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The effect of solar heat gain on climate responsive courtyard buildings

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Abstract

Traditional houses are regarded as the best examples of energy efficient design due to their climate responsive design approach. Thus, traditional Diyarbakir houses in the hot-dry climate zone provide passively comfortable indoor environments without consuming excessive energy by their proper design parameters. Especially, during summer period, cooling loads are reduced by virtue of their climate responsive design despite high outdoor temperatures and intensity of solar radiation. In this study, the effect of solar heat gain on heating-cooling loads in courtyard buildings derived from central courtyard plan with different A/V ratios is evaluated. Moreover, the alterations of indoor conditions between seasonal parts, which are placed around the central courtyard in order to obtain optimum amount of solar gain, are analyzed. As a result, the efficiency of heating-cooling load provided by climate responsive design is aimed to be highlighted by considering the passive building performance of courtyard buildings in hot-dry climate zones in relation to solar heat gain.

Keywords
Solar radiation, Hot-dry climate, Climate responsive design, Courtyard-building form, Heating-cooling loads.

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1. Introduction

Buildings should be designed not only to satisfy biological, psychological and socio-cultural needs of users but also to provide required indoor conditions regarding climatic comfort. However, nowadays buildings consume considerable amount of energy to ensure these conditions and add new issues to the growing environmental problems (IEA, 2015). Therefore, energy efficient buildings should be designed to minimize energy consumption of buildings and to benefit from sustainable energy sources despite the depletion of fossil energy sources. In this context, the integration of solar energy to the building structure by using active and passive systems is extremely important; thus, designing energy efficient buildings operated by solar energy will have minimized the damage of buildings to environment.

Designing buildings as passive systems in accordance with climate to benefit from solar energy is an important step though establishing sustainable and energy efficient built environments because these kinds of climate responsive buildings, which are designed by choosing appropriate values for design parameters based on the analysis of environmental conditions, minimize active energy needs due to optimum solar heat gain. In other words, by virtue of climate responsive design, the need of heating energy is reduced by maximizing solar heat gain during the winter period and cooling energy by minimizing solar heat gain during the summer period (Olgyay, 1963). Traditional houses are regarded as the best examples of energy efficient design due to their climate responsive design approach that offer comfortable indoor environments without consuming excessive energy. Today, the energy efficient design parameters of traditional buildings from different climate zones that had been developed based on knowledge gained through experience, may lead contemporary architecture in terms of energy conservation.

Turkey consists of five different climate zones that generate diversity with a rich cultural heritage in relation to traditional architecture. Especially in hot-dry climate zone, many restrictions experienced in conjunction with building design related to the characteristics of the climate had been consciously transformed into a unique architecture. The traditional buildings of this region where the highest solar radiation is seen, offer passively comfortable indoor environments by controlling the climatic conditions with their design parameters (Manioğlu & Koçlar Oral, 2012; Manioğlu & Yılmaz, Z, 2008). Among these design parameters, the climate influences the development of building form in the most obvious way. Courtyard building form is generally preferred to provide required comfort conditions against high summer temperatures and low humidity because courtyard functions as an outdoor space that provides an effective control of the climate elements such as temperature and humidity. Due to its substantial role, courtyard determines the characteristics of the structure and stands out as a key factor in building design for hot-dry climate zone.

Diyarbakir, as the pilot city of the hot-dry climate zone in Turkey, has a deep-rooted architecture, which is shaped under the influence of the climatic conditions as well as the great cultural wealth. Considering the design parameters of the buildings, the courtyard plan types have been found commonly used as in other regions of hot-dry climate zone around the world. In addition, the fragmentation of the plan into distinctive parts used periodically is considered as the most characteristic feature of Diyarbakır houses. The building parts are oriented in order to accord with different seasonal requirements by optimizing solar radiation as winter part, summer part and in some examples seasonal parts.

In this study, the effect of thermal gain obtained from solar radiation in courtyard buildings is evaluated in hot-dry climate zone by taking traditional Diyarbakır houses as reference. Moreover, the indoor conditions of seasonal parts are analyzed depending on the heat gain related with the orientation around the courtyard. Thus, it is aimed to highlight the efficiency of heating-cooling loads provided by courtyard building form along with other design parameters of traditional houses.

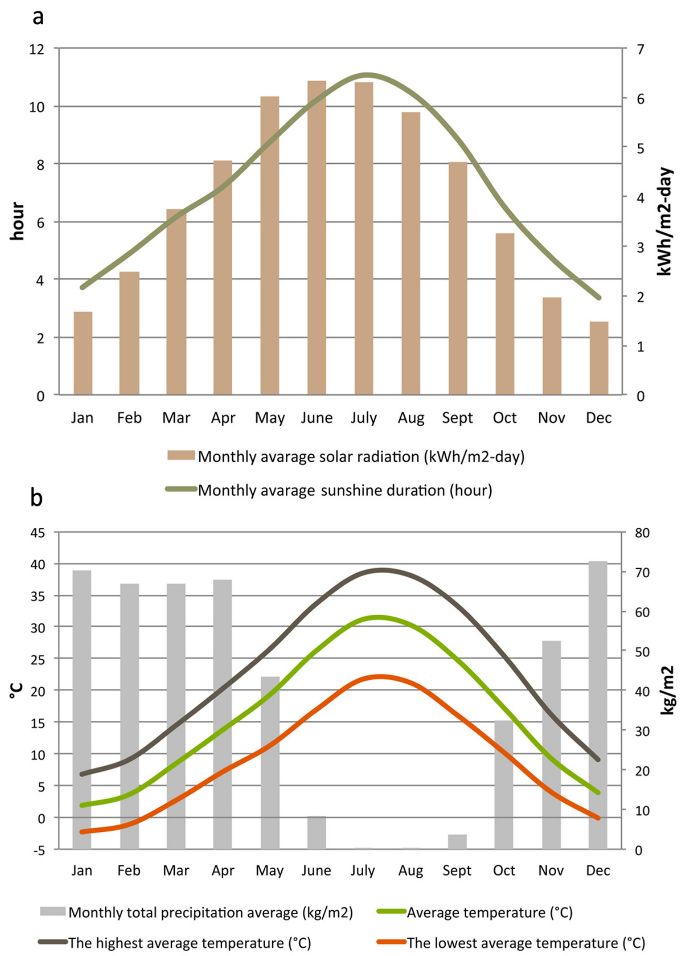

Figure 1. *(a) Avarage climatic data (1950-2015) (Url-1) and (b) solar radiation (Url-2) of Diyarbakır.*

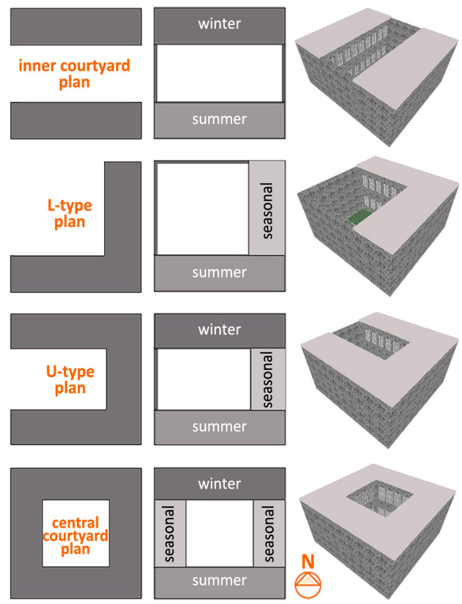

Figure 2. *Common courtyard building types of traditional Diyarbakır houses and placement of the seasonal parts.*

2. Traditional Diyarbakır buildings

Diyarbakır is located in the southeastern region of Turkey on a plateau surrounded by high mountains that is under influence of the continental climate. The summers are hot and dry due to the desert winds coming from South while the winters are not freezing because the Southeastern Taurus Mountains block cold northern wind waves. According to meteorological data given in Figure 1, in July, the highest average temperature is measured 31.2 ° C, while the lowest average was detected in January by 1.6 ° C (Url-1).

Old Diyarbakir settlement is established on a bordered area enclosed by city walls. Due to this obligation to settle in a restricted area, the buildings have interacted with each other and organic forms have emerged in adjacent settlement textures. In order to provide shady areas throughout daytime, the streets are quite narrow and enclosed with blind walls of self-closed buildings.

The impact of climate stands out as an important factor in the design of the traditional Diyarbakir houses (Dalkılıç, & Bekleyen, 2011). Courtyard building form is very common in this region in order to overcome extreme climatic conditions by using passive techniques. The courtyard removes the hot indoor air accumulated during daytime and cools the building structure during nighttime by natural ventilation. Besides, especially in summer period courtyard function as the main living space where most of the daily activities are carried out. In Figure 2, four distinctive courtyard plan types that are generally seen in traditional Diyarbakır Houses are given; L-type plan, U-type plan, inner courtyard plan and central courtyard plan. (Erdemir Kocagil & Koçlar Oral, 2014).

The most characteristic feature of traditional Diyarbakır houses is the fragmentation of buildings into the seasonal parts that are positioned around the courtyard based on optimal solar gain (Bekleyen, 1993). It is seen that these seasonal parts are emerged in order to provide passively comfortable interiors that are accord with different seasonal requirements.

The summer part placed on the south side of the courtyard is regarded as the most prominent section of the building which is exposed to less solar radiation in comparison with other seasonal parts because its main façade is faced to the north in order to minimize solar heat gain. Therefore, during summer period this part provides more shady and cool living spaces that are protected against thermal effects of the sun. Summer part both has lower radiative and average temperatures and can be cooled more quickly owing to the airflow created by convection in regard to higher ceiling and larger floor area (Baran et al., 2011).

The winter part is located opposite side of the summer part and its windows are faced to the south; thus, during winter period solar heat gain is maximized and the cold north winds are avoided. Besides, to reduce heat loses arising from air movements; both few smaller windows on the south façade and lower floor area to ceiling height ratios are preferred.

The building envelope of traditional Diyarbakır houses has developed to minimize the effects of higher temperatures and daily swings. Basalt stone, which is an igneous rock with thermal conductivity of 1.40 W/m°K, is commonly found in Diyarbakır due to volcanic origin of this region and is used as the main opaque structural materials (Erçin Kahveci, 2008). The exterior walls of the buildings are built quiet thick ranging between 50-80 cm and store heat to delay the effect of high exterior temperatures on the interior spaces.

In order to reduce solar radiation gain through exterior walls, traditional Diyarbakır houses are placed attached in order to minimize external surface area. There is almost no windows besides small ventilations openings are places on façades facing streets due to both socio-economical reasons and climatic control strategies; however, many large windows are placed on the courtyard façades of the buildings to gain controlled solar radiation and daylight (Tuncer, 1999).

3. Methodology

The purpose of the study is to analyze the effect of the courtyard building form considering traditional Diyarbakır houses on heating-cooling loads and the energy efficiency of the use of seasonal parts via energy simulations. The method is explained in the following steps.

3.1. Determination of the courtyard building alternatives

Firstly, the central courtyard plan is selected among four commonly seen plan types because the symmetrical placement of building masses around the central courtyard enables to investigate the impact of orientation. Thus, four identical building parts derived from positioning around central courtyard as summer part, winter part and seasonal parts are evaluated in order to compare heating-cooling loads in relation to solar heat gain depending on orientation. In this study, the reference building form alternatives are generated from central courtyard plan by combinations of different A/V (area per volume) ratios.

Building form can be defined by means of geometrical variables of the buildings. It is possible to determine building forms that have same volume with different exterior surface areas; therefore, each building form requires different amount of heating-cooling energy to assure required indoor conditions. Thus, the ratio of total façade area to building volume (A/V) is defined as the best indicator describing building form (Erdemir Kocagil & Koçlar Oral, 2015). In this study, to analyze the effect of building form as a variable on heating-cooling loads, reference building forms are generated by using central courtyard plan with different A/V ratios and the interaction between the area that loses heat (A) and the volume that is protected from exterior conditions is observed. The selected A/V ratios change between 0.50 and 1.00 with 0.10 intervals (0.50, 0.60, 0.70, 0.80, 0.90 and 1.00) and two storey buildings with 4 m floor height are originated from each ratio is created (Figure 3). To compare building alternatives under equal conditions, square formed plans are developed and each façade-facing courtyard has transparency ratio of 40%.

In central courtyard plan, four seasonal parts encircle the courtyard; on the south side of the courtyard the summer part, on the north side the

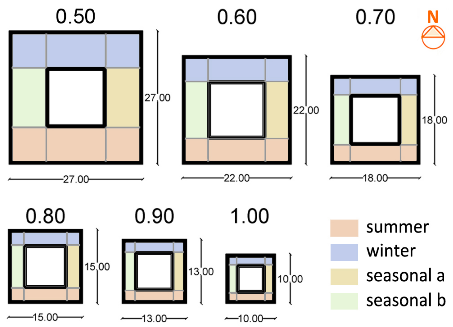

Figure 3. *Reference building form alternatives generated from central courtyard plan with selected A/V ratios.*

winter part and on the east-west side two seasonal parts are placed. To analyze the effect of orientation on heating-cooling loads, all seasonal parts of each building form alternative that have the same floor area and transparency ratio but different orientations are evaluated; thus, the energy efficiency provided by use of seasonal parts is observed.

Layering of the structural components used in this study is developed in accordance with the original traditional buildings by using local and sustainable materials. Basalt is the main material of the opaque structural components. Layering and physical properties related to heat transfer of each opaque structural component are given in Table 1.

3.2. Calculation of heating-cooling loads

The heating-cooling loads of developed building alternatives are calculated via energy simulations performed by Design Builder, which is a user friendly software utilizes Energy Plus simulation engine. Firstly, several assumptions regarding interior and exterior conditions are defined to analyze the alternatives equally. The indoor comfort temperature is set 26°C for summer period and 21°C for winter period. The climatic data for Diyarbakır is obtained from The International Weather for Energy Calculation files (IWEC).

In this study, to evaluate the heating-cooling performance of the central courtyard building form generated by different A/V ratios and the seasonal parts with different orientation, the results obtained from simulations are compared. To make accurate comparisons, the annual energy loads are given in per unit area (kWh/m^2) in order to eliminate spatial size differences stemmed from different A/V ratios.

The results given in Figure 4a shows that as A/V ratio increases, the amount of solar radiation gained per square meter and correspondingly the cooling loads increase but it is also seen that the heating loads increase at the same time. Hence, as higher A/V ratios have proportionately greater external surface area; both the amount of solar radiation gained and heat loss through building envelope rise. Comparing the alternatives developed in the study shows that as the A/V ratio increases, the amount of heat gained from solar radiation does not compensate the amount of heat loss; therefore, alterna-

Table 1. *Layering and physical properties of structural components used in the study.*

Structural Components	Material	Thermal Conductivity (Λ) [W/m°K]	Specific Heat (c) [J/kg°K]	Density (ρ) [kg/m³]	Thickness (d) [m]	U-value [W/m²°K]
Exterior Wall	basalt	1.40	1013.00	2852.00	0.20	0.98
	gravel aggregate	0.36	840.00	1840.00	0.20	
	basalt	1.40	1013.00	2852.00	0.20	
Internal Floor	basalt	1.40	1013.00	2852.00	0.10	0.36
	soil+lime	1.16	880.00	1460.00	0.20	
	wooden panel	0.13	2000.00	900.00	0.05	
	wooden beam	0.13	896.00	2800.00	0.25	
Ground Floor	basalt	1.40	1013.00	2852.00	0.10	1.50
	rammed earth	1.28	880.00	1460.00	0.40	
Roof	black grout	0.61	880.00	1680.00	0.20	0.22
	clay soil	0.47	1000.00	1200.00	0.30	
	straw	0.10	2100.00	300.00	0.05	
	particle board	0.14	1700.00	600.00	0.10	
	wooden panel	0.13	2000.00	900.00	0.15	
	wooden beam	0.13	896.00	2800.00	0.25	

tives with higher A/V ratios have higher heating loads depending on their proportionally larger exterior surface area.

All the building form alternatives give the results that cooling loads are remarkably lower than heating loads because the courtyard building forms, which are regarded advantageous in hot-dry climate zone, are designed to achieve thermal comfort against higher temperatures due to their formal features. Courtyards aim to provide shady areas during the daytime and cool the building structure down during nighttime by means of low temperatures. In other words, courtyards take an active role on passive climate control by reducing cooling loads.

Another characteristic feature of traditional Diyarbakır houses analyzed within the scope of the study is the effect of the use of seasonal parts on heating-cooling loads. Figure 4b shows the heating-cooling loads and solar heat gain of the seasonal parts reside in the building alternative with A/V ratio of 0.50 that procures the lowest heating-cooling loads. According to the results, while the summer part oriented to the north is exposed to the lowest solar radiation and consequently ensures the lowest cooling load; the winter part oriented to the south is exposed to the highest solar radiation and has the lowest heating load. Thus, the building parts that have exactly the same surface area, volume and transparency ratio, show different passive thermal performances only depending on orientation and this affects final heating-cooling loads of each part. In the study, the cooling loads of the summer part is reduced by 34.47% comparing to winter part due to the controlled solar radiation (20.40 kWh/m^2) by being orientated through northward. Moreover, the winter part oriented to the south receives more solar radiation (71.49 kWh/m^2) and the heating loads are reduced by 17.58% than the summer part.

Seasonal parts are considered two-storey and separate calculations are made for each storey to compare the differences in heating-cooling loads arised from solar heat gain. According to the results given in Figure 5, ground floors receive lower solar radiation than 1st floors in all seasonal parts; therefore; they require higher heating loads and lower cooling loads to provide same indoor conditions. The ground floor of winter part receives 50.54% less solar radiation and requires 15.84% more heating load than its 1st floor. On the other hand, the ground floor of summer part receives 57.17% more solar radiation and requires 26.43% less cooling load than its 1st floor. As a result of these calculations, it is seen the surrounding obstacles and the related shadowing effects are also influential on providing comfort conditions passively with respect to the amount of solar heat gain.

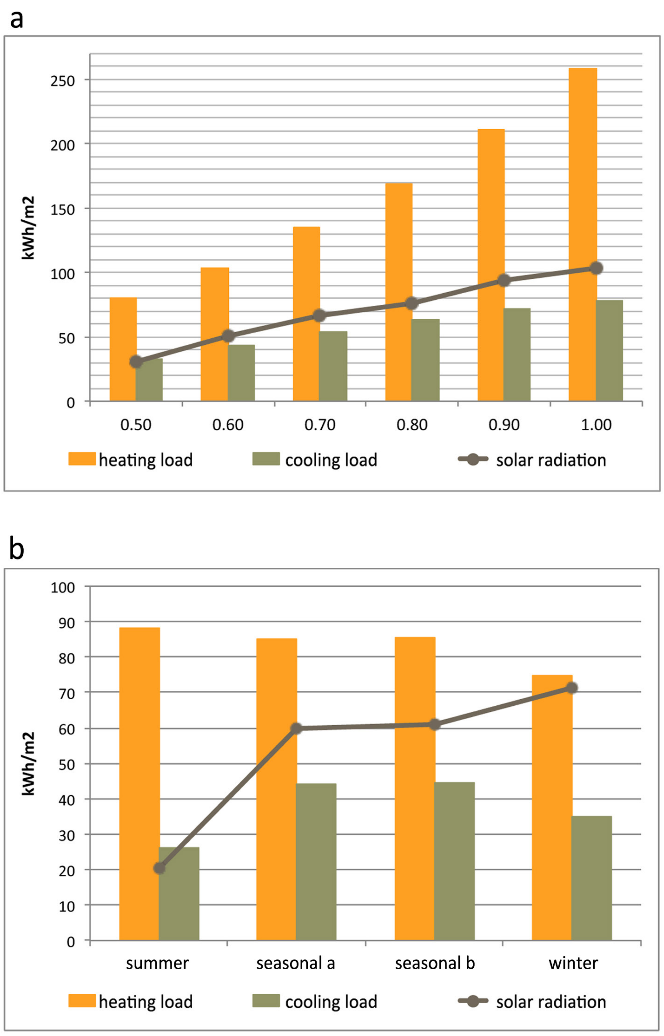

Figure 4. *(a) Heating-cooling loads and solar heat gain of the reference buildings with different A/V ratios.*
(b) Heating-cooling loads and solar heat gain of the seasonal parts resided in the building alternative with A/V ratio of 0.50.

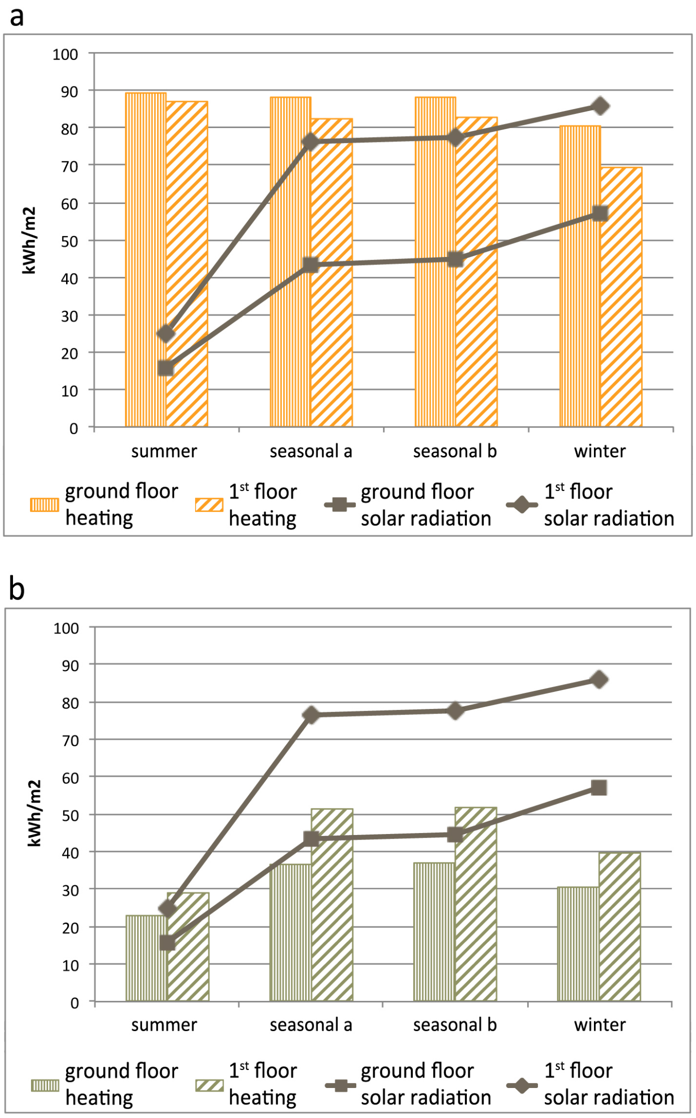

Figure 5. *(a) Heating loads and solar heat gain for the ground floor and 1st floor of the seasonal parts resided in the building alternative with A/V ratio of 0.50.*
(b) Cooling loads and solar heat gain for the ground floor and 1st floor of the seasonal parts resided in the building alternative with A/V ratio of 0.50.

4. Conclusion

In the study, the thermal performance of climate responsive courtyard buildings in hot-dry climate zone is analyzed in terms of heating-cooling loads by generating reference building forms from selected A/V ratios based on traditional Diyarbakir houses. The courtyard is regarded as a substantial space for traditional Diyarbakır houses because it creates not only shady areas throughout daytime but also ensures passive climate control against extremely high temperatures by providing comfortable indoors. Especially, the seasonal parts yield passively energy efficient results due to their proper orientations that accord with seasonal requirements by using proper values for design parameters and providing optimum solar radiation.

Firstly, after comparing the reference buildings generated from central courtyard plans with various A/V ratios, it is observed that the solar heat gain and accordingly heating-cooling loads are under influence of the building form. The simulations results show that the building alternatives with lower A/V ratios provide comfort conditions by requiring lower energy loads. The prominent feature of the Traditional Diyarbakir house is the use of seasonal parts which are developed by fragmentation of the building and properly oriented in order to optimize solar gain based on seasonal requirements. Although Diyarbakır is located in one of the regions that is exposed to the highest amount of solar radiation in Turkey, the summer part provides passive solar control by being oriented to the north and minimizes cooling loads in comparison with other parts of the buildings. Moreover, the heating-cooling loads are affected by surrounded obstacles depending on the storey in relation to the amount of solar radiation received; lower floors give more effective results in cooling loads.

As a result, the traditional climate responsive houses of Diyarbakır offer energy efficient solutions by selecting proper values to design parameters and optimizing solar radiation that result in comfortable environments without using excessive energy on heating and cooling. Therefore, their design principles should not be ignored in contemporary building design from the point of energy efficiency. In the future, it is essential to compile a guideline presenting the results of the studies about appropriate design parameters for different climate zones that will lead designers to produce climate responsive environments and this study may be regarded as the initial step through this way.

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