Energy Conservation Techniques for Residential Building in Arid Climate Regions

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Abstract:

According to the vision of Saudi Arabia 2030, more attention has been given for the application of renewable energy in addition to the optimization of energy consumption in standing residential and industrial buildings. It is well known that, residential buildings account for more than 60% of the total electricity consumption in Saudi Arabia due to cooling and heating loads. Most of research carried out aiming to improve building which is designed from the first stage. However, the dominant amount of energy is consumed by the exciting buildings which are built without guide for energy efficiency. The present paper provides different suggestions for standing buildings in hot and dry climate cities in order to be much efficient buildings through minimising their energy consumptions. A typical residential building's model in the city of Riyadh is simulated numerically to reduce the total energy consumption for heating and cooling loads using different strategies of energy saving. The numerical results are obtained using one of the most powerful energy simulations (TAS EDSL) which is used globally to predict energy efficiency in buildings. In general, the results obtained showed that the size of glazing system is the most important parameter which can be modified in the exciting buildings to become much efficient energy buildings.

Keywords:

Energy saving techniques, Numerical prediction, residential buildings, thermal analyses, hot and dry climate cities.

1. Introduction

One of the important goals of Saudi Arabia's vision 2030 is how to improve the energy saving techniques in all life sectors, especially, in residential buildings. Therefore, an increased attention has been recently turned to increase the building energy performance in Saudi Arabia in order to improve the global energy saving strategy and to achieve the required indoor thermal comfort [1]. The local climate boundary conditions in different area of Saudi Arabia can play an important role on the obtained thermal comfort and consequently, the appropriate design of the residential building in such areas [2]. It is common knowledge that the microclimate conditions depend on light regime, air and soil temperatures, humidity and solar radiation in specified area or region.

According to the rapidly increasing of population and a high level of economic growth, Saudi Arabia is experiencing a huge infrastructure expansion, especially with respect to residential buildings. Due to the hot and humid Saudi climate, approximately 70% of electricity is consumed by air conditioning systems alone for interior cooling throughout the year. As a result, energy demand for residential buildings has become a very high level in Saudi Arabia, especially in the hot-humid climatic regions. This high energy consumption sheds light on the extent of the problem in Saudi Arabia. Consequently, this indicates the urgent need to adopt a strategy to reduce the excessive use of energy in residential buildings [3].

An effective strategy can be based on passive architectural design principles relating to the thermal insulation materials being used for the building, as this offers the potential for a cost-effective solution for energy reduction and major savings in electricity needed for cooling and heating purposes in residential buildings [4].

In general, retrofitting refers to the addition of new technology or features to older systems. Renovation, retrofit and refurbishment of the existing buildings represent an opportunity to upgrade the energy performance of commercial building assets for their ongoing life. Often retrofit of buildings involves modifications to existing commercial buildings that may improve energy efficiency or decrease energy demand. In addition, energy efficiency retrofits can reduce the operational costs, particularly in older buildings, as well as help to attract tenants and gain a market edge. However, retrofitting the existing building can oftentimes be more cost-effective than building a new facility.

Since buildings consume a significant amount of energy, particularly for heating and cooling, and because existing buildings comprise the largest segment of the built environment, it is important to initiate energy conservation retrofits to reduce energy consumption and the cost of heating, cooling, and lighting buildings.

Conserving energy in existing buildings is not the only reason for retrofitting, but also a high-performance building should be obtained by applying different new strategies during the integrated, whole-building design process. In some cases, a single design strategy can meet multiple design objectives in obtaining less costly building, and contributing to a better, healthier, more comfortable environment for people in which they live and work. That can improve occupant health and productivity through decreasing moisture penetration and reducing mold which will results in improving indoor environmental quality.

The retrofit process should consider upgrading for accessibility, safety and security at the same time, and special attentions must be given when dealing with historic buildings.

In general, considering major renovations and retrofits for existing buildings to include sustainability initiatives will reduce environmental impacts and operation costs, and can increase building durability, adaptability, and resiliency.

Before taking the decision of the retrofit of existing buildings for energy and sustainability improvements, it is important to determine if the investment is worthwhile in perspective with the current building conditions. List of different potential performance indicators have been identified through the literature review [5, 6].

Once one has determined that other building conditions should be implemented to upgrading for sustainability and improved energy performance, an action plan and a sequence of activities should be applied in order to determine the best options for energy and sustainability improvements.

Different sustainability and energy-efficiency strategies can be adopted and realized in the existing buildings for energy and sustainability improvements. For example:

1. Minimize the consumption of energy and water systems.
2. Apply daylight, HVAC and lighting sensors in appropriate locations according to the occupancy patterns.
3. Incorporate energy efficient lighting into the interior as well as exterior of the existing buildings.
4. Reduce heating and cooling loads by means of natural ventilation techniques.
5. Design a renewable energy system that can replace the traditional energy system.
6. Replace existing windows with high-performance windows with Nano-coating glass.
7. Develop more responsive maintenance system form enhancing building performance.
8. Employ a green roof system for existing buildings if possible.
9. Reduce the windows area, or Glazing to Wall ratio.
10. Consider solar shading devices for external windows and doors, including those that can generate electricity by photovoltaic (PV).
11. Improve or apply the thermal insulation for the external as well as the internal walls of the existing buildings.

Building energy simulation (BES) models have been recently improved, taking into account local climatic conditions to conducting a proper assessment of building energy consumption in urban areas. Indeed, many investigations show that the urban microclimate has a significant impact on the energy consumption of buildings [7-14].

In the present paper, investigations are conducted in order to evaluate the effect of three strategies listed above; namely the items 9, 10, and 11. The residential building model is assumed to be located in Riyadh city distinguished with extreme Hot-Humid Climatic Region, and the most populated area of Saudi Arabia. The TAS energy simulation software, is used in order to evaluate the impact of such strategies on energy performance of a typical residential building.

2. Methodolgy

The present research utilizes the energy modelling simulation named TAS EDSL Software which is developed by Environmental Design Solutions Limited in 1989. It is counted as one of the most common used tool in order to predict building energy performance. The TAS version (9.3.4) is used to predict many variables for indoor building efficiency such as indoor air temperature, relative humidity, heating and cooling load and many others.

A typical residential building in the city of Riyadh, shown in Figure 1, is going to be evaluated to have reduction in the total energy consumption for heating and cooling loads using different strategies for energy saving. The base case of the building is associated with a single external wall without insulation material. The simulation is carried out by the usage of thermal insulation, the usage of shading devices and finally minimising the area of windows to 50%. Table 1 indicates the features of the building envelope used in both cases; the base case and the modified case, of the building as well as the thermal insulation properties.

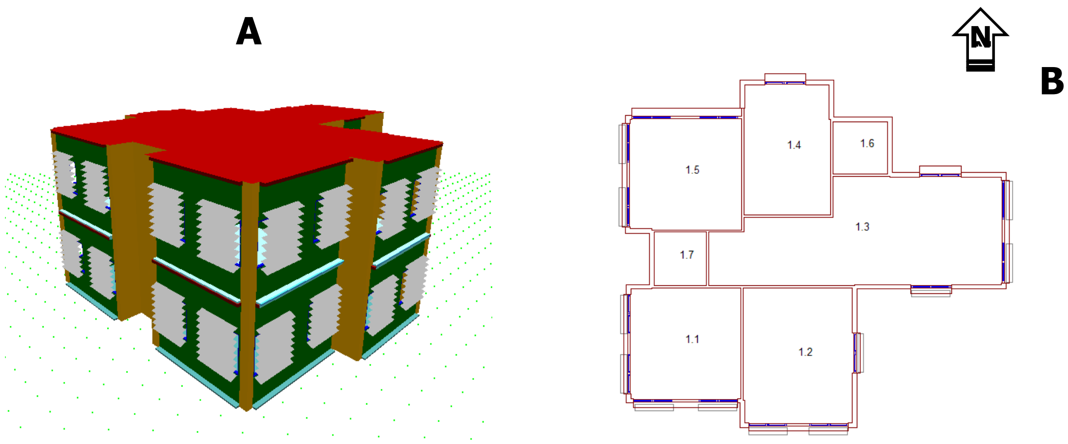

Figure 1. *View of the 3D modelling building with the use of shading devices (A), and the plan of the building (B).*

Table 1. *Building envelope features for building base case and thermal insulation properties.*

<table>
<tr><td colspan="8">BC building fabrication and its features</td></tr>
<tr><td></td><td colspan="2">Layers</td><td colspan="2">Width (mm)</td><td colspan="2">Conductivity (W/m² ℃)</td><td>Total U value (W/m² ℃)</td></tr>
<tr><td>External wall</td><td colspan="2">Block</td><td colspan="2">200</td><td colspan="2">0.31</td><td>1.24</td></tr>
<tr><td rowspan="2">Ground</td><td colspan="2">Concrete</td><td colspan="2">100</td><td colspan="2">0.87</td><td rowspan="2">0.99</td></tr>
<tr><td colspan="2">Sand dry</td><td colspan="2">1000.0</td><td colspan="2">0.32</td></tr>
<tr><td>Roof</td><td colspan="2">Concrete</td><td colspan="2">200</td><td colspan="2">0.87</td><td>2.5</td></tr>
<tr><td rowspan="2">Glazing</td><td>Type of glazing</td><td>Width mm</td><td>Solar reflectance</td><td>Solar absorption</td><td>Solar transmittance</td><td>Emissivity</td><td>Total U value (W/m² ℃)</td></tr>
<tr><td>Single</td><td>10.00</td><td>0.070</td><td>0.115</td><td>0.7</td><td>0.845</td><td>5.53</td></tr>
<tr><td colspan="8">Thermal Insulation fabrication and its features</td></tr>
<tr><td rowspan="2">External wall</td><td colspan="2">Insulation</td><td colspan="2">100</td><td colspan="2">0.04</td><td rowspan="2">0.33</td></tr>
<tr><td colspan="2">Block</td><td colspan="2">200</td><td colspan="2">0.31</td></tr>
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<tr><td>Insulated</td><td>22 with 10mm air gap</td><td>0.15</td><td>0.133</td><td>0.399</td><td>0.845</td><td>1.80</td></tr>
</table>

Riyadh city has a hot desert climate and over the course of a year, the temperature typically varies from 8 ℃ to 43 ℃ and is rarely below 3 ℃ or above 45 ℃. The warm season in Riyadh lasts from May 14 to September 26 with an average daily high temperature above 39 ℃. The hottest day of the year is August 1, with an average high of 43 ℃ and low of 28 ℃. However, the cold season in Riyadh lasts from November 29 to February 25 with an average daily high temperature below 24 ℃. The coldest day of the year is January 14, with an average low of 8 ℃ and high of 19 ℃. The Daily High and Low Temperature over the year can be seen in Figure 2.

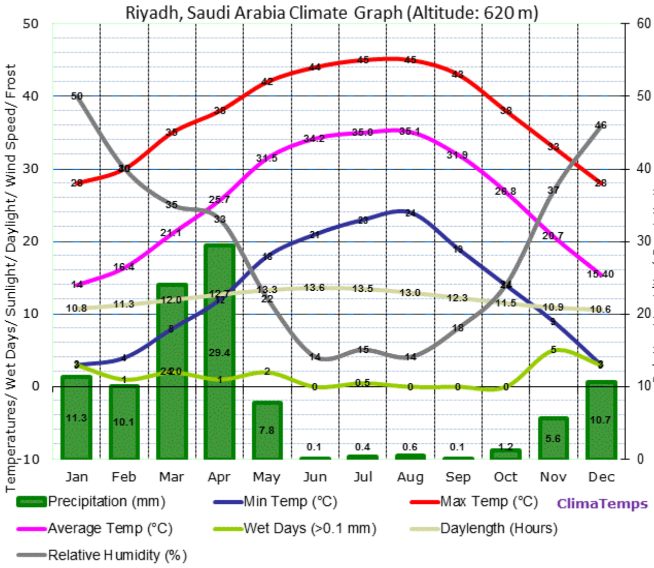

Figure 2. *Climate characteristic of Riyadh, Saudi Arabia.*

3. Results and Discussion

Figure 3 shows the results of the cooling as well as heating loads for the base case in the different sectors of the plan of the building. It is in prime importance not only to identify ways in order to improve building energy performance, but rather to clearly justify the most effect ones. This will enhance the designers, architects and engineers to execution their requirement and producing more friendly and green buildings which consume less energy. Looking at the results shown in figures 4-6, it can be noted that cooling (CL) and heating loads (HL) have inverse relationship. As heating load rise, cooling load fall. It can be seen that total energy required for cooling is higher than heating which is attributed to the extreme heat in summer time in the city of Riyadh where temperature could exceed 45 ℃. Larger spaces performed with higher heating and cooling loads such as 1.3 whereas toilet spaces had the lowest (1.6 and 1.7 zones). One of the most outcomes to consider is that thermal insulation method has the best energy pattern in comparison with all other techniques (base case, shading devices and control of glazing to wall ratio). Although other publications reveal that glazing to wall ratio is the leading element which determine the energy load in many regions [15], it is connected to the amount of glazing compared to the amount of external wall. Glazing to wall ratio might be more crucial when it is becomes lower than 10% or greater than 20% in hot regions.

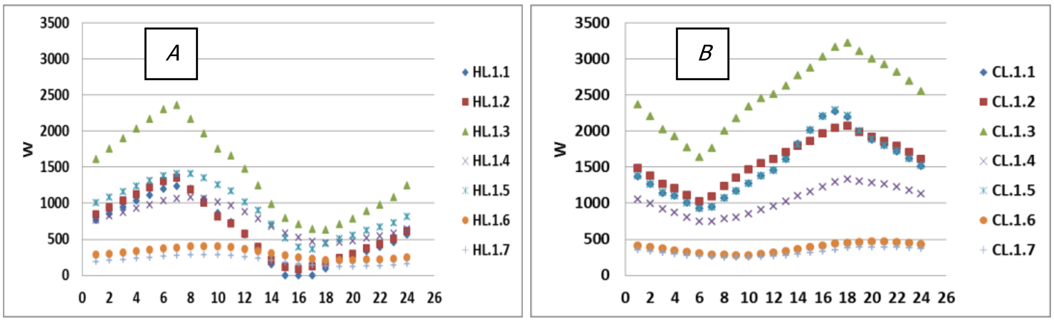

Figure 3. *Base case heating and cooling load, where: (A) is heating load, (B) is cooling load.*

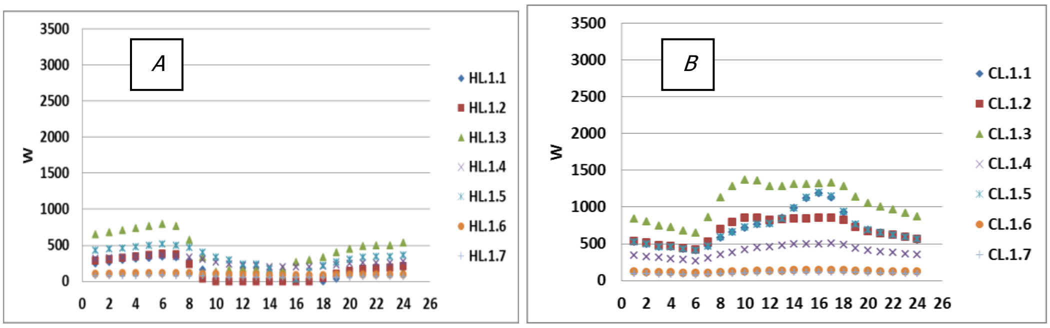

Figure 4. *Thermal insulation heating and cooling loads, where: (A) is heating load, (B) is cooling load.*

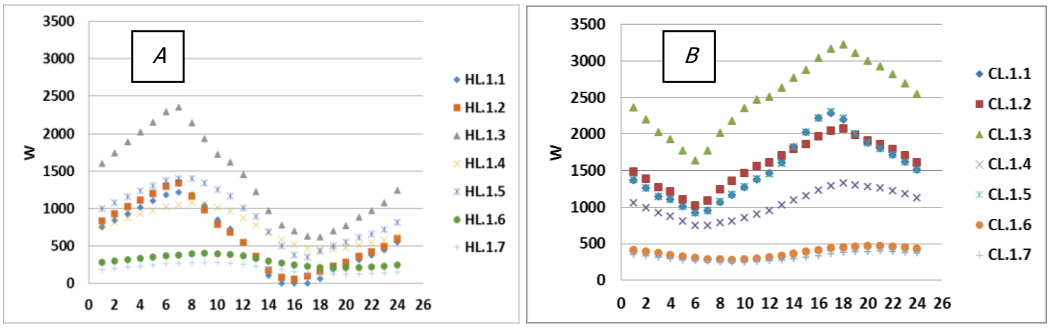

Figure 5. *Shading devices heating and cooling loads, where: (A) is heating load, (B) is cooling load.*

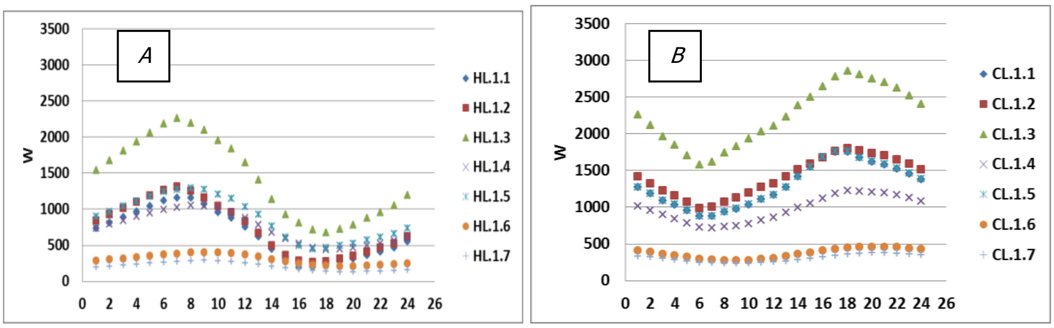

Figure 6. *Minimizing glazing area heating and cooling loads, where: (A) is heating load, (B) is cooling load.*

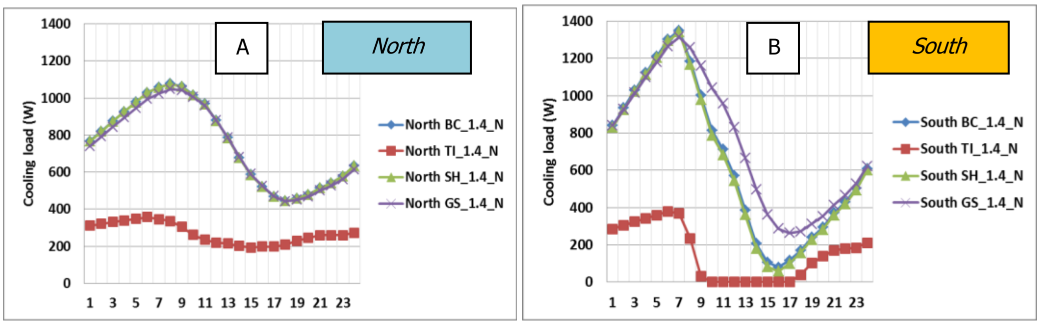

Figure 7. *Cooling load North and South zones with respect to all suggested designs, where: (A) is North facing, (B) is South facing zones.*

In order to properly understand the physical outcomes highlighted in the previous discussion, it is important to investigate some related aspects such as heat conduction and solar heat gain which can be seen in figures 8 and 9. In arid climates, it is always to consider north and south facing zones. This is the reason for taking further results considering only these directions as it can be seen in figure 7. The figures support the findings reveled in figures 3-6. Using shading devices and glassing to wall ratio is not comparable with the usage of thermal insulation. This is due to the location of the case study which is extremely hot in summer and extremely cold in winter. This sort of climate requires the use of thermal insulation to prevent much of heat flux in between envelop building. It can be noted that south direction require more specified design as direct solar gain take place in this face. Similarly, heat conduction and solar heat gain which can be seen in figures 8 and 9 respectively also show that south direction has more fluctuation due to direct solar gain. This make it clear that to make reduction in cost of building envelope, north facing zones should not receive any modifications which might raise the cost of the building such as adding thermal insulation, shedding devices and etc. The combination of applying thermal insulation to the building with minimizing size of glassing system can lead to the optimum building design in hot and arid climate.

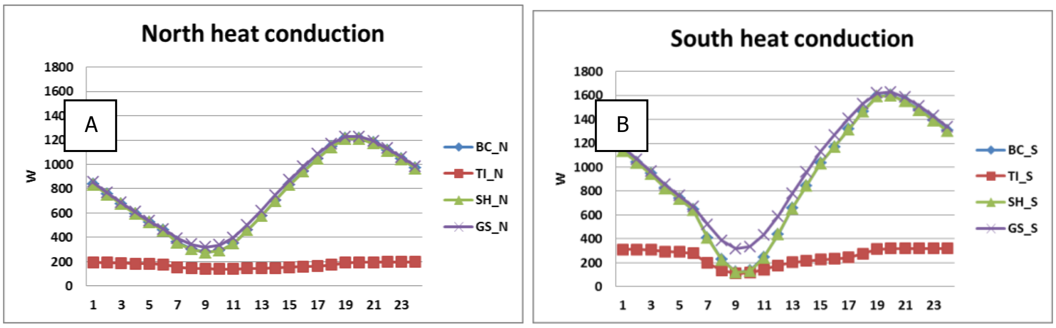

Figure 8. *Heat conduction in North (A) and South (B) zones with respect to all suggested designs.*

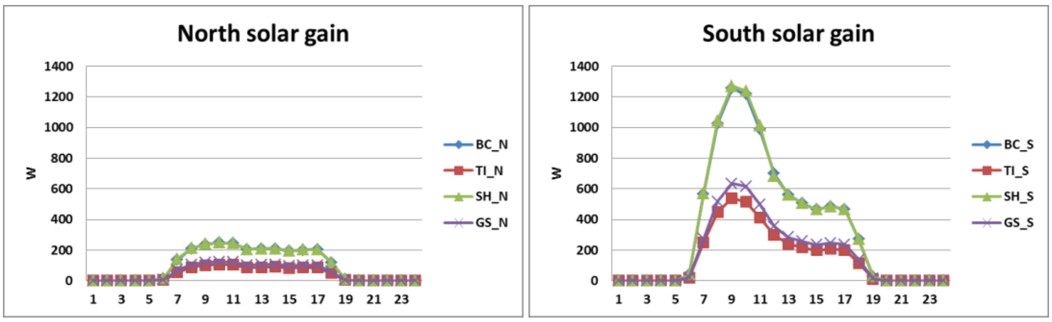

Figure 9. *Solar heat gain in North and South zones with respect to all suggested designs.*

In general, the presented results showed the improvement of building energy performance by adding external wall thermal insulations. This can be observed by reducing the required cooling and heating cool in the interior of the building. However, little effects of the implementation of shading devices or reduction of the windows area on heating or cooling loads. Through the usage of new as well as advanced insulation materials, the energy performance of th e building will be improved.

4. Conclusions

In the present paper, a comprehensive study of the energy consumption for a typical building in the city of Riyadh which is the capital of the Kingdom of Saudi Arabia is carried out. The presented simulations have been conducted using TAS energy simulation software. The investigated city is located within an extreme climate condition which is very hot in summer and very cold in winter. Different strategies for energy saving in buildings have been performed; namely: the usage of thermal insulation, the usage of shading devices and finally minimising the area of windows to 50%. The results of the assessments showed that adding thermal insulation to external walls and adopting an appropriate construction type could improve the energy performance of the building through a reduction of the heating and cooling loads required. The usage of shading devices and the minimising of the area of the windows showed a slightly effect on the reduction of the heating load and a negligible effect of the cooling loads. Consequently, it is recommended to apply the advanced material of thermal insulation in residential buildings of Riyadh city, instead of the traditional insulation materials in order to improve the energy performance of the existing buildings.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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