An Evaluation of the Total Energy Consumption of Educational Buildings: Prototype Case Studies in Saudi Arabia

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ABSTRACT

The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased, reaching figures between 20% and 40%. In terms of commercial buildings, educational buildings are one of the main components of this sector. Educational buildings are a unique type of facility which can house a large number of dwellers for the purpose of learning, propagation of knowledge and the development of skills for life. Therefore, the assessment of the energy efficiency of educational buildings has become a matter of particular interest to educational organisations, environmentalists and governments. In the Kingdom of Saudi Arabia (KSA), owing to the speedy growth in the infrastructure and construction sector, prototype educational buildings were designed with little attempt to exploit the natural resources such as ventilation and daylight in order to achieve a better indoor environments. The aim of this paper is to assess the energy consumption of current Higher Technical Institutes buildings in different cities presenting the climate zones in the KSA. This evaluation will investigate the energy consumption of these buildings and the appropriateness and response of their current design to the climate conditions in each region. A whole building energy simulation was used to investigate the sensitivity of various factors affecting energy use and a detailed computer model of a typical building in different cities in the KSA have been constructed using EnergyPlus with DesignBuilder as an interface. The results revealed that the energy consumption in this building differs significantly according to the project locations, which was also reflected by a significant variation in each city. Furthermore, it was found that the variations in the total energy consumption between the cities were a result of the consumption of the cooling and heating systems.

KEYWORDS
Total energy consumption, Energy modelling, Performance simulation, Educational buildings, Saudi Arabia

INTRODUCTION
Most of the current educational buildings in the KSA significantly relied on mechanical apparatus to cool interior spaces with limited use of natural lighting. However, undesirable consumption rates of materials, water and energy during the construction, operating and maintenance phases of projects are the result of the lack of consideration paid to sustainable construction principles during the conceptual phase of design (Al-Yami & Price 2006). Consequently, these buildings have become one of the major energy consumers. The demand for technical education and vocational training in Saudi Arabia has grown significantly during the past twenty years. In 1985 the government of Saudi Arabia established the Technical and

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Vocational Training Corporation (TVTC) as a principal government agency responsible for technical education and vocational training provided in technical colleges, higher technical and industrial vocational institutes, and training centres (Ministry of Economy and Planning 2010).

A large number of buildings have been required within a short time-frame to meet the growing needs, cost and time savings in educational building construction which were the essential goals of the TVTC. These buildings, especially Girls Higher Technical Institutes (GHTI), which often accommodate over 1200 students, have needed to assess the effectiveness of their energy consumption. Building more of this type of buildings without assessing its energy consumption and their appropriateness to the climatic conditions of different regions in Saudi Arabia, it will lead to increased consumption of energy, thus, increased burden on the Saudi Arabia's energy sector. According to King Abdulaziz City for Science and Technology (KACST), The Kingdom's energy sector faces great challenges due to the growing demand in electricity consumption (KACST 2002).

The main aim of this paper has been to assess the energy consumption of current GHTI buildings in different cities presenting the climate zones in the KSA. This evaluation will investigate the energy consumption of these buildings and the appropriateness and response of their current design to the climate conditions in each region. Specific information belonging to the case study such as: geometry; technology; performance; characteristics and location have been taken from the TVTC. This information used in the process of creating a model for the building by simulation software and subsequently analysed the energy performance of the building using the hourly dynamic simulation model. This method allowed the most influential aspects of the energy consumption in the building to be determined, which should be taken into account during the process of developing alternative solutions.

CASE STUDY AND THERMAL MODELLING

To achieve the objectives of this study, the design for GHTI buildings was chosen for the case study. GHTI is one of the latest building prototypes that are in the process of being established by the TVTC. The GHTI project consists of several parts connected via two courtyards, with a built floor area of 20,138 m^2. The main parts of the construction project are: three educational buildings, administration building, mosque, library and conference hall. The three educational buildings and the library are each comprised of three stories while the remainder of the project is comprised of two stories.

Figure 1. *General view of the main entrance to the GHTI building*

For the purpose of this study, the rear of the project (composed of three, three storey educational buildings) was selected for the whole building energy simulations to investigate the sensitivity of a variety of factors affecting energy use. Figure 2 illustrates the selected parts of the building. These portions contain 115 rooms utilised for various activities, with a building area of 8480.5m^2.

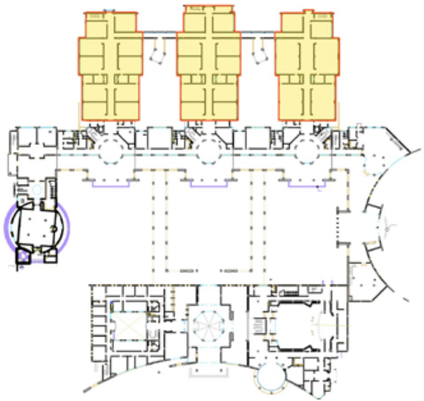

Figure 2. *The parts of the building selected for the energy simulation*

In order to assess the energy consumption of the current GHTI building and to achieve the objectives of this study, three cities have been selected to represent the three inhabited climate zones in the KSA. Riyadh represent desert subzone with hot and dry conditions, Jeddah represent hot and dry having a maritime desert subzone and Dhahran represent hot, dry and maritime subzone (Said et al. 2003). Figure 3 shows the locations of the three chosen cities in KSA as well as and the monthly diurnal averages of temperatures and solar radiation levels.

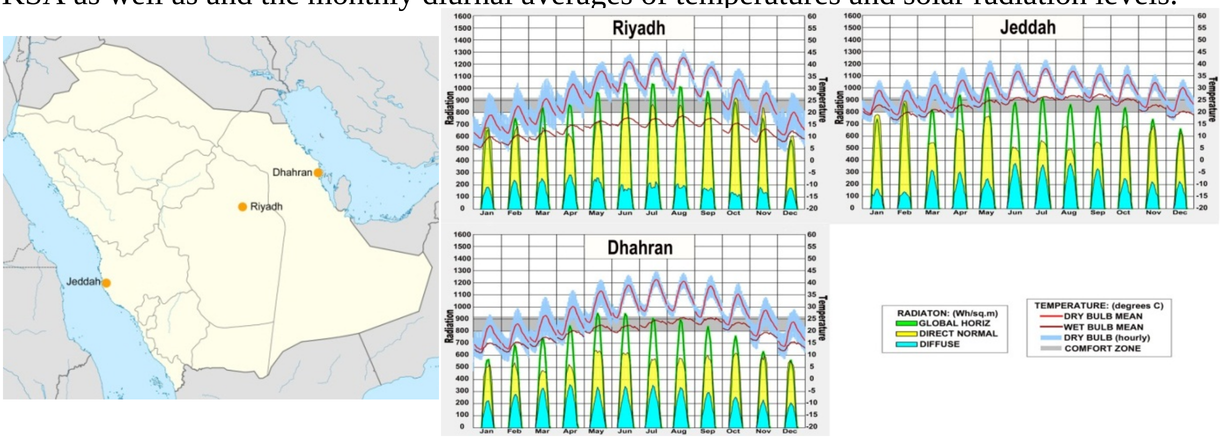

Figure 3. *The locations of the three chosen cities in KSA and the monthly diurnal averages of temperatures and solar radiation levels in Riyadh, Jeddah and Dhahran*

The energy simulation process involved creating 3D models for higher institutes for the building designs in the DesignBuilder. The second phase involved setting the input parameters to define the realistic boundary conditions of the study simulation. The final phase involved choosing appropriate output variables before running the simulation and managing the output data. A crucial factor, which was helpful in obtaining accurate results from the simulation analysis, involved the creation of an accurate 3D geometric of the building, similar to the real design, using the simulation tool. The next stage involved, creating the building's exterior geometry. This step contains three phases; the first phase was to generate the elements of the project required to calculate the energy consumed. This phase included dividing the structure into three buildings: the western building, which is referred in this study as Building (A), the eastern building which is referred to in this study as Building (C) and the building located in the middle, Building (B). The second phase involved generating a model of each of the three buildings using three floors. Then, the building adjacent to building A, B and C was created and its relationship with the chosen part was determined. This building is referred as a Building (D). The third phase was to create the remainder of the buildings in the project environments; these would affect the selected area in terms of shadows or air flow. It is worth mentioning that the project was oriented to the north so that the entrance to the project is positioned on the south side. Figure 4 is showing the locations of buildings A, B, C and D.

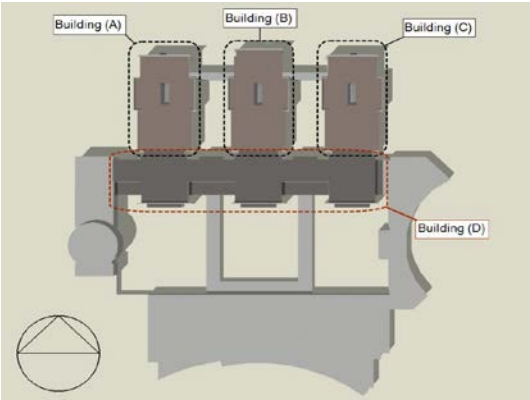

Figure 4. *The locations of buildings A, B, C and D*

Following this, thermal zones were defined for each room according to the schemes and activities needed for the project. The final phase involved identifying and creating the openings - doors and windows - for each zone, in addition to the skylights for the buildings.
The specification pertaining to the surfaces of the buildings included buildings A, B, C and D; the type of construction, the application of U-values and the type of materials that were used all play a vital role in deciding the boundary conditions under which the structure would be constructed. Various types of constructions have been demonstrated in Table 1, including the main features like the roof, glazing, the type of walls selected and the floors selected during the process.

Table 1. *Input parameters for building model construction*

	External Walls	***Internal Partitions***	***Glazing***	***Flat Roof***	***Internal Floors***
Outside Layer	20 mm Cement plaster	20 mm Cement plaster	Blue 6 mm	40 mm Gravel	10 mm Porcelain
Layer 2	150 mm Hollow concrete blocks	150 mm Hollow concrete blocks	13 mm air	50 mm Phenolic foam	10 mm Tile bedding
Layer 3	50 mm Extruded Polystyrene	20 mm Cement plaster	Clear 6 mm	10 mm Bitumen	150 mm Cast concrete
Layer 4	100 mm Hollow concrete blocks	-		200 mm Cast concrete	500 mm Air gap
Layer 5	20 mm Cement plaster	-		500 mm Air gap	20 mm Plasterboard
Layer 6	-	-		20 mm Plasterboard	-
U-value (W/m^2-K)	0,437	1.639	2.665	0.511	1.235

The internal heat gains of the buildings can be determined by identifying occupancy, activity type, equipment and operations schedules. It is important to determine the energy consuming equipment in each zone. In addition to their implications for energy consumption, equipment such as computers, office equipment and miscellaneous are key sources of internal heat gains.

Therefore, these devices not only affect the consumption of electricity, but also affect the burden of additional load on HVAC.

In addition to the normal equipment for educational buildings, the GHTI has specialised equipment commensurate with fields of training in the institute. For instance the gold forging lab and jewellery manufacturing lab require specialised devices to refactor gold. In this study, the requirements of each lab were calculated in terms of the additional needs of the equipment according to practical activities; these results were classified and calculated as miscellaneous equipment. In order to determine the amount of energy needed to provide thermal comfort in the interior environment of the educational building, HVAC system parameters were identified in all zones of the buildings. A required temperature inside the building for all conditioned zones was determined. In the case of this study, the standard ASHRAE Heat Balance method was implemented in EnergyPlus.

RESULTS AND DISCUSSION

In order to achieve the objectives of this paper, the results will help to estimate the total energy consumed in each building separately (A, B and C) and combined; these will refer to all the buildings at each location. The reasons for the consumption that have been focused on are: total cooling, room electricity, lighting, fans and heat generation plus domestic hot water (DHW).

Table 2. *Energy consumption of individual and combined buildings in the three cities per kWh*

Location	*Building*	*Total Cooling*	*Room Electricity*	*Lighting*	*Heat Generation + DHW*	*Fans*
Riyadh	A	510950.7	267632.2	120145.2	12245.77	14073.64
	B	326305.1	307603.3	81441.7	13929.81	12034.43
	C	835829.8	433411.1	209755.9	12908.1	17430.08
	Total	1673086	1008647	411342.8	39083.68	43538.15
Jeddah	A	949931.1	267637.9	120145.2	9254.42	14073.64
	B	599555.9	307609.2	81441.7	10939.73	12034.43
	C	1477797	433416.9	209755.9	10574.48	17430.08
	Total	3027284	1008664	411342.8	30768.63	43538.15
Dhahran	A	738638.9	267637.9	120145.2	9681.88	14073.64
	B	457513.1	307609.2	81441.7	11319.89	12034.43
	C	1177798	433416.9	209755.9	10971.47	17430.08
	Total	2373950	1008664	411342.8	31973.24	43538.15

The total Energy Utilisation Index (EUI) for the combined buildings in Riyadh is 374.47 kWh/m^2/yr and the cooling system consumes between 44% and 55% of the total energy consumed by the individual buildings, and 53% by the combined buildings. In terms of the energy consumption for heating purposes and DHW, the buildings in Riyadh are the highest energy consumers for the purpose of heating, amongst the three cities.

In Riyadh, building B cooling system consumes 326305.1 kWh, which accounts for 44% of the total energy consumption in the building. This percentage is considered good when compared with the percentages for buildings A and C, with 55% for each of them. It is also reasonable when compared with the overall percentage of energy consumption for cooling purposes in KSA cities which were evaluated at between 62% and 76% (Al-Najem 2002, Al-Arfag 2002). With total annual consumption of 4521597.58 kWh, the GHTI building in Jeddah is considered to be the lowest performance and the highest energy consuming of the three buildings. The energy consumption for cooling purpose is the highest in the KSA. In buildings A and C, the energy consumed reached around 70% of the total consumption by the buildings. In terms of the amount of the energy consumed in all the buildings for air conditioning this amount reached 3027284 kWh, representing 67% of the total energy consumed. Therefore, the EUI of all the buildings in Jeddah is the highest with 533.17 $kWh/m^2/yr$. This suggests that the highest EUI for individual buildings applies in the case of building C in Jeddah, at 773.19 $kWh/m^2/yr$. The total energy consumption for all the buildings in Dhahran represents the second highest amount of energy after Jeddah, with total consumption reaching 3869468.19 kWh, with a EUI of 456.24 $kWh/m^2/yr$. This high consumption of energy is a result of the need for air conditioning, which accounts for 64% of the entire energy consumption in both buildings A and C. In building B, the same consumption of air conditioning represents around 53% of the total energy consumption of that building.

The results that have been acquired revealed evidence that the energy consumption in the GHTI building differs significantly according to the project location. In Figure 5, it is also apparent that there is a significant difference in total energy consumption between buildings, A, B and C, in the same city environment that is determined according to the activities occurring inside them. This is the case even where the buildings are located in the same space, and is reflected in significant variations in EUI in each city. The electricity, lighting and fan consumption requirements of individual rooms are the same in all the cities surveyed. The considerable variations in the total consumption among the cities were due to the air conditioning, heating and DHW requirements, which increase or decrease in relation to the climate at each location. Comparison of the EUI results for those cities that represent the climatic zones within the chosen KSA cities clearly reveals significant variations between them, as classified in accordance with similarity in terms of climate zones.

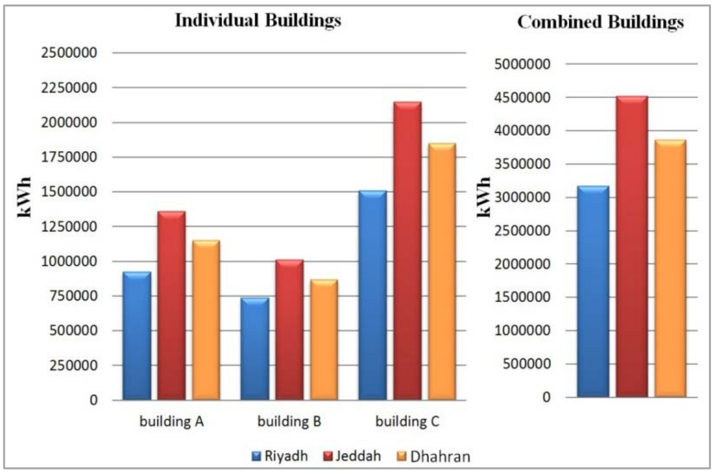

Figure 5. *Total energy consumption of individual and combined buildings per kWh*

The energy that is used for cooling purpose accounts for the majority of the total energy consumption in buildings at different locations around the Kingdom. This energy use, which varies considerably from one place to another, is responsible for between 50% and 70% of total energy consumption.

Jeddah and Dhahran are the regions where the conditioning system consumes the highest amount of the total energy consumed. Apparently this is due to the fact that these cities are coastal cities, with high humidity. In spite of the high temperatures in Riyadh during the summer, which are some of the highest in the KSA, the project in Riyadh consumes less energy than those in Jeddah and Dhahran.

Heating and DHW only consume between 0.3% and 2% of the total energy consumption of the buildings in the chosen cities. The buildings in Jeddah and Dhahran consume the least amount of energy for the purposes of heating and DHW at 30768.63 kWh and 31973.24 kWh respectively, whereas this consumption increases to 39083.68 in the Riyadh building.
This consumption is reasonably acceptable when compared with that in other regions. In terms of individual buildings, building A in Jeddah is the lowest consumer at 9254.42 kWh, while the highest is building B in Riyadh at 13929.81 kWh.
Energy Utilisation Index is considered to be one of the best methods to measure building energy consumption performance; especially in cases where the goal is to seek to establish energy consumption benchmarks according to building type. The results of total energy consumption generated from simulation tools are analysed in relation to previously built areas of individual and combined buildings to calculate the EUIs of each of them. The results that are revealed in Figure 6 clearly show the considerable variations in EUI in the case of individual or complete buildings, which relates to the location of the building on the site and the city's location.
The buildings labelled B, in all the cities, are the best in terms of energy performance. The results show that the EUI in B buildings ranges between 253.66 kWh/m^2/yr in Riyadh, which is the best recorded performance, and 346.13 kWh/m^2/yr in Jeddah, which is the worst recorded performance.

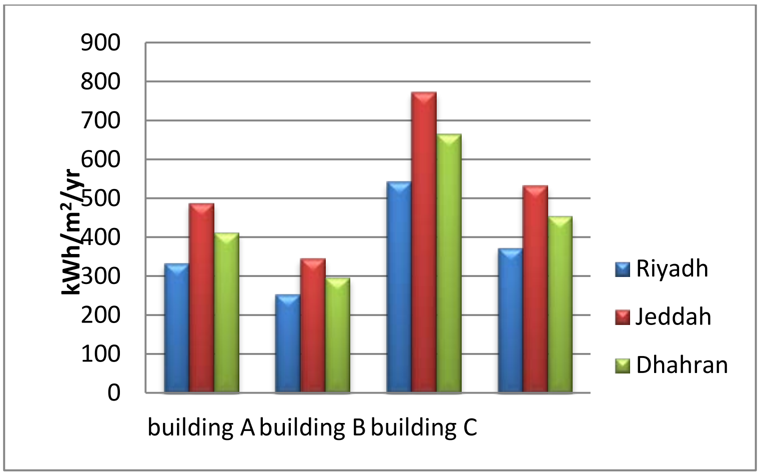

***Figure 6**. EUIs of buildings in KSA cities*

In terms of buildings labelled A, the energy performance variations between the buildings resemble the B building results. Building A in Riyadh has the best performance at 332.87 kWh/m^2/yr. Building A in Jeddah and Dhahran represent the highest EUI results at 489.75 kWh/m^2/yr and 413.88 kWh/m^2/yr respectively. Buildings C in all cities have the worst performance. EUIs extend in these buildings to between 543.05 kWh/m^2/yr in Riyadh and 773.19 kWh/m^2/yr in Jeddah. The high consumption of energy in buildings C in all locations is due to the fact that there are a large number of specialised laboratories within the building that requires special equipment. Therefore, they consume larger amounts of energy in addition to the heat gain produced by this consumption. In the case of combined buildings, the buildings in Riyadh have the highest performance at 374.47 kWh/m^2/yr. The building EUI in Dhahran rises to 456.27 kWh/m^2/yr while it increases in Jeddah to 533.17 kWh/m^2/yr which is the highest level.

CONCLUSION

The main objective in this study has been to assess the energy consumption of educational buildings in different locations within the KSA. Filippín (2000) proposed that for each location in which a building is positioned different standard energy requirements and environmental costs arise, predicated on the particular constraints within each environment. To achieve the objectives of the study, the total energy consumption of current GHTI building designs in three cities representing the three climate zones in the KSA were assessed. This evaluation investigated the energy consumption of the buildings and the appropriateness and relationship between their current design and the climate conditions in each region.

The results analysis concentrated on four aspects: total cooling, heating and DHW and the buildings' EUI and comparison of the results for the KSA cities with the cities that represent the climatic zones. The results of the total energy consumption throughout the GHTI building revealed that the energy consumption in this building differs significantly according to the project's location, which was reflected by a significant variation in EUI in each city. Moreover, they clarified that there were differences in total energy consumption between the buildings, A, B and C, in the same city according to the activities occurring inside each building. In addition, it was found that the variations in the total energy consumption between the cities were a result of the consumption of the cooling and heating systems.

Therefore, the study has established that KSA requires its own building energy benchmarking classification system if it is to develop best or good practice energy standards for buildings within the country. For optimising the energy consumption in educational buildings in KSA, each region should have its own guidelines according to the climatic conditions of each region in KSA, and this is applicable to other types of buildings.

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