Building envelope and energy saving case study: a residential building in Al-Riyadh, Saudi Arabia

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Abstract

Around the world, most energy is consumed by buildings; residential buildings consume 40% of energy globally. In the Kingdom of Saudi Arabia (KSA), buildings consume 50% of all energy, and 70% of the buildings in the KSA are not insulated well. Creating an envelope is a key to decreasing energy consumption and providing thermal comfort and healthy internal spaces. Thus, the main aim of this study is to test the effect of selected passive cooling strategies by using a simulation program to evaluate a variety of envelope (floor, external and internal walls and roofs) thermal characteristic proposals to create an eco-interior space, to provide the most comfortable conditions for users and to save energy in buildings in hot climates in Riyadh, Saudi Arabia. One residential building case was selected, and some of the passive cooling strategies were tested. Simulation software—Design Builder—was used to calculate the total energy consumption in 1 year and compare the results before and after applying these strategies to the selected residential building.

Keywords: passive cooling strategies; creating envelope; Eco-interior spaces; DB (Design Builder) software; hot arid climate; KSA houses;

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1 INTRODUCTION

1.1 Background

Even before the Saudi 2030 Vision outlined a future for the Kingdom beyond oil and gas, the government considered ‘... energy efficiency ... a major topic and a strategic imperative for decisions related to the increase in demand for fuel and feedstock’ [1]. Figure 1 shows how total energy consumption in the KSA follows average temperatures, reflecting the importance of air cooling in the summer, when the energy demand is double that in the winter.

One of the most comprehensive building energy efficiency codes in the region has been developed by Saudi Arabia. This code, introduced on a voluntary basis in 2009, became compulsory for new government buildings in 2010, which covers all energy systems in a building, including the envelope, mechanical, lighting, electrical and domestic hot water systems [2]. Table 1 illustrates the climatic variation in cooling and heating degree days of five cities in Saudi Arabia [3]. Riyadh is in the center of the Saudi Arabia and has a dry hot climate. For this study, the analysis focuses on a residential unit in Riyadh.

Building an envelope serves a function other than just being a structural or architectural component. It can be designed to provide a healthy environment for users. Specifically, the envelope affects the energy demand for thermal comfort in buildings. For example, the thermal capacity of envelope elements, such as walls, can help control indoor temperatures without the use of mechanical systems. Reduction in the efficiency of the cooling system means that more energy will be used, which has a significant impact on total energy consumption [4].

A study carried out by Opoku and Abdul-Muhmin [5] determined the distribution of housing in major cities in the KSA, which concluded that 40% are villas (single and detached
private homes), while 35% consisted of apartment and 12% were duplexes. Thus, these residential buildings can play a significant role in minimizing energy consumption by improving its energy performance and creating an eco-interior space in addition to providing the most comfortable conditions for users in the KSA.

### 1.2 A review of previous research

Several studies have assessed the utility of energy saving for residential buildings in the KSA, specifically in testing the insulation, window glazing, shading and thermal mass in hot regions. A study was conducted by Al-Sanea and Zedan to improve the thickness of wall insulation in Riyadh [6]. Three types of walls were examined. The study concluded that the optimum insulation basically depends on its position in the wall. The critical thermal mass thickness and energy savings were calculated by Al-Sanea et al. [7] to estimate the thickness of the thermal mass, which can assess the required level of energy savings. Another studies by Aldawoud [8] explored the impact and performance of traditional shading and compared it to electrochromic glazing for hot regions. It concluded that window shading and glazing properties have a significant effect on minimizing heat gains. An analysis of energy consumption patterns in Jeddah was performed by Aldossary et al. [9] using Integrated Environmental Solution-Virtual Environment to conduct energy modelling. To investigate energy savings, an annual simulation is conducted for measures such as shading devices, window glazing and renewable energy sources.

### 1.3 Statement of the problem

Saving energy in buildings has become an increasing issue of concern in Saudi Arabia. The environmental impact due to energy consumption is the main goal—not only the minimization of oil and gas depletion. In hot climates, solar radiation throughout the day is the most influential factor, not the high ambient air temperature. This requires designers to consider different designs to reduce heat gain in buildings [10].

### 1.4 Research aim

The research aimed to test the application of selected cooling strategies by using a simulation program, DB, to evaluate a variety of envelope (floor, external and internal walls and roofs) thermal characteristics proposals to create an eco-interior space to provide the most comfortable conditions for users and to save energy in buildings in hot arid climates.

### 2 THE STRATEGIES OF PASSIVE COOLING

Four principals of passive cooling strategies were selected. A brief description of each strategy is presented below.
2.1 Shading and louvers
Shading is the fractional or imperforate barrier of sun rays directed at a surface. This varies in position and size, depending on the geometric relationship of the sun and the building's façade. An analysis should be carried out to measure the integration between these two elements. A simulation of the daylight performance can be carried out at the design stage to allow the designer foreknowledge of the daylight assessment of the building. Check Figure 2. The roof is an integral part of the shading elements because it is the overall cover of the building and its overhang provides shade around the building, therefore protecting the building envelope from unwanted heat [11]. Materials with low thermal capacity should be used near the opening so that they quickly cool down after sunset so as not to reinject their heat back into the building [12].

2.2 Glazing
Heat loss and heat gain are most transferred by doors and windows than any other element of the envelope. The glazing system
must be designed in such a manner that it reduces glare and improves indoor thermal quality. A well-designed glazing system reduces the total energy demand to cool a building, which is the main purpose of this paper. The thermal performance of the glazing must be adequate and glare resistant while allowing solar radiation into the building. Some of the glass can be double or even triple glazed depending on the design specification or building regulations. According to (http://www.yourhome.gov.au), 87% of unwanted heat in the summer enters a building through the windows and doors. Check Figure 3. Glass is a good thermal conductor and, as such, double and triple glazing traps air or gas and serves as a barrier between indoor and outdoor space.

2.3 Insulation
Minimizing heat loss in the winter to keep the building warm and minimizing heat gain in the summer to keep the building cool involves the barrier of the heat flow. In adequate insulation, air leakage is the main cause of heat loss. It is essential to make the building envelope resistant to external climatic factors, especially the unwanted elements, hence the need and importance of insulation. The building envelope comprises walls, floors and roofs, and all of these elements of a building can be insulated from either heat loss or gain. The type and quality of insulation material are strongly determined by the climate because different insulation materials offer different advantage [13].

2.4 Green roofing
One of the weaknesses in the building’s envelope is where solar heat is absorbed through the barrier; thus, high insulation can minimize heat conduction into interior spaces. The major sustainable issue is producing oxygen, minimizing the heat island that affects temperature reduction and the urban environment. There are two types of green roofs: intensive or extensive. The intensive type requires more maintenance for a large roof; it is thicker and needs a variety of plants. An extensive roof requires less maintenance. This type of roof needs a variety of light plants to create a light roof [14].

3 METHODOLOGY
The goal is to evaluate the optimal design for residences in the KSA with a defined prototype (a detached private house). So, the first step to this goal is to build the selected prototype on a computer-based simulation tools—Design Builder (DB)—that make it possible to simulate the cooling loads and indoor temperature in the current phase of the prototype and after editing it. After that, four passive techniques were added to the building consecutively starting from shading and louvers where wooden shading devices were installed to the southern, eastern and western facades to block the direct during the daytime, and the whole prototype was simulated in DB. After that the second phase started by upgrading the glazing type that was used in the outer shelter from clear single glazed windows to clear insulated double-glazed windows, followed by the simulation process of the prototype. Then the third phase was installing insulation to the outer roofs and walls through inserting a 20 mm layer of mineral wool beneath the core layer of the wall or the roof towards the
outer environment, then the prototype was simulated in the DB. Finally, the last phase was adding a layer of 200 mm of local herps and few grasses with an extra weight of 73 kg/m$^2$, which is suitable to the construction system and affordable. After that, the simulation process started with the prototype to calculate the cooling loads reduction and indoor temperature. Finally, all the cooling loads and indoor temperature for the prototype phases of passive techniques implementation was compared to reach out the effect of each passive technique on the cooling loads and indoor temperature.

EnergyPlus is the most authoritative program and has been extensively used and validated by the research community. It has several user interface add-ons (with DB being one). It is essentially the accumulation of 60 years of experience by the US Department of Energy. DB is a progressive software tool for checking building energy, carbon, lighting and thermal comfort performance. Developed to facilitate building simulations, it allows one to quickly compare the performance of building designs and deliver results on time and within the budget.

4 CASE STUDY

4.1 Climate of Riyadh
Riyadh is located in the center of the kingdom, 600 meters above sea level. Winter, which is from December to February, is mild: the average temperature in January is 13.5°C, but the temperature can approach 30°C, check Figure 4. Only 100 mm of rain falls yearly, from December to May, with a maximum of 30 mm per month in March and April. Rain never falls in the summer, from June to September. At this time, temperatures are very high, ~44°C in July and August, and the humidity is very low, check Figure 5.
Figure 8. Schematics of the selected cooling strategies applied.

Figure 9. Detailed of the passive techniques implementation into the DB.

Table 2. Internal radiant temperature in the base case.

| Hour  | Cooling off | Cooling on | Cooling off |
|-------|-------------|------------|-------------|
|       | Temp. (°C)  |            |             |
| 0:00  | 26.6        | 26.4       | 25.9        |
| 1:00  | 26.5        | 26.2       | 26.5        |
| 2:00  | 27.2        | 26.8       | 27.3        |
| 3:00  | 27.9        | 27.3       | 27.9        |
| 4:00  | 28.0        | 28.0       | 28.3        |
| 5:00  | 28.3        | 28.3       | 28.8        |
| 6:00  | 28.5        | 28.1       | 28.1        |
| 7:00  | 28.9        | 28.4       | 29.4        |
| 8:00  | 29.3        | 29.3       | 30.2        |
| 9:00  | 29.3        | 29.0       | 30.1        |
| 10:00 | 29.0        | 28.3       | 28.3        |
| 11:00 | 28.3        | 27.6       | 27.7        |
| 12:00 | 27.6        | 27.0       | 27.3        |
| 13:00 | 27.9        | 27.3       | 27.7        |
| 14:00 | 28.0        | 27.9       | 28.1        |
| 15:00 | 28.3        | 28.4       | 28.7        |
| 16:00 | 28.5        | 28.8       | 29.0        |
| 17:00 | 29.1        | 29.3       | 29.5        |
| 18:00 | 29.3        | 29.4       | 29.7        |
| 19:00 | 29.5        | 29.6       | 29.9        |
| 20:00 | 29.7        | 30.0       | 30.2        |
| 21:00 | 30.0        | 30.3       | 30.5        |
| 22:00 | 30.3        | 30.6       | 30.7        |
| 23:00 | 30.5        | 30.8       | 30.9        |
4.2 Case study characteristics

Al Malqa is a new urban settlement that contains many types of residential villas, one of which was selected as a case study for this research; the location is demonstrated in Figure 6.

Figure 7 also shows the floor plans of the case study selected for this research. This building is decline 24° with north being anticlockwise.

5 THE ANALYSIS OF BUILDING PERFORMANCE (DISSECTION)

Active systems are often used to cool a hot, arid climate, creating buildings that are more comfortable for users. This effect on the energy demand led to an increase in energy consumption. Passive strategies can minimize active system loads if effectively applied as demonstrated in Figure 8 by using the DB software, total performance and energy consumption due to the selected strategies was analyzed.

The base model of the characteristics was set in DB. The cooling system was set at 23.0°C, and the set point was 28.0°C. The air infiltration rates were set to 0.5 Ac/h as an average rate. Figure 9 also demonstrates the passive techniques implementation into the DB.

5.1 The base case analysis

The base case—where none of the mentioned passive strategies were installed and the cooling systems were turned off—was
simulated in DB for the highest indoor temperature during the summer design day (specified in DB as 15 July) and the designed cooling loads. The simulation results were demonstrated in Figure 10 and Table 2. The highest recorded operative temperature was 30.8°C, and the designed cooling loads are 93.49 KWH.

5.2 The first case after adding the louvers and shading devices
The first case—where the first mentioned passive strategy, in which the louvers and shading were installed, and cooling systems were turned off—was also simulated in DB for the highest indoor temperature during the summer design day (specified in the DB as 15 July) and the designed cooling loads. Simulation results are shown in Figure 11 and Table 3. The highest recorded operative temperature was 30.3°C, and the designed cooling loads are 85.15 KWH.

5.3 The second case—after upgrading the glazing type
The second case—where the second mentioned passive strategy, where the glazing type was upgraded, the cooling systems were
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5.4 The third case—after adding the insulation to the outer walls and roofs

The third case—where the third mentioned passive strategy, which involves adding insulation to the outer shelter of the building, the cooling systems were turned off, and the louvers and shading devices were kept—was also simulated in DB for the highest indoor temperature during the summer design day (specified in the DB as 15 July) and the designed cooling loads. The simulation results are shown in Figure 12 and Table 4. The highest recorded operative temperature was 29.2°C, and the designed cooling loads are 80.17 KWH.

5.5 The fourth case—after adding green roofs to the outer roofs

The fourth case—where the fourth mentioned passive strategy involves adding green roofs to the outer roofs of the building and the cooling systems are turned off while keeping the three previous strategies—was also simulated in DB for the highest indoor temperature and the designed cooling loads. The simulation results are shown in Figure 13 and Table 5. The highest recorded operative temperature was 27.9°C, and the designed cooling loads are 39.54 KWH.

6 CONCLUSIONS

The results indicate that the selected passive cooling systems in this research are a promising alternative to minimize energy consumption and providing thermal comfort for building users. Figure 15 demonstrates the decrease in the temperature and cooling loads in each case. The third case—with insulation—resulted in the highest decrease in the cooling loads and indoor temperature.

Figure 16 also shows that the air and radiant temperature decreased to 16% from 30.8°C to 26.1°C after applying the selected strategies, and the total design cooling of the building before utilizing the selected passive strategies was 124.760 Kw, which became 50.170 Kw; after utilizing the selected strategies, it decreased to 59.78%.

The order of applying the passive strategies definitely affects the decreasing rate in the cooling loads. However, the research concluded that applying insulation could be considered the most influential passive technique among all techniques, while adding shading devices is the second most influential technique. However, it can be seen that adding green roofs did not have as much of an effect because it was applied after adding the insulation materials, which caused the thermal conductivity of the roofs to decrease before applying the green roofs. This prompts consideration of the effectiveness of applying green roofs along with thermal insulation in the roofs.

CONFLICT OF INTEREST:

There is no conflict of interest.

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