Vernacular Architecture And Energy Use In Buildings: A Comparative Study

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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. In 2013, the global emission of carbon dioxide due to fossil fuel use was 36 giga tonnes, showing an increase of 61 per cent compared to the year 1990. This trend cannot continue due to the devastating effects that existing patterns of energy consumption may have on our future. The traditional and localised methods of design and construction of buildings, namely vernacular architecture, are known to have superior qualities compared to the modern ones. In this paper we aim to show how energy use in buildings can be minimised by using the principles that we adopt from vernacular architecture in Iran. This is shown by identifying and testing the principles of Iranian vernacular architecture. This paper has three sections. The first two sections will discuss Iranian vernacular architecture and current energy consumption of modern buildings. The last section, which is our case study, will simulate both modern and vernacular buildings in the same climate conditions. This paper presents the energy performance comparison between both modern and Iranian vernacular architecture, which enables the identification of performance problems based on a comparison of measured performance data and simulated performance data representing design goals. The paper will indicate an untapped potential to reduce energy consumption of buildings and highlight the gap between modern buildings and vernacular buildings.

Keywords: Iranian vernacular and modern architecture, Energy Consumption, Thermal comfort

I. INTRODUCTION

Our planet is facing devastating challenges that are manifested by a change in climate, in particular global warming. The research community cannot ignore the importance of seeking alternative methods of energy generation as well as savings in energy consumption in buildings as a major contributor to the problem. Renewable energy refers to heat and electricity that is generated from the natural resources such as wave, sun, and wind which are sustainable and never run out. Furthermore, using sustainable energy reduces greenhouse gas emissions, while decreasing our dependency on fossil fuels. The appealing aspect of renewable energy is that, unlike fossil fuel, this type of energy will never run out (Solomon et al., 2009). According to Action with Communities in Rural England (ACRE) (2013), the use of renewable energy sources globally has been on the rise for the last two decades. Renewable energy can also save money on domestic energy bills, and generate income through the feed-in tariff. The importance of environmental considerations and use of renewable energy sources in Iran as a developing economy is a given. The climatic conditions in Iran are such that in theory architects can easily make use of natural resources, such as wind and the Sun for supplying energy, particularly in buildings. However, environmental sustainability and sustainable architecture in Iran are still relatively new concepts. There has been some effort in Iran since the 1950s to follow more environmentally sensitive approaches to architecture (Gissen, 2002), yet as Vellinga (2006) argues there have not been many studies or research on the concept of vernacular architecture, particularly in the context of Iran and its climate. Similarly, there is no systematic study of principles of such architecture with regards to their implementation to modern buildings. In developing a case for promoting the application of principles of vernacular architecture the paper first reveals the traditional methods of sustainable design and the principles of Iranian vernacular architecture, and then discusses their usage and their functionality. The paper also compares energy consumption in a modern building and vernacular building by using current methods and techniques, by creating a digital prototype and computer analysis.

II. RENEWABLE ENERGY AND THE BUILDING SECTOR

One of the most significant environmental pollutants such as Co², in cities is generated by using fossil fuels to create heat in residential buildings in particular (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. In fact, fossil fuels constitute the pillars of the industry both in Iran and other parts of the world (Rifkin, 2012). This growing problem in the construction industry and cities is due to the lack of consideration of the designers and constructors to bring their designs in harmony with the natural conditions of their surrounding environment. Modern buildings are criticised for their incompatibility with their surroundings (Farshchi and...
Fisher, 2000). Poorly designed buildings can lead to extensive use of electrical equipment in order to maintain desired thermal comfort conditions. As a result, it is thought that one of the major sectors to consume energy is the building sector (Abbaspour et al., 2013; Farahmandpour, 2008; Ayatollahi, 2003). In developing countries, the building sector consumes around 40 per cent of the proportion of total energy use (Levine et al., 2007). This is expected to double in the next 25 years, with an annual average growth rate of 2.8 per cent (Lombard, 2008). The building sector is a considerable consumer of energy in the UK, India and Iran with contributions of 46, 39 and 36 per cent respectively (Forouzanmehr & Nicol, 2008). Unfortunately, a large share of energy consumed is wasted due to inefficiencies (Zyga, 2011). In the UK, for example, it is claimed that with adequate insulation of the existing building stock, energy consumption could be halved (Roaf, 2004, p.130).

In contrast to modern architecture used in most cities in developing countries, vernacular buildings tend to be climate-responsive in many ways. Vernacular buildings represent a guide to informing sustainable design principles because they are made of locally available materials, employing local people, mainly using renewable sources of energy, and adopting construction practices that favour recycling and respect for nature (Halicioglu 2012; Heal et al., 2006; Yilmaz, 2006). The solution to buildings which are more adequately responsive to our environmental problems cannot ignore the knowledge that has been created over many centuries, and is showing us how to live in harmony with surrounding nature. From vernacular architecture, we can find out and learn how natural resources can be used to create a comfort zone for the occupants in the harsh outdoor environment.

The traditional ‘builder’ (called Memar) in Iran in the past was trained by an older master builder, who taught him building skills and techniques. By the passing on of his of tacit knowledge which he had gained from previous generations, in turn he trained, and passed on those skills to, the forthcoming generation. With the dominance of the modern building philosophy, the precious techniques and principles of vernacular architecture which can provide us with effective solutions to minimise the use of fossil fuels are under threat.

An emerging phenomenon, in the past two decades both in the developed world as well as the developing economies, has been the increasing popularity of tall buildings. With high rise building construction, it is essential to use mechanical heating and cooling systems to heat/cool the building (Lombard, 2008). However, the architects in the pre-industrialised societies had no option but to rely on natural ways to render the inside condition of the buildings pleasant. With the loss of knowledge of the traditional methods and the prevailing trend in favour of ‘modern’ buildings it is not strange to find that new construction techniques in Iran do not use principles of the past climatic conditions and hence use inappropriate materials that consume a lot of energy and are very expensive (Ahmadkhani, 2011). Given the limitation of fossil energy resources and the imminent energy crisis, it is strictly necessary to focus on sustainable and renewable energy resources in designing buildings (Atkinson, 2009). The rapid growth in many regions of the world which has manifested itself by the vast movement of population from rural areas to cities has posed the question as to how the newly urbanised areas should plan their energy consumption. Within this process an architectural response which has been ignorant of the geographical conditions and regional specificities has caused further problems. The process of urbanisation has created additional demand for energy whether fossil fuels, oil or electricity several times more than in the past (Debach and Benzagouta, 2014). Naseri (2013) has claimed 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. Misuse of architectural design is particularly relevant to Iran, because a major part of Iran’s surface area, almost 90 per cent, has an arid and semi-arid climate (Alavipanah, 2006). In Iran, the Sun shines an average of 2360 to 3330 hours annually; central and southern parts of Iran are among the sunniest regions of the Earth with more than 3000 sunny hours annually offering great potential for supplying solar energy.

III. IRANIAN VERNACULAR ARCHITECTURE STYLES

History provides crucial evidence. An examination of Iranian vernacular architecture offers valuable lessons from the period prior to dependency on fossil fuel and non renewable energy, which influenced the building design. Ecosystem has been one of the most important development principles of the Iranian architecture in the past. Due to the unavailability of fossil energies and extreme climatic conditions in different regions, architects had to use natural energies and design buildings according to the climatic conditions of a given area. In the rest of this section, the strategies used in hot and arid climates and their application in today’s constructions will be discussed.

Iranian vernacular architecture has shown an intimate connection with nature, responsive to climate and 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 a natural climate approach 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 compatible with the climate (Bahreini, 2003). They provided humans with comfort in difficult situations such as in deserts (Ahmadkhani, 2011). The Iranian vernacular architecture can offer numerous 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). Iranian traditional builders tried in designing buildings 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 while 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 and main orientation of the building due south)
- 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 and the site and the surroundings

The deterioration of vernacular architecture is mainly due to popularity, application and use of new technology and modern design which are not really suitable for the climatic conditions of Iran. El Kafrawi (1998) states that modern buildings are foreign to this region since the technology has been applied without the philosophy which underlies it. It is not hard to see why modern architecture in Iran has replaced the traditional vernacular architecture principles given the rapid urbanisation since the mid 20th century. However the loss of such principles has a social and environmental cost that ultimately has to be paid by future generations. Resulting from the accumulated experience of many generations the Iranian vernacular architecture has instead offered a sustainable environment suitable for human life without a need to destroy the environment (Tabhbaz and Djalilian, 2008).

The presence of various types of land (for example, mountains, deserts, forests, arable land) lead to a variety of climatic conditions (for instance, wet, wet and dry, arid and semi arid, cold, hot) over the vast area of the country, and the Iranian native architecture has successfully adapted to all such weather conditions. The passage of time has clarified the importance and efficiency of this factor. The responsiveness of the Iranian vernacular architecture to the external environment has been achieved, for example, by protecting external surfaces exposed to direct sunlight using sun shades, or by making use of wind catchers, basements, or centrally located open spaces, suitable to the specific locational factors. In such a fashion internal comfort has been achieved without using electrically powered mechanical intervention (Sarami, 1997).

IV. ENERGY CONSUMPTION IN THE RESIDENTIAL SECTOR IRAN

In Iran, the residential sector is a great consumer of energy. Recent buildings designed in Iran account for approximately 36 per cent of the energy consumption of the country (Iran Energy and Electricity Planning Committee, 2013). Energy consumption in the Iranian building sector is 2.5 more than the global average, and this sector accounts for 26.4 per cent of the CO² 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 costs of pollutants emission in the household sector are estimated to be 12726 billion Rials (£307 Million). This is in contrast to industrialised countries where the major part of pollutants is produced by industries, and the household sector has a relatively small contribution. It can be concluded that Iran’s environmental problems are due to excessive energy consumption in the construction sector. A revision of energy consumption in the sector should be considered as a top priority for national energy optimisation especially for energy consumption during the construction process so that environmental impacts would not result in reduced quality of life imposing unwanted social costs on the households. Cities like Yazd in the centre of Iran, with extreme hot weather conditions, are more dependent on air-conditioning systems and electricity and mostly unable to adapt to a harsh and extreme climate. Bakhshi (2001) claims that in recent times the Iranian vernacular architecture has lost its identity and methods, while its strategies are undervalued and unused in modern buildings. This is in spite of the fact that vernacular architecture captures the cultural values of the society. It seems that vernacular
architecture is drawing its last breaths. As shown earlier, the Iranian residential sector is a major consumer of energy and therefore any reduction in energy consumption of the buildings for heating and cooling systems can be of significant importance.

V. CASE STUDY AND ANALYSIS

In this section we aim to show the energy performance of a building designed using the principles of Iranian vernacular architecture against a building designed using current high rise principles of the modern architecture. The comparison is based on simulation of energy consumption against the design goals. Here we demonstrate the potential energy reduction in buildings based on energy saving solutions from vernacular architecture. Buildings’ energy performance problems are well-documented (Mills. 2005). According to Scofield (2002) several studies show that heating, ventilation and air conditioning (HVAC) systems in buildings do not operate as predicted during design because of performance problems. Furthermore, buildings have a very long life-cycle and as a result their impact on the environment would be long-lasting. Despite this, energy performance in buildings is often inadequate given the design sustainability goals. In addition to energy consumption during the life cycle of a building, the entire process of the production of the built environment involves activities such as material extraction, processing and utilisation of natural resources which may cause further environmental problems. To reduce the damage to the environment, it is of vital importance to reduce the impact of the whole building production process, including design, construction and operation, on the environment. A number of studies have so far focused on issues relating to the life-cycle of green buildings as well as building products that are regarded sustainable. It has been suggested that, in general, the earlier green building features are incorporated into the design process, the lower the cost would be. In return, it is shown that sustainably designed buildings provide financial benefits over the life cycle of the project that conventional buildings do not offer such as energy and water savings, reduced waste, improved indoor environmental quality, greater occupant comfort/productivity (Acuff et al., 2005). The methodology used to evaluate energy consumption in two buildings designed using a) vernacular principles, and b) the traditional modern principles is simulation using existing dedicated software. Among the software packages which offer analysis and design of solar energy systems are Energy Plus, Design Builder and Integrated Environmental Solutions (IES). An energy consumption analysis using such software attempts to articulate all of the energy needs and usage in buildings. Building energy analysis simulations are used to predict energy flows in buildings. These include temperature, system performance, and electrical loads. By having more detailed measured data, a more detailed performance assessment is possible. However, the increased number of measured data point requires a structure to organise these data results. Integrated Environmental Solutions (IES) software permits measurement of energy consumption whether in an existing or 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 study below tries to show the energy consumption on a yearly basis. Furthermore, occupant behaviour 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 building’s envelope, including the surfaces;
- The performance of the air-conditioning and ventilation systems;
- The control strategies, sequencing of plant and equipment, controlled settings;
- The design relative humidity range;
- The different energy types, e.g. electricity.

VI. DESIGN SPECIFICATIONS

This section 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.

Table one illustrate the area and energy consumption of both buildings.

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Apartment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>657</td>
</tr>
<tr>
<td>Peak Cooling Load (W)</td>
<td>35726</td>
</tr>
<tr>
<td>Peak Heating Load (W)</td>
<td>40648</td>
</tr>
<tr>
<td>Cooling Load Density (W/m²)</td>
<td>78.77</td>
</tr>
<tr>
<td>Heating Load Density (W/m²)</td>
<td>89.35</td>
</tr>
</tbody>
</table>
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VII. THE GEOGRAPHICAL LOCATION FOR THE SIMULATED CASES

Figure 2 refers to the solar angle in Tehran during the whole year, and Figure 3 shows the intensity of direct radiation (w/m²) on 15th June (US Department of Energy). The latter refers to the amount of power that would be received by tracking radiation concentration in the absence of cloud. The time is the local solar time.

Sources:
- DOE, 2013
- Honsberg and Bowden, 2006

VIII. ANALYSIS AND RESULTS

This section outlines the energy simulation analysis of the two virtual buildings designed using IES software and Climate Consultant 5. Calculating the impact of energy consumption on a wide range of uses, offers the total building loads which will help us find out, not only which building consumes more energy, but also which of the elements in a building (for example, vernacular design building) can help reduce the consumption of energy. For the simulation purposes 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, e.g., walls, windows, HVAC, and ground, which together form a system driven by the environment and internal loads. Each of the two buildings demand a set of building energy services (for instance, heating, cooling, water heating, cooking, lighting, appliances). 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. After calculation it has been identified, a modern building needs 41 kW/m² to consume energy in 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. According to the Carbon Foot Print calculator, a modern building with 41 kW/m² produces 0.02 tonnes of carbon. In a vernacular building this number is 0.

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 to 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.

Window overhangs or operable sunshade and flat roofs in vernacular buildings work well in hot/mild dry climates (especially if they are light colored). Furthermore, this will 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). 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. Effective evaporation requires a continuous flow of air which was easily available in open courts over the central pool and fountains.

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. Furthermore the patios experience a radiation heat-loss during night-time. 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, convection currents are 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 and dry climates use enclosed, well-shaded courtyards, with a small fountain to provide wind-protected microclimates. Hot and 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 nighttime, 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, this actually has its own advantages. As the cool air dissipates from the floor and adjacent rooms, convection current is created and this therefore adds to the comfort within the house. The figure 7 illustrates various cooling loads in a modern building in a real environment.
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. 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 11 kW/m² energy while the modern one consumes 45 kW/m² energy to maintain comfortable conditions.

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 figure 8 and 9 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 8: Modern building
Figure 9: Vernacular building

The service demands 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 building’s energy consumption comes predominantly from electricity. In addition, the total annual energy consumption of the modern building studied ranged from 24 kW/m² to 68 kW/m²; these measured values compared to the vernacular building, which was between 16.5 kW/m² and 23 kW/m², show that the modern building consumes much more energy.

CONCLUSION

Vernacular architecture does not rely on high-tech energy-consuming systems for heating, cooling, ventilation and lighting, but on the immediate natural systems in the local environment. Current energy consumption charts and graphs lead us to believe 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 (Szupinger and Csoobod, 2011).

The examination and analysis of the modern work indicates a lack of use of appropriate natural resources. 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. The existing data is enough to properly quantify important energy consumption in both buildings. Based on the identification of the building’s performance energy consumption, which was the main focus at this stage of the paper, it is possible to specify elements and principles of Iranian vernacular architecture which reduce the energy consumption of the construction.

Comparative studies reflect upon the fact that for a modern building to achieve a comfort zone for its occupants, mechanical energy needs to be used 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. It is clear from the research analytical validation work that the simulations correctly show the huge 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 modern buildings.

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
- The use of straight lines in the design

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• 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

REFERENCES


[26] RIBA. London.
[31] Irreversible climate change due to carbon dioxide emissions. PNAS, 106, 1704–1709.

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