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The Influence of a Building's Orientation on the Overall Thermal Performance

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Abstract

Containing and then reducing greenhouse gas (GHG) emissions require designing energy efficient buildings which save energy and emit less GHG. Orientation has an impact on the building's overall thermal performance and designing heating and cooling to reach occupants' thermal comfort.

Correct orientation is a low cost option to improve occupant's thermal comfort and decrease cooling and heating energy. An appropriate building orientation will allow the desirable winter sun to enter the building and allow ventilation in the summer by facing the summer wind stream. In this paper, a building module in Jordan will be assessed using DesignBuilder Simulation packages to find the effect of the building orientation on the overall thermal performance.

It was found that the larger windows should be in the southern walls in the northern hemisphere to provide the most heat to the building through the window which allows the sun in winter to enter the building and heat it up. This will reduce the amount required for heating by approximately 35% per annum.

Keywords

Thermal Performance; Building Orientation; Sustainable Design

1. Introduction

Energy consumption of buildings covers about 40% of the total energy (Laustsen, 2008), mainly used for operating and constructing buildings, which emit one third of global greenhouse gas (GHG) emissions (UNEP, 2009). To save buildings operating energy and reduce GHG emissions, sustainable building design should be used to correctly predict the amount of energy that will be consumed.

Energy consumption is partly dependent on the weather, for example, in a cold year, more energy is consumed to maintain comfortable internal temperature than in a warmer year (Holmes & Hacker, 2007). However, it is not only dependent on climate characteristics but also building designs influence energy use. The building envelope is the focal interface between indoors and outdoors and has an important role in controlling differences in the outdoor climate conditions, providing thermal comfort for residents and therefore determining the heating/cooling loads of the building (Florides, Tassou, Kalogirou, & Wrobel, 2002). A building with a poor design envelope does not perform as well as a building with an energy efficient envelope regarding energy use.

Energy consumption is the amount of fossil fuels, renewable fuels and electricity consumed by end use sectors: industrial, residential, transport and service. One of the largest sectors that consume a significant amount of total energy in the world is the residential sector. In Jordan, energy consumption has increased dramatically during the past years, whereas in the year 2000, the electricity usage was about 6.1 billion kWh, which has increased gradually to 13.54 billion kWh (kilowatt-hour) in 2014. Residential buildings in Jordan account for approximately 22% of the energy consumption of the country, with the residential sector responsible for around 43% of total electricity consumption, industrial and commercial follow with 25% and 15% of total demand respectively (JMEMR, 2013).

The contribution of buildings to environmental problems is increasing significantly. A considerable amount of energy is being used for the heating and cooling of a building to maintain its resident's thermal comfort (Albatayneh, Alterman, Page & Moghtaderi, 2017). Due to this known fact, measures to reduce space heating and cooling energy use through proper design of the building envelope supplies should be supported if the country is to play a part in diminishing the global problem of climate change. At the same time, a reduction in energy consumption of buildings by using precise design strategies, which perform to keep inhabitants' thermal comfort within acceptable limits should take place (Mohammad & Shea, 2013; Albatayneh, Alterman, Page & Moghtaderi, 2016).

Simulation software provides significant contributions in dealing with climate adaptations regarding responsible and efficient energy planning (Albatayneh, Alterman, Page & Moghtaderi, 2015). These simulation tools are widely used by engineers to permit investigation and evaluation of various design alternatives (Albatayneh, Alterman, Page & Moghtaderi, 2016; Albatayneh, Alterman, Page & Moghtaderi, 2017). Such tools provide an understanding of the performance of the whole building and enables architects to estimate and optimize the thermal performance of the building envelope, occupant thermal comfort and, ultimately, the energy performance of the finished building.

In this paper, the software DesignBuilder is used, DesignBuilder is a state-of-the-art software tool for examining building energy, carbon, lighting and comfort performance. Developed to simplify the process of building simulation, DesignBuilder allows you to rapidly compare the function and performance of building designs and deliver results on time and on budget. DesignBuilder's simulation operating engine is EnergyPlus. EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting, and plug and process loads—and water use in buildings (Gerber, 2014).

Accurate orientation, correct location on a site, and landscaping changes may decrease the energy consumption of a typical building by 20% (Spanos, Simons, & Holmes, 2005) and provide the building designers with the economical tools to reduce energy consumption.

There are two ways to ensure optimal orientation: Analyse various parameters and certify optimal design and orientation for each building but this approach consumes more designing time and cost. The second way is to develop 'adaptable' designs which perform well across a range of orientations, which are used in the volume build industry (Morrissey, Moore, & Horne, 2011), but this approach does not give the optimum building orientation.

2. Methodology

Simulating a typical residential building that would characteristically match 60% of the buildings found in Jordan using the DesignBuilder software also preliminary data gathering that also included obtaining the thermal transmittance (U-values) of the structures used in simulating the apartment from the Jordanian building code. Consequently, after complete familiarity; organize, plan and propose a schedule to finalize the building design as shown in Figure 1. The building was rectangle shape with around 10m length and 15m width were the long axis facing east and west.

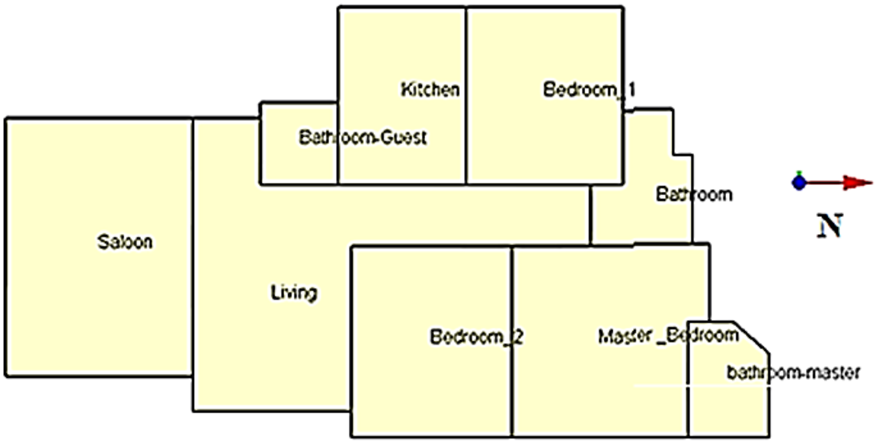

Figure 1. Layout of the building used in this simulation.

DesignBuilder was used as shown in Figure 2 to model the dynamic thermal performance of a typical building located in Amman and simulated using hourly weather data over a complete year. Amman's climate is considered Sub-Mediterranean climate with a warm summer and cold winter with almost all the rain and sometimes snowfall in the winter.

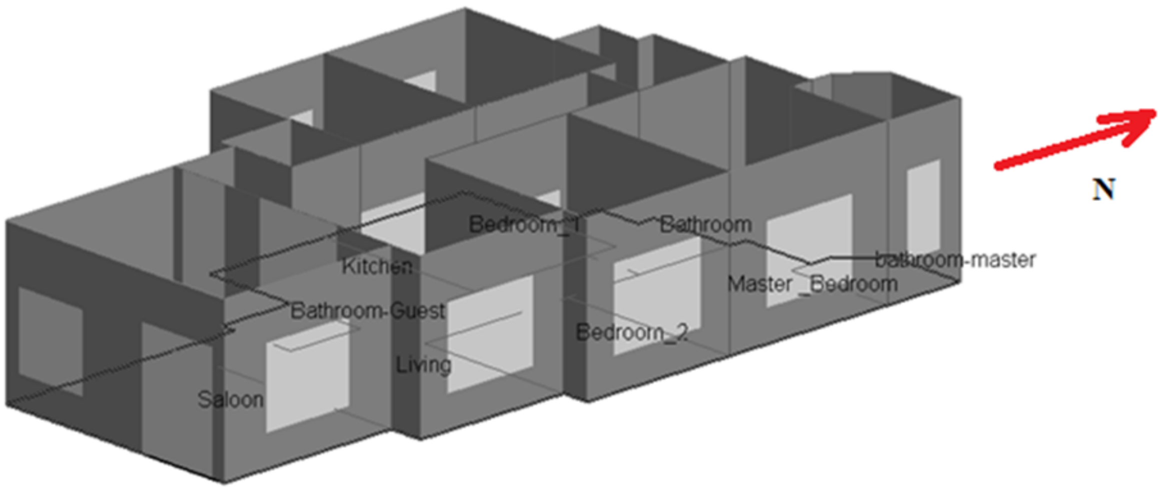

Figure 2. Overview of the building in DesignBuilder mode.

The building has no wind obstacles and, due to not experiencing any shading, the building receives a substantial amount of solar radiation. The values and parameters that were entered in DesignBuilder include heating, cooling, lighting, external and internal walls data. The number of hours that each system would be functioning was also needed to be entered. After the data entry, the simulation could be run over any specified period whether hourly, daily, monthly or yearly.

This structure is reinforced concrete that is composed of reinforced columns, beams and lightweight hollow bricks, representing most of the residential building technology in Jordan. Using this "Base Case" and with the alteration of some of the simulation parameters, mainly the type of wall structure chosen, we were able to simulate and obtain the results that lead us to the best, worst, and most energy efficient orientation. The Energy consumption rates were studied to find the usage trends and patterns, and to identify and control any irregular behaviour.

Rotating the Base Case building in a clock wise direction each time the building will rotate by 45° from the previous location as shown in Figure 3.

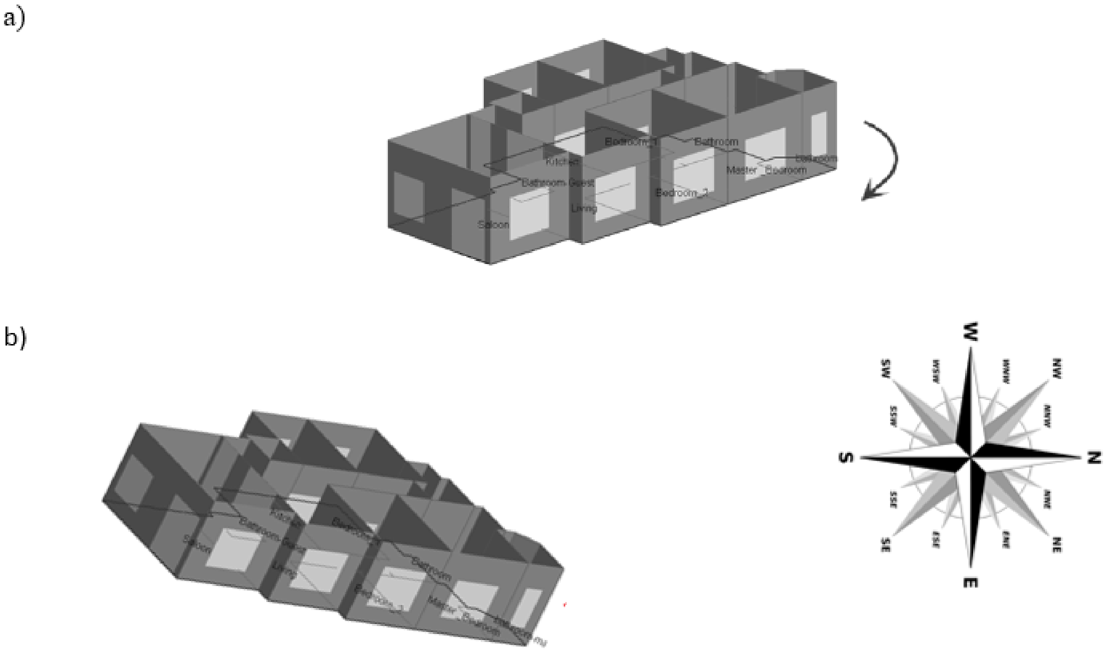

Figure 3. BaseCase. b)Rotating the building from the Base Case by 45° clock wise.

3. Results and Discussion

The overall thermal performance of the building was largely influenced by the weather conditions (i.e. solar radiation, wind and external air temperature). Fluctuations in the solar radiation during the day had a direct impact on the thermal behaviour of the building. In summer environments, high solar radiation produced high external surface temperatures on the roof, eastern and western walls and was limited on the south facing wall. The northern wall just received diffused solar radiation.

In the winter, the incident solar radiation on the exterior surfaces of the building's western and eastern walls was decreased compared to summer. However, the major difference was the significant increase in the solar radiation on the south side due to the lower sun altitude in the sky which results in warmer winter temperature when the largest glassing side faces the south as shown in Figure 4. The diffused solar radiation on the northern wall remained as low as it was in summer. The high solar radiation fallen on the southern wall throughout the whole day acts as a crucial heat source for the building. There is around 2 degrees of temperature difference between the Base Case design and when rotating the building by 90° (when most of the glassing area is facing south).

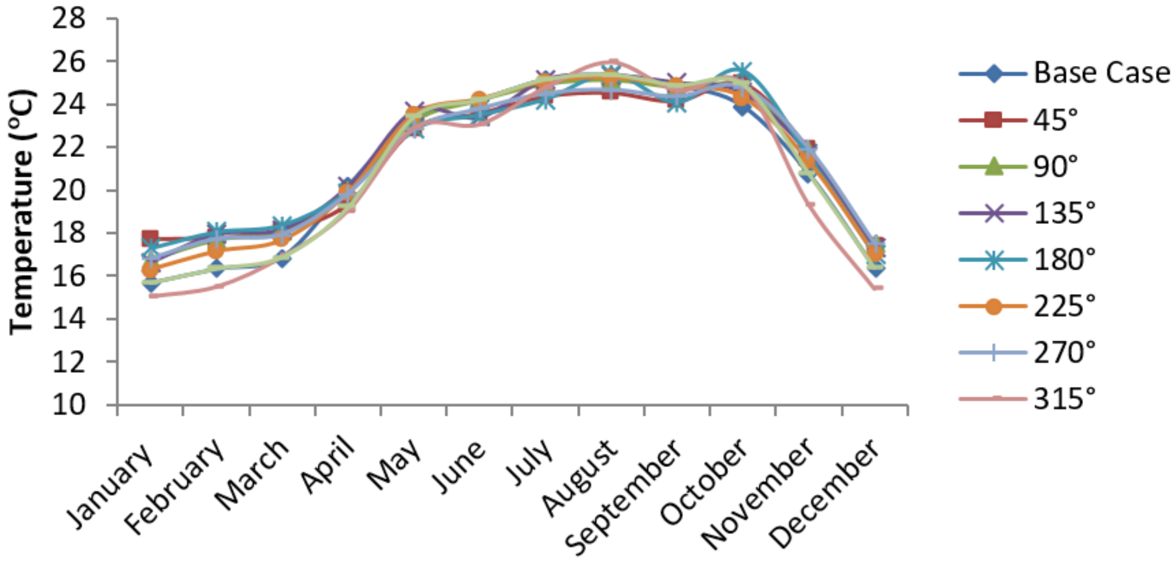

Figure 4. Temperature variations for different building orientations.

To sustain thermal comfort in the summer, the cooling temperature is set to 25°C for the summer and 22°C in the winter. In the winter, there is a significant increase in the solar radiation on the south side due to the lower sun altitude in the sky which results in warmer winter temperature due to the largest glassing side facing the south where the incident solar radiation on the western and eastern walls was decreased compared to the summer. The high solar radiation fallen on the southern wall throughout the whole day acts as a crucial heat source for the building. For the heating loads in the winter, the highest load required was in the Base Case around 975kwh/year and when rotating the building by 90° or 270° the heating load drops by almost 35% to around 655 Kwh/year as shown in Figure 5 which is a significant drop using a budget-friendly option by just orienting the building to the right direction.

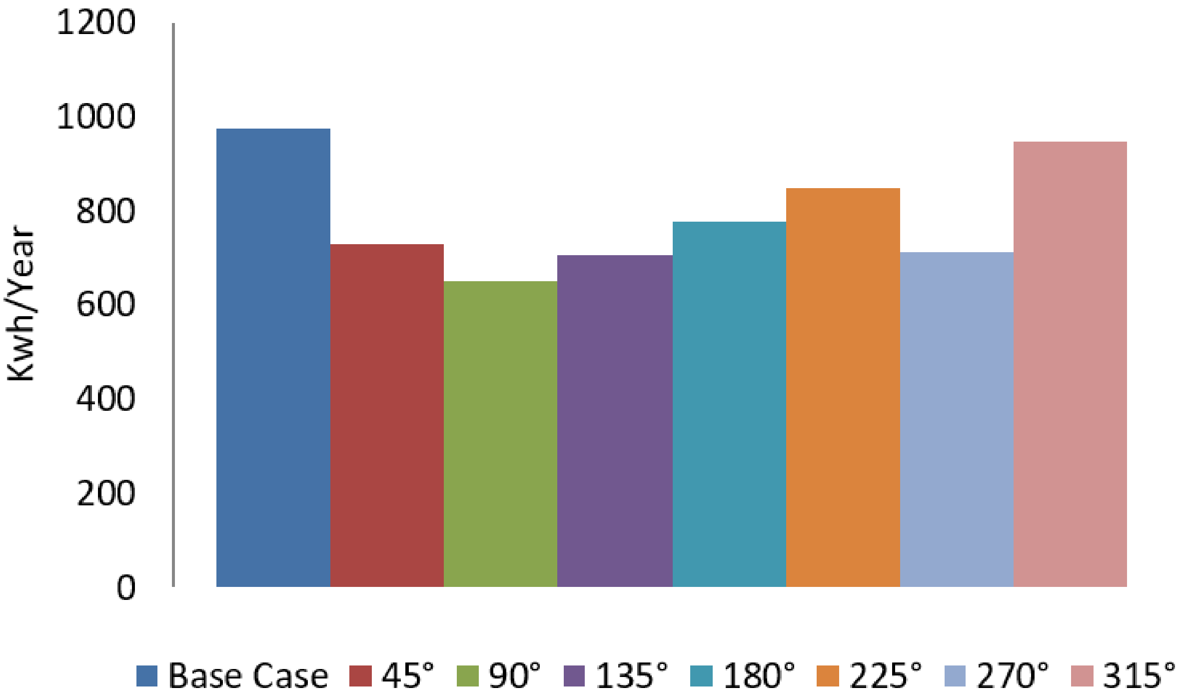

Figure 5. Energy consumption (cooling loads) to sustain thermal comfort for different orientations.

For summer months the cooling loads were peaked for the Base Case and when the buildings were rotated by 180°

as shown in Figure 6 and this is due to the largest glassing areas on the east and west walls. In the summer, solar radiation produced high external surface temperatures on the roof, eastern and western walls and was limited on the south facing wall. The northern wall just received diffused solar radiation.

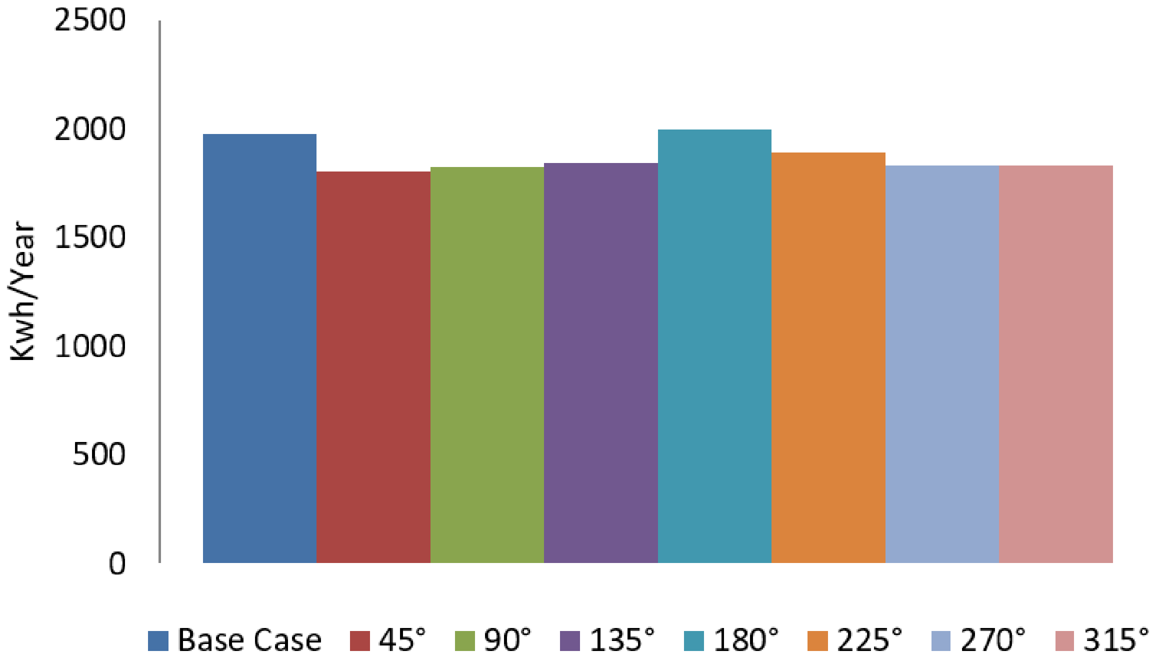

Figure 6. Energy consumption (heating loads) to sustain thermal comfort for different orientations.

Shading has a great influence on the building overall thermal performance, the requirements for shading vary according to the house's orientation and the climate (to eliminate the summer sun and allow the full winter sun to enter the building). Shading in the summer in a hot climate improves comfort and decreases energy bills.

Changing the building orientation from Base Case to any other direction showed a significant enhancement to the thermal performance especially when the long axis is facing north and south.

4. Conclusions

To tackle climate change and global warming, measures need to be taken to reduce greenhouse gas emissions such as designing low energy buildings. In this paper, the influence of the orientation of a typical Jordanian building on the overall thermal performance was analysed.

The final results confirmed that an appropriate orientation is a low cost option to improve comfort and decrease energy bills. Changing the building's orientation where the long axis to either the east or west will heat the building during unwanted time (summer) because the east and west windows lose more heat than they gain in winter and gain more heat in summer and this will reduce the cooling load by almost 10%. On the other hand, the best orientation is when the long axis faces north/south to allow the winter sun's radiation to enter the module and to avoid the main wind stream. Appropriate orientation helped to minimise heat loss in the winter months and reduce heating energy by almost 35% compared to the Base Case building which impressively improves the overall thermal performance.

The effect of orientation on the overall thermal performance of buildings should not be neglected and can be used as a simple measure and budget friendly option to improve the thermal performance of the building and reducing the mechanical heating and cooling required to sustain the occupants thermal comfort. The site limitation may limit the capability of applying the appropriate orientation but these techniques can be applied wherever possible to reduce the amount of heating and cooling required.

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