An Investigation on Energy Efficient Courtyard Design Criteria

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Abstract—As energy consumption has become a serious concern, energy efficiency is emerging more of a priority in recent years. As a result, there has been a general movement towards finding effective design strategies to lower the energy demands of buildings and to encourage further awareness of energy-conscious design. Passive solar building design can result in higher requirements than a conventional building; however those systems can reduce the auxiliary heating costs in buildings, without compromising occupant comfort. The courtyard as a passive solar system was developed mainly in response to climatic requirements. Poor or inappropriate design may create challenges for controlling temperature, glare, and energy consumption in courtyard. For this reason, based on literature review this paper investigates energy efficient courtyard design with respect to shape, ventilation and performance of the courtyards in terms of daylight factor, so that, energy efficacy performance of the building can be improved. Thus, it is expected; findings of this study encourage building designers and decision makers to be carefully considered in the design phase of building in terms of environmental concerns and energy efficient building design.

Keywords—courtyard design criteria, energy efficient building, sustainable building passive system

I. INTRODUCTION

The concerns over global warming and need for reduction of high emission of greenhouse gases, demand the utilization of strategies for indoor climate modification in promoting comfortable indoor environment. With modern materials and technology, the buildings of present architectural style results in high energy consumption, in an attempt to provide thermal comfort indoors. It means that the modern day practice does not give due respect to passive and natural environment control measures in buildings. Environmental architecture is the one that would provide a comfortable indoor environment in response to the energy conservation and reduction in greenhouse gases. The vernacular architecture at any place on the other hand has evolved through ages by consistent and continuous effort for more efficient and perfect solutions. Now, the researchers in the field of energy efficient and sustainable design in various parts of the world are extracting the time tested passive control techniques embedded in the vernacular architecture. Irrespective of the extreme climatic conditions that prevail outside, the building indoors should keep its occupants physiologically comfortable. A courtyard building in this respect presents a great flexibility in promoting areas of internal passive zones in buildings and therefore passive architecture. A courtyard can provide security, privacy, and a comfortable place within the building. The courtyard not only provides comfortable condition and beautiful setting but also, offers a private and isolated space through which all rooms grouped around it receive sunlight, natural ventilation and visual as well as physical communications.

II. HISTORIC PROGRESS AND CLASSICAL CONCEPT OF COURTYARD BUILDINGS

For many centuries and to the present day, the courtyard house has been one of the most characteristic forms of residential architecture in hot-dry, and warm-humid climates [1]. The courtyard was developed mainly in response to climatic requirements. The residents of such climates utilized the courtyard to serve as a collector of cool air at night and a source of shade in the daytime [2].

A. Mesopotamia

Courtyard housing is one of the oldest forms of residential dwelling development. The earliest example of the courtyard house known to us from archaeological exploration was found at Ur on the Euphrates River in Mesopotamia [Figure 2 and 3]. Its floor plan was constructed around a square courtyard. All rooms were organized around it. The second floor of the house was open to the courtyard. The building material was mainly fired brick. The house dated to about 2000 B.C. [3]. Courtyards were used for a variety of living purposes. In the Mediterranean house, the courtyard was used as a recreational room, a kitchen, a living room, or some other familiar general all-purpose family room.

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B. China

The Chinese courtyard was a place of privacy and meditation. The courtyard often consisted of a garden and water feature. The Chinese courtyard house is an arrangement of several individual houses around a courtyard; each house belonged to a different family member [Figure 4 and 5]. The courtyard was used as a cooling technique in the warmer tropical climate of southern China [3].

C. Italy

By about 700 B.C, the Etruscans in Italy had begun to build a special kind of courtyard house known as the atrium house. The atrium house had several rooms around a small courtyard, with a cistern in the center of the courtyard catching the rainwater from the roof for drinking. The courtyard was open to the sky, and served as a private outdoor space [Figure 6 and 7].

When the Romans conquered southern Italy from the Greeks, around 275 BC, Roman architecture became a composition of elements inherited from the Etruscans and the Greeks. The atrium house met up with the Greek per style house (court enclosed by columns). People began to build larger houses that combined the two styles, the atrium-per style house. There would be an atrium in the front, near the street, and as per style in the back of the house [3]. [Figure 8and 9]

D. Medalist

Courtyards in the Middle East were used in order to achieve the best inside thermal comfort, day or night, within the local limits of material. Most activities were relocated throughout the year as appropriate to accommodate the changes in temperature and the location of the sun. In some Islamic cultures, private courtyards provide the only outdoor space for women to relax unobserved within a sheltered courtyard with trees, a pool, and outdoor furniture [Figure 6].

In addition to the above features, courtyards provided other benefits in the hot-arid climates. With their tall walls, the rooms (built around the courtyard) provided wind shading effects for one another, thus reducing the infiltration of hot and often dusty winds to the rooms. With their trees, flowers, shrubs and a pool of water, the courtyards created a micro-environment, a few degrees lower in air temperature and slightly higher in relative humidity. The tall trees in the courtyards shaded the walls and the ground from the intense direct solar radiation of summer. All these features reduced the heat gains of the building [2].

III. REASONS FOR INCLUDING COURTYARDS IN BUILDINGS

The inclusion of courtyards into low buildings and houses has many benefits which are as follows:

- Psycho-Social benefits: The courtyard provides a sense of enclosure and privacy to the residents of the house.
- Cultural Benefits: The courtyard is used as a cultural element which separates the public and private spaces within the house. The inner court is more restricted to the family and is usually a protected outdoor space enjoyed by the female members of the house in full privacy [3].
- Energy Benefits: Courtyards have been generally referred to as a "microclimate modifier" in the house due to their ability to mitigate high temperatures, channel breezes and adjust the degree of humidity [4].
- Architectural Benefits: Courtyards generally function as a center in buildings and houses, connecting the different areas and functions.
- Symbolical-Religious Benefits: The courtyard is both symbolically and religiously significant. This open-to-sky yet enclosed space within the surrounding walls of a house has been considered the central focus of interest in the house [3].
- Economic Benefits: Some financial benefits are closely associated with the courtyard form and construction. Courtyard house designs show efficiency in land use, as they do not require a conventional yard for outdoor space. Especially when adjoining courtyard houses share walls,
the cost of both construction and maintenance is significantly reduced.

II. ENERGY PERFORMANCE OF COURTYARDS

Energy efficiency is becoming more of a priority in recent years as energy consumption has become a serious concern and is becoming a crisis [1]. The commercial buildings sector consumes a huge amount of energy and their energy consumption pattern will likely increase sharply in the near future [5]. As a result, there has been a general movement towards finding effective design strategies to lower the energy demands of buildings and to encourage further awareness of energy-conscious design [6].

For buildings in general and for commercial buildings specifically, using artificial lighting is considered as a key problem that can lead to excessive energy usage as it affects cooling and heating loads requirements of the buildings [5]. Kramt (2000) estimated that artificial lighting accounts for 25%-40% of total energy consumption [7]. Many papers and researches reveal substantial opportunities for improving energy efficiency in the building by incorporating courtyards into buildings as daylight-enhancing techniques to bring light into the interior and consequently to minimize space conditioning (cooling and heating) and lighting loads. For this reason, all aspects of the courtyards in buildings (i.e. their proportion, orientation, shape and size, height, shading control, glazing type and ratio, and the thermal mass of walls) need to be carefully considered in the design phase. Poor or inappropriate design may create challenges for controlling temperature, glare, and energy consumption [8].

Myths in passive solar design may result in higher requirements for a passive solar building than for a conventional building [9]. Gratia and Herde (2002) have stressed that passive solar energy can reduce the auxiliary heating costs in office buildings, without compromising occupant comfort [10].

There are various studies on the energy performance of the courtyards. The researches mainly focused on the shape, ventilation and performance of the courtyards in terms of daylight factor. Main researches have been briefly summarized in the following paragraphs:

A. Shape of the Courtyards

Several studies tried to find optimum size of circular, polygon, rectangular and square form of courtyard in different climates and location latitude. Mohaisen and Gadi (2005) showed that changing the form’s proportions in circular model significantly influences shading or exposure potential of the internal courtyard envelope and that shallow courtyards perform better than the deeper ones[1].

Muhaisen and Gadi (2006a) used computer tool (IES) to carry out the effect of solar heat gain on the energy demand of courtyard building form with different proportions. They found that courtyards having deep forms require low energy for cooling in summer [11]. Mohaisen and Gadi (2006b) stressed that in polygon models deep courtyard forms with any geometry are recommended to achieve maximum internal shaded areas in summer. However in winter, shallow forms were desired for obtaining sunlit areas [12].

Mohaisen (2006) carried out a modeling study into the effect of rectangular courtyard proportions on the shading and exposure conditions on the internal envelope of the form in four different locations. The outcomes showed optimum courtyard height to obtain a reasonable performance in summer and winter are three stories in hot humid climates, two-story in hot dry and temperate climates, and one-story in a cold climate [13].

B. Ventilation of the Courtyards

Natural ventilation has been used as a building ventilation strategy since the ancient time. Natural ventilation is a passive system that the performance would rely on the characteristics of the building openings. However, it is sometimes overlooked since the invention of mechanical systems. Natural ventilation can improve the indoor environment and save energy,
Haw et al. (2012) highlighted that beside wind towers, there are other architectural features, such as atriums, courtyards, wing walls, and dome roofs which have been integrated into building designs that have significant influence on improving the indoor air quality. Haw et al. (2012) also stated that courtyards are transitional zones that improve comfort conditions by modifying the microclimate around the building and by enhancing the airflow in the building. Haw et al. (2012) concluded that courtyard can provide a relatively enclosed space to channel and direct the airflow which is promoted by large openings (gates, doors, arches, etc.) and results in convective natural ventilation in and around a building [14].

Yasa and Ok (2010) tested effects of ventilation of the openings on the building with a courtyard in a wind tunnel. It is observed on buildings disposing openings at different configurations, (compared courtyard building lacking openings) that openings on vertical surfaces are increasing the speed of air flows inside courtyards. They also indicated that openings located on perpendicular surfaces increase the velocities of airflows within courtyards in proportion to their dimensions and positions [15].

Bansal et al. (1994) stated that having a courtyard is preferred in warm and humid climates especially when courtyard can induce ventilation due to stack effect where the wind direction should be taken into account. In summer conditions, buildings are typically a net source of heat, and the use of the natural ventilation to eliminate some of this heat from the building is very energy efficient. Most modern building designs in hot and humid regions are not equipped with passive architectural features for improving natural ventilation except through window and door openings [16].

Nguyen et al. (2011) showed that the distribution and configuration of the openings should be adjusted to improve natural ventilation and lighting. They found that courtyard house played a significant role on ventilation flow rate of the rooms facing the courtyard. Their investigation highlighted that courtyard facing windows sometimes played a more important role than street-facing windows. The research indicated that wind velocity in the courtyard house was independent from wind conditions at point in front of the house. They suggested that it is suitable and effective to employ natural ventilation, building orientation, building shape and solar shading strategies in Vietnamese climatic conditions while earth cooling, thermal insulation and high thermal mass are inappropriate [17].

Shanthi et al. (2012) studied on vernacular settlement pattern of Nagapattinam in India that breathes through the smaller indoor open spaces like courtyards because of its location in urban fabric. The buildings were designed to achieve cross ventilation through courtyards, wind catchers, etc. The study showed that during the night times the courtyard becomes a heat sink and by natural convective cooling this courtyard allows the hot air to be moved up and thereby acts as an excellent thermal regulator and creates a comfortable living environment. The horizontal surface insulates the inside from outside and creates temperature zone helping the courtyard to become a heat sink. They also presented that during summer time, due to the principle of buoyancy, low pressure develops in the courtyard and that there was an air movement from inside which is pushed towards the surrounding spaces to move out through the openings (doors, windows and ventilators) in the leeward [18].

Al-Sallal et al., (2013) achieved considerable improvement over the square-form house (typical Emirati house) and the basic courtyard house (envelope not yet improved) with 59% and 55% reduction in the greenhouse gas emissions and the utility bill, respectively. They suggested that their methodology could be valuable to other building professionals in the UAE who might search for a clear application model. The results of their study showed a potential in reducing the energy use of the house (compared to the improved envelope or the baseline case) by 19% for cooling and 13% for lighting and equipment; and helped to reduce the greenhouse gas emissions and the utility bill by 12%. The research also indicated the lower part of the courtyard is the coolest part inside the building as the cooler air settles at the bottom and the hot air travels up due to stalk ventilation. Since the courtyard buildings were located in the coastal region the outdoor relative humidity reaches to 95% while the indoor relative humidity is maintained around 80%. This is achieved because of the presence of the wind catchers, courtyards, etc. [19].

C. Performance in terms of Daylight Factor in Courtyard

Al-Masri and Abu-Hijleh (2012) compared conventional and courtyard buildings by using computer simulation (Virtual Environment by Integrated Environmental Solutions) to determine the overall energy consumption, energy savings potential and available daylight levels. The simulation calculated effects of number of floors, type of glazing, wall thickness, and insulation type as well as insulation thickness on the performance of a courtyard type.

The result showed 11.16% reduction in the overall year-round energy consumption in optimized courtyard model compared to the reference conventional form building.
Assessment between the daylight performances of the two forms highlighted that the courtyard form provides more usable daylight without excessive glare [20].

Luis and Perez-Garcia (2004) studied seasonal control of the solar gains on the roof apertures. Refurbishment of an open courtyard by installing an innovative roof which, apart of other solar features as the integration of PV modules and a device to promote natural air movements, it has been designed to maximize solar gains during the winter months and minimize them in summer to reduce the corresponding space thermal loads [21].

Heras et al. (2005) analyzed the energetic performance of a courtyard covered by saw tooth roof in the building of University of Almeria in Spain. The measurement carried out by equipment, thermal and meteorological sensors for a year. Thermal evolution in typical summer and winter days and thermal comfort analyses showed a good thermal behavior in winter; stratification did not appear during all year and this fact produced overheating in summertime. They stated around the noon an increase in the air velocity happens, consequently the chimney effect is greater during these hours. The results also highlighted that, the needed annual thermal loads required to obtain comfort conditions are lower into courtyard than in a conventional saw tooth roof. The loads values are different depending on monthly requirements [22].

![Fig 12: courtyard covered by saw tooth roof](image)

**III. CONCLUSION**

The design features of courtyard buildings are almost the same in different regions of the world with some small variations from one location to another. These differences are dependent on the materials and technologies available, as well as on the climatic features of each site. Energy performances of courtyard buildings are dependent on many variables. This includes the internal envelope’s finishing and materials, as well as the proportions of the physical parameters of the courtyard form. The courtyard geometry and proportions have a great impact on the shading conditions produced on the form’s internal surfaces. The solar radiation received on the surfaces of the courtyard building effects required cooling and heating loads. With the climate variations, this has resulted in subtle regional variations to the courtyard form of building. Agreement between courtyards building geometry, enclosure, orientation and access to wind flow can carry considerable architectural implications in modifying the microclimate of the courtyards.

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