	Not researched	Green surface	Materials	Not researched	Not researched	Not researched	Not researched	Not researched
Ghajar	2011	Book	Not researched	Not researched	Not researched	Not researched	Materials	Not researched	Not researched	Not researched	Not researched	Not researched
Haj Soghta	2011	Book	Orientation	Dense texture	Repetition	Green surface	Materials	Not researched	Not researched	Not researched	Skylight	Not researched
Jazayeri and Gorginpour	2011	Journal	Not researched	Not researched	Not researched	Not researched	Materials	Wind catcher	Not researched	Not researched	Not researched	Not researched
Kazemi and Shirvani	2011	Journal	Not researched	Not researched	Not researched	Not researched	Materials	Wind catcher	Not researched	Not researched	Skylight	Cistern
Lavafpour and Surat	2011	Journal	Orientation	Not researched	Not researched	Green surface	Materials	Wind catcher	Courtyard	Not researched	Not researched	Cistern
Mohammada[illegible]	2011	Journal	Orientation	Dense texture	Not researched	Green surface	Materials	Wind catcher	Courtyard	Not researched	Skylight	Not researched

Appendix M- Prioritise of principles

Author	Year	Source	Discussion principles	Theme	Major Debate	Orientation (1)	Dense texture (2)	Repetition (3)	Green surface (4)	Materials (5)	Wind catcher (6)	Courtyard (7)	Fountain (8)	Skylight (9)	Cistern (10)
Ahmadkhani	2011	Journal	Materials/ Wind catcher/ Courtyard/ Fountain/ Cistern	Architects were obliged to rely on natural energies to render the inside condition Wind catcher were the most important means by which the interior was cooled Wind catcher operates according to the condition of the wind and sun radiation in the region Wind catcher is like a chimney whose end is in the underground and the top is set over a specific height on the roof warm Wind will pass over a pond with a fountain gets cool and wet through evaporation Wind catcher is made with mud-brick, gets cool by radiation and convection	Passive and low energy cooling system in Iranian vernacular buildings					✖	✖	✖	✖		✖
Ashrafian and Mahdavi	2011	Journal	Orientation/ Repetition/ Green surface/ Wind catcher/ Courtyard/ Cistern	Lack of fossil energy resources on the earth is a vast problem because of population explotion Using sustainable desert energy in buildings Use solar energy and the way of decreasing infiltration inflow weather from outdoor and absorption of the heat of solar energy Using traditional wind catcher illustrated and suggested similar system for new tall tower and buildings that can be used in other hot climates	Using sustainable and renewable energies in Iranian vernacular architecture	✖		✖	✖		✖	✖			✖
Bakhshi and Mofidi	2003	Journal	Orientation/ Green surface/ Materials/ Skylight	Local materials that have the least negative impact on the environment Reducing energy consumption by using local materials	Sustainable construction in conjunction with the Iranian vernacular architecture	✖			✖	✖				✖	
Dabaieh	2011	Thesis	Orientation/ Dense texture/ Green surface/ Materials/ Wind catcher/ Courtyard/Skylight	Vernacular architecture has always been the product of a sustainable building cycle Create a theoretical conservation model for thinking revernacular in a contemporary context how to adjust contemporary desert vernacular housing to contemporary life-style Global ambitions and socio-economic development are factors for disappearing of vernacular architecture	Discussion of vernacular buildings by testing a conservation model	✖	✖		✖	✖	✖	✖		✖	
Dehnavi et al	2011	Journal	Orientation/ Green surface/ Wind catcher/ Courtyard/ Fountain	Review demonstrated wind catchers characteristics with emphasis on their morphology Evaluate the performance of square wind catchers in order to find the most efficient form of square wind catcher in decreasing the indoor air temperature Results were evaluated by numerical method	Study of wind catchers with square plan	✖			✖		✖	✖	✖		
Ebrahimi et al	2013	Conference	Orientation/ Dense texture/ Repetition/Materials/ Wind catcher/ Courtyard/ Fountain/ Cistern	Understanding vernacular architecture of every region may have significant impacts on developing green strategies for the new architecture study adapted field studies as well as archival research followed by qualitative methods of content analysis	Impact of climate on the foundation of the vernacular architecture	✖	✖	✖		✖	✖	✖	✖		✖
Eiraji and Namdar	2011	Conference	Wind catcher/ Cistern	Sustainable architecture, the way of architectural design which is based on environmental aspects Due to lack of access to modern heating and cooling equipment in ancient times the architects were obliged to rely on natural energies Use convection and evaporation in their design and certainly wind and water play the main roles	The availability of sustainable methods in Iranian vernacular buildings						✖				✖
Esfandiari	2007	Conference	Orientation/ Cistern	Inventing ways and means of procuring water from the places where it could be found and diverting it to the places where it was needed for irrigation Qanat system was invented by the people of the plateau of Iran Up to twenty years ago, the seventy-five per cent of all water used in Iran came from Qanats	Qanat; Iranian's most remarkable ancient irrigation system	✖									✖
Foruzanmehr and Nicol	2008	Journal	Orientation/ Green surface/ Wind catcher/ Courtyard	Vernacular architecture is more adaptable to the environment according to principles evolved over many generations vernacular technologies are energy efficient and sustainable Identify and find the extent to which principles are viable and useable Vernacular passive-cooling strategies investigated, including: cultural acceptance, thermal comfort of occupants and energy performance	Integrating vernacular passive-cooling systems into modern buildings in Iran	✖			✖		✖	✖			
Frahmanpour et al	2008	Conference	Dense texture/ Materials	Iran's ultimate energy consumption pattern over the last decades is inefficient and contributes towards the excessive consumption of fossil fuels which produces several quantities of pollutants and green house gases	Analysis of ultimate energy consumption in Iranian buildings		✖			✖					
Ghadiri et al	2013	Journal	Wind catcher	Wind catchers have been utilized as a solution in order to improve indoor air quality and decrease energy consumption most common ventilation device in hot and hot-humid areas of Iran was wind catcher appraisal of the wind catchers' individuality with prominence on their morphology is presented	Performance evaluation of a type of windcatcher in different geometreis						✖				
Ghobadian	2003	Book	Orientation/ Dense texture/ Materials/ Wind catcher/ Courtyard/ Fountain/ Skylight/ Cistern	Adobe as a building material has a distinctive thermal characteristic Correctly orientated building can save a lot of money in no longer required heating and cooling costs expenditure	Climate analysis through sustainability of Iranian vernacular buildings	✖	✖			✖	✖	✖	✖	✖	✖
Heal et al	2006	Conference	Orientation/ Green surface/ Materials	Innovative approach to teaching and learning the subjects of vernacular architecture and sustainable design Illustrates both the educational process and outcomes that have been achieved using vernacular architecture as a source of information and inspiration	The vernacular building as a symbol of sustainable architecture	✖			✖	✖					
Heidari	2009	Journal	Orientation/ Dense texture/ Materials/ Courtyard	Using passive methods for cooling or heating of the building	Thermal comfort in Iranian courtyard housing	✖	✖			✖		✖			
Heidari	2000	Thesis	Orientation/ Dense texture/ Green surface/ Materials/ Courtyard	Investigated thermal comfort for naturally ventilated housing in Iran Methodology used for this study was field studies Results showed that passive systems as a main comfort strategy could be applied to housing design	Thermal comfort in Iranian courtyard housing	✖	✖		✖	✖		✖			
Hejazi and Mehdizadeh	2014	Book	Orientation/ Dense texture/ Repetition/ Green surface/ Materials	Persian traditional buildings are based and methodologies used for their preservation describes the construction materials used in architectural heritage structures, traditional construction technology and structural analysis of architectural heritage, arches, vaults, and domes	Discussion about persian architecture and their influnce and their influnce in the environent	✖	✖	✖	✖	✖					
Hossein ghadiri et al	2014	Journal	Wind catcher	Wind catchers are traditional natural ventilation systems attached to buildings in order to ventilate the indoor air CFD simulation recommended as a perfect way to evaluate the wind catcher performance The CFD simulations are validated with detailed wind tunnel experiments	Analysis of Natural Ventilation Behaviour in one type of wind catcher						✖				
Hosseini	2012	Journal	Cistern	These reservoirs are usually located behind the shading wall and at its south Ice house is a reservoir to store and preserve ice Passively procured ice during the hot days of the summer is an enlightening inception It was also a place to keep meat, dairy products and other food stuff fresh and healthy during the hot summer days	An overview of Iranian water and ice reservoir										✖
Iranmanesh and Bigdeli	2009	Conference	Orientation/ Dense texture	Lacking attention to the climatic design and depending merely on artificial cooling and heating systems, the buildings are very hot in summer and are so cold in winter and in result they are quietly uncomfortable	Climatic design and low carbon city regarding the traditional experiences	✖	✖								
Karimi and Hosseini	2012	Conference	Dense texture/ Repetition/ Materials/ Courtyard/ Fountain/ Cistern	There are reasonable relations between human lifestyle and the architecture of the place Houses are compressed to each other and have merged walls in order to minimize the contact of wall surfaces with air so there would be less thermal exchange between inside and outside of the buildings. Material with heavy thickness with walls surrounded the house function like a capacitor that observe solar heat during the day and transfer the heat to the environment during the nights time Iranian vernacular buildings is as yet little known in the West	The influence of Iranian islamic architecture on vernacular buildings		✖	✖		✖		✖	✖		✖

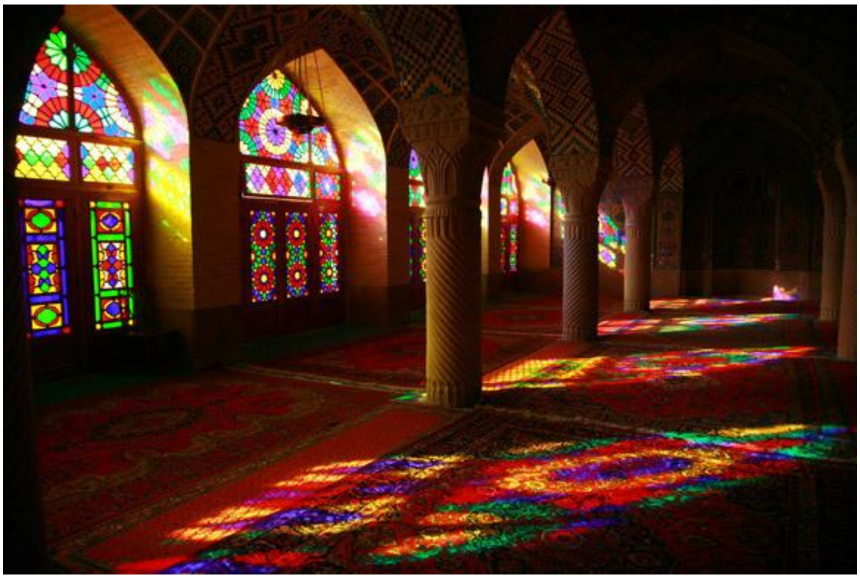
Karimi and Hosseini	2012	Conference	Dense texture/ Repetition/ Materials/ Courtyard/ Fountain/ Cistern	during the day and transfer the heat to the environment during the nights time	The influence of Iranian islamic architecture on vernacular buildings										
Kazemi and Shirvani	2011	Journal	Materials/ Wind catcher/ Skylight/ Cistern	Iranian vernacular buildings is as yet little known in the West Study of the craftsmanship involved in the construction of the mud brick vernacular architecture of Iran expanding the existing knowledge	An overview of Iranian vernacular techniques as a sustainable methods					✖	✖			✖	✖
Lavafpour and Surat	2011	Journal	Orientation/ Green surface/ Materials/ Wind catcher/ Courtyard/ Cistern	Buildings can be designed to require far less than the energy of today's average Design strategies in terms of energy efficiency is considered based on proper building form, material selection and orientation and by taking advantages of passive cooling strategies and ventilation	Towards new approaches for converting principles of vernacular architecture into energy efficient buildings	✖			✖	✖	✖	✖			✖
Mahmoudi	2009	Journal	Wind catcher	Wind catchers have been served as a cooling system, used to provide acceptable ventilation by means of renewable energy of wind Learning about wind catchers in this study is done by means of field surveys. Research method for selection of the case is based on random form, and analytical method	Discussion the wind catcher as a natural cooling system in Iranian vernacular architecture						✖				
Mashhadi	2012	Thesis	Orientation/ Dense texture/ Repetition/ Green surface/ Materials/ Wind catcher/ Courtyard/ Cistern	Climate is a fundamental environmental factor, which effects the formation of vernacular architecture throughout the world The research evaluate and compare urban textures and traditional houses	Comparison of Iranian and Turkish vernacular buildings	✖	✖	✖	✖	✖	✖	✖			✖
Mohammad and Shea	2013	Journal	Orientation/ Dense texture/Materials	Found the most appropriate alternative to the traditional un-fired clay and brick materials the best and worst wall type in terms of their cyclic thermal performance and their ability to moderate outdoor conditions is identified	Performance evaluation of modern building thermal envelope designs	✖	✖			✖					
Mohammadabadi and Ghoreishi	2011	Journal	Orientation/ Dense texture/ Green surface/ Materials/ Wind catcher/ Courtyard/ Skylight	Green architecture holds a special place among the architecture experts Scrutinising the principles of green architecture in clinical centres, a suitable design for green architecture in these buildings based on Iranian vernacular architecture using modern technologies	Green principles in Iranian vernacular architecture	✖	✖		✖	✖	✖	✖		✖	
Monshizadeh	2008	Conference	Orientation/ Dense texture/ Repetition/ Materials/ Courtyard/ Fountain	Native architecture in the desert is the consequence of expreince based knowledge Traditions of vernacular architecture have many lessons for seeking sustainable forms The form of Iranian vernacular buildings are inward looking	The desert city as an ancient living example of ecocity	✖	✖	✖		✖		✖	✖		
Montazeri and Azizian	2008	Journal	Wind catcher	Wind catcher as a natural ventilation system is increasingly used in modern buildings to minimize the consumption of non-renewable energy and reduce the harmful emissions experimental wind tunnel, smoke visualization testing and computational fluid dynamic modeling were conducted to investigate ventilation performance of wind catchers Experimental investigations were conducted in an open circuit subsonic wind tunnel	Experimental study on natural ventilation performance of wind catcher						✖				
Nabavi and Teo Goh	2013	Journal	Orientation/ Repetition/ Courtyard/ Skylight	Iranian traditional houses had shown an intimate connection with nature The vernacular architecture is responsive to climate and occupant's requirement Courtyard houses is the most prominent house type in hot arid region and physical feature of it reflects natural needs and environment responding Analysed the application of the building elements and solutions to bring daylight into different parts of these traditional courtyard houses	Design Strategies: A Lesson from Iranian Traditional Houses	✖		✖				✖		✖	
Najafi	2013	Journal	Orientation/ Green surface/ Materials/ Wind catcher/ Courtyard/ Fountain/ Cistern	Climate is an important factor in logical formation of urban structures and their type of architecture promote energy efficient architectural design in semi hot-arid climates by introducing the technics that the traditional architects used to design buildings	Influence of Iranian vernacular buildings in terms of energy saving	✖			✖	✖	✖	✖	✖		✖
Pirhayati et al	2013	Journal	Wind catcher	Iranian vernacular architecture is full of creativity and innovation which indicate the intelligence Wind catcher is an engineering architectural masterpiece of earth to deal with this unbearable heat Buildings were derived and inspired from the nature and environmental conditions and utilised the elements of nature with the best way related to the architecture	Discussion about the creation of windcatcher and their influence in environment						✖				
Pourvahidi	2010	Thesis	Orientation/ Green surface/ Materials/ Wind catcher/ Courtyard/ Fountain/ Skylight/ Cistern	Classify the climates for architectural purposes to understand Iranian vernacular architecture Bioclimatic design in the buildings tries to maximise thermal comfort and minimise the buildings need for energy for heating and for cooling Retrieving the climatic data from all Iranian meteorological stations found the characteristic of each region and new bioclimatic charts achieved	Bioclimatic analysis of Iranian vernacular buildings	✖			✖	✖	✖	✖	✖	✖	✖
Saeidian	2013	Journal	Materials/ Wind catcher/ Cistern	a creative traditional solution has been a unique kind of water reservoirs (cisterns) These structures typically consist of an underground cube or cylindrical reservoir with a massive covering dome and one or more wind towers for ventilation and a staircase for taking water	Sustainable traditional water supply system in hot arid regions					✖	✖				✖
Soltani et al	2012	Journal	Orientation/ Wind catcher/ Cistern	Having a highly developed technology make these vernacular buildings still alive, by using an incredible use of natural resources with ought consuming extra energy	Energy management in Iranian vernacular buildigns	✖					✖				✖
Soufiandost	2013	Journal	Orientation/ Dense texture/ Wind catcher/ Courtyard/ Fountain/ Cistern	Vernacular buildings are much more environmentally friendly and are not relying on high tech energy consuming systems The building direction in desert textures is effective in benefiting natural potencies and resources within reach	Climate,architecture and air conditioning in Iranian vernacular buildings	✖	✖				✖	✖	✖		✖
Tahbaz and Djalilian	2008	Journal	Orientation/ Dense texture/ Materials	Modern buildings causes essential use of mechanical heating and cooling systems Adapting new constructions to the mode rate and humid climate Design principles which are adjusted to the life style, economic situation and climate conditions is presented	Challenge of vernacular architecture and modern life style	✖	✖			✖					
Wahid	2012	Journal	Orientation/ Dense texture/ Materials/ Wind catcher	Vernacular principles can be employed to address solutions for sustainable design particularly for creating high style sustainable architecture Vernacular architecture is a consequence of local conditions as it tends to evolve over time to reflect the environmental, cultural and historical context in which it exists	Adaptive vernacular principles for sustainable architecture	✖	✖			✖	✖				
Yousefi et al	2013	Journal	Orientation/ Dense texture/ Green surface/ Materials	The trends in contemporary Iranian architecture, traditional architecture with thought energy far has been the traditional procedures, will be necessary Vernacular architecture and itsdifferent regions are formed in such a way to preserve cultural identity construction	Energy and sustainable development in vernacular buildings of rural settlements	✖	✖		✖	✖					
Zabihi, Habib and Mirsaeedie	2012	Journal	Orientation/ Green surface/ Materials	Impact of the building construction on the environment during the construction process The impact analysis by taking a survey of different construction projects	Discusion for sustainability in building and construction	✖			✖	✖					
Zandieh, Khaleghi and Rahgoshay	2012	Journal	Materials/ Cistern	Study of thermal mass buildings, especially, a kind of masonry building called cistern, where most of the buildings are constructed out of mud or sun-dried bricks Such traditional solutions may help to overcome the energy crisis which the mankind faces today and may face in the future	The discussion of a thermal mass in Iranian vernacular architecture					✖					✖
Zarghami et al	2012	Conference	Materials	Materials used in traditional and local architecture in Iran derived from their deployment environment and are provided the necessary compatibility with the environment Use of such materials in buildings, reduce the natural resources use and other energy resources saving during the production process materials	The use of calcareous materials in the vernacular buildings of Iran					✖					
						27	17	7	15	26	23	18	9	7	17 Total 166
						16.26%	10.24%	4.21%	9.03%	15.66%	13.85%	10.84%	5.42%	4.21%	10.24%

Appendix N- Qanat

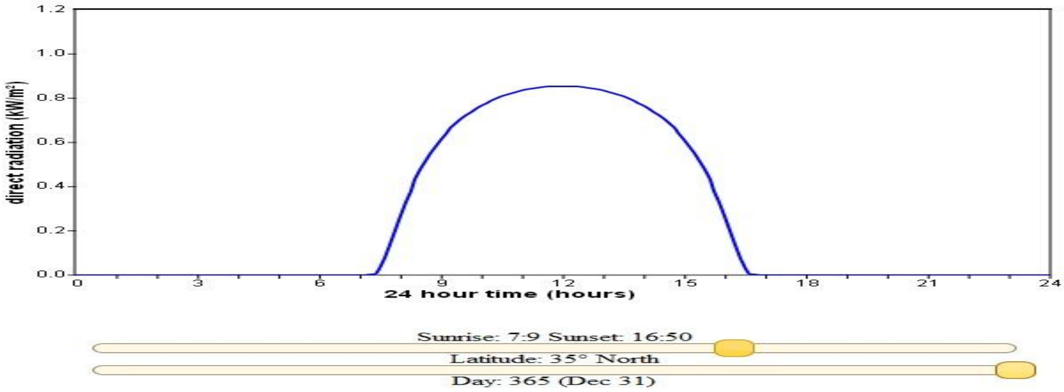


Appendix O- Sabaat (Narrow passage to protect people from direct sun and heat)

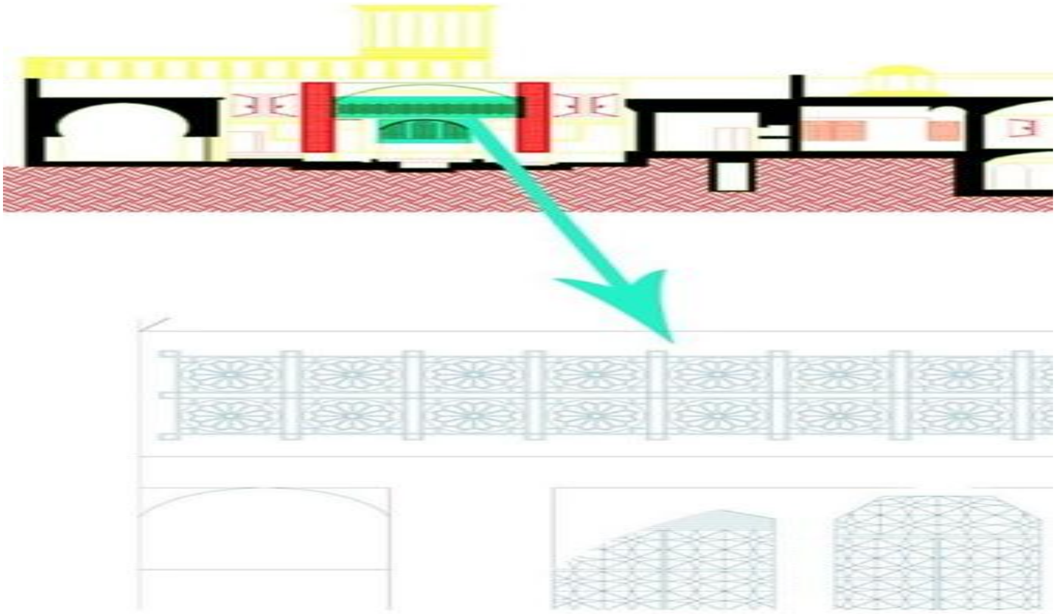
Appendix P- Nodes and designs on wooden windows



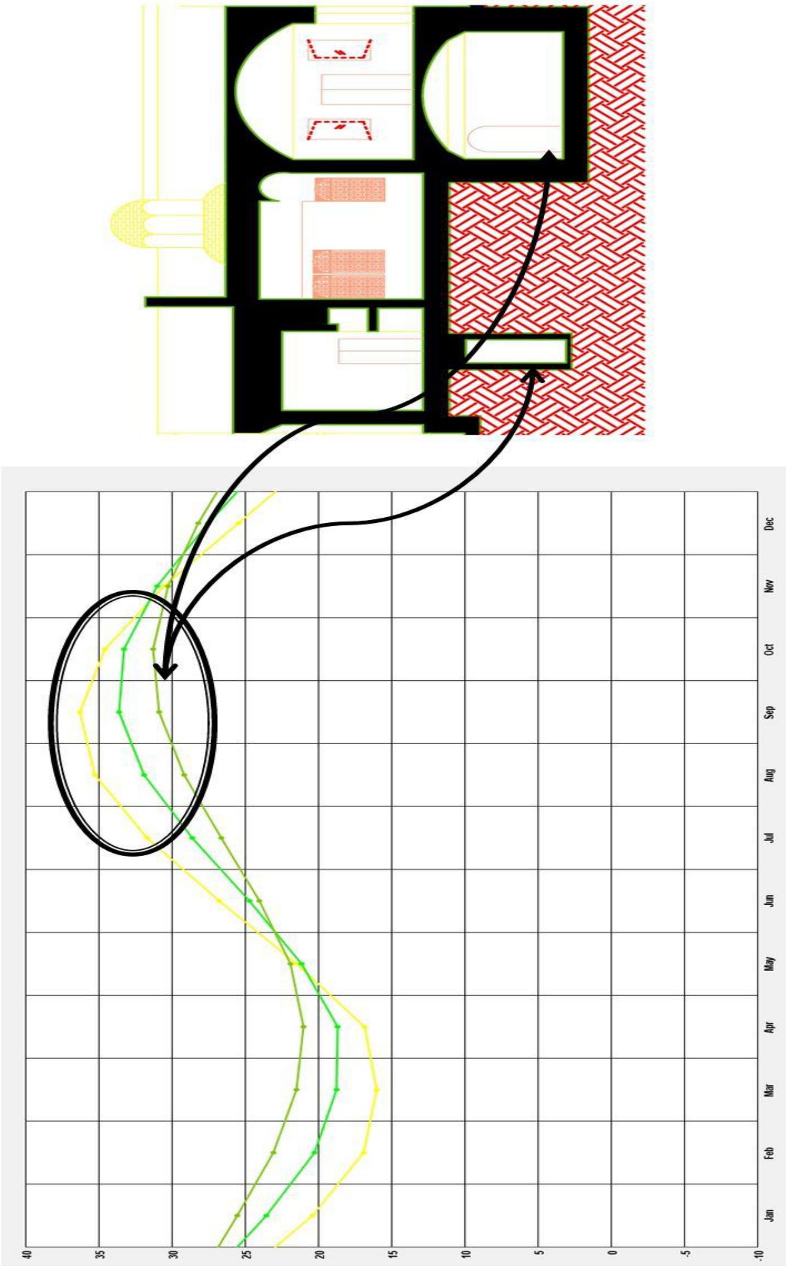
Appendix Q- Tehran daylight on 31 Dec



Appendix R



Appendix S- Comparison of ground temperature in different periods



Appendix T- Cover letter and consent form for the questionnaire

To whom it may concern

Dear Sir/ Madam

I am currently pursuing my PhD at London South Bank University, focusing on the vernacular architecture in cities of Iran. The primary goal of this study is to identify, examine, and critically assess the characteristics of vernacular architecture in the historical hot cities in Iran. The study aims at establishing the key principles of Iranian vernacular architecture that contribute to energy efficiency and principles of sustainability. Alongside this, the study aims to design a successful virtual prototype to reduce the carbon emission and energy consumption for occupied buildings by relying on natural resources. Importantly, the results obtained here will not only be of value to the individual students, but will also help the Iranian architects, academicians and other professionals who are interested in either promoting or abandoning the vernacular architecture in the modern days in Iran. The representative sample comprises of the constructors, engineers and qualified professionals in Iran, who have specialised knowledge concerning vernacular architecture. Your attitudes and opinions are very critical to the success of this study. There are no correct or incorrect responses, only your much needed opinion to validate and evaluate the collected information. All answers will be treated in confidence and used for academic purposes only. I recognise the value of your time, and I appreciate your efforts in completing the survey. Furthermore, the individual responses will be held anonymous. Please take your time to complete the survey and submit your response at your earliest convenience.

Sincerely,

Ehsan Mohammadzadeh

Doctoral research student

London South Bank University

Email: mohamme5@lsbu.ac.uk

Appendix U- The T-Test result

Ttest: Strongly agree vs Agree	Ttest: Strongly agree vs Disagree	Ttest: Strongly agree vs Strongly disagree
0	0	0
Ttest: Agree vs Disagree	Ttest: Agree vs Strongly disagree	
0.00098722	2.64282E-10	
Ttest: Disagree vs Strongly disagree		
6.28167E-08		

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