Energy Efficient Building Design: Revisiting Traditional Architecture

Naseer M A

National Institute of Technology Calicut, India

0526

The Asian Conference on Sustainability, Energy & the Environment 2013

Official Conference Proceedings 2013

iafor
The International Academic Forum
www.iafor.org

1. Introduction

Energy Efficient design of buildings and their operations are becoming more and more important in the world. A building is a system that is linked to its surrounding environment and is subject to a range of interactions between the external conditions and the indoor comfort condition. Buildings are major consumers of energy in both their construction and operation. They account for 40% of world's energy use. It is estimated that 40-60% of this goes for heating and ventilating the indoors.

Modern architecture - to a large extent - does not respect the environment in creating built spaces. Often, the indoors thus created are not comfortable and require artificial means to condition them. These artificial systems are causing significant environmental problems across the globe.

Traditionally, the buildings were designed for the most comfortable indoors condition, irrespective of the outdoor hostile environment. Environmental factors have been a major determinant in the development of traditional architecture. Traditional built forms have been developed on the principles of passive design by continuous process of experimentation and improvement.

Study of traditional architecture proves that it is possible to create a built space that respects the environment by natural means through a judicious design that is sustainable.

This paper reviews the concepts of passive design and the sustainable practices in traditional buildings from different countries and discusses the findings of a research conducted in South-Indian peninsula.

2. Energy Consumption: Global Scenario

The International Energy Outlook 2013 (IEO2013) projects that world energy consumption will grow by 56% between 2010 and 2040 [1]. Much of the growth in energy consumption occurs in countries outside the Organization for Economic Cooperation and Development (OECD) known as non-OECD, where demand is driven by strong, long-term economic growth. Energy use in non-OECD countries increases by 90 percent; in OECD countries, the increase is 17 percent. The share of residential sector in the energy consumption in the year 2011 is 22% as compared to 31% by the industrial sector, which is the largest consumer [2]. Growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside the buildings is today a prime objective for energy policy at regional, national and international level [3]. Among building services, HVAC systems uses the maximum energy [2,3].

The growing concern worldwide for environmental conservation calls for immediate intervention in making buildings energy efficient thus reducing the energy consumption. Energy efficiency in buildings can be achieved through a multipronged approach involving adoption of energy efficient building design, use of energy-efficient building systems and low energy materials coupled with reduction of transportation energy, and effective utilization of renewable energy sources to power the building [4].

3. Energy Efficient Building Design

The concept of energy efficiency in building design is related to the energy required to achieve desirable environmental conditions that minimize energy consumption [5].

The most important design parameters affecting indoor thermal comfort and energy conservation in buildings are the following [6]:

1. Orientation of the building
2. Building form
3. Size and position of openings
4. Thermal performance of the building envelope

3.1. Orientation of the building

The level of direct solar radiation received on the building facade depends on the azimuth in the wall, and thus, on the orientation angle of the building [7]. The orientation of the facade also influences other parameters of passive design, such as shading or the performance of the solar envelope [8, 9].

3.2. Building form

Heat exchange between the external environment and the indoors occurs primarily through the skin of the building. Configuring the geometry of the building suitably can control the heat exchange. The ratio of the surface area to the volume (S/V) determines the magnitude of the heat transfer in and out of the building. The larger the S/V ratio, greater would be the heat gain or loss for a given volume of space. Hence the overheating through the building surfaces could be minimized by keeping the surface area to the minimum in tropical climate [10].

The shape of the building also plays a major role not only in terms of heat exchange but also for ventilation due to wind effect. The pressure gradient created between the windward and leeward faces of the building can induce air flow for better ventilation. The building envelope could be suitably shaped for this effect [11].

3.3. Size and position of openings

Arrangement of openings on the external surfaces of the building can influence the air flow indoors. The size of the openings both on the windward and leeward side can induce and channelize the air flow as established in various studies [11, 12].

The size of the window openings is critical in tropical climate. The indoors in such a climate require high rate of ventilation for the removal of perspiration due to higher humidity. This may be achieved by increasing the size of the openings thereby allowing a large volume of air to pass through the interior spaces. But the outdoor air admitted in large volume can bring a lot of heat to the indoors as the outdoor air temperature in such climate especially during summer (when the ventilation is most essential) is more than the body temperature. This will in turn create uncomfortable situation than a soothing one. Hence, this kind of situation demands an optimum arrangement of openings in terms of size and positions.

3.4. Thermal performance of building envelope

The building envelope consisting of walls, roof, doors, and windows and the period of the heating are the factors that have the greatest impact on the total energy consumption of the building [13]. The envelope determines interior climate conditions, and thus, the additional energy demand for heating and cooling [14].

The heat gain in the indoors is of major concern in the tropical climate especially in summer as the outdoor air temperature is higher than the occupants' body temperature for a larger period of the time. The days are hotter and the air temperature drops down only in the night, a few hours after the sunset.

Though there are means of reducing the heat gain by orienting the building suitably, by modifying the building configuration and by arranging the internal spaces, the indoors can still be at a temperature higher than the optimum. This situation demands modification of the building envelope itself by incorporating various means of thermal insulation. Thermal insulation of the building envelope can be achieved by appropriate use of building materials and by employing suitable techniques of insulation. Building thicker walls, cavity walls and use of infill are suitable for reducing the heat gain through conduction. The roof of the building (the surface that receive the maximum solar radiation) require special attention for suitable thermal insulation. Roof with suitable external finishes for maximum reflection and thereby minimum heat absorption, installation of insulative materials, use of cavity layers etc. can be employed to reduce the heat flow indoors.

4. Lessons from Traditional Architecture

Contemporary architecture is frequently seen as the example of an internationalism, which eradicates local traditions and transforms the globe into a faceless urban sprawl [15]. It is often forgotten and even ignored that architectural traditions are rich in content, given that they have found the right harmony between the necessities of living, the environment, material resources and ideas on the use of space [16].

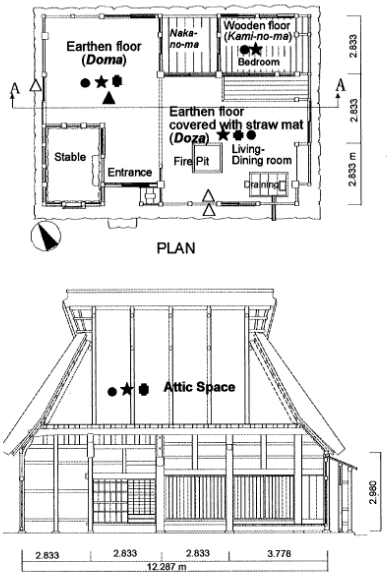
It is commonly acknowledged that traditional architecture represents local tradition, culture and climates, thus the difference between regions lead to the diversity of vernacular architecture. In despite of the diversity, traditional building around the world share the common characters of energy-saving and environment friendly, which are approached by local building material and climate responsive strategies etc. By the fact that no electric power could be used to achieve thermal comfort in ancient time, passive means are mainly applied in building to provide thermal comfort by intellectual manipulation of spatial form and building elements which utilize the advantages of climate or resist the disadvantages [17].

Studies on passive environment control methods of achieving thermal comfort in buildings and studies for extracting methods and techniques from traditional buildings have been conducted in various countries around the world. [19–25].

The following section gives an overview of a few selected studies conducted on traditional houses from across the world. Among the available literature, only those studies where the climatic parameters were actually measured on-site and analysed have been presented.

4.1. Japanese Traditional House

The indoor climate of a traditional house located in Hokuriku district was studied in summer and winter. The three room type house called "Horiguchi" has mud walls and floor and a roof with reeds [26].



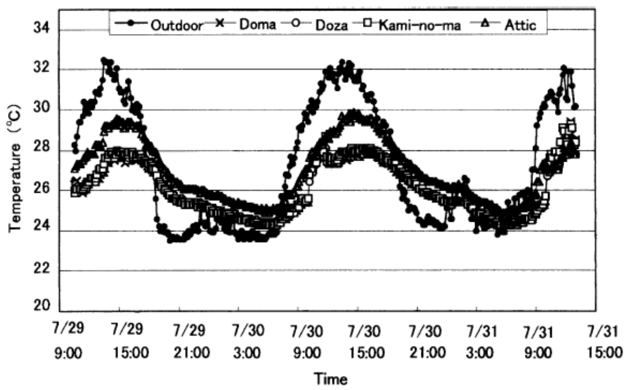


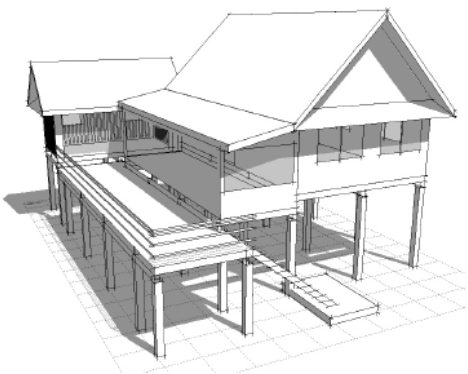
Fig.1a (left): Japanese traditional house

Fig. 1b(top): Variation of temperature at indoors compared to outdoor temperature

The observation proved that the temperature indoors was maintained between 240 and 280C while the temperature outdoors was between 23.50 C and 32.50 C.

4.2. Traditional Houses of Thailand

The study was conducted to compare the thermal performance of a contemporary house with that of traditional houses from three different regions [27].



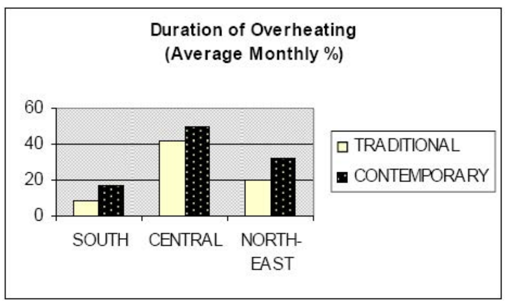


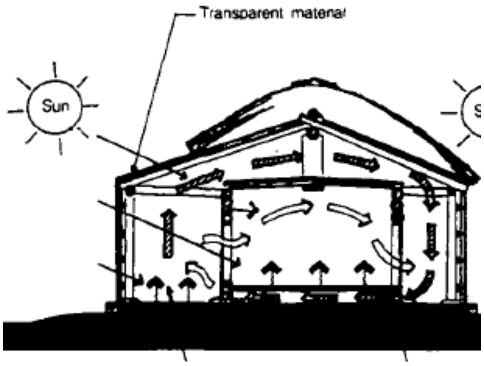
Fig.2a (left): Thai traditional house

Fig.2b(top): Indoor overheating in contemporary house vis-a-vis traditional houses from different regions

It was revealed that the cooling load of the contemporary house was significantly higher than the traditional houses.

4.3. Traditional Houses of Korea

Traditional houses in Tumakgyp in Ullung island made of timber logs with mud infill provide a very comfortable indoor environment from a snowy and cold outdoor climate [28].



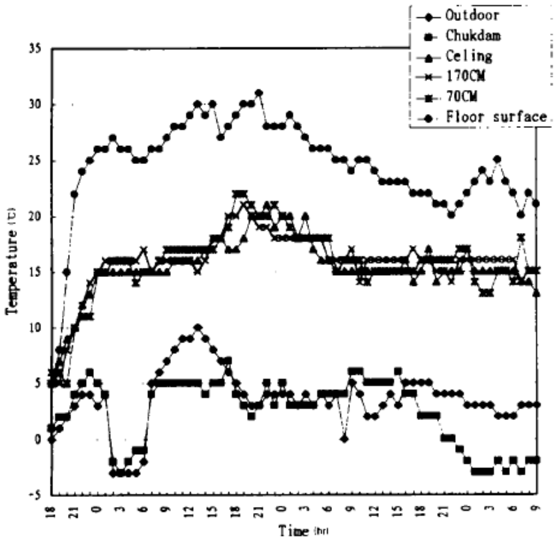


Fig.3a (top): Korean traditional house

Fig.3b(right): Indoor temperature at different locations in comparison to outdoor

The highly insulative building envelope made of wooden logs is responsible for the indoor environment

4.4. Traditional Malay house

Malay houses are designed to respect nature. The stilted houses made of timber and roofed with locally available coconut leaves and hay are best suited for warm-humid climate [29]

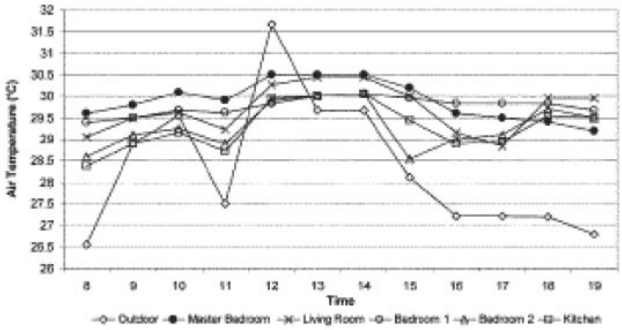


Fig.4a (left): Traditional Malay house; Fig.4b(right): Indoor temperature at different locations in comparison to outdoor

4.5. Traditional houses of Turkey

Traditional houses of Diyarbakir in Turkey are typical examples of buildings adapted to a hot dry climate. These houses are built around a courtyard [30]. The walls are made of basalt stone and the roof is of timber. The arrangement of the blocks around the court and the semi-open room are carefully designed for cooling for the hot dry climate. The orientation and interior plans shows that dominant hot period conditions were considered in the design of the buildings. The compact and low buildings with small courtyards provide protection from solar radiation and shelter from hot dusty winds. The massive buildings with a high volume to surface ratio are advantageous since this will reduce the high range of external air temperatures between night and day.

It is not surprising that these studies conducted in different parts of the globe have returned similar kind of results proving the efficiency of traditional system in maintaining the required comfort conditions indoors irrespective of the outdoor conditions prevailing at various times of the year [31].

In order to understand the performance of traditional architecture in providing sustainable solution, a detailed investigation was conducted on traditional residential buildings of Kerala, located at southern end of Indian peninsula.

5. Traditional buildings of Kerala

The land of Kerala lies between the Arabian Sea on the West and the Western Ghats on the East stretching from $8^0 18^0$ to 12^0 48' N Latitude. It's warm–humid climate is characterized by heavy rainfall and high relative humidity, and relatively moderate temperature. The monthly normal climate is given in Table 1 [32]. Temperature vary from 21^0 C to 33^0 C and relative humidity (RH) varies from 65% and will be above 70% in most of the seasons.

Table 1
Monthly normal climate of Kerala [18].

Months		January	February	March	April	May	June	July	August	September	October	November	December
Temperature (°C)	Max	32	32	33	33	32	29	28	28	29	30	31	32
	Min	21	22	24	25	25	24	23	23	23	23	23	21
Rainfall (mm)		14	15	31	108	247	556	502	304	208	277	172	49
No. of rainy days		1	1	2	6	11	21	20	16	11	12	8	3
Relative humidity (%)		65	70	75	80	77	85	90	90	86	83	80	65

The traditional houses of Kerala are built according to the principles of Vaastushastra, the Indian discipline on architecture [33]. The basic module of traditional house is known as nalukettu with four blocks built around an open courtyard. They are generally rectangular or square in plan with blocks topped with a sloping roof on all four sides while the courtyard is left open to the sky for letting air and light inside. There is an internal verandah around the courtyard for protection from rain and sun. A typical layout of a traditional Kerala house is shown in Fig. 5.

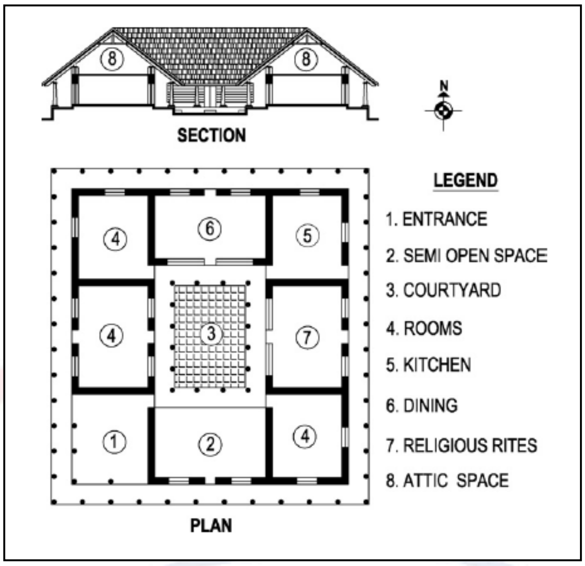


Fig. 5: A typical layout of traditional Kerala house

Depending on the size and importance of the household, the buildings may have one or two storey or further modules with enclosed courtyards. The enclosed courtyard is usually sunken. The verandahs opening to the courtyards prevent the intense solar radiation entering the rooms. The roofs have steep slopes up to almost 450 and the gables are provided at the ends of roof to enhance ventilation and to allow the warm air to escape. The attic space that is formed by the wooden false ceiling over the rooms is ventilated.

5.1. Energy Efficient Characteristics of Kerala Traditional Building

The traditional houses of Kerala are designed strictly based on the parameters of energy efficient design. The principles followed in their design are explained in detail in the following section.

5.1.1 Orientation of the building

The traditional houses of Kerala are oriented strictly according to the cardinal directions as per Vaastushastra. This makes them more perfect to control its environment with maximum comfort in different seasons. The cardinal directions are determined correctly using traditional techniques based on solar path and shadows [33]. The entry to the house is provided from South or East. The spaces that are used during the day time are mostly placed on the North and South sides while those used during the nights are on the West.

The positioning of spaces is very much important in spatial planning. The living spaces which are semi-open are on the Southern side with optimum number of openings for ventilation. The rooms are positioned on the western side in order to capture the prevailing wind from the south-west. The kitchen is positioned at the North-East corner of the house as the wind from south-west would help to drive the hot air from kitchen to the outside and prevent spreading to other spaces. All other spaces are arranged around the courtyard in such a way as to permit adequate air movement in all seasons wherever required.

5.1.2 Building Form

The traditional houses are generally rectangular or square in plan with blocks topped with a sloping roof on all four sides arranged around a courtyard that is left open to the sky for letting air and light inside. An internal verandah is provided around the courtyard for protection from rain and sun. The internal functional spaces can be suitably arranged depending on the requirement of such spaces for heating, cooling or ventilation. For example the spaces such as store which is not habitable can be placed on the face of the building that is subject to heating and spaces such as toilets and kitchen that require the ventilation and removal of foul air or fumes can be placed on the leeward side so that they do not vitiate other indoor spaces.

5.1.3 Size and position of openings

Most of the traditional houses in Kerala are set amidst large parcels of land. Hence they are opened up for better air movement. Open planning and free spaces between houses help to capture wind and achieve good ventilation. They have large number of openings in the form of windows and ventilators. Provision of open or semi-enclosed spaces also gives ample scope for air movement. Another remarkable feature in the traditional architecture of Kerala is the provision of open gables in the roof and the provision of wooden jalli in the external walls at appropriate positions. These wooden jalli in the external walls helps to draw external air with the effect of courtyards.

5.1.4 Thermal performance of building envelope

The thermal insulation in Kerala traditional houses is achieved by the effective use of materials and the techniques used in the construction of walls and roof. The external walls of traditional houses are usually very thick up to a maximum of 750 mm with double layer of laterite masonry with a gap in between that is filled with fine sand. This makes the external wall highly insulative. In order to achieve thermal insulation from the roof, wooden ceiling (tattu) is also provided beneath the roof. This provides a large air space at the attic which acts as an insulation layer against the conduction of external heat through the roof. Further, the breathing space that exists between the clay roofing tiles helps in ventilating the underside of the roof reducing the temperature.

5.2 Discussions on the Outcome of the Investigation

The investigation showed a very low diurnal variation of indoor temperature (26^0 to 30^0 C) compared to that of outdoor ambient air temperature (22^0 to 34^0 C) due to high thermal insulation property of the building envelope. The absence of conductive heat gain and time lag between outdoor and indoor air temperatures proved the thermal insulation property of the building envelope and the high degree of natural ventilation maintained through the building.

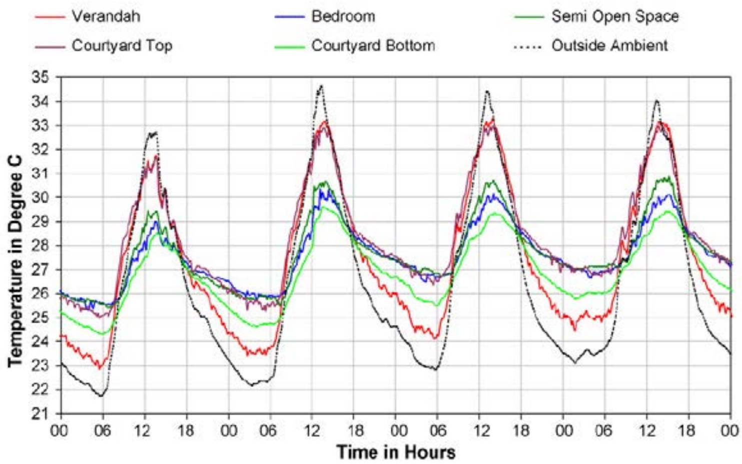


Fig 6. Indoor temperature at different locations in comparison to outdoor

The air movement recorded clearly showed that the building system was maintaining a continuous and controlled air flow indoors. This accelerates the evaporative cooling by continuous exchange of air that is in contact with the occupant's body especially when the RH is higher (77 to 84%) along with high temperature. This was achieved due to the influence of internal courtyard.

The building was thus able to provide a condition well within the comfort region of the bioclimatic chart and very near to the comfort zone. The PMV-PPD analysis also confirmed the effectiveness of the passive control system of traditional building in providing the comfortable indoor environment during various seasons of the year [34].

6. Conclusion

Traditional built forms have been developed out of constant and continuous process of experimentation and improvement for more perfect solutions. Traditional architecture throughout the world thus gives us sustainable solutions with minimum adverse impact on the environment while providing the most energy efficient built environment. The researchers in the field of energy efficient and sustainable design in various parts of the world are therefore extracting the time tested sustainable design techniques embedded in the traditional architecture. This paper reveals the passive control system of traditional architecture of Kerala in providing thermal comfort to the occupants that is highly energy efficient.

In the context of modern architecture that does not respect the environment to a large extent by creating spaces that are not really comfortable, but later on conditioned by using artificial means, a judicious use of suitable traditional techniques using appropriate materials is required for a sustainable, energy efficient and comfortable human life. Therefore it's time to revisit the traditional wisdom that was probably lost in a haste to blindly follow that was modern.

7. References

1. US Energy Information Administration, "International Energy Outlook 2013", as available in the website http://www.eia.gov/forecasts/ieo/
2. US Energy Information Administration, "Annual Energy Review 2011", September 2012.
3. Luis Perez Lombard, Jose Ortiz and Christine Pout, "A review on buildings energy consumption information", Energy and Building, 2008, 394-398.
4. Ministry of New and Renewable Energy, "Representative Design of Energy Efficient Buildings in India", Tata Energy Research Institute, 2001.
5. Wang W, Rivard H, Zmeureanu R., "Floor shape optimization for green building design", Advanced Engineering Informatics, 2006;20:363–78.
6. Z Yilmas, Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate, Energy and Buildings, 2007; 39; 306–316.
7. Mingfang T. Solar control for buildings. Building and Environment, 2002; 37; 659–64.
8. Capeluto IG. Energy performance of the self-shading building envelope. Energy and Buildings, 2003; 35; 327–36.
9. Morrissey J, Moore T, Horne RE, "Affordable passive solar design in a temperate climate: an experiment in residential building orientation", Renewable Energy, 2011; 36; 568–77.
10. J K Nayak, J A Prjapati, "Handbook on Energy Conscious Buildings", Bureau of Energy Efficiency, 2006.
11. Bureau of Indian Standards, "Handbook on Functional Requirement of Buildings (SP41)", BIS, 1987.
12. O. H. Koenigsberger, et al., Manual of tropical Housing and Building—Climatic Design, Orient Longman Private Limited, 2007.
13. Manioglu G, Yilmaz Z., Economic evaluation of the building envelope and operation period of heating system in terms of thermal comfort, Energy and Buildings, 2006; 38; 266–72.
14. R. Pacheco, J. Ordónez, G. Martínez, Energy efficient design of building: A review, Renewable and Sustainable Energy Reviews, 2012; 16; 3559– 3573.
15. M.Umbach and B.Huppauf, "Vernacular Modernism: Heimat, Globalization, and the Built Environment", 2005, Stanford University Press.
16. A. Tzonis, L. Lefaivre and B. Stagno, "Tropical Architecture: Critical Regionalism in the Age of Globalization", 2001, Wiley-Academy.
17. Lingjiang Huang and Fangfang Liu, "Thermal Analysis of Tibetan Vernacular Building - Case of Lhasa", Engineering and Technology, World Academy of Science, 2010; 68.
18. K.H. Lee, D.W. Han, H.-J. Lim, "Passive design principles and techniques for folk houses in Cheju Island and Ullng Island of Korea", Energy and Buildings, 1996; 23; 207–216.
19. F. Wang, Y. Liu, "Thermal environment of the courtyard style cave dwelling in winter", Energy and Buildings, 2002; 34; 985–1001.
20. R. Ooka, Field study on sustainable indoor climate design of a Japanese traditional folk house in cold climate area, Building and Environment 37 (2002)319–329.
21. L. Borong, et al., Study on the thermal performance of the Chinese traditional vernacular dwellings in summer, Energy and Buildings 36 (2004) 73–79.
22. D.-K. Kim, The natural environment control system of Korean traditional architecture: comparison with Korean contemporary architecture, Building and

Environment 41 (2005) 1905–1912.
23. M.S. Sozen, G.Z. Gedık, Evaluation of traditional architecture in terms of building physics: old Diyarbakır houses, Building and Environment 42 (2007)1810–1816.
24. Y. Ryu, S. Kim, D. Lee, The influence of wind flows on thermal comfort in the Daechung of a traditional Korean house, Building and Environment 44 (2009) 18–26.
25. T.J. Kim, J.S. Park, Natural ventilation with traditional Korean opening in contemporary house, Building and Environment 45 (2010) 51–57.
26. Ryozo Ooka, Field study on sustainable indoor climate design of a Japanese traditional folk house in cold climate area, Building and Environment 37 (2002) 319–329.
27. Paruj Antarikananda, Elena Douvlou and Kevin McCartney, Lessons from traditional architecture: Design for a climatic responsive contemporary house in Thailand, Proceedings of the 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, September 2006.
28. Kyung-Hoi Lee, Dong-Wook Han, Ho-Jin Lim, IG, Passive design principles and techniques for folk houses in Cheju Island and Ull ng Island of Korea, Energy and Buildings 23 (1996) 207-216.
29. Climate Responsive Building Design, as available in the website: http://www.gobookee.net/climate-responsive-building/
30. Mujgan S-erefhanog lu So zen, Gu lay Zorer Gedik, Evaluation of traditional architecture in terms of building physics: Old Diyarbakır houses, Building and Environment 42 (2007), 1810–1816.
31. Paruj Antarikananda, Elena Douvlou and Kevin McCartney, "Lessons from traditional architecture: Design for a climatic responsive contemporary house in Thailand",
PLEA2006: The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September 2006.
32. Meteorological Data, India Meteorological Department, Meteorological Centre, Thiruvananthapuram, 2009, No. C. 201 (A)/729.
33. A. Achyuthan, B.T.S. Prabhu, An Engineering Commentary on Manusyalayacandrika of Tirumangalat Nilakantan musat, Vastuvidyapratisthanam, Calicut, Kerala, 1998.
34. A.S. Dili, M.A. Naseer, T. Zacharia Varghese, "Passive control methods for a comfortable indoor environment: Comparative investigation of traditional and modern architecture of Kerala in summer", Energy and Buildings , 2011; 43; 653–664.

****