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Courtyard Design Variants and Microclimate Performance

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Abstract

Courtyard is often regarded as a microclimate modifier that improves comfort conditions of the surrounding environment. While several literature have identified aspect ratio of a courtyard and its orientation as two design variants that are critical to the microclimatic performance of courtyards, this claim need to be substantiated with empirical evidence. This study assessed the microclimate performance of a U-shape courtyard in a General Hospital in Malaysia. The intention was to verify two critical design variants affecting the performance of an institutional scale courtyard in a tropical climate. The study combined experimental and simulation method. The field study recorded three physical environmental variables namely the air temperature, humidity and wind patterns. The simulation study was performed using IES <VE> suite in two parts beginning with a calibration procedure, followed by the parametric analysis. The result verifies that the manipulation of courtyard configuration and its orientation impact its microclimate modifying ability.

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Keywords: Courtyard environment; physical environment; design variants; microclimate performance; simulation

1. Introduction

Courtyard is a building element that originated from the hot dry regions (Edwards, et al., 2006), and now have gained wide acceptance in various parts of the world. It is defined as an enclosed area surrounded by a building or wall and open to the sky. The courtyard is amongst the oldest architecture footprint that has been used in buildings by human. They are found in houses or in public buildings that offer pockets of meeting places that activate communal and family oriented activities such as gardening, cooking, working, playing, sleeping, or even in some cases as places to keep animals.

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The application of courtyard that disregards its basic design characteristics and placement would affect its potentials. The design variants that are said to affect its performance include its configuration and aspect ratio, orientation, boundary conditions and degree of exposure, and wall types (Reynolds, 2002).

The shapes of courtyards nowadays have taken more dynamic forms other than the rectilinear shapes of the traditional footprint, in response to several factors such as a designer's creativity, as well the contextual needs such as site restriction, and specific functions. This has resulted in creation of new and modern shapes typified as U, L, T or Y (Saeed, 2007). According to Meir (2000) a good modern courtyards are semi-enclosed (three or two sided) with good consideration on its orientation so as to maximize its microclimatic performance.

Other authors have made similar observation of the importance of design variant considerations, highlighting the fact that the thermal condition inside courtyards is highly dependent on the amount of solar radiation. Hence they deduced that the orientation, size of footprint and the height of walls that surrounding of the courtyard could have a significant effect on the thermal conditions inside the courtyard and the surrounding spaces (Al-Masri & Abu-Hijleh, 2012).

Thermal is a principal issue that influences environmental performances in the hot and humid regions (Muhaisen & Gadi, 2006a). Many studies and discussions about the ways and means of resolving thermal issues within a courtyard environment have been covered by several authors including Muhaisen, (2006b) ; Rajapaksha, et al., (2003); Tablada, et al., (2005). For example, assessment on semi-enclosed courtyards oriented to the west and south have been investigated in the Negev desert in Israel during 4 representative days of summer, winter and autumn by Meir et al. (1995). The evaluation of thermal comfort was carried out by comparing the air temperature inside the courtyard and outside. The results show that correct orientation of semi enclosed courtyard can improve the thermal conditions of the surrounding spaces. The wind speed and direction have caused a reduction of air temperature by 2C° - 3C°.

Al-Hemiddi & Al-Saud (2001) have studied the effect of natural ventilation on the cooling effect on human. The study was performed experimentally in a village house that has an internal courtyard in Saudi Arabia. The windows of internal and external were opened alternately during the day and night times to allow for natural ventilation and cooling change. The effect of a covered/uncovered courtyard was also measured. The study concluded that covering the courtyard during daytime and opening it during the night provides significant lowering of the average courtyard temperature.

Besides field measurements, another method frequently used for environmental investigation are by using simulation software. Capturing the complexity of real environmental behavior is one of the primary aims of using computer simulation (Ibrahim, 2006). With this technique, numerical studies can be done in a way that does not require reduction to limited numbers of variables. The variety of ways and methods that can be used to investigate many variables that provide better understanding of the future of environmental behavior of a given model (Groat & Wang, 2002).

Courtyards have been studied using computer simulation tools as it allows faster and cheaper way to test out alternative and scenarios of the design variants (Al-Masri & Abu-Hijleh, 2012; Berkovic, et al., 2012). For instance, Berkovic, et al., (2012) have studied thermal comfort for various courtyards using ENVI-met 3.1 BETA II. The study tested three different scenarios of the courtyard geometries with the optional openings in two opposite sides. Result shows that the significant reduction of MRT is obtained in shaded areas. Among the two opening heights studied, 3 m and 5 m, the lower openings allow less heat and radiation and, therefore, are more comfortable.

In order to ensure the simulation results are valid, calibration procedure is desirable. As stated by Bagneid, (2006) the calibration of site measurement data with the base case model in the simulation tools will introduce ultimate solutions for environmental studies.

An example of a study that combined experimental and numerical evidences are by Sadafi, et al., (2011) who examined the interaction between indoor and outdoor thermal comfort. The aim was to study the influence of internal courtyards on the comfort of terrace houses in Malaysia. A terraced house was chosen as a case study for field measurement. The results of three days recording in naturally ventilated spaces of the house were used to develop a base-line model for simulation study. ECOTECT software as simulation software was used to investigate the effect of applying an internal courtyard on the thermal comfort performance of the terrace house. The results show that applying internal courtyards in the house will result in better natural ventilation and thermal comfort especially with areas that open to the outside environments. The study also highlighted the effect of the envelope opening sizes on the thermal conditions. The study suggests that the internal courtyard in a house could have a great effect when considering the surrounding spaces and provided sufficient and efficient opening aided with shading means.

The impact of courtyard on energy consumption has also been investigated. The study by Muhaisen and Gadi (2006b) concluded that deep and long courtyard forms results in less energy consumption due to the shading effect that such configuration present. The shallow courtyard forms is thus better suited for cold climate as it will increase the solar gain and results with less heating loads in winter time.

Aldawoud (2008) has mentioned that the integration of the courtyard is found to be energy efficient in all climates, specifically in the hot arid and hot humid climates. The study investigated different types of glazing and U-value that facing the courtyard. Results have outlined that the low U-value glazing type with a lower percentage of wall window ratio (WWR) has clear reduction in energy consumption.

Besides the environmental advantages of a courtyard, the psychological potential has frequently been highlighted (Rust, 2010). Courtyard is said to be a place for quiet healing in contemporary hospitals that allow the mediation between the natural and the manmade environment. A lot of environmental and healing properties can be introduced to the courtyard in hospital such as shade, water, trees and flowers, sound of wind, pavement, colors and many more that stimulates the five senses on the human body (Abbas & Ghazali, 2010).

It can be concluded that many past performance studies have investigated courtyards applied in low-rise residential type conditions. Empirical research on courtyards within a non-domestic building scale, under the hot humid climate influences is still scarce.

In this paper, the U-shape (semi-enclosed) courtyard in a General Hospital setting was selected for environmental study by investigating two types of design variants. The aim is to study the effect of these design variants in the actual site as well as in simulated environment by generating alternative scenarios of the courtyard. The study is limited to examine two design variants only, which are the orientation of the courtyard and the height of the courtyard walls.

2. Study approach

The research combined site measurement and computer simulation study. The phases of research are as illustrated in figure 1.

2.1. Site measurement

Situated close to the equator, the climate of Malaysia is hot humid, characterized by high temperature, high humidity and abundant rainfall throughout the year. The field measurement was conducted on a U-shape courtyard situated in a public hospital in Malaysia. The hospital is located in the district of Sepang in the state of Selangor. It is situated between101° 43' 12.07"E longitude and 2° 58' 37.38"N latitude. Table 1 presents further information of the courtyard configuration.

The environmental parameters recorded were air temperature, humidity, and the speed and direction of the wind. The measurements were taken using PortLog- Weather Station, placed within the central part of the courtyard at 1.5 m above ground level measured continuously at 15 minutes intervals (figure 2). A continuous measurement was taken inside the U-shape courtyard during working hours beginning at 10:30 am until 5:30 pm on Tuesday 23rd of October 2012. The logged data were later exported to Microsoft Excel 2010 spreadsheet for analysis.

Table 1. The U-shape courtyard design configuration

Courtyard	Area m²	Configuration	No. of multi floors	Opining side
U-shape	893	Three sided and has a rectangular shape	North side : 5 floors East side : 4 floors West side : 3 floors	South

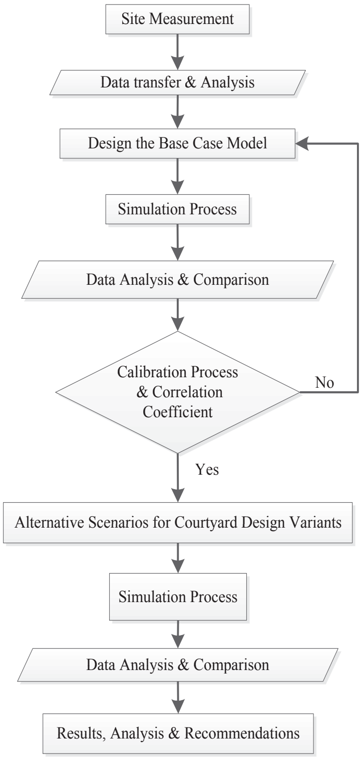

Fig. 1. The overall methods of this paper

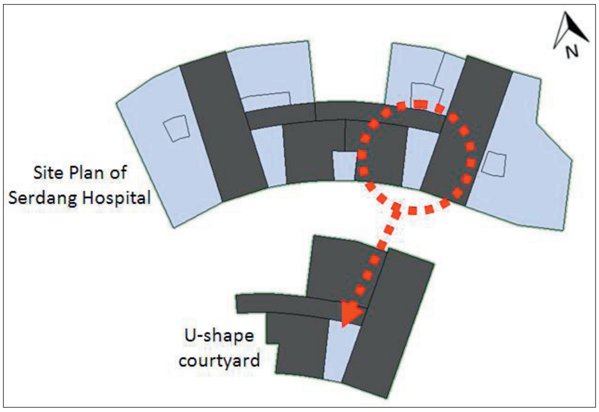

Fig. 2. The U-shape courtyard site plan in Serdang hospital

2.2. Simulation study

Integrated Environmental Solution IES <VE> is a comprehensive software frequently used for environmental parametric analysis. Parametric analysis tests the performance of a building through progressive modifications of specific design elements. The APACHE component of the IES <VE> suite performs the thermal calculation based on weather data input of a designated location. The simulation was run using ASHRAE design weather data for Subang / Kuala Lumpur that are readily linked to the IES <VE> software.

2.2.1. Calibration of the base case model

Prior to the parametric analysis a calibration procedure was performed to compare the simulation results to the field measurements to check for accuracy differences so as to validate the software. This follows similar procedure performed by Leng, et al. (2012). In this study the air temperature parameter only was used to calibrate.

2.2.2. Parametric analysis of the courtyard design variants

Past studies have observed that aspect ratio and orientation are critical design variants that affect the performance of a courtyard. The impact of these two design variants were tested as follows:

- Courtyard height

In addition to the base case condition, this study tested the effects of changing the courtyard enclosure height to 4m and 24m. These represent a single story and six storey high building, respectively.

- Orientation.

From the three scenarios that were tested earlier, one scenario was selected to investigate the effectiveness of orientation. Four scenarios were investigated that represent the main cardinal directions namely north, south, east and west.

3. Findings

As mentioned before, three physical environmental parameters were measured in the U-shape courtyard for a day, namely air temperature, humidity and wind. In the following section, results of the experiment and simulation study are presented and explained.

3.1. Site measurement

3.1.1. Air temperature and relative humidity

The U-shape courtyard is a rectangular courtyard oriented to east-west and opened towards the south. This shape promotes capturing and movement of a natural flow of ventilation into the courtyard space. The readings for air temperature inside the courtyard were compared to the overall outdoor temperature. The outdoor temperature was obtained from an online weather station, Accuweather. This source has been referred to by previous professionals and researchers. As shown in figure 3 (a), the air temperature inside the courtyard was lower at all times, between 0.5 to 5 degrees difference compared to the outdoor temperature.

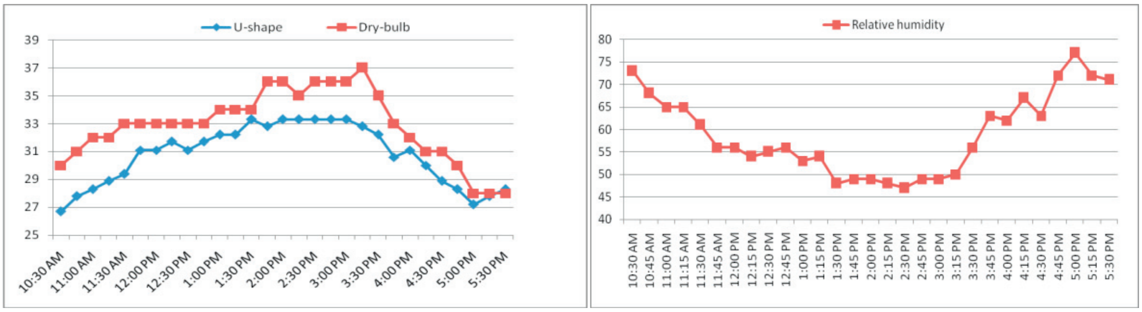

Fig. 3. Environmental measurement inside the courtyard; (a) air temperature (b) relative humidity

The relative humidity pattern reflects a typical hot humid climate condition whereby the RH progressively escalates as the sun sets, and begins to drop during the day. As indicated in the graph, in the span of the clinic operation period, the relative humidity (RH) in the courtyard reached as high as 77% and dropped no less than 47%.

3.1.2. Wind speed and direction

As illustrated in Figure 4, the wind direction fluctuates throughout the day. The wind speed progressively escalates and peaked at 3:30pm. It is evident that the microclimatic influences were taking place throughout the logging period as indicated by the frequent change in wind direction. Based on Beaufort scale rating, the wind speed within the courtyard ranged from calm (0.3 m/s) to breezy (1.5 – 8 m/s) , with lowest reading of 0.3 m/s to a maximum 2.7 m/s.

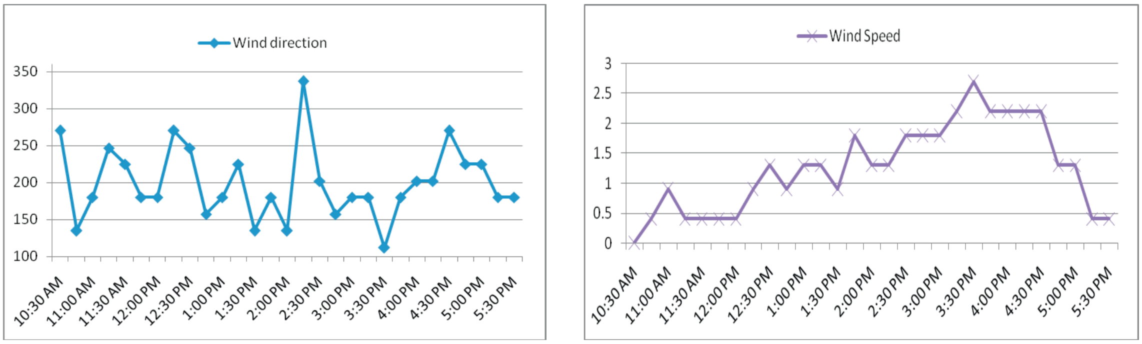

Fig. 4. Wind speed and direction

3.2. Simulation study

3.2.1. The base case model

A simulation model was constructed using a modeling software, SketchUp Version 8 and later used to produce a series of modifications that reflect the performance of the simulated building system. These simulation models are extremely powerful tools and can provide accurate and detailed thermal analysis of the simulated building.

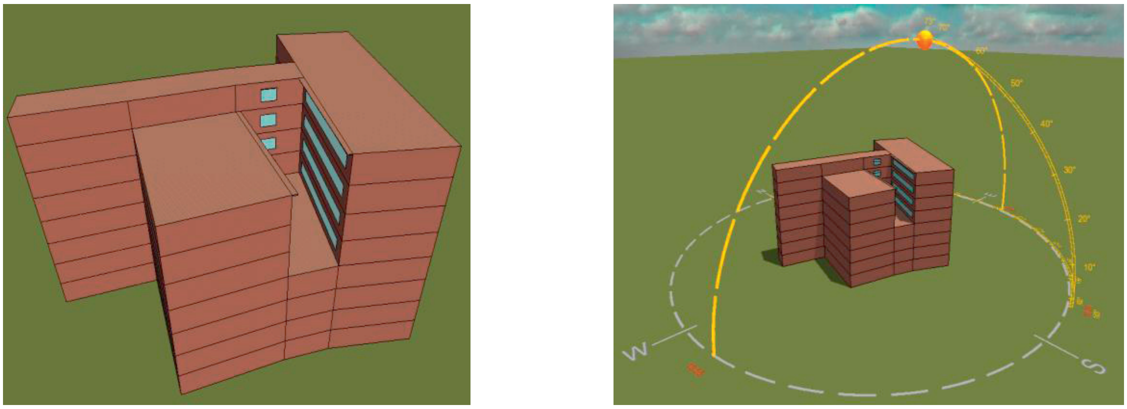

Fig. 5. The base case model

As shown in Figure 5, the base case model was based on the actual courtyard dimensions, while the exterior windows and details were kept constant. The size of windows on the walls surrounding the courtyard were modeled closely to the actual situation - 60% glazing for the east and west walls, and 30% glazing for the north walls. The simulation data were recorded at 10 minutes increment.

The building materials were kept constant for all the models. They reflect closely to the actual construction. The internal environment of the surrounding rooms was modeled as fully air-conditioned at 22C°.

3.2.2. Calibration of the base case model of U-shape courtyard

Comparison analysis for this study was carried out between the field measurement readings and the simulation results from IES<VE> of the air temperature for the courtyard. This is for the purpose of calibration between the existing building and the base case model that will be used to generate more scenarios of design variants of courtyard.

The results show that the correlation coefficient between the simulated courtyard and field measurement readings were 93%, especially between 10:30am until 4:00pm in terms of air temperature (figure 6). After 4:00pm the result shows slight differences. This may be attributed to the weather on the day of the experiment which was cloudy with light rain. Thus, the results proved the validity and reliability of IES<VE> to be used for further simulations for the courtyard modifications.

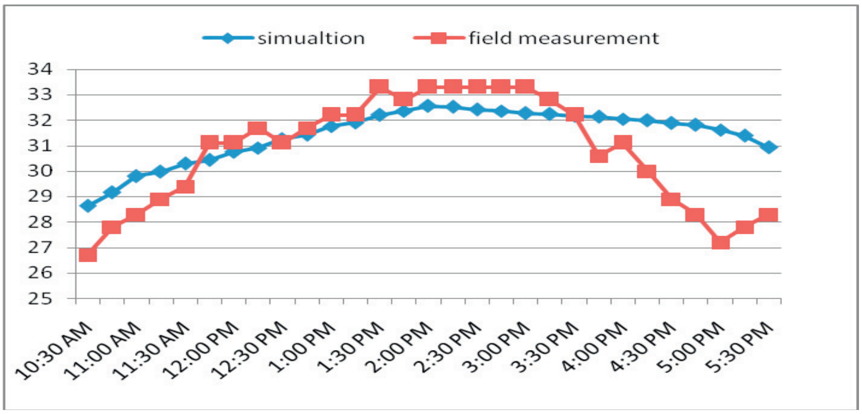

Fig. 6. Calibration the base case model with the data recorded on site

3.2.3. Alternative scenarios for courtyard design variants

The parametric analysis was performed by changing the courtyard design characteristics of the base model to test the effect of increasing the height of the courtyard by adding the number of floors and sun orientation. The study assessed 7 scenarios and their performances were then compared. A summary of the courtyard design variations is shown in table 2.

Table 2. Courtyard scenarios for simulation

Design variants	Code	Scenarios	Comments
Base case	S1	Actual courtyard	The same design variants of number of floors and orientation
Number of floors	S2	Courtyard surrounded with one floor	
	S3	Courtyard surrounded with six floors	
Orientation	S4	N	The orientation refers to the opening side of the courtyard
	S5	S	
	S6	E	
	S7	W	

3.3. Discussions of courtyard scenarios in simulation

As mentioned earlier, the simulation investigated the effect of varying two design variants of a courtyard, namely the courtyard height and orientation.

The scenario that performed better thermal performance in the number of floors will be taken to test the effectiveness of orientation of the courtyard as a second design variants of courtyard.

3.3.1. The effect of number of floors

In determining the correlation between the performance of number of floors and air temperature of the courtyard, simulations were performed to evaluate the performance of the two types of number of floors that commonly used in buildings, namely, one floor and six floors. These two models are beside the base case model that also considered as one scenario. All other design variants in the simulated model were constants.

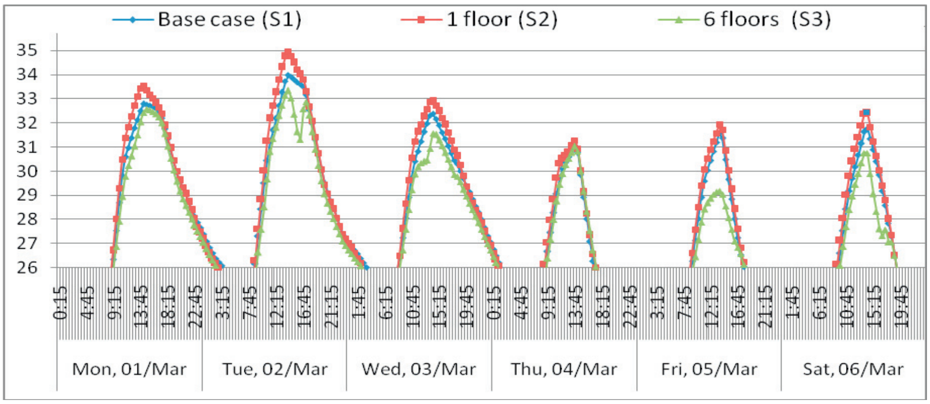

Fig 7. The differences of air temperature in the three scenarios of number of floors during one week

The results indicate significant effect of courtyard wall heights on the air temperature. For example, figure 7 shows the differences of air temperature in the three scenarios of the number of floors during one week. The scenario 2 with one floor shows clear increase of air temperature compared to the base case model.

In contrast, the scenario 3 with 6 floors shows decrease of air temperature compared to the base case model. This is due to increased shaded surfaces caused by the courtyard wall.

3.3.2. The effect of orientation

As we consider the courtyard, in this simulation, the scenario 3 with six floors was tested further to assess the impact of orientation. Four scenarios of the courtyard in each main direction was tested to investigate the effect of each direction and if there was significant differences between each other. The four scenarios are explained graphically in figure 8.

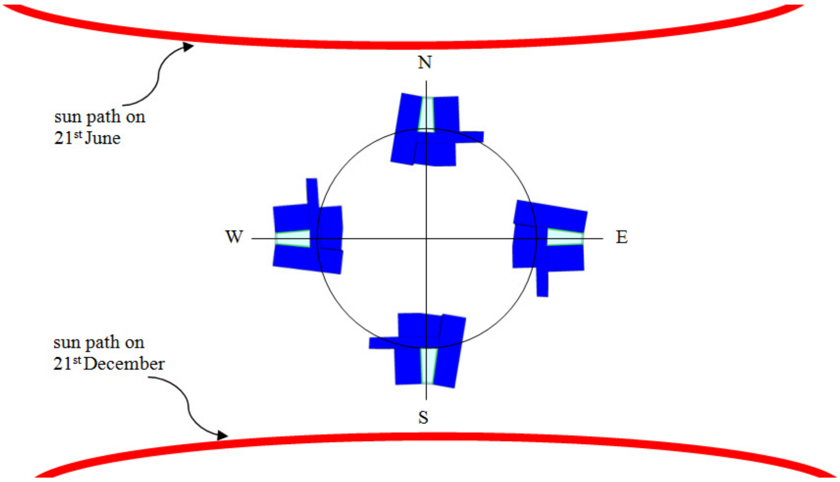

Fig. 8. courtyard orientations, sun path and their simulation scenarios

Results indicate that orientation could be a significant variant affecting micro climatic potential of courtyards. For instance, figure 9 shows two days of the simulation analysis, on 28 and 29 March. Orientation to the west (S7-W) was the worst followed by east (S6-E). As the length of courtyard go parallel with these two directions as well as the sun path from east to west.

Subsequently, courtyard oriented to the north (S4-N) and south (S5-S) results in the lowest air temperature compared to the other orientations (figure 9).

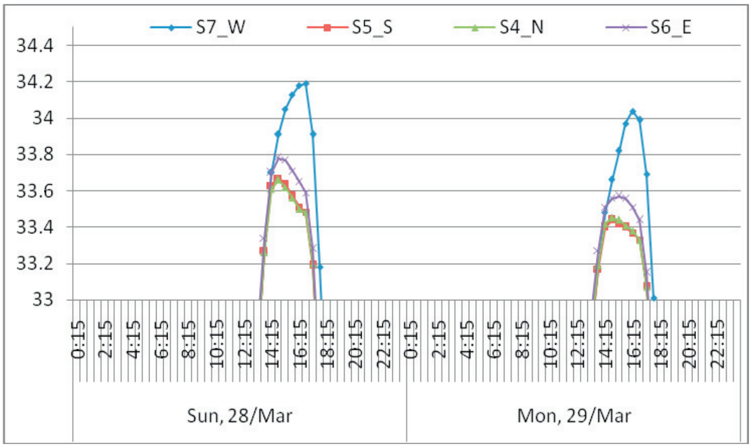

Fig. 9. Effect of orientation of courtyard in the four scenarios (main directions) on air temperature

4. Conclusion

The potentials of a courtyard can be optimized in terms of its thermal performance if the critical design variants are known. The increment of height of courtyard enclosure reduces air temperature inside the courtyard as well as the rooms located at the peripheral of the courtyard. The effect of orientation as observed from the recorded air temperature data, shows that the effect is less but significant.

The study was performed only to investigate 2 design variants. The boundary condition, which is another critical design factor was not investigated and discussed in this paper. It is anticipated that manipulation of the wall conditions in terms of size of opening and construction materials could improve further the courtyard potentials, and thus further investigation is recommended.

This study also demonstrates the potential of simulation software as a useful tool to predict environmental performance of an architectural footprint such as courtyard. The calibration process of the base case model shows a good match between the field measurements and the simulation outcome. The differences between the two measurements are within an acceptable accuracy margin. This validates the IES <VE> as a tool for analysis.

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