

Towards new approaches for integrating vernacular passive-cooling systems into modern buildings in warm-dry climates of Iran

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Abstract

Currently, energy constraint and global warming are the biggest challenges confronting the planet. The building sector is one of the major energy consumers in the world. In hot climates, most 20th century buildings are dependent on air-conditioning systems and electricity, reliant on fossil fuels and increasingly unable to adapt to a warming climate. In contrast to modern buildings, vernacular architecture in these regions is more adaptable to the environment according to principles evolved over many generations. .

Many vernacular technologies are energy efficient and sustainable, although some of them are currently no longer properly functioning because of changed cultural and ecological situations. In this regard, the key challenge is to learn fundamental lessons and principles of vernacular architecture, and to find ways of integrating those principles into development programmes to plan new settlements or to upgrade existing ones. Studying traditional techniques to understand the sustainable strategies used in arid central Iran should make a valuable contribution to the field.

This paper provides an introduction to and methods for research focusing on vernacular passive-cooling strategies (VPCSs) in warm dry climates. The main objectives are firstly, to find the extent to which VPCSs are viable and useable, and secondly how much reduction in reliance on air-conditioning will be achieved if these strategies are applied in modern dwellings. Three aspects of VPCSs will be investigated, including: cultural acceptance, thermal comfort of occupants and energy performance.

The results of the research will define the extent to which VPCSs are applicable to modern dwellings and clarify how much this application could improve their performance, cut their energy consumption and adapt them to climate change. Some preliminary results of the study shows that traditional passive courtyard buildings in central parts of Iran, work very well in terms of modulating the temperature swings, lowering the ambient temperature and providing the occupants with spaces of various temperatures in the hot summer times.

Keywords: Vernacular architecture, thermal comfort, passive cooling, CO₂ emission

1. Introduction

1.1 *Energy, global warming and the role of buildings*

Currently, energy constraint and global warming are the biggest challenges confronting the planet. Energy is a vital part of every aspect of life in the modern world. Demand for energy is rising rapidly. The analysis carried out by the US Energy Information Administration (EIA) estimates that, by 2030, global energy consumption will have grown by over 70% (EIA,

2007). The world population, which has increased more rapidly than ever before over the last 50 years (Population Reference Bureau, 2005), indicates huge future demand for houses and the energy to run them.

The building sector is one of the major energy consumers in the world. The proportion of total energy use attributable to buildings generally ranges from 10 - 15% in undeveloped countries to more than 40% in the developed countries (Robertson, 1992, p.129). In the UK, building use currently accounts for 46% of total energy consumption and it has been calculated that this energy could be almost halved if the existing building stock were adequately insulated (Roaf et al., 2004, p.130). In Iran statistics show that buildings account for about 39% of total energy consumption (IFCO, 2007). According to a report in “The 2nd conference of Fuel Conservation in Buildings” in Tehran (2003), the amount of energy consumed in buildings in Iran is equal to 30% of its annual oil income (equivalent to US\$15 Billion in 2005), with 50% of this being wasted. Using and wasting energy, air-conditioned energy-dependent buildings result in more emissions of green-house gases that drive global warming.

Global warming is one of the most critical components of environmental degradation. Global temperature which has risen by over 0.7°C in the last 300 years is predicted to rise by up to 8°C by 2050 in the worst global warming scenario (IPCC, 2007). The Intergovernmental Panel on Climate Change (2007) believes most of the warming in recent decades is ‘likely’ (at least 90% certain) to be the result of energy-related human activities, mainly because of carbon dioxide emitted from burning fossil fuels. Knowledge of the likely effects of climate change predicts that extreme weather conditions, including higher summer temperatures, will follow (Roaf et al., 2004, p.313). The increase in summer average temperatures can be intensified in urban areas where cities replace natural land-cover with man-made materials and structures. On hot summer days, according to the U.S. Environmental Protection Agency (EPA), urban air can be 2-6°C hotter than in the surrounding countryside. Furthermore, added waste heat from vehicles, factories and air-conditioned buildings raises the need for air-conditioning; therefore energy demand and cost, green-house gas emissions, air pollution levels and thus heat-related illnesses and mortality rise. Thus there is a need for urgent action, and in such action buildings are, as Roaf *et al.* (2004, p.130) have said, the ‘front line of our defence and must be designed to shield us from the effects of climate change and global warming.

1.2 Vernacular versus modern buildings

In hot climates, most of 20th century buildings are not suitable even for present conditions. They are dependent on air-conditioning systems and electricity, reliant on fossil fuels and increasingly unable to adapt to a warming climate. A large proportion of these modern buildings are poorly designed for the prevailing climate, leading to extreme use of electrical equipment and energy to maintain desired indoor conditions. These buildings, without enough insulation, un-shaded, over-glazed and tight-skinned and with inefficient air conditioning, are using vast amounts of energy to provide thermal comfort, especially when the weather conditions are harsh and extreme. Development in many hot climate countries, including Iran, is badly hindered by the crippling high cost of energy. At a time when brown-outs and black-outs are predicted due to high consumption levels, problems in production of electricity and the increasing summer temperatures, people will not be able to stay in many buildings if the electricity fails particularly during the day. In hot climates, if the air-conditioning goes off, buildings, very quickly become unoccupiable (Roaf, 2004, p.314), and in a short time such

structures will have soaring internal temperatures in summer.

In contrast to modern buildings, vernacular architecture in these regions is more adaptable to the environment in many ways. Traditionally builders used knowledge passed from generation to generation to ensure that their buildings could modify the impact of a hostile outdoor environment. Vernacular buildings in the desert are equipped with thick high walls, wind catchers, courtyards, ponds, fountains, rich gardens and vaulted chambers, according to principles evolved over many generations. These principles include physical functionality, beauty, low-energy use, comfort, durability and affordability. Such buildings use local construction materials, passive cooling and heating, and renewable energies. Vernacular resources, technologies and forms are generally seen to be well adapted to local climate conditions and are often considered an appropriate base for environmental design.

In spite of its importance, traditional architecture and its methods and strategies, especially those of the hot-arid climates of Iran, are undervalued and unused in new constructions. Many architects are less experienced in the traditional architecture of warm and dry climates, and most of the limited research in this field is not engaged in utilization and revival of traditional solutions and techniques in new constructions and modern buildings. It has been suggested that these solutions are for all environments and cultures, not just for architecture in hot arid zones. Recognition and use of this traditional knowledge will enhance human thought and culture, as Fathy has said (Fathy et al., 1986): ‘The principles that produced the traditional solutions must be respected. This is the only way modern architecture can surpass in human and ecological quality, the achievement of vernacular architecture in the hot arid regions of the world.’

It must be recognized that many vernacular technologies, resources or forms are suitable and sustainable, although it should not be ignored that some of them are currently no longer properly functioning because of changed cultural and ecological situations. We can not simply go back to traditional buildings, for they were designed for a different culture and climate. In this regard, the key challenge in the 21st century is to learn fundamental lessons and principles of vernacular architecture, and to find ways of integrating those principles into development programmes to upgrade existing settlements and to plan new ones. The challenge is to find out how the achieved knowledge, skills and experience of the world’s vernacular builders may, as Vellinga (2006) has said, be fruitfully applied in a modern context. What is required is a method that enables us to scientifically test the actual performance of vernacular traditions and generate an understanding of how they may be upgraded to provide truly sustainable buildings for the future.

1.3 *Gap of knowledge in this area*

Although some basic facts and figures are available, not many studies have identified general principles and concepts of vernacular architecture, particularly in Iran. Many of the early studies failed to pay much explicit attention to the way in which traditional technologies might, as Vellinga has said (2006), contribute to the creation of future built environments. Even in developed countries, the way in which vernacular knowledge and experience may be used to respond to 21st century challenges has so far not been the subject of many discussions (Oliver, 2003, p.14). Research projects that explicitly address the application and use of vernacular knowledge and skills in contemporary architectural practice are rare (Vellinga, 2006). Few attempts have been made to investigate the vernacular architecture of central Iran. Most of the existing literature in this field does not deal with vernacular traditions in terms of

the application of vernacular strategies to a modern development context. Beazley (1982), Roaf (1988), Pirnia (1991), Memarian (1993), Tavasoli (2002) and Ghobadian (2003) have conducted studies on vernacular architecture in Iran but these studies are mostly history-oriented and descriptive, introducing and describing how this kind of architecture worked in the past. The difficulties in using traditional technologies, and the opportunities they could offer to today's architecture, have not been addressed. Except for a small quantity of research such as the one undertaken by Ben Gurin University and Oxford Brookes University (Meir and Roaf, 2006), the way traditional architecture works now, and can work in the future, in relation to energy and thermal performance, is a neglected area. Moreover, there is no comprehensive study on the relationship between temperature increase resulted from global warming and the effectiveness of passive-cooling systems. The extent to which traditional systems could provide comfort conditions in the buildings, has not been subject of much studies and the way buildings can withstand extremely hot summer temperatures has not been well addressed.

2. Necessity and the overall aim of research

What is needed in this area is research that critically and systematically tests the actual performance of vernacular buildings and technologies and generates an understanding of how they may be upgraded to provide truly sustainable buildings for the new millennium. Studying traditional techniques to understand the sustainable strategies used in arid central Iran should make a valuable contribution to the field. Extending this subject further to assess how the application of traditional passive techniques to new and existing buildings could improve their performance, cut their energy consumption and running costs and adapt them to climate change, would, it is hoped, break new ground.

In this regard, this research focuses on vernacular passive-cooling strategies (VPCSs) in warm-dry climates of Iran. The overall aim of the research is to evaluate the extent to which VPCSs can be successfully incorporated into existing modern buildings in Iran to improve their energy performance, carbon reduction, cultural acceptance and thermal comfort of occupants.

3. Research methodology

The research project will be conducted in two main stages.

3.1 *First stage*

The first stage consists of a comprehensive review of recent relevant literature, the definition and selection of case studies, design of research instruments and field work.

This stage is a combination of theoretical (literature review) and practical (field-work) activities in which following objectives are expected to be achieved:

- § To evaluate existing passive-cooling strategies employed in vernacular buildings in the warm-dry climate of Iran in terms of their energy performance, thermal comfort of occupants and cultural acceptance.
- § To classify modern building types in warm dry climates of Iran by their construction and form, and evaluate their energy performance.

To achieve the aforementioned objectives, relevant data and information will be collected from existing literature, through direct in-situ observations and by taking measurements of

case-study buildings. Case-study buildings will be chosen from a range of traditional passively-cooled and air-conditioned buildings according to criteria such as size, layout design, ventilation type, current functionality and the physical condition of the building. In the first stage of the research, three main aspects of vernacular buildings will be studied and analyzed:

- 1- Physical and cultural aspects;
- 2- Thermal comfort aspects;
- 3- Energy performance aspects of vernacular building in comparison with modern buildings.

3.1.1 Physical and cultural aspects

Buildings are more than mere shelters. They are built to meet people's needs. They reflect their lifestyle and have social, economic, cultural and environmental meanings. If vernacular buildings and their methods are to be understood, they should be identified and critically examined in the context of modern life. In this research, to identify the physical and cultural aspects of traditional building types compared to their modern counterparts, following tasks will be undertaken:

- 1- Review existing literature to find definitions, principles and interpretations of vernacular architecture;
- 2- Define what is addressed as vernacular architecture in this research;
- 3- Investigate how vernacular buildings worked together within the social and cultural environment in warm-dry climates of Iran
- 4- Find how they may have evolved over time, looking at different aspects such as chronology, history (historical comparisons), social order, forms and causes (social order, community, family, material, technology, etc.), shape, space, style, type, function, architectural technology (how natural resources are processed and labour is organized - skill continuity), material (local, imported), composition (interior-exterior), decoration (massing against ornaments)
- 5- Identify the architectural patterns in warm dry areas in Iran, looking at problems and solutions including:
 - § Patterns for family area (house): place, orientation, private/semi-private domain, room, wall, dome, window, porch, basement, courtyard, wind-catcher, Hashti (entrance), outdoor sleeping area;
 - § Patterns for neighbourhood: local space, passages, door, gateway; and
 - § Patterns for public area: town centre, market, public square, garden, greenery, water.

Studying the aforesaid issues, it is possible to set up criteria for selecting case-study buildings considering their size, layout design, ventilation type, current functionality and the physical condition of the building.

Furthermore, semi-structured interviews with local experts (design professionals, local authorities, architects, builders and material suppliers) – three representatives for each group – and also with inhabitants will be carried out. Interviewees will be representative of the residents of case-study areas and selected based on age, sex and profession. Survey questionnaires will also be administered to the residents of case-study areas. Based on the

theoretical framework established in the literature review, they will consist of questions about occupants' behaviour and their opinions about historic and identity importance, safety, sanitation, procurement and running costs of the buildings, and the expenses and difficulties of repairing traditional buildings.

The qualitative data from interviews and literature review will be analysed in the second stage to identify the patterns which are still valid and the suggestions they could offer to apply in modern buildings

3.1.2 Thermal comfort aspects

Another subject to be studied is thermal comfort and the extent to which traditional buildings provide their occupants with it. To investigate the thermal comfort of vernacular buildings according to occupants' opinions, a number of theoretical and practical activities will be undertaken. Theoretical work comprises the study of current relevant literature on:

1. Thermal comfort as it relates to building design;
2. Comfort models and predicting comfort temperature;
3. Acceptable comfort models for naturally-ventilated buildings in hot dry climates;
4. Adaptive approach to thermal comfort and its relationship to outdoor temperature;
5. Adaptation and acclimatization in hot dry climates;
6. Likely impacts of global warming on thermal comfort.

Practical work includes following actions:

1. Record climatic variables (globe temperature, air temperature, humidity, air speed) at 1 hour intervals, or get them from local meteorological offices;
2. Administer questionnaires related to thermal conditions in vernacular case-study buildings, including:
 - § Comfort vote (7-point Bedford scale: 1- much too cold, 2- too cold, 3- cool, 4- comfortable, 5- warm, 6- too warm and 7- much too warm);
 - § Preference vote (5-point scale: 1- much warmer, 2- a bit warmer, 3- no change, 4- a bit cooler and 5- much cooler);
 - § Skin moisture (4 points: 1- none, 2- slight, 3- moderate and 4- profuse);
 - § Activity (including: lying down, sitting resting, sitting working, standing and moving);
 - § Clothing (descriptive list: shoes, sandals, socks, scarf, chadors, caps, etc.);
 - § The use of controls (window, fan, blind, curtain, door, air conditioning, types of lighting, etc).

The data from thermal comfort survey will be analyzed in the second stage of the research to determine the most comfortable temperature (or comfortable for the largest number of people) in the summer in passively cooled case-study buildings.

3.1.3 Energy performance aspects

To investigate the energy performance of modern case-study buildings and their potential for saving energy, an energy audit will be carried out. This will include examination of building fabric and services and identification of energy consumption building factors (type, occupancy, exposure and location). The outcomes of energy audit will illustrate the heat gain/loss through fabric, windows and infiltration, and will clarify the energy performance of modern case-study buildings before the application of VPCSs.

3.2 *Second stage*

The second stage will consist of the development and running of computer-simulated models of case-study buildings, data analysis, and development of recommendations. In this stage the following objectives will be achieved:

- § To assess the effect of incorporating selected culturally accepted VPCSs into modern building types for different global warming scenarios, in terms of energy performance and thermal comfort of occupants.
- § To develop recommendations to reduce carbon emissions from existing modern building types by incorporating vernacular passive cooling systems.

First, effectiveness of the integrated vernacular strategies will be evaluated in relation to reducing energy consumption and CO₂ emissions and providing thermal comfort in the warm dry regions of Iran. Quantitative data from thermal comfort survey and energy audit will be analyzed using SPSS and other methods. Qualitative data, contents of open questions in questionnaires and the response from interviewees, will first be combined and then divided under main headings. They will then be revised, modified and put into workable lists for descriptive and interpretive analysis. The analysis will set up some criteria based on which the effectiveness of passive-cooling strategies can be evaluated. The result of this evaluation will clarify which strategies are culturally acceptable, still valid and effectively workable in the modern context.

Applying these valid strategies into computer simulated models, they will be further examined in this stage. For this, computer-simulated models of case-study building types will be developed, based on the information on building geometry, component specification, occupancy patterns and weather data, all derived from the literature review, field survey and measurements taken in the first stage.

A modelling programme will be chosen from the variety of thermal modelling software (such as Rad Therm, Natural Environment, Ecotec, TAS or IES) with regard to the accuracy and effectiveness of their latest version to resolve the research requirements. Models will be calibrated with the data from the survey of case-study buildings which will be conducted in the first stage. Selected vernacular passive-cooling systems (identified in the earlier steps) will be used in the models. The models will be run and new thermal and energy performance will be measured, based on different global warming scenarios. Results and data from running simulated models will be analyzed to assess the effectiveness of integrated vernacular strategies and to compare and evaluate the consequences of various options in existing building types. Recommendations will be developed for applying vernacular architectural strategies to existing modern buildings, meeting the applicability, compatibility and actual requirements of people. It is hoped that the research will yield effective designs which both increase energy saving and yield maximum socio-cultural benefits.

4. **Some preliminary outcomes**

As a part of this research, a study on thermal performance of the Lariha House (a naturally ventilated building in the city of Yazd, Iran) was carried out on 19th, 20th and 21st June 2007. Lariha House is a one storey courtyard house, built some 130 years ago. The courtyard is large and elaborate, surrounded and overlooked by verandas (*eyvans*), reception halls and rooms (Fig. 1).



Fig. 1: A view of Lari-ha house, Photograph by author, 2007.

Behind the *veranda (eyvan)*, there is a tall windcatcher (*badgir*) which is visible from within the courtyard. Unusually, this windcatcher is located at a corner of veranda rather than the main axis of the courtyard. Service areas are located in its corners. The courtyard is rectangular and its longitudinal axis lies in an approximately northeast-southwest direction. The cellars (*sardabs*) and storage areas of the house are located underground and are all connected via stairways to the courtyard's floor or the corridors leading to them. Twelve i-Button temperature data loggers were installed in twelve different spaces of this building. They were set to record the temperatures at five minute intervals for a period of 2280 minutes (access to the building was restricted due to the security issues; and time limits for staying didn't allow a longer record time). Fig. 2 illustrates the location of data loggers on the plan of the house.

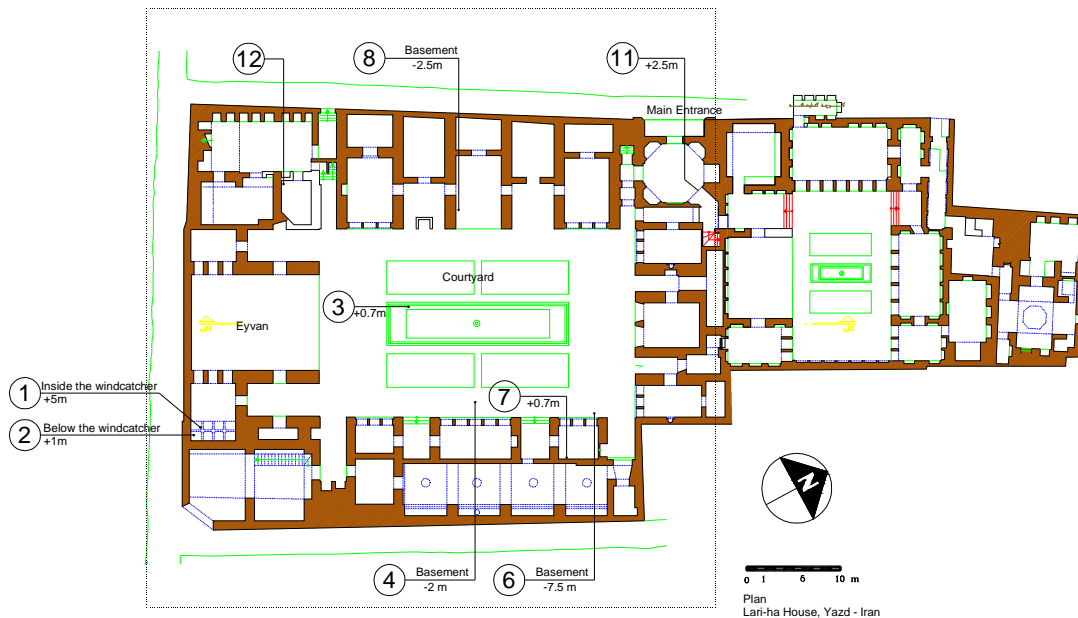
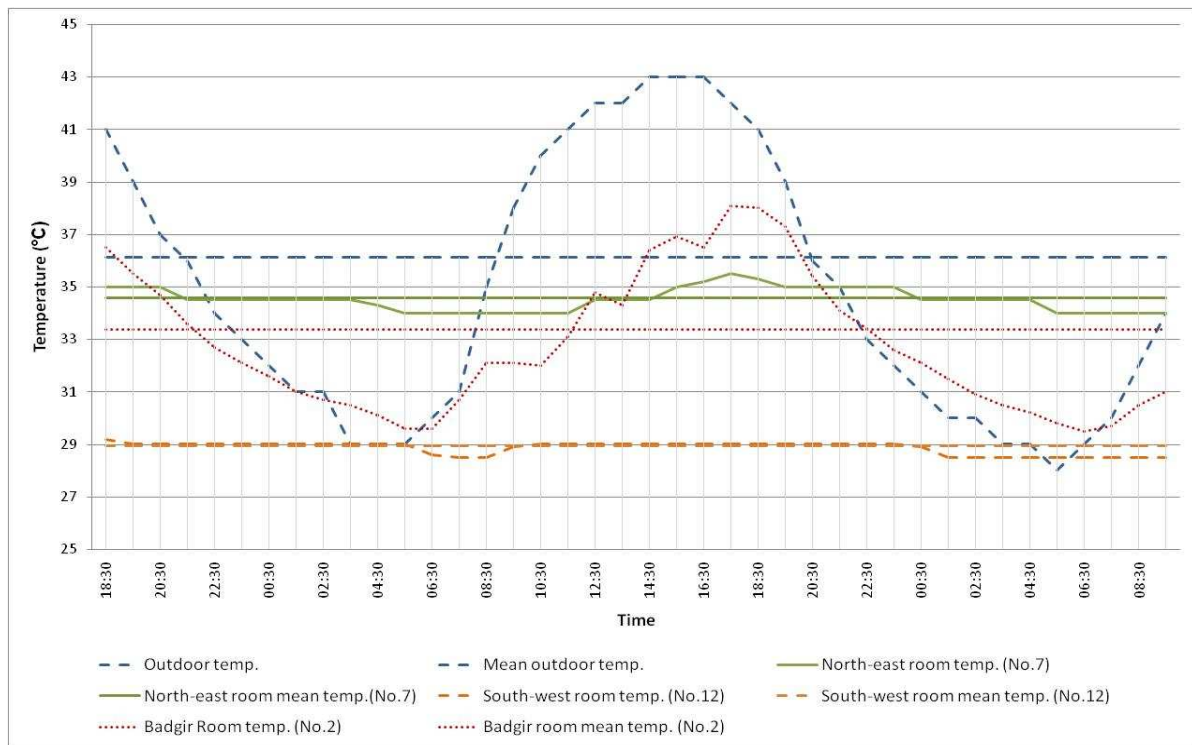


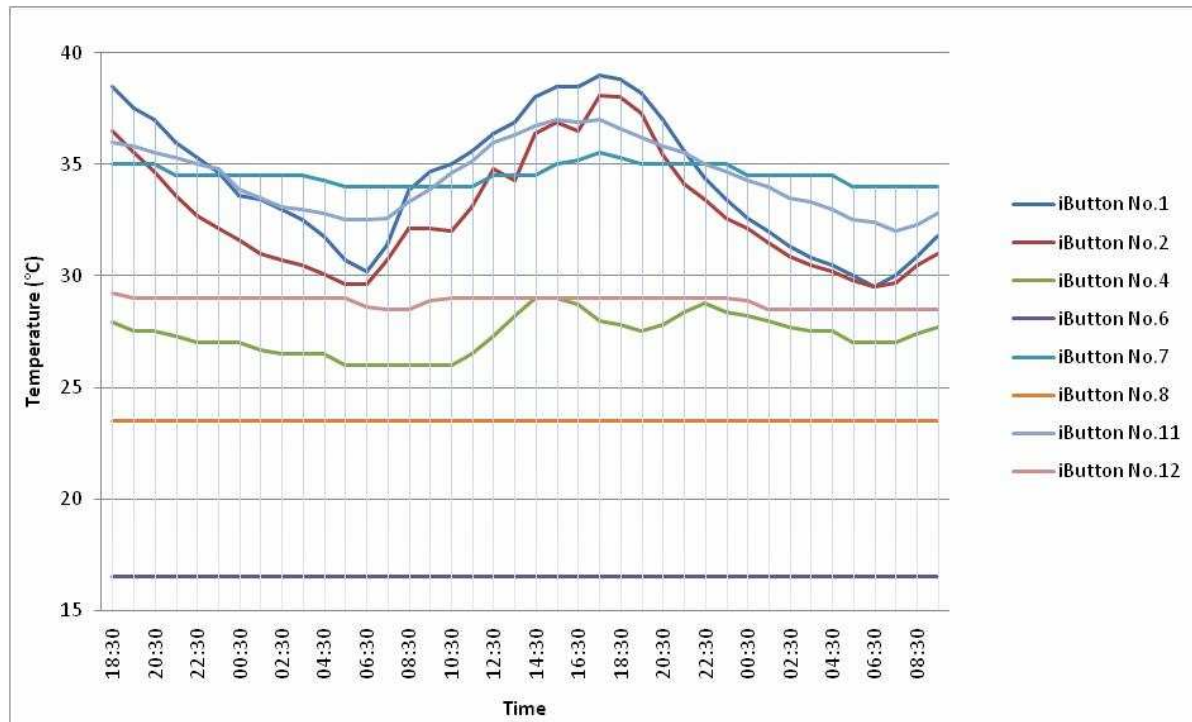
Fig. 2: Plan of Lariha House (drawn by the Iranian Cultural Heritage Organisation, 1988) and location of data loggers.

Fig. 3 demonstrates outdoor and indoor temperatures in three different locations (rooms) in the house: 1- *badgir* room: a summer room directly ventilated by the windcatcher (*badgir*), 2- North-East (NE) room: a room exposed to the afternoon sun, and 3- South-West (SW) room: a summer room facing into the courtyard with no direct sunlight. A comparison between mean outdoor temperature (i.e. 36.1°C) and mean indoor temperature in different rooms (34.6°C in NE room, 28.9°C in SW room and 33.4°C in *badgir* room) demonstrates a reduction of 2.7°C to 7.2°C in summer rooms which is a sign of a good passively cooled building.



At the time when records demonstrated a fluctuation of 14°C in outdoor temperature on 20th June 2007, the *badgir* room experienced much smaller fluctuation of only 8.6°C. Surprisingly, a temperature swing of just 1.5°C was recorded in the NE and SW rooms, which highlights the huge effect of thermal mass in modulating the temperature inside the house. In addition, closed doors and windows in the NE and SW rooms are other reasons for this phenomenon.

Fig. 4 illustrates the diversity of indoor temperatures in different spaces of the house. It emphasizes the fact that the occupants of the building can experience a variety of temperatures by moving around the house. For example, when the deep cellar is constantly at 16.5°C, the room below the windcatcher gets to 30-38°C. The constant cool temperature of basements and cellars underlines the idea of having a cool room for the time when it is very hot outside.



According to the Iran Meteorological Organization (2008), the mean temperature in June 2007 was 30.7°C. Comfort temperature was calculated 29.6°C±2 and 28.4°C±2 based on Nicol's (Nicol, 2004) ($T_c=12.9 +0.543T_{om}\pm2$) and Heidari's (Heidari, 2000) ($T_c=17.3 +0.362T_{om}\pm2$) adaptive models respectively. Upper limits of the comfort zone can be further extended 2°C if ceiling fans are used (Nicol, 2004). Fig. 5 shows that the temperature in the NE room was completely outside the comfort zone. It also indicates that the room ventilated by *badgir*, even if it was fan assisted, would have exceeded the comfort threshold from 12:00 to 22:00 based on Nicol's model. The period of discomfort would be longer if Heidari's model was used. The S.W room would be within the comfort zone for both models if it was cooled by ceiling fans.

The study of temperature variations shows that this building, as a representative of complete passive courtyard buildings in central parts of Iran, works very well in terms of modulating the temperature swings, lowering the ambient temperature by the use of different traditional passive cooling strategies and providing the occupants with spaces of various temperatures in the hot summer times.

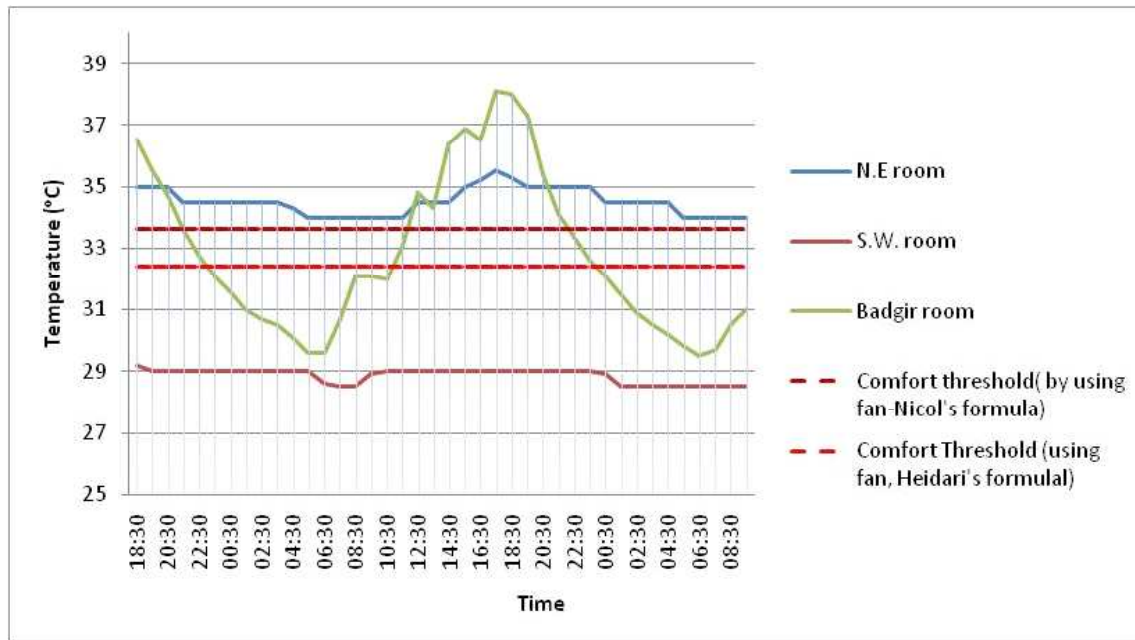


Fig. 5: Comfort thresholds and the diversity of indoor temperatures in Lariha house

4. Discussion

The research is expected to result in findings that provide a greater understanding of the relationship between variables which influence acceptability/applicability of traditional Iranian architectural technologies in a modern context as well as their effectiveness in reducing energy consumption and CO₂ emission. The research should help to raise issues and awareness of energy efficiency in vernacular architecture and it is hoped that the outcomes will contribute positively to housing programmes in warm dry climates in developing as well as developed countries by providing practical recommendations for applying vernacular passive technologies. Vernacular passive-cooling technologies can provide us with the inspiration for new and innovative approaches to the design of adaptive and resilient dwellings for dry and warming climates and give us an indication of our ability to survive in such regions without air-conditioning. By investigating the factors affecting the success/failure of vernacular building strategies, it should be possible to propose the means for successful future implementation of energy efficient community-based housing programmes, particularly in Iran.

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