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Residential building energy performance evaluation for different climate zones

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Residential building energy performance evaluation for different climate zones.

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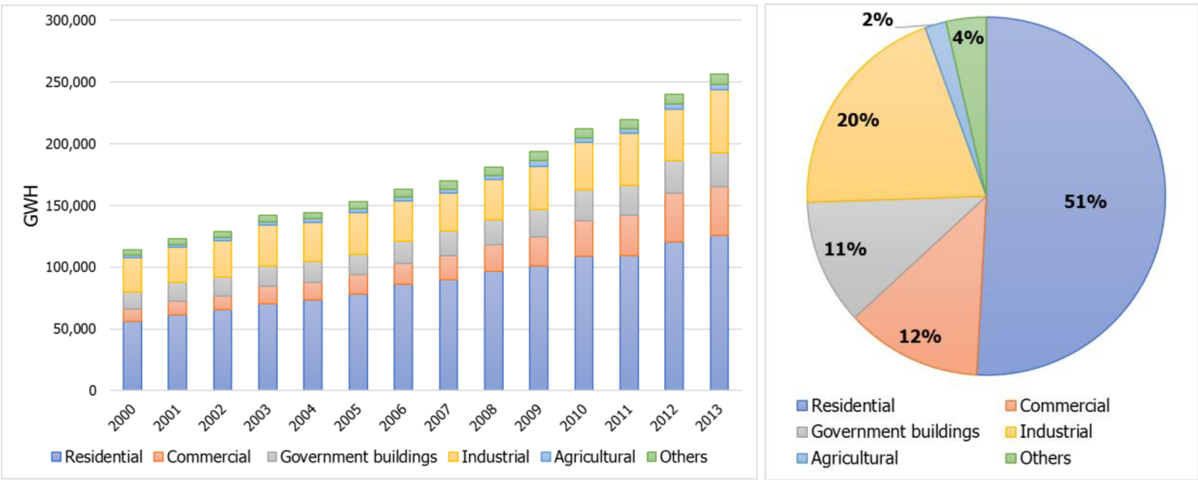
Abstract. The building sector in the Kingdom of Saudi Arabia accounts for a large proportion of energy consumption. This paper investigates energy consumption in residential type A villa buildings constructed by the Ministry of Housing. The study specifically investigates energy consumption of a case building in three climate zones of the country identified in the KSA Building Code (SBC-602E). The software package IES-ve was used to simulate power consumption of the case building taking into account the climate characteristics of each zone. In total 6 cities were considered from the three zones to evaluate and compare annual and monthly power consumption loads of the building. It was found that there is some distinction of energy consumption for heating and cooling in the three zones (e.g., peak monthly power energy consumption for cooling varied from 6.371 MWh in Riyadh (zone1) to 1.663 MWh in Abha (zone3) and no heating requirement for Jaddah (zone 1) while Turaif (zone 3) heating consumption is 23.835 MWh) however, further work is required to identify clearer the climate specifications within each zone to address the excess energy consumption of this type of buildings.

1. Introduction

Increasing energy consumption in buildings and resulting pollutants emissions has led many countries to introduce tighter construction regulations and best practice codes. For example, in the Kingdom of Saudi Arabia (KSA) the building sector has expanded very fast from early 1980s to address in part housing shortage for the growing population. Figure 1(a) shows that the building sector is a major energy consumer in KSA with an annual growth rate of about 10% and a share of 79% of the total electricity used in KSA. Furthermore, Figure 1(b) illustrates that the residential sector alone accounts for the consumption of more than half of the total electricity generated in KSA [1, 2]. This energy consumption trend of the building sector is expected to be maintained in the foreseeable future [1]. Therefore, to alleviate the economic and environmental impacts of the sector, the Saudi government initiated an energy efficiency strategy that attempts to reduce demand for fuel and raw materials in the construction sector [1]. For example, a National Energy Efficiency Program (NEEP) has been launched at King Abdulaziz City for Science and Technology (KACST) to support research projects that rationalise energy use as part of the government's policy to reduce carbon emissions by 130 million tonnes by 2030 as inscribed in Saudi Arabia's 2030 vision. Among the promoted solutions include adoption of energy efficiency and renewable energy technologies [3] through, for example, the Saudi Energy Efficiency Centre (SEEC) and a Mandatory Energy Efficiency Plan for government organisations [4].



(a) (b)

Figure 1: Building sector electricity consumption in KSA (a) Trend of energy consumption (b) Average breakdown [1]

Low energy prices, improved living standards and access to air conditioning systems created a strong correlation between power demand profile and ambient temperature. As illustrated in Figure 2, electricity demand nearly doubles in hot summer months [2]. It is estimated that over 50% of total electricity use in buildings is for space air conditioning in buildings [2], creating a compelling case for improving energy use in the domestic sector through the introduction of energy conservation measures and efficient building designs that do not compromise thermal comfort of buildings' occupants.

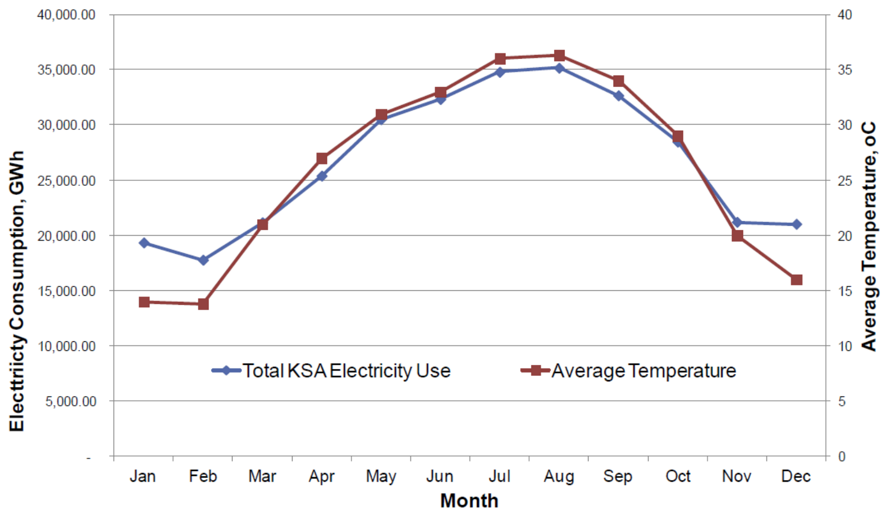


Figure 2: Monthly total KSA electricity consumption and average ambient temperature during 2014 [2].

KSA is located 23.88^o N and 45.08^o E and has an area of approximately 2.15 million km^2 and coast line of 3800km, creating distinctive climatic regions [5]. However, for a long time, the prevailing climate of KSA was classified as a single zone of arid desert, disguising the climatic differences between continental desert (hot and dry), costal line (hot and humid) and high altitude regions (hot/moderate in summer and cold in winter) [6]. This diverse climate has been reflected in the Saudi Buildings Energy Conservation Code 602E which divides the country into three major climatic zones as can be seen in Figure 3. However, the classification still does not consider the apparent disparities of climatic characteristics of Riyadh and Jeddah with hot dry and hot humid climates respectively. This was pointed out by Said et al.[7] in the study on climatic zones for building design purposes which proposed six climatic zones.

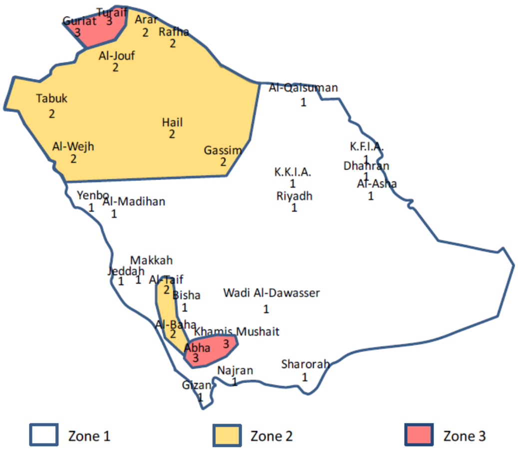


Figure 3: KSA Building Code (SBC-602E) climatic zones [8]

The main objective of this paper is to investigate the thermal performance and associated energy consumption of a typical individual residential villa building type in KSA three climatic zones. This is carried out with the aid of computer simulation using IES-ve software package, data of construction materials and building envelope extracted from the project document and energy bills of residents. Areas of improvement of the building envelope to conserve energy is highlighted.

2. Selection of cities in the three climates zones

To cover the wider climatic diversity of KSA, six cities located in the three climate zones identified in the Saudi Buildings Energy Conservation Code 602E and the study conducted by Said et al. [10] were selected. This includes Riyadh (which is a hot and dry with a desert subzone) and Jeddah (which is a hot and dry maritime subzone) in zone 1, Qassim (which is a hot and dry with a desert subzone) and Alwajh (which is a hot and dry maritime subzone) in zone 2, and Turaif (that a cold and dry with a desert subzone) and Abha (which is a subtropical with a Mediterranean subzone and a mountainous subtype) in zone 3. Weather data for these cities was taken from meteorological stations of the General Authority for Meteorology and Environmental Protection.

3. Selection of residential building type

The residential sector in KSA is varied and predominantly composed of flat apartments and individual villas. In this work type A villa building constructed by the Ministry of Housing has been selected as the base case study. The Ministry of Housing records show that 12,161 buildings of this type were constructed in 38 different regions so far. These buildings were designed to take into account local architectural and construction practices with the construction phase be implemented by an approved contractor and under competent supervision. A layout plan and photo of the building front façade are shown in Figure 4. It consists of 3 bedrooms, a guest room, kitchen, living room, dining room and four toilets with a total floor area of 245 m^2. The building walls were constructed from insulated hollow concrete blocks with windows and doors to wall area ratio of 6.29%. Rooms are air conditioned using window mounted units.

(a) (b)

Figure 4: (a) Type A villa layout plan. (b) Front elevation.

The main design parameters of the building envelope as specified in the project documentation are summarised in Table 1.

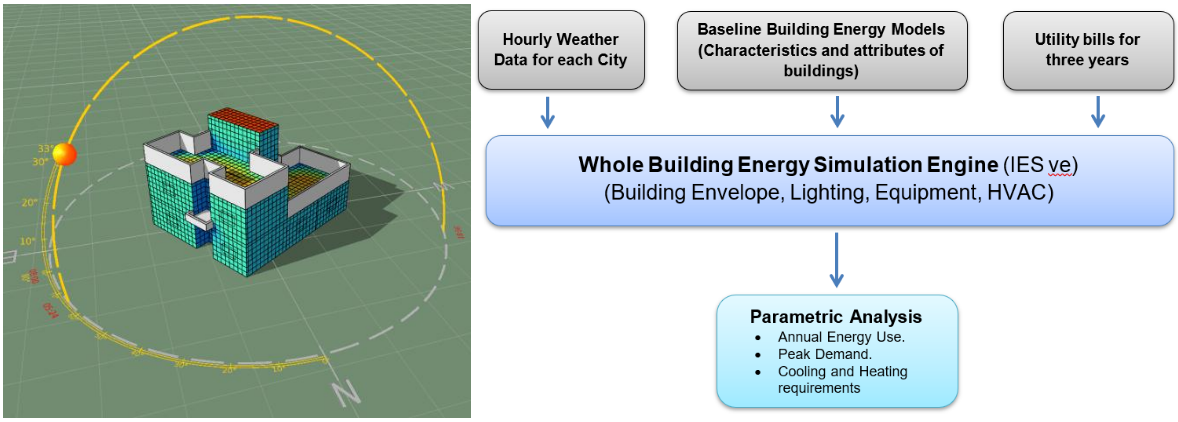
Table 1: Envelope elements U-Values.

Envelope Elements	U-Value (W/m^{2}K)	Envelope Elements	U-Value (W/m^{2}K)	Envelope Elements	U-Value (W/m^{2}K)
Exterior Wall	0.6993	**Internal Floor**	2.3417	**Interior Door**	1.8661
Interior Wall	1.3858	**Slab on-grade**	2.3876	**Windows**	2.2310
Roof	0.4510	**Exterior door**	Steel with Lexan (Polycarbonate) 8mm thickness		

Other design parameters include indoor design temperature of 24^o C in summer and 20^o C in winter and air infiltration rate of 1 ACH.

4. Building Energy Performance simulation

The building plan profile and energy performance evaluation was carried out using IES-ve software. Input parameters from the location weather database, the building energy model (envelope u-values, infiltration rates, indoor design temperatures and approximate occupancy schedule) to estimate annual energy consumption of the whole building. Operation parameters of the HVAC plant were also considered in IES-ve using specification data from commonly installed air conditioning equipment. To establish good confidence of the simulation results, a 3-year average electricity consumption data from energy bills of a case building in Qassim city (zone 1) was used to validate the model. Figure 5(a) shows a 3-D plan and sun path of the simulated building and Figure 5(b) shows a flow chart of IES-ve simulation block parameters of the buildings.



(a) (b)

Figure 5: (a) 3D plan of the building, (b) IES-ve simulation flow chart.

In this work the availability of reliable long-term climate data was particularly helpful in undertaking a comprehensive a comparative analysis of energy consumption in the three climate zones described in the building code.

5. Energy performance results and analysis

The power consumption simulation for the typical A type villa building in six cities located within the three climate zones was performed. The energy performance data assesses the building heating, cooling and total power consumption presented as monthly load profiles, as shown in Figure 6 (a), (b) and (c) respectively.

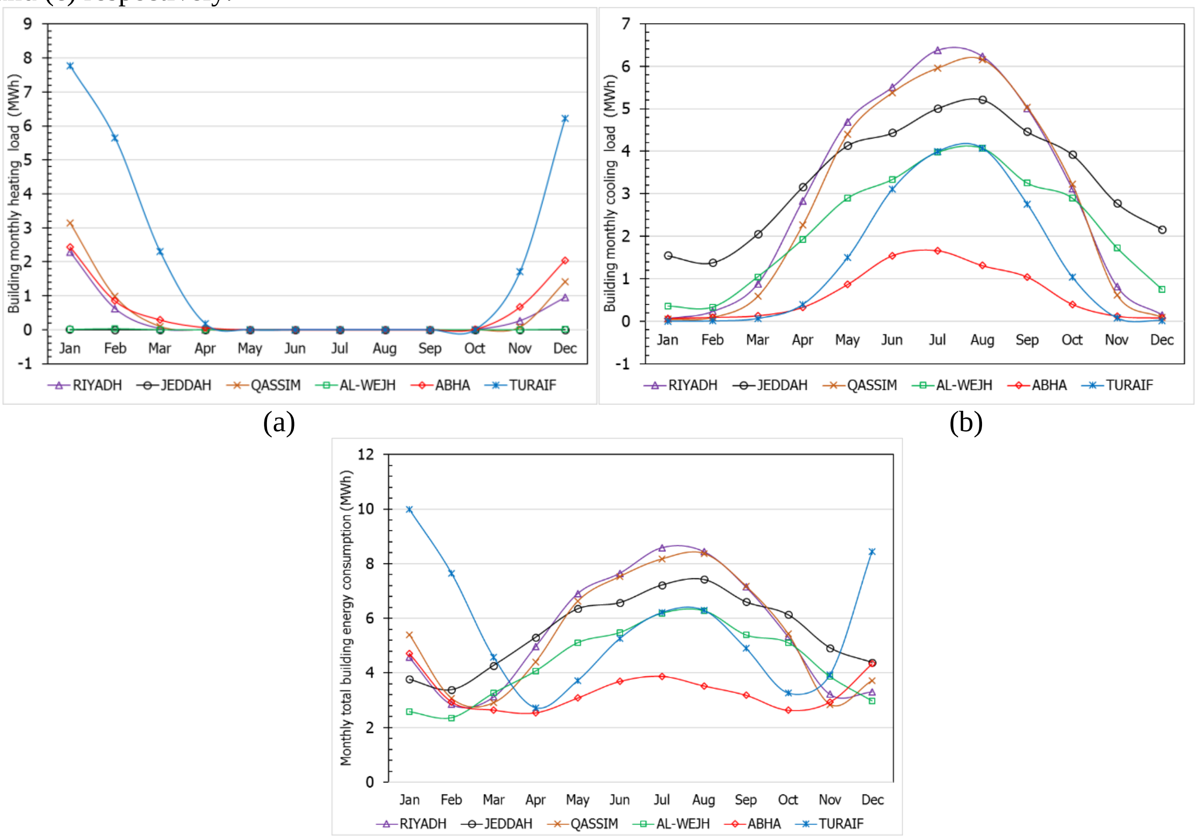


Figure 6: Building monthly power consumption load profile, (a) heating (b) cooling and (c) total.

Figure 6 (a) vindicates in part the climate zone classification of buildings in KSA. For example, Turaif (zone 3) requires the largest power consumption for heating during the heating season (October to April). Whereas the coastal city of Jeddah (zone1) has no heating load at all for the whole of the year, while Alwajh (zone 2) recorded only a low monthly heating load of about 0.0223 MWh in February.

Similar analysis was conducted for the power consumption for cooling loads, where Figure 6(b) shows monthly consumption profiles for the six cities. As expected, Riyadh (zone 1) and Qassim (zone 2) with prevailing hot and dry climate have the largest power consumption for cooling with peak demand in July of 6.371 and 5.954 MWh respectively. Power consumption for cooling in Abha and Turaif (both in zone 3) is lowest and recording 79% and 37% lower than Riyadh.

Figure 6(c) shows the aggregate monthly power consumption for space heating, cooling, and other electric appliances (lighting, fans/pumps, and Domestic Hot Water (DHW)) of the considered type of residential building. It is markedly clear the building located in climate zone 1 (Riyadh and Jeddah) consumes more power for cooling. It is also worth noting the large swing in demand for heating and cooling in Turaif (Zone 3) due to large variation in ambient temperature between the heating and cooling season with peak heating load in January exceeds that of cooling load in summer. In contrast, the building located in Abha (zone 3) exhibits particularly a flat annual energy load profile due mainly to the smaller seasonal temperature variations associated with mild climates.

The total power consumption of the building was further broken down into weather sensitive (i.e., HVAC consumption such as heating and cooling) and non-weather sensitive (i.e., lighting, DHW, and other equipment). The simulation input parameters for non-weather related energy consumption and occupancy pattern is assumed to be the same for all six locations. Figure 7 presents the proportion of energy consumption by category, location of the building and its zone. It can be seen that weather related energy consumption (i.e., heating and cooling) forms the largest part; 54 and 61% in zone 1; 51% in zone 2; and 35 and 61% in zone 3.

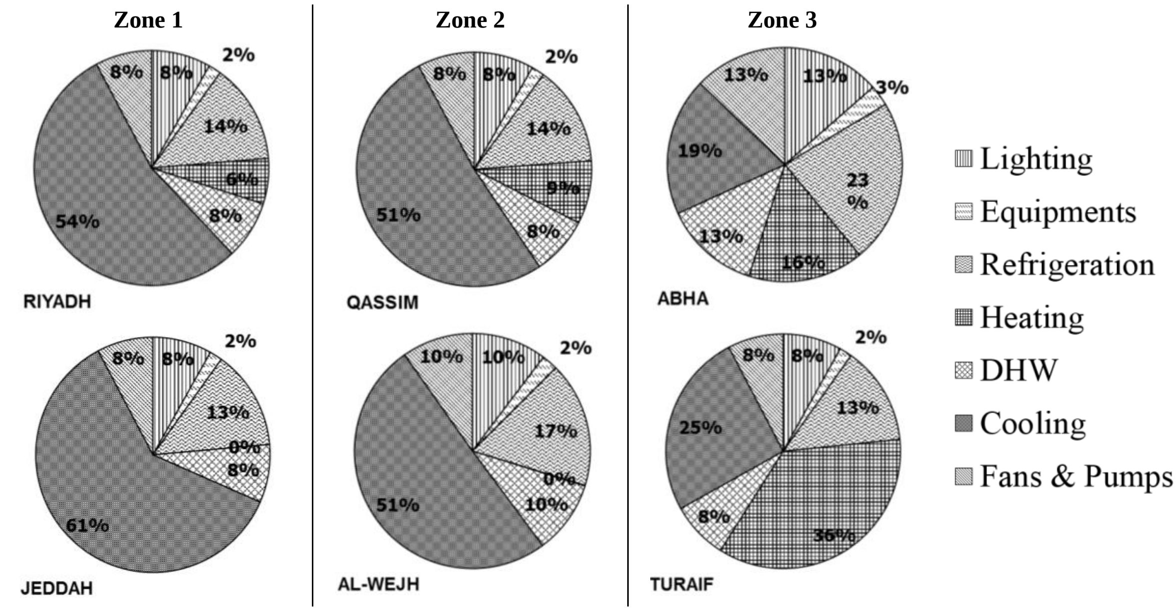


Figure 7: Breakdown of power consumption

Further analysis of annual power consumption data is presented in Figure 8. Figure 8 shows that the total energy consumption in the three zones is comparatively similar in Riyadh and Jeddah (both zone 1), Qassim (zone 2) and Turaif (Zone 3) amounting to about 66 MWh/year. While Alwajh a (zone 2) and Abha (zone 1) recorded the lowest power consumption of 52 and 40MWh/year. It is also shown that HVAC (heating and cooling) account for a minimum of about 14 MWh in Abha to a maximum of about 41 MWh in Turaif. The power consumption for heating and cooling varies significantly between the three zones (cooling: 7.641MWh in Abha and 40.260MWh in Jeddah; heating: 0 MWh in Jeddah and 23.835 MWh in Turaif).

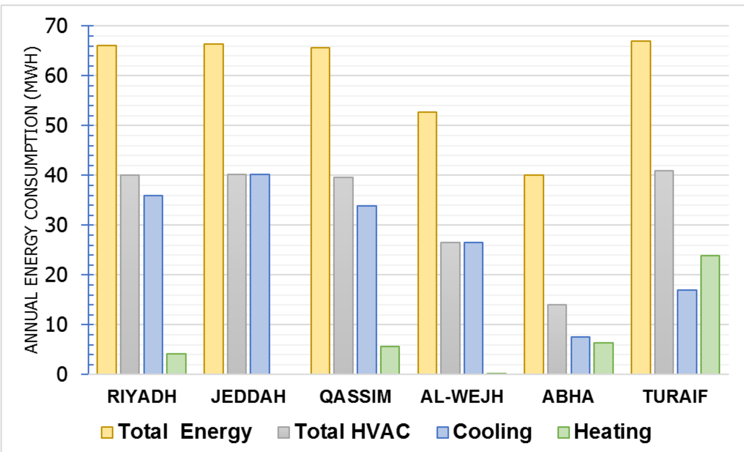


Figure 8: Annual power energy consumption.

6. Discussion and conclusions

There is a growing concern about energy use in Saudi Arabia. With rapid building development programmes and improvements of living conditions, the building sector will continue to be a major energy end consumer. This study examines annual power consumption of a type A villa building in six major cities in three different climate zones as identified in KSA Building Code (SBC-602E) - namely zone 1: Riyadh (hot and dry- desert subzone), and Jeddah (hot and dry - maritime subzone); zone: Qassim (hot and dry - desert subzone) and Alwajh (hot and dry- maritime subzone); and zone: Abha (subtropical- Mediterranean subzone and mountainous subtype) and Turaif (cold and dry- desert subzone). The annual power consumption in the case building was analysed for the three zones using the building envelope design parameters for villa type A that built according to the specifications of ministry of housing, along with HVAC equipment specification and occupancy schedule. The computed results from IES-ve were also validated using electric consumption bills. It was found that there is a wide variation in weather related energy consumption. For example, the annual power consumption for heating ranged from 0 MWh in Jeddah (zone 1) to a peak of 8 MWh in January in Turaif (zone 3), which is characterised by cold winter climate. On the other hand, Jaddah (zone 1 with hot, humid climate) had the largest annual power consumption for cooling- 40.260 MWh, while Riyadh (zone 1 with hot, dry climate) had the largest cooling peak of 6.371 MWh in July. This is about 74% bigger than that power consumption for cooling in Abha (zone 3), reflecting the extent of the climate differences in the two zones. The total annual power consumption in the three zones also varied greatly.

The study shows that current KSA Building Code (SBC-602E) differentiates to a certain extent between the construction specifications of the three zones based on climatic conditions. It was also shown that maybe further zones such as coastal lines (e.g., Jeddah, Alwajh, etc) be classified as a separate zone due to humid climate and slightly lower temperature variation that do not need heating in winter. Further work of this study will focus on reducing weather related heating and cooling loads through using lower u-values envelope elements, shading and other passive construction techniques.

References

[1] SEC, "Electrical data 2000-2013," Saudi Electricity Company, KSA, Riyadh2014, Available: http://www.se.com.sa, Accessed on: 28th March 2019.
[2] M. Krarti, K. Dubey, and N. Howarth, "Evaluation of building energy efficiency investment options for the Kingdom of Saudi Arabia," *Energy*, vol. 134, pp. 595-610, 2017.
[3] J. Mitchell and B. Mitchell, "Paris Mismatches: The Impact of the COP21 Climate Change Negotiations on the Oil and Gas Industries," *Chatham House Energy, Environment and Resources Department Research Paper,* 2016.
[4] M. Asif, "Growth and sustainability trends in the buildings sector in the GCC region with particular reference to the KSA and UAE," *Renewable and Sustainable Energy Reviews,* vol. 55, pp. 1267-1273, 2016.
[5] SGS, *Kingdom of Saudi Arabia: Facts and figures*, 2 ed. Jeddah: The Saudi Geological Survey, 2017, p. 170.
[6] B. Y. M. Ahmed, "Climatic classification of Saudi Arabia: An application of factor--Cluster analysis," *GeoJournal*, vol. 41, no. 1, pp. 69-84, 1997.
[7] S. Said, M. Habib, and M. Iqbal, "Database for building energy prediction in Saudi Arabia," *Energy conversion and management,* vol. 44, no. 1, pp. 191-201, 2003.
[8] *Saudi Energy Conservation Code, Low-Rise (Residential) Buildings, SBC 602 E*, 2018.