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Simulation-based Approach to Optimize Courtyard Form Concerning Climatic Comfort in Hot and Humid Climate

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ABSTRACT
In hot and humid regions, in order to provide indoor thermal comfort conditions, most important design strategies are to maximize shady areas and natural ventilation. Courtyard building form was developed mainly in response to climatic requirements especially in hot climates. A courtyard is an unroofed area that is completely or partially enclosed by walls or building spaces. The function of the courtyard is to improve comfort conditions by modifying the microclimate around the building. The proportion of the courtyard affects considerably the shadows produced on the building envelope, and consequently the received solar radiation and the comfort conditions in the building. Moreover, courtyards are claimed to be highly effective in enhancing the ventilation and decreasing humidity level. This study intends to investigate variations in indoor thermal conditions according to different design configurations and scenarios. All calculations are made for a surrounded space of the courtyard. Thermal comfort conditions of this space are evaluated according to its orientation, ventilation type and courtyard configuration. In the study, different courtyard proportions, orientations and ventilation types are developed. Indoor comfort conditions of the selected space are calculated for Antalya which is a representative city of hot and humid region of Turkey. The software EnergyPlus, is used as a tool for simulating the thermal performance of the selected space. Operative temperatures, indoor humidity, and solar gains are calculated by using this dynamic thermal simulation program and a comprehensive evaluation on the aspects of thermal comfort conditions is carried out. In conclusion, the importance of the systematic approach in order to optimize the decisions taken during the design stage of thermally comfortable and conservative buildings is discussed.

KEYWORDS
Courtyard building, hot-humid climate, thermal comfort conditions, orientation

1. INTRODUCTION

The number of new residential buildings has been growing steadily in the southern coastline of Turkey with hot and humid climate conditions due to increasing population. However, contrary to traditional buildings, construction of new buildings without due consideration of energy efficiency and climate responsive criteria increases energy costs and presents itself as an important consequence. Since most of the energy in buildings is used for heating and cooling, reducing consumptions in this area and achieving energy efficiency in buildings have become a priority (Yılmaz, 2007; Manioğlu and Oral, 2015). Reducing energy consumption in residential buildings is possible through taking correct decisions about energy efficient design variables (Kocagil and Oral, 2015).

One of the most effective ways to have thermal comfort conditions in buildings is to design climate responsive buildings according to existing climate conditions for each climatic region (Lechner, 2014). Protection from the heating effect of sunlight and mitigating the effect of excessive humidity in hot-humid climatic regions play an important role in ensuring comfort conditions. In this climatic region, buildings with courtyards are frequently preferred to reduce the area of façades which are affected by solar radiation. It is possible to create shades in the courtyard during the day with spaces surrounding the courtyard and high walls that separate the courtyard from the street. Courtyard dimensions and courtyard orientation are determinant factors to locate shades within the courtyard. When courtyard dimensions change, heat loss and gain through courtyard walls and thus indoor comfort conditions will also change (Muhaisen, 2006; Muhaisen and Gadi, 2006).

The courtyard form has a configuration that also supports natural ventilation (Ghaffarianhoseini et al. 2015). The process of daily changes in temperature and humidity in summer in hot-humid climate regions can be studied in three phases. In the first phase, during the night cool air descends into the courtyard and into surrounding rooms. The courtyard loses heat by radiation. In the second phase, at midday direct sunlight affects the courtyard floor. Some of the cool air begins to rise and leaks out of the rooms. This induces convective currents in rooms. At this phase, the courtyard acts as a chimney depending on its size. In the third phase, the courtyard floor is warmer than interiors and convective currents occur in the late afternoon. After sunset, the air temperature falls rapidly and the courtyard radiates heat and cool air begins to flow to the courtyard and from there to interiors (Gallo et al. 1988; Talib, 1984). During this entire process, due to their effect on solar radiation gain and air movements, courtyard dimensions and sizes of the windows and ventilation types preferred in surrounding spaces have a direct impact on interior thermal comfort conditions (Ok et al. 2007). Therefore, this study evaluates with a parametric approach, indoor comfort conditions of a building with a courtyard in hot-humid climatic region, which are affected and changed according to different courtyard dimensions, different orientation and different ventilation types. Building form and courtyard dimension alternatives evaluated in this study are taken from the author's master's thesis (Bekar, 2018).

2. METHODOLOGY

This study intends to have an approach to evaluate the effects of orientation and ventilation options of a building with varying courtyard dimensions on the thermal comfort conditions in the building. A total of 72 building energy simulations have made by shifting the orientation of the courtyard facing space of 6 building forms with the same courtyard width but different depths to north, east, south and west and by using different ventilation alternatives.

2.1 Determining building and climate related variables

Buildings included in the study are situated on a level land in Antalya with the following coordinates: 30°73'(E) and 36°87'(N) Calculations are made based on the assumption that there are no other buildings that can cast a shade on these buildings and that the buildings are located in the countryside. In the evaluation there are 6 building forms with different courtyards with the same width (400 cm.) but with different depths (50 cm., 100cm., 150cm., 200cm., 250cm., 300cm.). The interior space facing the courtyard with the dimensions 400x400 cm. is the same in every building form. The dimensions of the model created for the study are shown in Figure 1. The transparency ratio on the wall facing the courtyard and the opposing wall is set at 12%. No transparent material is used in other façades in the model. Recommended (TS 825) and existing overall heat transfer coefficients (U values) for Antalya are shown in Table 1.

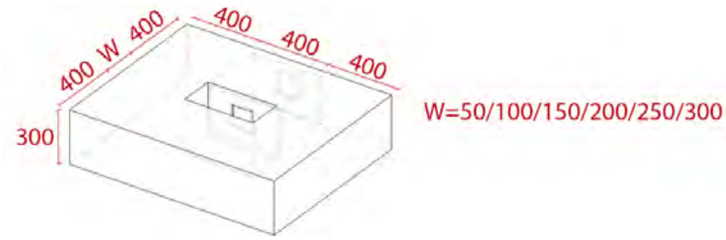

Figure 1: Dimensions of the building with courtyard model (cm)

Table 1. Recommended (TS 825) and existing U values for Antalya

	U_{wall} (W/m²K)	$U_{ceiling}$ (W/m²K)	U_{floor} (W/m²K)	U_{window} (W/m²K)
U_{TS825}	0.66	0.43	0.66	1.8
$U_{existing}$	0.633	0.399	0.646	1.5

2.2 Determining variables in calculations

The change in comfort conditions when the orientation of this space facing the courtyard is north, east, south and west are analysed. The indoor comfort conditions for 6 different courtyard dimensions and for all orientations (S, W, N, E) when there is one window each on the wall facing the courtyard and the opposing wall (cross ventilation) are evaluated. In the study three different ventilation types are defined: windows are open all day (open between 00:00-24:00); windows are closed all day (closed between 00:00-24:00); and windows are closed during the day and open during night (open between 00:00-09:00, closed between 09:00-21:00, open between 21:00-24:00). There assumed to be 2 occupants in the building and one occupant was present between 08:00 - 19:00 and two occupants were present between 19:00 - 08:00 both during week days and on weekends. Lighting level is set 8 W/m² per space.

Calculations of indoor comfort conditions of building models with courtyards with different courtyard dimensions, orientation types and ventilation options were done with EnergyPlus 8.3.0. This is a building energy simulation program with high calculation capacity which uses algorithms such as transfer function, finite difference method and finite elements and with which heating, cooling, lighting, ventilation and other energy flow system can be modelled. Climate data in epw format for Antalya was used in calculations. Operative temperature, relative humidity and solar radiation values on July 21st which represents the hottest day of the year were calculated separately to evaluate the performance of the selected space. Relative humidity and operative temperature values in the spaces with cross ventilation are shown in Figure 2 and total transmitted solar radiation values through windows of the buildings are shown in Figure 3.

3. RESULTS

When the courtyard depth changes, operative temperature values in the space depending on whether the window facing the courtyard has a south or north orientation show similarities for all ventilation types. When the courtyard window of the space is east or west oriented and when windows are closed all day and night ventilation is done, operative temperatures increase with the increasing courtyard depth. When the window facing the courtyard is east and west oriented in the models with the same courtyard depth, operative temperature values are higher than those obtained when window is south and north oriented (Figure 2).

The lowest operative temperature values are obtained in the alternatives with night ventilation and the highest operative temperature values are obtained in the alternatives with windows open all day for the models with the same courtyard depth (Figure 2).

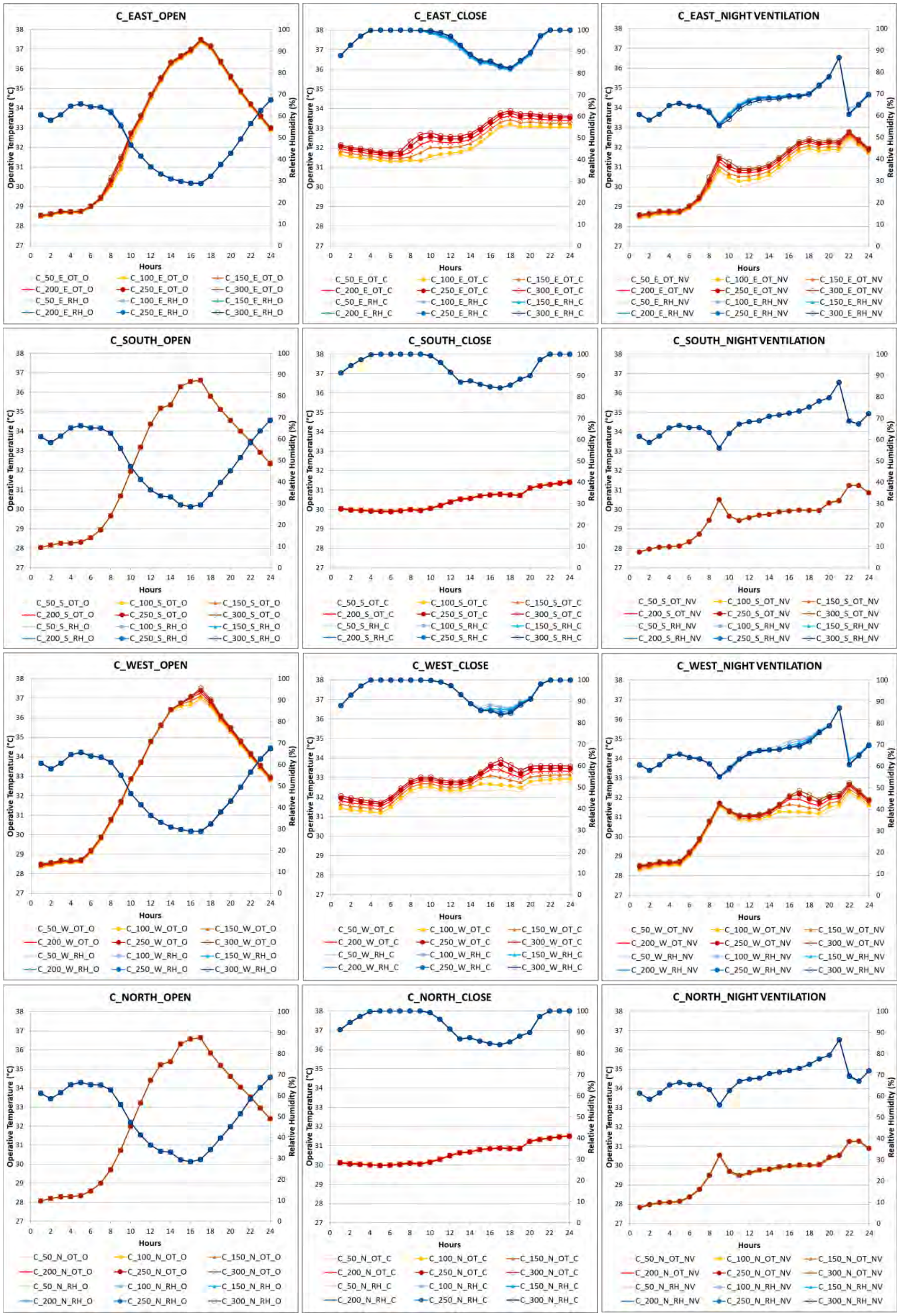

Figure 2.Relative humidity and operative temperature values when windows are open all day (open), closed all day (closed) and with night ventilation

However when a comparison is made for orientation; when courtyard window is west oriented, even if there is night ventilation, lower operative temperature values are obtained between 07:00 - 24:00 hours in all alternatives where courtyard window is north or south oriented and windows are closed all day. The alternative with the lowest operative temperature values is the alternative where courtyard window is south oriented, courtyard depth is 300 cm and night ventilation is used (C_300_S_NV). The alternative with the highest operative temperature values is the alternative where courtyard window is west and east oriented, courtyard depth is 300 cm and windows are kept open all day (C_300_E_O, C_300_W_O) (Figure 2).

When the courtyard depth changes, the relative humidity values in the space, in the case the window facing the courtyard has a south or north orientation, show similarities within themselves when all ventilation types are considered separately. For spaces with east and west oriented courtyard windows; a similar trend continues in the alternative where the window is open all day however in the alternatives where windows are closed all day and night ventilation is done, as the courtyard depth changes, relative humidity values in the space also change albeit small. Relative humidity values in spaces are the lowest in the alternatives where windows are kept open all day and the highest in the alternatives where windows are closed all day (Figure 2).

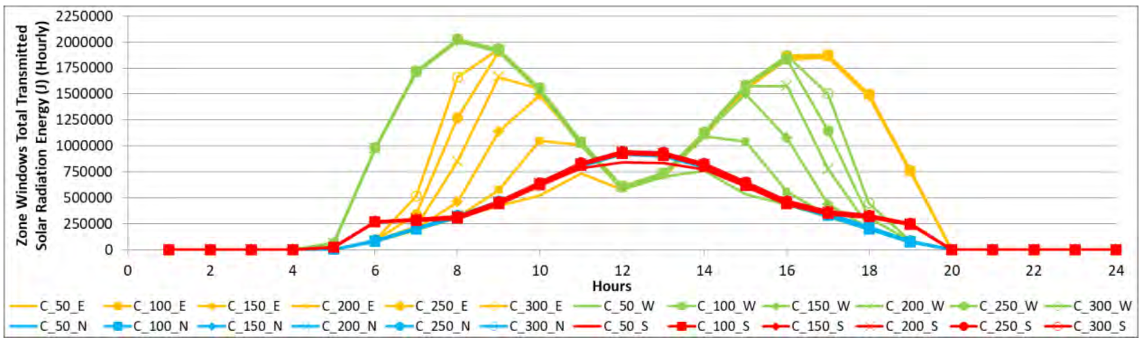

Figure 3. Total solar radiation values transmitted through windows according to orientation of the windows

When courtyard depth is 50 cm, higher solar radiation values are obtained with south and north oriented windows than with east and west oriented windows. When courtyard depth is 100, 150, 200, 250 and 300 cm., higher solar radiation values are obtained with east and west oriented windows than with north and south oriented windows. Solar radiation values decrease before noon in the alternatives with east facing courtyard window and afternoon in the alternatives with west facing courtyard window and with the decreasing courtyard depth as the opposing courtyard wall casts a shadow. In all models, as the courtyard depth increases, solar radiation transmittance through windows increases. The lowest values are achieved when the courtyard depth is 50 cm and the highest values are achieved when the courtyard depth is 300 cm (Figure 3).

4. CONCLUSIONS

This study examined 72 different alternatives to evaluate the effects of orientation and types of ventilation of a building with varying courtyard dimensions on the thermal comfort conditions in the space. When operative temperature and relative humidity values are evaluated together, the optimum result for indoor comfort conditions is achieved with the alternative C_300_S_NV. The findings of the study are;

- Courtyard dimensions, orientation of spaces facing the courtyard and ventilation alternatives of spaces have a direct impact on the indoor climate conditions and consequently on the energy consumption for cooling.
- Courtyard dimensions in the east and west oriented spaces facing the courtyard have more effect on the change of indoor operative temperature values. Orientation of the space has more effect compared to ventilation options for spaces facing the courtyard.
- When different ventilation types should be selected depending on the building function (office or residential building etc.), the most suitable alternative can be created using different courtyard dimensions and orientation options.
- When the building is used in different times of the day depending on the building function (day or night use) the most suitable alternative can be created using different courtyard dimensions and orientation options.
- Courtyard dimensions affect operative temperature and transmitted solar radiation values through windows depending on the orientation of the space facing the courtyard.

It is possible to identify the most efficient building form alternative, orientation and ventilation option which provide the optimum comfort conditions and minimum cooling loads using the parametric evaluation method discussed in this study. In future studies, designs that provide optimum comfort conditions with minimum cooling energy consumption will be possible by also analysing air movements in building forms using computational fluid dynamic methods.

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