Investigating the Effect of Building Orientation on Thermal Comfort and Energy consumption in Educational Buildings.

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ABSTRACT

This paper investigates the effect of architectural design on energy consumption in buildings. It provides analyses for human thermal comfort and energy consumption for cooling and heating in architectural spaces. It evaluates the architectural variables such as building orientation, vertical shading devices, area of architectural spaces, and type of glass, in terms of their effect on energy efficiency and solar accessibility. The study took Jordan University of Science and Technology as a case study to test its offices for this purpose. Computer simulation was conducted for calculating the heating and cooling loads in the offices; DEROB – LTH developed simulation software was used for this purpose. The calculations were performed in a dynamic way for each hour during a specified period of simulation. The results show that building orientation is essential variables for achieving good human thermal comfort with low energy consumption.

1. INTRODUCTION

Recently, research work has been conducted to find alternatives for non-renewable energy resources, which are limited and going to be depleted someday in the future [1].

Since the solar energy is the most important renewable energy resources, many countries try to focus their efforts to take advantage of it and conduct research to utilize this tremendous source [2, 3, 4].

Different means of technology play a vital role in energy conservation systems being very important tools for improving the efficiency of thermal systems. Basically, these technologies decrease the overall energy consumptions in buildings.

Statistics shows that Jordan imports 5.0 million tons of crude oil yearly [5]. It is estimated that buildings consume 50% of all energy produced in our planet for heating, cooling, and lighting. Fuel consumption has caused a growing awareness of the need to conserve energy in the construction sector. Recent studies show that all known reserves of the world fuel resources would last 34 years, if the consumption continues at an annual growth rate of 5% [5].

Solar-based heating techniques have been studied in different research papers [6]. In conventional solar heating, solar radiation through building envelopes is the main source of renewable energy in buildings [7].

Basically, solar heat gain depends on solar radiation available at building locations. It is also related to the orientation and the optical and thermal properties of the receiving surfaces (their solar transmittance/ absorption and thermal heat transfer coefficients), in addition to the use of shading devices [8, 9, 10]. Most of these factors can be manipulated to control the solar heat gain in buildings.

The Arab world, including Jordan, is rich in solar energy due to its geographical locations. Therefore, the governments and decision makers should pay attention to the utilization of solar energy by setting new legislations and regulations for buildings.

However, there are few studies in Jordan related to architectural design strategies. This study is conducted to investigate the impact of building parameters on heating and cooling energy in academic institutions in Jordan. It estimates the heating and cooling loads in the offices of Jordan University of Science and Technology (JUST). The study used commercial software (DEROB-LTH) for analyzing and understanding the complex behaviour of building energy usage. Its advantages and capabilities to predict heating and cooling demands have been demonstrated accurately in several validated studies with full-scale measurements.

The study also concerns with human comfort measured by the Predicted Mean Vote (PMV). The PMV is an index for predicting the human thermal sensation based on a seven-point scale (+3= hot, +2= warm, +1= slightly warm, 0= neutral, -1= slightly cool, -2= cool, and –3= cold). For the evaluation of thermal environment, it is important to know human responses to various thermal conditions; P.O. Fanger expresses the PMV index as follows [11]:

$$PMV = (0.303\, e^{-0.036M} + 0.028)\, L \qquad (1)$$

Where,

PMV = Predicted Mean Vote Index,
M = metabolic rate,
L = thermal load.

The thermal load (L) is defined as the difference between the internal heat production and the heat loss to the actual environment for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level [11,12].

2. METHODOLOGY

The study took the offices of Jordan University of Science and Technology as case studies. The thermal performance of the office spaces in the architectural department was investigated using the simulation program DEROB-LTH. Four offices with different sizes and orientations were studied in terms of heating, cooling, and thermal comfort (See Figure 1).

The main variables handled in the simulation were building geometry, thermal and optical properties of building elements, internal loads, airflow, and schedules.

The hourly values for the climatic data in DEROB are read from an embedded sequential data file. The output of the software appears in the form of hourly values for each volume (office). The heating and cooling demands are given in watt-hour representing the heating and cooling loads needed to maintain the standard comfort temperature in the offices.

All simulated offices were calculated by using the geographic data for JUST University in the city of Irbid, which is located at latitude of 32° N and a longitude of 36° E.

The weather data used in the software took the climate of Jordan as a reference. Jordan is predominantly Mediterranean; a hot dry summer and cold winter characterize the climate in this country. The climatic data in the software contain hourly information such as outdoor temperature(C°), solar radiation (MJ/m^2.day), relative humidity (%), wind speed (m/s), sunshine (hours/day), and rainfall (mm).

In the simulation process, two offices have been oriented east and the other two offices have been oriented west to examine the influences of orientation on the energy demands and human comfort.

The openings of the offices at the west facades are shaded by vertical elements to attenuate the solar radiation in summer. There are horizontal narrow windows over the major ones to increase the illuminance levels in the offices.

The windows of the east offices are smaller in width but have the same height as that of the west windows (Table 1).

Each office was considered as one volume for the purpose of fulfilling the simulation requirements. The dimensions of each west volume are 3.60 m (width) × 4.20 m (length) × 2.8 m (height). The window size is 3.50 m (W) × 1.7 (H) occupying 60% of the wall area in the external envelope of the office. The shading devices are 1.40 (Length) × 0.6 m (Width) × 0.10 m (thickness) (Table 1, b). The transmittance factor of the window glass used in the simulation is 0.87.

The dimensions of other volumes oriented east (V1, V2) are 3.60 m (width) × 7.20 m (length) × 2.8 m (height). The window area is 3.025 m² and occupying 29% of the wall area of the external envelope of the office (Table 1, a). The transmittance of the window glass used in the simulation was 0.87.

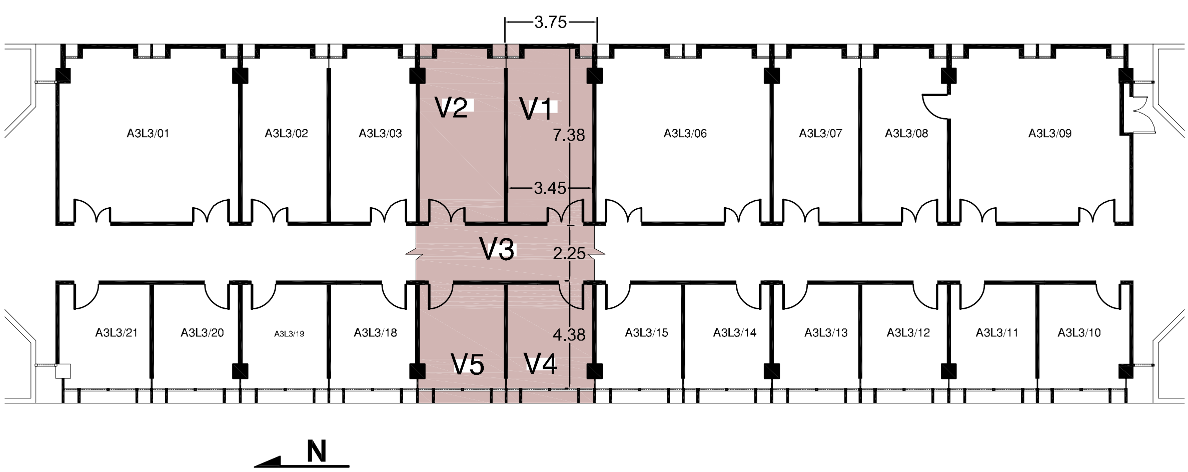
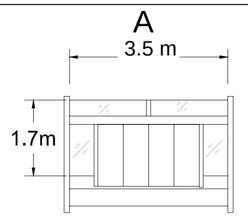
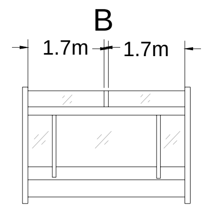


Figure 1: A plan for the offices used to conduct computer simulations for energy analyses, (Authors, 2011)

Table 1: Views for the interiors and external facades of the studied offices.

	East offices	**West offices**
Interior shots		
	a) Interior of an east office	b) Interior of a west office
AutoCAD drawings		
	c) AutoCAD drawings for east and west windows	
Exterior shots		
	d) East windows	e) West windows

The construction materials of the building used in the simulation were as follows: the external walls: pre-cast concrete. The roof: five layers: gravel jeer, polypropylene sheet, extruded polystyrene, waterproof membrane and reinforce concrete. The floor: polymerize vinyl, ceramic tiles, cement mortar, sand, and reinforced concrete slab. The thermal properties of building elements are shown in Table 2. The absorption of walls and ceilings is 70%, and the emittance is 87%.

The optical properties of the glazed surfaces that are made of a single clear glass with 4 mm thick are shown in Table 3. For all simulations, the following were assumed:

- The indoor temperature is constant and equal to 24°C in winter and 21°C in summer.
- The office equipments are computer, heater, and coffee maker.
- The internal loads and infiltration have been estimated from ASHRAE handbook according to their functions.
- The number of occupants in each office is one person.

Table 2: Material properties for opaque elements.

Type	Materials	Thickness (cm)	U value (W/m^2 °C)
External wall	Concrete	15	3.872
Internal wall	Cement plaster	2.5	3.370
	Concrete	15	
	Cement plaster	2.5	
Roof	Gravel jeer	5	0.096
	Poly propylene sheet	0.05	
	Extruded polystyrene	3	
	Waterproof membrane	8	
	Reinforced Concrete	10	
Floor	Polymerize vinyl	0.2	0.16
	Ceramic tiles	3	
	Cement mortar	2	
	Sand	10	
	Reinforced concrete slab	10	
	Air space at 21°C	70	
	Fuels ceiling Gypsum	1.2	

Table 3: Thermal and optical properties of the office windows.

T-sol	G-Value	U-value (W/m^2 °C)	Materials
Single glass	5.88	0.636	0.45

3. RESULTS AND ANALYSES

The influence of orientation on the heating and cooling loads has been explored by simulating the offices for all directions: south, north, east and west. (Tables 4, 5, and 6).

For all cases, the results show that heating load is low when the offices oriented south. The maximum value of heating loads obtained when offices directed to the north.

On the other hand, thermal human comfort was observed high when the offices exposed to the south for both December 21st and July 21st. The results for PMV obtained from DEROB-LTH software are shown in Table 7. On December 21st, the PMV value in Volume 1 varies between 0.16 ~ -1.05 which is around ‘neutral’ to ‘slightly cool’. The PMV values for Volume 2 varies between -0.3 ~ 0.34 which is around ‘neutral’.

The PMV values for Volume 3 varies between -4.10 ~ -0.18 which is considered ‘very cold’ to ‘neutral’. The PMV value for Volume 4 varies between -0.25 ~ -0.01 which is around ‘neutral’. The PMV value for Volume 5 varies between -4.23 ~ -0.23 which means around ‘very cold’ to ‘neutral’ in the scale of PMV.

On the other hand, The PMV values on July 21st, for Volume 1 vary between -1.48 ~ 1.24 which means ‘slightly warm’ conditions for the occupants. The PMV values for Volume 2 vary between -0.10 ~ 1.42 which means around ‘neutral’ to ‘slightly warm’. The PMV values for Volume 3 vary between -2.05 ~ 2.19 which is considered ‘cold’ to ‘warm’. The PMV values for Volume 4 vary between 2.68 ~ 3.08; this range reflects a ‘warm’ to ‘hot’ status. The PMV values for Volume 5 are around 0.22, which is ‘neutral’ for the office occupants (see Table 7).

Table 4: The influence of orientation on heating and cooling loads for east and west orientations.

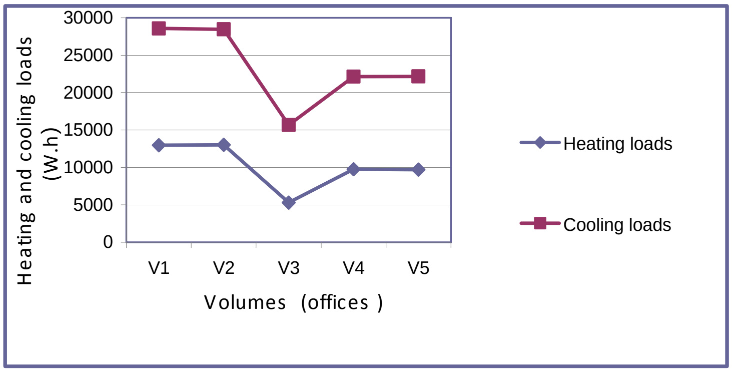
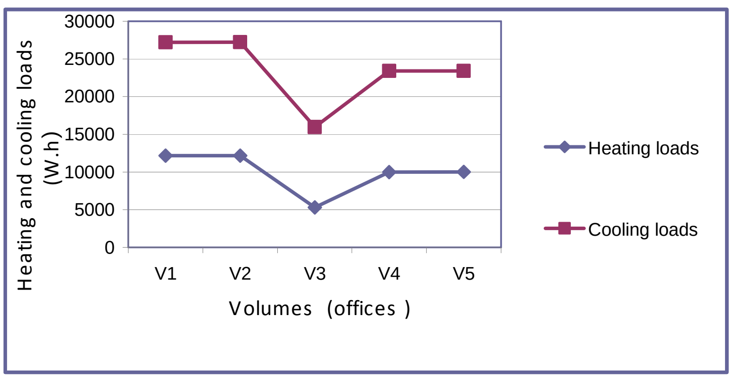
	Heating and cooling loads (Watt-hour).
V4, V5 oriented west. V1, V2 oriented east.	
	The heating and cooling loads for all offices when V4, V5 oriented west and V1, V2 oriented east.
V4, V5 oriented east. V1, V2 oriented west.	
	The heating and cooling loads for all offices when V4, V5 oriented east and V1, V2 oriented west.

Table 5: The influence of orientation on heating and cooling loads for south and north orientations.

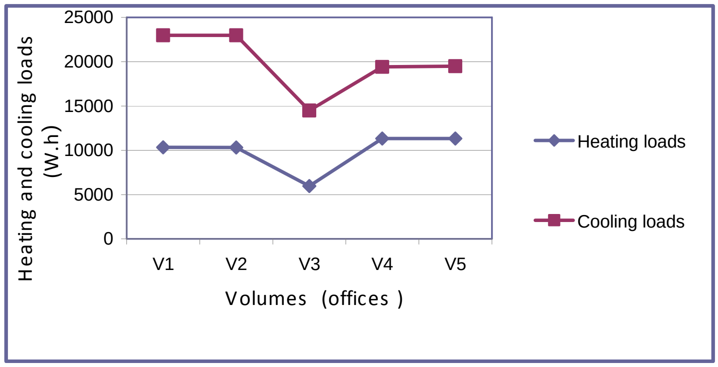
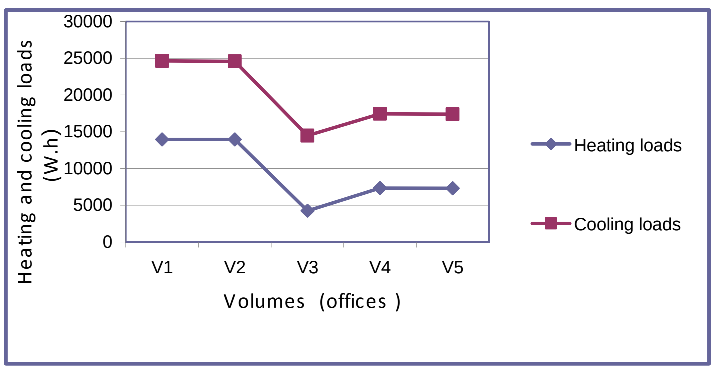
	Heating and cooling loads (Watt-hour).
V4, V5 oriented north. V1, V2 oriented south.	 The heating and cooling loads for all offices when V4, V5 oriented north and V1, V2 oriented south.
V4, V5 oriented south. V1, V2 oriented north.	 The heating and cooling loads for all offices when V4, V5 oriented south and V1, V2 oriented north.

Table 6: The effect of orientation on heating and cooling loads for all offices.

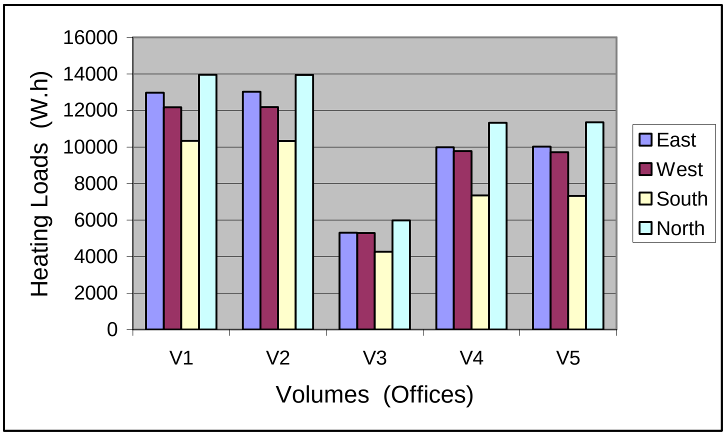
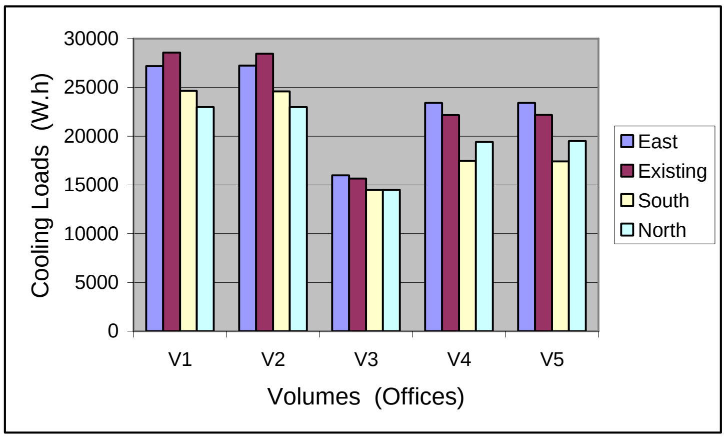
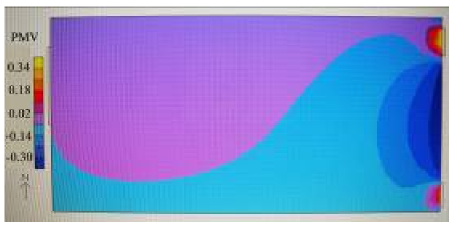
	Heating and cooling loads for all offices in all directions
Heating loads	 The effect of orientation on heating loads for all offices.
Cooling loads	 The effect of orientation on cooling loads for all offices.

Table 7: The Predicted Mean Vote (PMV) results for each volume for the original orientation on December 21st and July 21st.

Volume	Dec. 21st	July 21st
Plan of office 1 (V1)		
Plan of office 2 (V2)		
Plan of the corridor (V3)		
Plan of office 4 (V4)		
Plan of office 5 V5		

Assessing the performance of different positions of shading devices was investigated to find the optimal situation in terms of good daylighting with minimum amount of heat gain in spaces. Different cases of shading devices were tested at different positions on windows for different building orientations (Figure 2).

The purpose was to show the effect of shading devices on energy saving and thermal human comfort. First, a vertical shading element was added at the center between the two existing shading devices directed in the same orientation of the building (West offices: V4 and V5). The results show that the heating load in winter is greater than that of not having a shading element at the center of the window (Table 8). On the other hand, the results show that the cooling loads in summer is higher than that of having a vertical shading element at the center of the window.

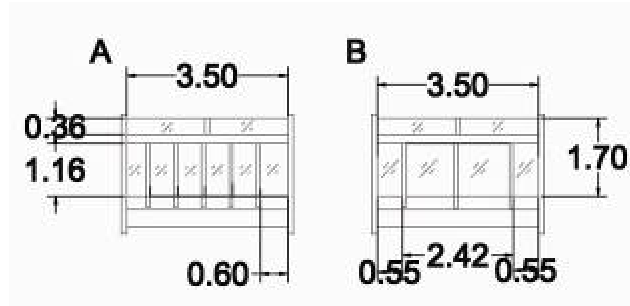
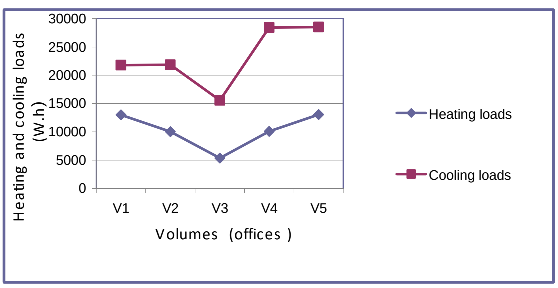
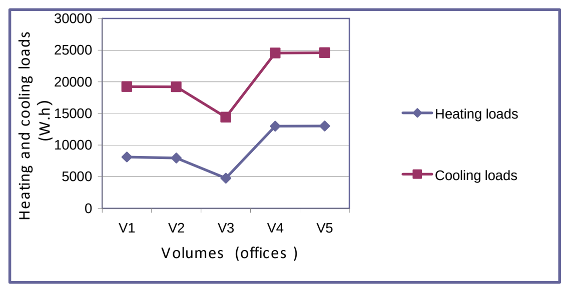
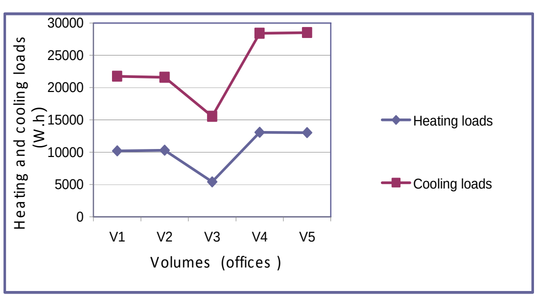
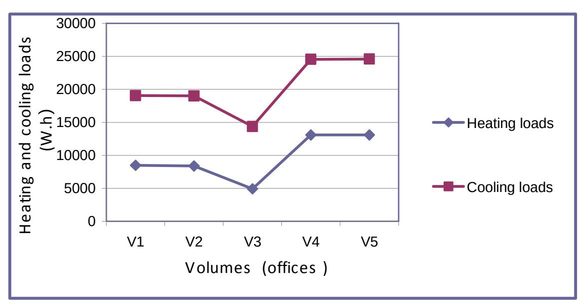


Figure 2: A) Vertical shading elements placed at 60 cm apart, B) A shading element added at the center between two existing shading elements.

Table 8: The effect of placing shading elements on windows on heating and cooling loads.

	With vertical shading device at the center	With vertical shading device placed at 60 cm apart.
West orientation		
	Heating and cooling loads for all offices when V4 and V5 oriented west with a vertical shading element placed at the center between the existing shading elements.	Heating and cooling loads for all offices when V4, and V5 oriented south with a vertical shading element placed at the center between the existing shading elements.
South orientation		
	Heating and cooling loads for all offices when V4, V5 oriented west with vertical shading elements placed at 60 cm apart.	Heating and cooling loads for all offices when V4, and V5 oriented south with vertical shading elements placed at 60 cm apart.

Similarly, shading devices were also placed as in the previous cases, but the offices were oriented south (Table 8). The results show that the heating load is much less than that of having a shading element at the center. Another alternative of shading elements placement was also tested; shading elements were placed on the window at 60 cm apart (Figure 2 and Table 8).

The effect of window size on heating and cooling loads was also examined. Larger window areas lead to lower the heating loads in winter. This indicates that the heat gain from solar radiation is larger than the heat loss by conduction in case of large windows. The ratio of window area to office area with relation to heating loads is shown in (Figure 3).

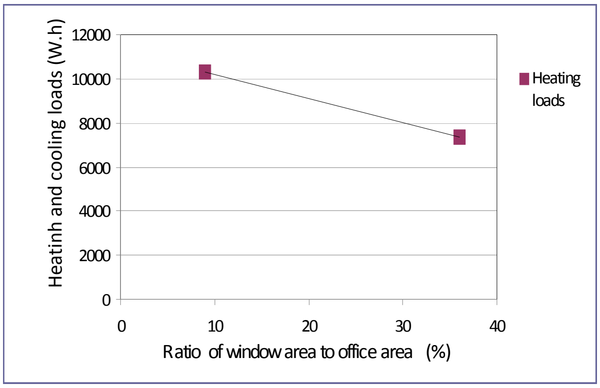


Figure 3: Heating loads for offices and the ratio of window area to office area (Note: all offices oriented south).

4. CONCLUSIONS

In this work an evaluation study for solar contribution to energy saving and thermal human comfort for offices has been conducted based on Jordan climate using Derob-Lth program. It was concluded that the orientation of offices has significant effect on both heating and cooling loads. The considerable reduction of heating loads, which exceeds the increasing of cooling load, is achieved when offices oriented south.

Passive solar techniques can reduce energy consumptions in offices by 40 percent keeping very natural environment in buildings. It was seen from the results that passive building consideration of all building elements and parameters should be taken into account.

Vertical shading devices can effectively minimize the energy consumption maintaining a good level of human thermal comfort in spaces based on their positions and orientation on windows.

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