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A deep courtyard as the best building form for desert climate, an introduction to effects of air movement (Case study: Yazd)

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Abstract

A basic aim of low energy architecture is to create a thermally comfortable internal environment for building occupants whilst consuming the least possible amount of energy. In desert countries this aim is more difficult to achieve since high ambient air temperatures create a barrier to comfort. Traditional building types of these countries, such as courtyard building, have evolved to try and help people to adapt to a state of thermal comfort under these adverse conditions. Their indigenous people were known to have operated sophisticated irrigation systems for their living, and to have adapted to an appreciation of the nature and dynamics of physical systems.
This paper looks at the desert climate and its effects on architectural design and the significance of the living conditions in such environments. A best solution for building design, just in terms of building's form, could be made. The implication of the conclusion on architectural design gives useful guidelines in designing naturally ventilated buildings with internal courtyards in desert condition.

Key words: Desert climate; Architectural design; Courtyard; Energy efficiency

1. Introduction

In desert area of developing countries there have been two major phrases of architectural production: firstly, the introduction of *Modern Movement* and the *International Style*, and secondly, the versions of regionalism, searching for identity. While the former was declining and virtually defunct in the 1980s, the latter gained momentum in that decade. It seems that architecture which once showed its own characteristic response to the traditional ways of local lifestyle, i.e., traditional architecture, was designed and developed following from the path of modernism and contemporary needs, but now has experienced a renewal of interest to show its individualistic expression [2]. Today, in desert, it is admitted that the life styles of their people have been changed since the advent of industrialisation and modernism. In terms of building design, unfortunately, the rational architecture in desert has disappeared and the contemporary or modern architecture shows many pitfalls and problems. Rapoport [1] has given a number of reasons in this case:

● many types of contemporary functions and buildings are too complex to create in traditional fashion and this introduces the rise of specialisation and differentiation which involve various trades and professions;

● loss of common accepted and shared value system and image, is of great significance, such as the lack of the spirit of co-operation between designers and the public, and in turn, it leads to the advent of such controls as building regulations, codes and zoning rules; and

● a premium on originality, striving for its own sake, is pushed as a dominant feature in the modern society, while the traditional cultures ignore the novelty and regard it as undesirable.

Nevertheless, this should conclude with this statement [2] that: "old architecture especially

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the vernacular has much to teach us as it always develops a typology of fundamental common sense." The distinction between traditional and modern societies is understood in terms of the contrast between informal controls, affective and consensus in the former, and impersonality and interdependent specialisation in the latter. Therefore, a contemporary paradigm, or a sort of modern tradition is a piece of architecture which is clearly the outcome of an individual's idiosyncratic effort.

1.1. Desert climate

Desert climates have no exact definition, but the best way to define is to describe their common climatic feature. The most important indicator, by the well-know saying *"the nights are the winter of the desert"*. The desert areas are exposed to extreme conditions with 38°C annual mean maximum day temperatures in shade, rising in some instances to 45°C and even more; night temperatures average 20°C, dropping as low as 10°C in the cool months. Generally, the humidity is low and rains are few. In desert a large percentage of the radiation reaches the ground. At night the surface of the earth is usually colder than the air as a result of long-wave radiation to the sky, and so the net heat exchange is reversed and air in contact with the ground is cooled. Dusty wind is an important factor in the desert climate which is very unstable. Strong wind may raise dust and create a dust haze. The main question for present paper, however, is: with such harsh conditions, what could be done by architect for a best building design?

1.2. Building design and its problems

Although, the functions of buildings are basically the same everywhere: to provide shelter for a comfortable living and working environment and to avoid extreme weather; but the designs and processes for buildings in different climates are significantly different. In desert, under hot conditions the concept of the application of thermal control in buildings consists of three objectives are: preventing heat gain, maximising heat loss and removing any excess heat by cooling [13]. There are many ways to solve the problems, but none of them could be suitable as much as central courtyard form for all building's types. The best building forms is a deep courtyard which all spaces are around it. It is highly recommended in desert areas and this paper provides a significant conclusion of it but, just in terms of maximising heat loss by effect of air movement.

1.3. General Consideration

Courtyards in general are part of an architectural language common through the history of many regions. The courtyard, especially central courtyard, is one of the generic strategies available to architectures and engineers in their quest to provide more energy efficient and environmentally suitable buildings. Internal courtyard maximizes the thermal interaction between the building and the outdoor environment, introducing the outdoor into the heart of the building's core. The courtyard buildings all obey one fundamental rule of being planned around a central open courtyard. A typical courtyard generally has a planted, paved section, one pool, various trees and flowers. Depending on the time of the day there is always a shaded area, enabling the people to carry on their activity and at the same time to enjoy nature, water and cool breezes. The main advantage of courtyard is the relative isolation from outside environment. There are some thermal advantages for courtyard concept, for example reducing the effect of solar radiation, although solar radiation is not completely eliminated, but the courtyard geometry itself shades at least two of the courtyard wall surfaces and part of courtyard floor surface. The shade from trees in courtyard is usual. The shade from a tree is better than the shade from a man-made canopy because the tree does not heat up and reradiate down. At night, trees work against natural cooling by blocking long-wave radiation. Consequently, the diurnal temperature range is smaller under trees than in an open space. Shading by trees together with the building itself and the walls surrounding the courtyard, can isolate the air mass within the courtyard and keep the wind from mixing the cooled air with the warmer ambient air as it otherwise would [3].

However, the level of thermal comfort in a courtyard is determined by the microclimate forces acting on it, most notably air velocity. The effects of this parameter may be evaluated with respect to the courtyard's geometry. Donham [4] suggested that, the small courtyard is an excellent thermal regulator in many ways. This is because, if the courtyard's size is kept small enough to achieve shade during the day, it will allow less thermal impact and more heat dissipation from surrounding indoor spaces. Olgyay [5] has shown that the optimum form is a rectangle in plan having a proportion of

(1:1.3). Importantly the height around the courtyard is the most important factor of courtyard plan size but, Olgyay did not mention this important point. Obviously, the control of height around the courtyard can be a main factor on effect of air-velocity in the courtyard. Increased air movement is an easier and cheaper solution to the thermal problems under hot condition. Because of this fact the vernacular architecture was designed to take advantage of the prevailing winds. But, the wind speed within a central courtyard is usually lower than the ambient wind speed. Is it suitable for desert people, who are using courtyard? How much, if the answer is yes?

1.4. Air velocity and human thermal comfort

Beside of the courtyard condition, the effect of air movement on human thermal comfort is important and also, is different. It depends on environmental temperature and humidity, as well as on the clothing and metabolic rate. When air temperature is above the skin temperature (like desert condition, but day-time), the effect of air movement will be the same as other climatic factors and the increase of air movement will raise the skin temperature. Air movement is more noticeable when the air is cool and the difference between skin and air temperature is large (like desert condition, but night-time). Conversely, if the air is only slightly below skin temperature, very large increases in air speed are needed to achieve an increase in convective cooling. However, variation in air velocity is important. The air movement, in combination with air temperature, will affect the rate at which warm air or vapour (for example) is taken away from the body, thus affecting body temperature. If the air in a space is still, a person loses heat by natural convection [6].

ASHRAE standard - 55 [7] sets an upper limit of around 0.2 m/s (assuming typical turbulence around 40%) for air velocities within the basic comfort zone to reduce the risk of discomfort from drafts. Nicol in his analysis on Webb's [8] data in Iraq and India noted that air movement reduced discomfort from heat at temperatures above 31°C; below this temperature there were few votes indicating heat discomfort. A theoretical analysis by Humphreys [9] suggests that where the air velocity is above 0.1 m/s and fairly constant, this allowance can be equivalent to rising the comfort temperature by $\{7-[50/(4+10V^{0.5})]\}$. There are assumptions built in to this equation, but the result is not particularly sensitive to the accuracy of this assumption.

2. Materials and method

Place of the study

The study was performed in the city of Yazd - centre of Iran. Yazd is mostly hot and arid with the extremely high day temperatures of 27°C to 45°C or even more in shade. Nights are cool and the temperature dropping to the 0°C or sometimes less than it. The city normally has cloudless skies fairly low relative humidity [19].

A field study was conducted with 353 subjects in transverse sampling at about 41 courtyard houses, all were naturally ventilated. The experimental work was carried out from 15th July to 4th August 2002. The subjects completed questionnaires when they were in their dwelling's courtyard. The questionnaires requested information on thermal sensation {ASHRAE seven point scale- from cold (-3) to hot (3) with neutral of (0)} and clothing value (ISO-7730 table). Air temperature was obtained from Sky; Data Hog, data- loggers that gathered and stored results automatically. The data loggers were carried from subject to subject. The time was accurately written on the questionnaire. At the same time outdoor temperature was recorded. For present study, the measure of air velocity was necessary but presents a number of problems. It is so variable from place to place in a courtyard as well as in direction and magnitude. Despite of it, an air flow meter, Solomat MPM 500e, measured air velocity.

3. Results

Courtyard air temperatures ranged from a low of 16.5°C to a high of 35.6°C, with a mean of 28.4°C. Mean of air velocity was 0.27 (m/s) in the range of 0.01 to 0.53 (m/s). Clothing value as physical data has a great effect on thermal comfort. It is individual and has a difference from one person to another. Mean clothing value was 0.37 Clo, between 0.31 Clo. to 0.70 Clo. In terms of sensation vote, the mean was 0.48 or slightly warm and the range was between cool (-2) to warm (2). There was no subject who indicated (-3 or 3).

3.1. Correlation coefficient between variables

Correlation coefficient is a statistical technique used to explore the relationship between two variables. Table (1) shows correlation coefficient between variables. The correlation of air temperature and air velocity was relatively low. It is interesting, when the temperature is in lowest amount; the air movement is higher and indicated that subjects using air movement as adaptation behaviour in hot condition. The sensations votes also are well correlated with air temperature and in all spaces were significant. The negative correlation between air temperature and clothing value shows a very good relationship between these two variables. The warmer it is the less people wear. It is an indication that the subjects were using clothing as a way of adjusting to the thermal environment. The correlation coefficients between air temperature and thermal sensation votes was (r=0.698). Thus the main cause of comfort was affected by air temperature rather than other variables.

Table 1. Correlation coefficient between variables

Variables	Air temperature : Sensation vote	Air temperature : Clothing	Air temperature : Air velocity	Air velocity : Sensation vote	Clothing: Sensation vote
Amount	0.698	-0.941	-0.017	-0.295	-0.622

3.2. Neutral temperature and acceptability

Simple linear regression was performed of the ASHRAE scale responses versus air temperature to determine the strength of the relationship between them. As shown in Figure (1) the slope of sensation responses is around 0.123/°C and the neutral temperature is 25.6°C (R: 17.5 – 33.8°C). It is comparable with neutral temperatures from other field studies in Iran (e.g [10], [11], [12]).

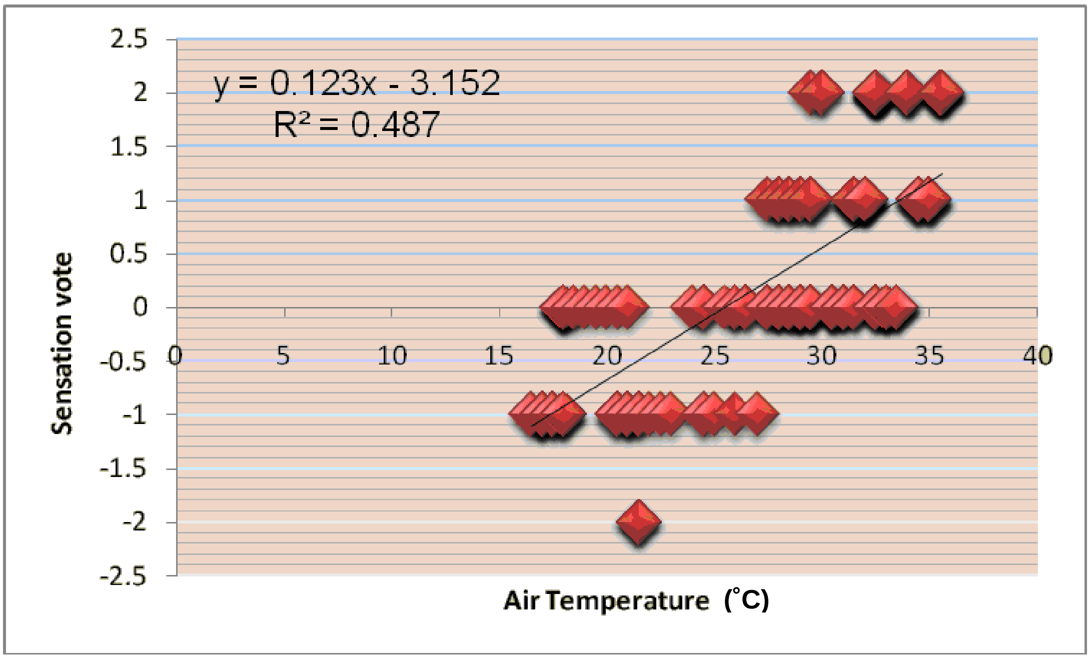


Fig. 1. Neutral temperature and acceptable condition

4. Discussion

The study has identified several thermal comfort adaptive actions that a person might take to achieve comfort. Relationship between such actions and environmental factors were strong and significant in this study. In the survey relationship between clothing values and air temperature was significant. Clothing insulation had a strong linear dependence on air temperature. Figure (2) shows scatter diagram between air temperature and clothing value, which indicated that value of clothing insulation, is related to air temperature. Air velocity is another indication of behavioural adjustment to temperature. Building occupants, particularly in desert, might be expected to increase general air movement within their occupied zone. In hot condition, the rate of air movement is one of the best means of improving thermal comfort. Figure (3) shows effect of both air velocity and clothing value at different temperatures zones on thermal sensation.

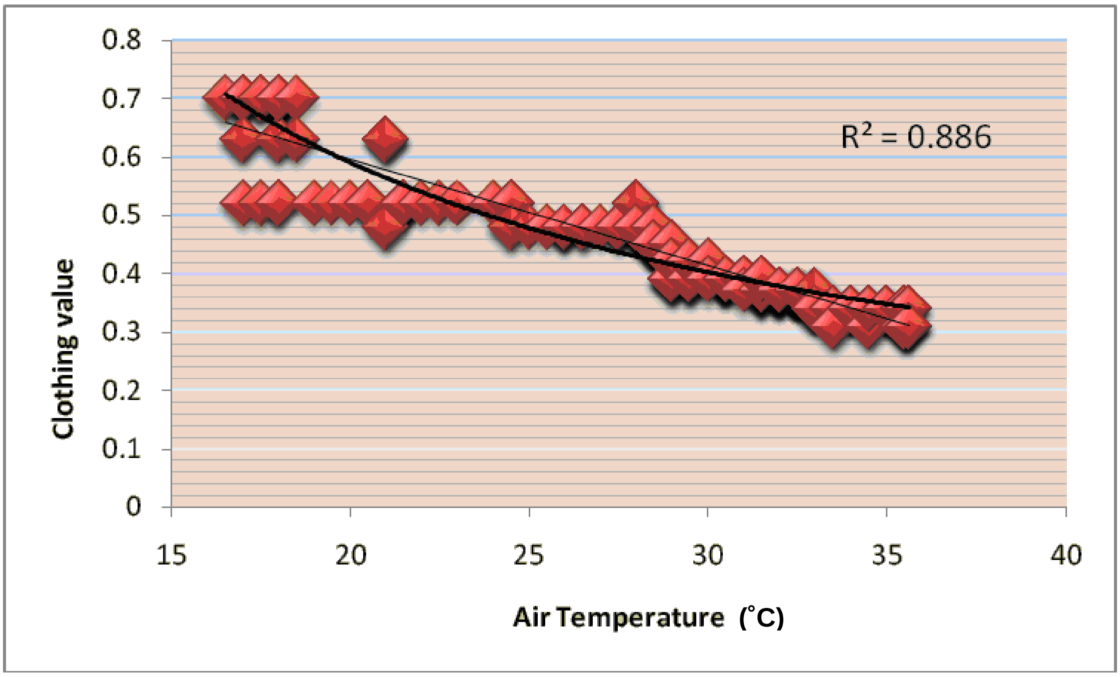
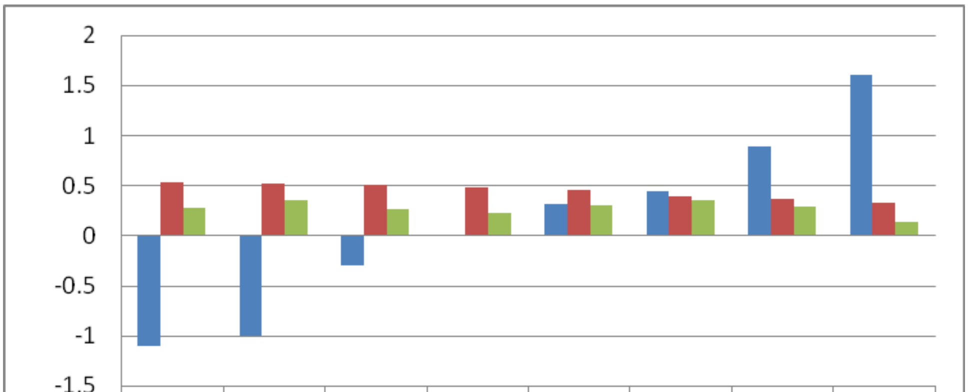


Fig. 2. Relationship between air temperature and clothing insulation of subjects



	20-22	22-24	24-26	26-28	28-30	30-32	32-34	34-36
Sv	-1.1	-1	-0.3	0	0.32	0.44	0.89	1.6
Clo	0.53	0.52	0.5	0.48	0.45	0.39	0.36	0.33
V	0.28	0.35	0.26	0.23	0.3	0.35	0.29	0.13

Fig. 3. Effect of air velocity and clothing at different category of temperatures on thermal sensation

4.1. Comparison of PMV and AMV

The PMV (Predicted Mean Vote) in Yazd are determined by Fanger's equations. The AMV (Actual Mean Vote) and PMV of subjects and air temperature is plotted in Figure (4). The regression coefficient of the PMV is 0.335/°C and is much higher than that of the actual mean vote of 0.183/°C. Such a discrepancy between estimated neutral temperature from PMV line and AMV line exists. The neutral temperature of the actual mean vote is more than 27°C while the predicted temperature from PMV is less than 26°C.

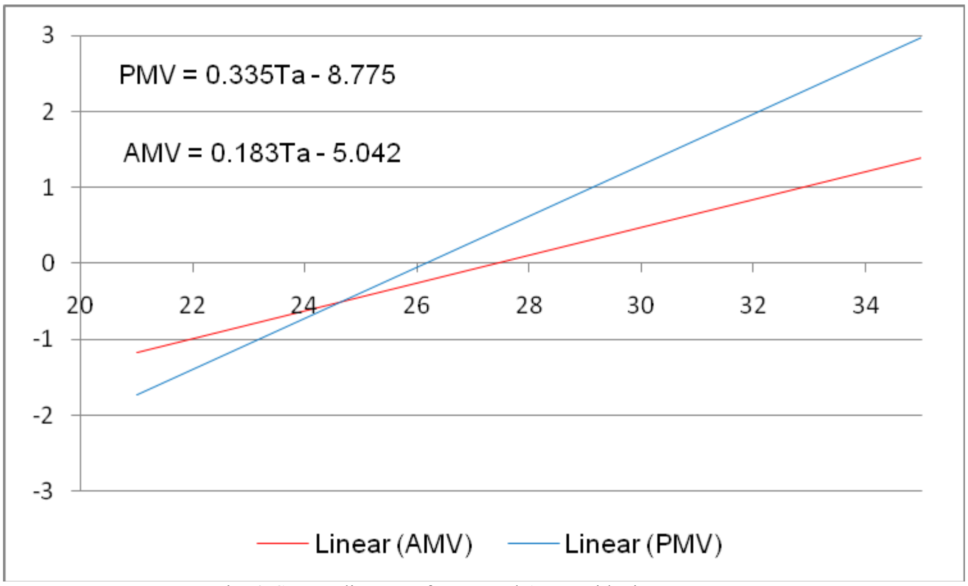


Fig. 4. Scatter diagram of PMV and AMV with air temperature

4.2. Applying the results to courtyard design

Like, a theoretical analysis by Humphreys, this study suggests that the amount of air velocity can be equivalent to rising the comfort temperature by [1.06*ln(V) +3.05], when $0.1 \leq V \leq 0.8$ (m/s) in desert condition. It means if neutral temperature is T_n the air-velocity can rising the comfort condition between 0.6°C to 2.8°C. Figure (5) Shows the maximum courtyard temperatures, which often occurred at noontime, are well below maximum outdoor temperatures. However, due to the large diurnal range of the outdoor temperatures in both condition (Max. or Min.) a considerable part of the day is usually inside the acceptable range. With increasing 0.5 (m/s), the acceptable condition could be the same as courtyard condition and it is surprising and interesting.

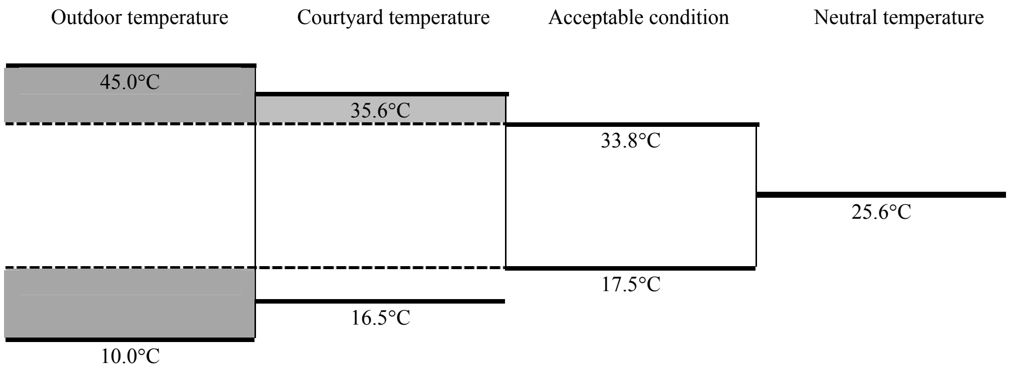
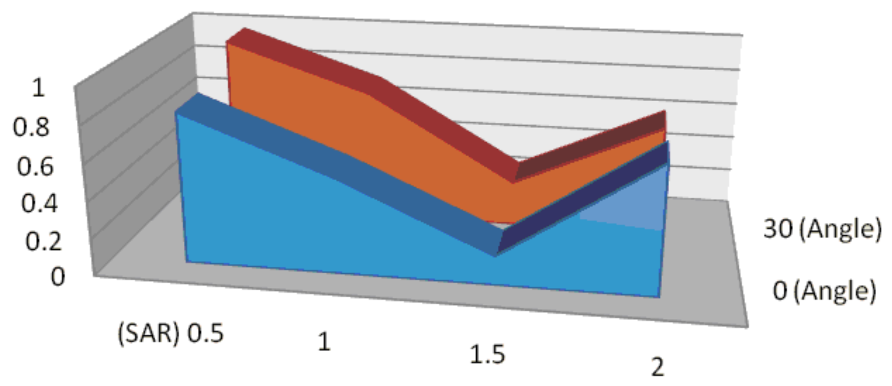


Fig. 5. Comparison between outdoors, courtyard and acceptable condition for Yazd people

After this magnificent results, back to previous statement which was:
[*the wind speed within a central courtyard is usually lower than the ambient wind speed. Is it suitable for desert people, who are using courtyard? How much, if the answer is yes?*]
According to the result of experimental work, the answer is clearly ***yes***. So the next question is how much?

From the field work by Heidari [10], it well showed that the effect of the courtyard for mass-air heat exchange and thus lowering the daytime indoor air temperatures below the corresponding levels of shade ambient temperature was correlated with the air-flow pattern. This correlation indicates that the potential of the courtyard to act as a passive cooling strategy is a function of the air-velocity. Obviously, air-velocity patterns in courtyard are a function of courtyard depth to width ratios. Thus, data of courtyard's wall surface pressure and internal flow should be measure. The researcher measured wind pressure on the central axis of the courtyard faces and the wind velocity of the front of the roof top. He found that when the dimensions of the courtyard were changed, the pressure coefficients on the upwind external faces are found to vary. The change of the average pressures on the courtyard walls with the change of the courtyard area, and for different incidences of the wind, is shown in Figure (6). In this Figure the sectional aspect ratio is the ratio between the courtyard depth (D) and the courtyard wall height (H), called (*SAR*) and (*Cp*) is the velocity at the roof top. Figure (6) is showing that the pressure coefficients on the courtyard walls according to wind angle are different in the one condition to another.



	(SAR) 0.5	1	1.5	2
0 (Angle)	0.82	0.52	0.16	0.7
30 (Angle)	0.98	0.72	0.25	0.61

Fig. 6. Variation of Cp on courtyard wall surface with different amount of *SAR*

At an incident angle of the face of 0° and 30° the pressure were found to be the lowest at *SAR*=1.5 and rose significantly with the increase of the courtyard size. The pressure fields in the small courtyards seemed insensitive to wind angle. The effect of changing the courtyard size was less than that of changing the wind incidence [20]. So, because of the strong wind in desert condition, it seemed that courtyard with SAR less than 1, is suitable and this is answer of question 2.

5. Conclusion

This article discusses desert architecture and its influences upon design, particularly the effect of desert climates. The fundamental functions of buildings are explained and their development since the modern period is briefly described. It is clearly seen that there are two distinct separations of architectural movement: the contemporary and the traditional. While the former has hardly proved successfully, the latter seems to gain a renewal of interest. For building designs, the factors which have been affected, are considered. The concept of the central courtyard for desert architecture as a main strategy is explained. The small courtyard is an excellent thermal regulator. This is because, if the courtyard's size is kept small enough to achieve shade during the day, it will allow less thermal impact and more heat dissipation from surrounding indoor spaces. The solutions have nevertheless been suggested, which lead to the trends in desert architectural design. However, the important points in this study were:

- In a central courtyard it is possible to design the entire landscape, including a pond that is surrounded by trees and effectively shaded, all can improve the humidity level to achieving comfort condition
- Air-flow patterns in courtyard are a function of their depth to width ratios.

● The potential of courtyards to act as passive cooling can be correlated with a building composition in terms of airflow rate and pattern.
● In this study, air temperatures are well correlated with thermal sensation votes and clothing values.
● The neutral temperature for subjects was 25.6°C with a thermally acceptable range of 17.5°C to 33.8°C. The results of this study showed the strong relationship between prevailing temperatures and neutral temperature. This range also, is much wider than some standards like ISO-7730 or ASHRAE-55.
● The comfort zone is much wider than recommended by Iranian standard thus by applying such results it is possible to 39% 0f energy in buildings.
● The range of acceptable temperatures shows a great opportunity for the building designer to provide thermal comfort in desert climate, without waste of the energy.
The implication of this conclusion on architectural design gives useful guidelines in designing naturally ventilated buildings with internal courtyards in desert condition.

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