ENERGY EFFICIENT ARCHITECTURAL DESIGN STRATEGIES IN HOT-DRY AREA OF IRAN: KASHAN

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(Received April 2009 and accepted August 2010)

Climate had a major effect on the performance of the traditional building architecture and its energy consumption in hot dry area of Iran. Lack of water and harsh climate of these areas forced people to build their houses with some strategies based on efficient energy consumption. Heating and cooling usually use largest portion of energy consumption of buildings. Therefore, builders tried to use natural climatic strategies for coping with harsh conditions. These strategies include layout orientation, distance between buildings, building orientation & form, climatic elements such as Eyvan (porch), Wind catcher, central courtyard and etc.

The paper aims to introduce the mentioned strategies and then, categorize these characteristics in three levels: a) macro scale, b) medium scale and, c) micro scale. In addition, the strategies will be explained in their level of performance. Finally it focuses on lessons that we can learn from our past experiences to improve our energy consumption patterns in contemporary architecture.

Keywords: Climate responsive design, design strategies, hot-dry area, traditional architecture, Kashan.

1. INTRODUCTION

Climate has a major effect on the performance of the building and its energy consumption. Reducing energy consumption requirements, using natural resources and providing comfortable, healthier and sustainable living spaces are the aims of a climatically responsive sustainable building design [1]. Sustainable design and construction strategies are of great importance nowadays. Anyhow, one may say that sustainability was already a driving force in the past, showing its validity in those days in different forms and techniques. Therefore, from Vitruvius till today, problems and precautions in design and construction did not change fundamentally, although a lot of development has been seen in materials and technology. Moreover, these developments may have had some negative effects. For this reason why the building process should be discussed in a holistic way. In other words, in climatically responsive design, selection of materials and building techniques must be evaluated together and the final product should perform well during its whole service life. When sustainable design and construction strategies of Iran’s traditional architecture are under scrutiny, then it is possible to observe how traditional buildings and settlements in this region were designed in harmony with the local cultural, topographical and climatic conditions and how their design and construction could be integrate in today’s design practices [2]. This study is based on a research, which has been carried out for the hot-dry area of Iran.
2. CLIMATE RESPONSIVE DESIGN STRATEGIES IN HOT AND DRY AREA

The most important design parameters affecting indoor thermal comfort and energy conservation in building scale are distance between buildings, building form, building envelop, self-efficiency in building materials and optical and thermo-physical properties of the building envelope. Among these parameters building envelope, as it separates the outdoor and indoor environment, is the most important parameter. All of these parameters are related to each other and the optimum values of each parameter should be determined depending on the values of the others and their optimum combination should be determined according to the climatic characteristic of the region.

2.1. Kashan - A hot arid city

Kashan is a city in the central region of Iran and is located in the province of Isfahan. The climate of central region of Iran is relatively similar to desert climate. This region represents the arid and hot area with a high temperature difference between day and night. Kashan can be accounted as one of the archaic cities of Iran. Archeological discoveries in the Siyalk Hillocks which lie 4 km west of Kashan reveal that this region was one of the primary centers of civilization in the pre-historic ages. Through evaluating traditional architectural examples, it can be seen that designers were more sensitive and they presented the most suitable design and settlement examples for each climatic region based on this three scales; macro, medium, and micro scale.

3. CLIMATE RESPONSIVE DESIGN STRATEGIES IN KASHAN

3.1 Macro climate responsive design strategies

- Distance between buildings
  In the design of traditional houses in the hot and dry area in Iran, there are several precautions taking against the hot climate. Houses are surrounded by high walls and isolated from the street. During the day, external walls of houses provide usually shady areas in narrow streets and especially in courtyards. By means of thick and heavy walls, cool environment in summer and warm environment in winter could be provided easily.

- Enclosed urban environment
  As a whole the city structure resembles a battlement fully enclosed from all directions which prevents the invasion of enemies from any side. In fact it is for the defense purpose and prevents high velocity winds and sand storms to penetrate into the town. For that reason the inside of the city is wholly different from outside facing and the inside air is more static than the outside air.

- Narrow and irregular streets
  The main streets in the town are facing the direction of the wind. Of course the streets are narrower than streets built for other purposes (in other regions). Surely if the streets were not narrow more wind would have flown into the streets and the moving sands of the desert and ferocious winds would have penetrated into the city districts. Meanwhile the compacted nature of the buildings prevents the very high temperature of sun radiation to penetrate into the town.

Figure 1 Narrow and irregular street in compact texture of Kashan (from Google Earth).

3.2 Medium climate responsive design strategies

- Building form
  In Iran, in hot and dry climate, the most preferred plan type is the courtyard houses. In order to
minimize the area affected by the solar radiation, compact forms are chosen. By arranging those forms with courtyards, shady areas can be obtained. In courtyards, with the help of water and plants for evaporative cooling, the floor temperature can be minimized by the high walls surrounding the courtyard, shaded areas can be obtained and the open areas can be used during the day. Channels for water poured out from the pool are important elements for cooling. Water is often spread by channels to the floors of the courtyard and evaporative cooling from the surface of the courtyard floors which are made of porous stone is efficient. Courtyards are always in the ground floor and have different forms depending on the landscape of the house.

- Self-efficiency in materials

The use of local materials to reduce energy expenditure during the occupation is a wise decision since it will also reduce the initial embodied energy as well as cost, especially transportation cost [4]. Every building material in a desert town is composed of mud and its derivatives. In fact, nothing but mud and mortar can be used in such regions because there are no other building materials in the region. Here one must refer to the question of self-sufficiency in desert regions because all the earth excavated during housing construction is used as building material in the form of mud. In such regions, one cannot find any other building material except unbaked bricks and mud which strongly resist the incessant sun rays in the very warm months of July and August. In the meantime during cold seasons the chambers are warmed with very little additional heat and even the unbaked brick walls turn into massive and intact blocks after drying and are fully resistant and hardy. Due to very hot temperatures, the building materials absorb heat from the sun and make it available later when the sun goes down. In other words, this energy is retained in the walls about 8 hours and the other parts of the building envelope and is gradually transferred to the inner compartments. Such a quality provides leads to two alternatives in cold and warm seasons.

In cold seasons the absorbed temperature serves as an isolation barrier which protects the inside air from being affected by the chilly winter desert climate specially at nights because during daytime the temperature is absorbed by the walls and the building and although the air is cold outside, the inside of the house remains warm. During hot seasons the absorbed temperature causes problems and the conditions inside the building prevents full comfort for residents. As a result during nights the people prefer to sleep on the roofs for comfort.

Use of vernacular materials such as brick and adobe is always one of the concerns in the architecture of Kashan buildings. As an illustration, they used to use excavated foundation soil in order to make bricks. There are many examples like this which are incorporated in today’s architectural concepts for sustainable building design. Vernacular material selection, compatibility, embodied energy, application of passive energy and design environmental strategies in waste and technology management concerning the impacts in the environment are all concepts that are part of sustainable building design [5]. There are many examples of mosques, public baths, schools and different kinds of buildings in Kashan which have been made of vernacular materials. Many of these buildings are preserved by archeologists and conservators.

- Optical and thermophysical properties of the building envelope

In the hot and dry climatic area in Iran where the continental climate is effective, in traditional architecture examples, to benefit from the time lag of the building envelope, materials with greater thermal mass have been chosen. These kinds of thermally massed envelope details are very convenient for continental climates, where the summers are very severe with high swings in daily temperature variations. This big thermal mass will slow down the heat transfer through the envelope and thus higher day-time temperatures will be reached indoors when outdoor air temperature is much lower and consequently more stable indoor thermal conditions will be provided. On the other hand this thermal mass, which has higher surface temperature on outer side will rapidly lose heating energy to the atmosphere via radiation at night to start the next day from a cooler level [6].

When observing traditional examples, it can be seen that the transparency ratio of the building envelope is chosen as low as possible and the opaque parts of building envelope were constructed by the materials with a high heat capacity as thick as possible. The high heat capacity of the opaque component provides a high time lag for the transmission of the outside temperature to the internal area while the low transparency ratio minimizes the direct solar radiation gained through the windows [7].

In hot and dry climate, by means of the high heat capacity of the building envelope, the effect of the outside temperature is minimized and a cool internal area can be obtained during the day. Therefore, calcareous rock, stone, mud and the combinations of those materials are always preferred in this climate [8]. In this climate, other precautions against the solar radiation are:

- Minimization of the area and the number of windows;
- Construction of a window at a high level to block the floor radiation;
- Minimization of the absorptivity of the facades by white or light colors;
- providing natural ventilation especially at night;
constructing a part of the house into ground, which is to be always cooler than the outer ambient temperature in summer.

3.3 Micro climate responsive design strategies

- Atrium and Courtyard:

A common natural ventilation and thus cooling technique in traditional houses of Kashan is the use of atria and courtyards. Both are used as centerpieces in buildings and are in direct contact with the outside environment. A 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. An atrium works in a similar way and is used to provide comfort through a progressively acceptable transmission of the external environment to the inside. In addition, the green covering and water pools in central courtyards causes the increase in moisture and mildness of hot and dry climate in the mentioned region. Moreover, the necessary light for different parts of houses would be provided through the central courtyard. Furthermore, in Iranian and Islamic beliefs, creating such a pleasant environment (green covering and water pools in the central courtyard) in hot and dry regions (like Kashan) is an earthly symbol of the Garden of Eden (Heaven) as the God promised to human [9].

- Eyvan and Revak

Eyvan and Revak, semi-open areas, are used to create shaded and cool living spaces during the day. The Eyvan, three side closed passageway in front of the ‘‘rooms’’, permits a common life inside. Usually they are oriented to the south [2]. Especially south and east oriented Eyvans are very cool and shady places for summer afternoons. The Revak semi-open colonnade arranged in the courtyard always provides shady areas.

- Wind catcher (Air trap)

Traditional architects were obliged to rely on natural energies to render the inside condition of the buildings pleasant. A wind catcher was the specific feature of architecture in the majority of warm regions. Only when the region is placed at the bottom of hills and the town is relatively cool or is attacked by storm and warm winds air trap is not used. Air traps were normally in a suitable location in the house according to the size of the building, the number of air traps that was necessary to cool the summer apartment. In cities where suitable wind is blowing from a specific direction the air trap is open at one direction and closed from the other three directions.

In ancient times and in traditional buildings in arid and dry regions the air trap functioned like the present modern air conditioning system. Air trap is like a chimney whose end is in the underground and the top is set over a specific height on the roof. At the upper outlet many small openers or ducts are set. At the end of the air trap at the bottom of the door often a pool is set whose water was provided by Qanats (aqueducts). The height of the surface of the cross sections, the number of openers and the location of the air traps versus the building differed in different buildings. The air trap operates according to the condition of the wind and sun radiation in the region. The inside and outside walls absorb a lot of temperature during daytime. As a result they cause a balance of temperature at night and bestow the attracted warmth to the cold night air. The wind catcher functions on several principles. They are built with their long ventilation shafts positioned to catch any hint of a passing breeze to channel down into the house. The interlinking rooms of old buildings were designed to circulate the air that fluted down the wind catchers. The sun-dried mud bricks that were used to build the houses retained their coolness in the summer and their warmth in the bitter winters. The air was channeled all the way down to the elaborate function rooms built in the basement where the family would mostly live in the stiflingly hot summers.

Figure 2. The function of a wind catcher[10].

Figure 3. Cross Section of a wind catcher (designed by authors).
Finally, in a windless environment or waterless house, a wind catcher functions as a stack effect aggregator of hot air. It creates a pressure gradient which allows less dense hot air to travel upwards and escape out the top. This is also compounded significantly by the day-night cycle mentioned above, trapping cool air below. The temperature in such an environment can’t drop below the nightly low temperature.

When coupled with thick adobe that exhibits high heat transmission resistance qualities, the wind catcher would be able to chill lower level spaces in the middle of the day to frigid temperatures. This traditional Iranian element can help us to develop our purpose of sustainability in contemporary architecture. The thickness of the air trap walls and the dimension of the holes inside it were designed in a manner to allow enough heat. The light warm air inside the air trap ascends and is sucked by upper elevations. As a result cool air flows from windows and doors into the house and continues all the night.

If wind blows at night, the air will circulates on the opposite direction in the air trap. In other words the cold air is sucked by the air trap into the house. Of course in such a condition the cold air flowing from the air trap duct which has been heated during the day time will warm the inlet air a little. Nevertheless air circulation again refreshes the inside temperature. During daytime the air trap acts contrary to a chimney. In other words the upper parts of the air trap has been cooled the night before and upon contacting the walls of the air trap the warm air cools down and moves towards the bottom and eventually circulates into the house and exits from doors and windows. The flow of air at daytime accelerates the ventilation process.

4. CASE STUDY
Boroojerdi- ha House in Kashan:

The construction of this mansion, as attested by the inscription running around its reception hall, dates back to 1875 AD. According to a reliable estimate, the construction of the building was completed in 1892 AD, 18 years after it was begun, and that more than 150 masons, stucco carvers, mirror cutters and other artisans took part in its construction [12]. In this part of the paper, we will examine the mentioned design strategies to cope hot dry climate of Kashan in this traditional house.
On this account, we can see macro strategies by looking at the location and orientation of the house. This strategy allows the house to get minimum heat from its pyramid. We also can see this strategy in such buildings that want to have minimum relationship with outdoor harsh climate. Like wise, in the medium scale, we can see the linear form of this house that allows the building to be divided into two cubic volumes by a central courtyard. This courtyard provides deep Eyvans that create shady and cool living spaces. In addition, the building is built by earthen vernacular materials. Last but not the least; in the micro scale of consideration, we can see wind catchers and a deep Eyvan in figure 6 that provide a cool space for users.

5. LEARNING FROM THE PAST

There are many lessons that we can learn from our past experiences to review and improve our energy consumption patterns in contemporary architecture. As categorized in this paper, we can find out some architectural solutions in three levels; macro, medium and micro scales. In the macro scale, climatic strategies are mostly based on orientation of buildings in the city texture that has the most important role in responsibility of the city from climatic point of view. The orientation of buildings in the city texture in this case is defined as a function of how urban designers can adopt urban environment with natural elements such as winds’ puff or distance between buildings. Building forms and envelope in medium scale can be mentioned to architects to develop designing patterns of contemporary buildings. Using courtyard and providing more shaded areas in living spaces is examples of these lessons. Using local materials such as adobe or thatch can provide more self-efficiency characteristics for buildings. Finally in micro scale some elements that are most recently neglected in new constructions can be noticed. Most of new cooling systems are based on using irreversible sources of energy that can be replaced with reversible kinds.

6. CONCLUSION

Climate responsive design strategies in hot and dry area of Kashan were discussed in this paper through three levels. In the first level, distance between buildings, enclosed urban environment and narrow and irregular streets were considered as macro strategies. Review and development of these traditional urban patterns should be considered in hot and dry cities. Medium scale strategies cover building form, building envelop, self-efficiency in materials and optical and thermophysical properties of building envelop. Sustainable architecture necessities force us to re-think and synchronize traditional methods of construction and use of local-materials. Several propositions are given in this paper for architects and urban designers to consider how to relate energy efficient traditional
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design strategies and technologies to the design of contemporary architecture.

Table 2. Climatic responsive design strategies of traditional architecture of Kashan and suggestions for future use in contemporary architecture.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Past Climate Responsive Design Strategy(s)</th>
<th>Solution(s) for Future Design</th>
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<tbody>
<tr>
<td>Macro</td>
<td>Distance between buildings; Enclosed urban environment; Narrow and irregular streets</td>
<td>Adopting urban environment with natural elements (such as winds’ puff) from urban design point of view</td>
</tr>
<tr>
<td>Medium</td>
<td>Building form; Building envelope; Self-Efficiency in materials; Optical and thermophysical properties of the building envelope</td>
<td>Developing shady areas in contemporary designs; Developing methods of using domestic materials in constructions</td>
</tr>
<tr>
<td>Micro</td>
<td>Atrium and Courtyard; Eyvan and Revak; Wind catcher (Air trap)</td>
<td>Revival of some architectural elements and developing for current uses; Inspiration from traditional systems to create energy efficient systems based on local possibilities</td>
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REFERENCES