Assessing the adaptability of the Saudi residential building`s energy code for future climate change scenarios

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ABSTRACT: Due to the expectation of climate change and increasing global temperature, new building rates will face challenges. Nearly 40% of world-wide carbon emissions can be linked to building's energy consumption. Therefore, it is significant to understand how a building's energy consumption will behave under future climate change in order to reduce carbon emissions. The residential sector's demand for energy in the KSA is massive at 50%. Based on recent government initiatives of KSA, mandatory new residential buildings must meet stringent energy codes. This study investigates the effects of applying the new Saudi residential building energy codes for a detached single-family house (villa) located in Jeddah, KSA. This study aims to see how the code might perform under current and future climate change scenarios. Although the current code already shows a significant improvement in combating future climate change, a total reduction of 38% in the annual cooling demands of existing villas in Jeddah after applying the new standards will be illustrated. However, increases in cooling energy demand due to climate change still exist. Applying more passives strategies that are not included in the code would assist the researcher in knowing if there are other means to achieve significant decreases in cooling demand.
KEYWORDS: Climate Change, Energy Consumption, Residential Villas, Energy Code, Hot Climate

1.1 INTRODUCTION

Saudi Arabia mainly depends on oil and natural gas as sources of energy. More than half a million barrels of oil is being used daily in the country in order to generate electricity[1]. The per capita CO2 emissions that results from the energy consumption in the KSA in 2012 increased and is ranked the highest in comparison with many developed countries in the world[2]. The building sector is a major contributor to energy demand in the Kingdom of Saudi Arabia (KSA) due to the reliance on air conditioning for cooling. Buildings (residential, governmental, and commercial) consume around 75% of the total electricity generated in KSA with an annual growth rate of 7%[3]. Among different types of buildings, the residential building sector represents more than 50% of the total electricity consumed in the country figure 1.[4] This is due to the fact that currently most of the residential buildings are not insulated. In addition to this, the hot climate of KSA causes high demands for air conditioning particularly during the summer season. Furthermore, the building sector is considered to be in a need for building 2.32 million new houses by 2020 in order to meet the requirements of population growth, as at present only 24% of the Saudi citizens have their own home[5].

In view of this issue, many researchers have indicated that setting out energy standard and code can play an important role to enhance the buildings energy efficiency[1]. Based on the recent initiative provided by the government of KSA, a mandatory new build residential buildings` energy code has been established to reduce energy consumption. According to the Saudi Energy Efficiency Centre(SEEC), this code is expected to achieve 30-40% energy reduction in the residential sector[3]. However, the issue of energy consumption of the existing and new build residential buildings will be exacerbated because of climate change. Based on the study conducted by Almazroui et al.2012[6], it was found that the temperature in KSA will increase at a rate of 0.72°C mean temperature each decade. Furthermore, by 2050 the temperature will see an increase in a rate between 2.0–2.75°C. Therefore, the building capability to tackle future climate change is critical [7]. Based on reviewing the residential buildings` energy code, it was found that predicted future climate change was not given any consideration. Therefore, this study focuses on examining the capacity of the Saudi residential building`s energy code to cope with future climate change.

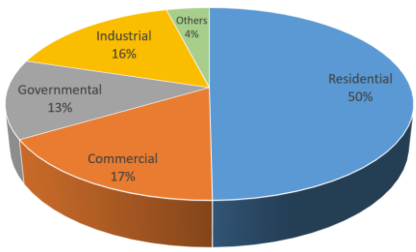


Figure 1: Energy consumption by building sectors in Saudi Arabia.

1.2 LITERATURE AND BACKGROUND

Due to advanced building technologies, the lifespans of buildings are increasing, so the demolition rate of buildings will fall in the future.

Another important consideration is that worldwide building energy consumption contributes around 40% of global total carbon emissions. Therefore, to achieve rational use of energy in the context of future climate change, it is crucial to understand the potential impact of global warming on the thermal performance of a building and to take appropriate measures to prevent unnecessary energy waste, through both energy-saving designs and operational management.[8] The influences of global warming on building energy performance and the corresponding adaptive strategies have gained much attention worldwide.

A recent research was conducted by Radhi to assess the potential impact of climate change on residential buildings in the United Arab Emirates. The study found that the energy demand for cooling buildings would increase at a rate of 23.5% when the temperature increased in Al-Ain city by 5.9°C.[9] Wong et al. investigated future trends of cooling load in the residential sector in subtropical Hong Kong under dynamic weather scenarios in the 21st century. The results of the study show that the percentage increase for the last 30 years of the 21st century is predicted to be 21.6%.[10] Another study in Australia was conducted to evaluate the climate change impact on residential building's heating and cooling energy requirements. It was found that the predicted increase in the total heating and cooling energy consumption was up to 120% and 530% if the global temperature increases 2°C to 5°C respectively.[11]

Although the Gulf region has it's fair share of academic research on this subject, the topic of global warming and its effects on building energy performance is surprisingly scant. The bulk of research on construction energy performance has been conducted on buildings assumed to be constructed in limited weather conditions.[9] The aim of this study is to shed light on the effects of climate change on the energy usage of newly-built and existing air-conditioned living residences in The Kingdom of Saudi Arabia.

1.3 DESCRIPTION OF THE CODE

In response to the crisis of high energy consumption that results from massive growth of building sector, in 2012 the government of Saudi Arabia introduced a royal Decree No.6927 by applying the thermal insulation for all building sector and this was aimed at improving the energy efficiency in buildings mainly by requiring the use of thermal insulation. In 2013, the standard No.2856/2014 Thermal Transmittance Values for Residential Buildings was issued by the Saudi Standards Metrology and Quality Organization. This standard is derived from Saudi Building Code Chapter 601(Energy Conservation).The standard particularly regulates maximum thermal transmittance U-values for residential buildings envelope such as Walls, roofs and window glazing. These U-values were applied and become a mandatory for all residential buildings in two stages as code 1 and code 2. Code 1 was implemented for all the residential buildings that were built after 2013. Then, code 2 was applied to be required for all residential buildings that were built after January 2017.

1.4 BACKGROUND AND CLIMATE OF JEDDAH CITY

This research selected Jeddah city as a case study to investigate. This city faces the western coast of Saudi Arabia and it has tropical arid climate base on Koppen's climate classification. Jeddah is also one of the fastest growing city into a future buildings construction in the region .Jeddah city is a vital city in Saudi Arabia with a population more than 4 million which accounts for almost 15% of the total population of Saudi Arabia.[12] Furthermore, the severity of Jeddah`s weather necessitates the investigation of energy consumption in this city as it is considered one of the greatest challenges in the country.

Jeddah city has a hot climate with high humidity most of the year especially in the summer season which extends from May till October. The monthly average temperature range is between 30°C to 33°C and the maximum temperature reaches 40°C in July. The Winter season is from November to April with monthly average temperature from 23 °C to 27°C. Figure 2 shows the maximum, minimum and monthly average dry-bulb temperature for Jeddah city.

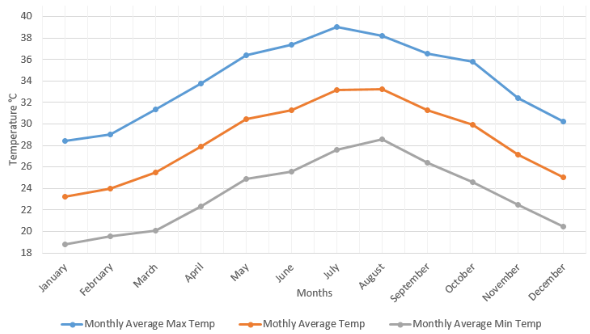


Figure 2: The monthly maximum, minimum and average outdoor temperature for Jeddah, Saudi Arabia.

2.1 METHODOLOGY

In order to evaluate the performance of the residential buildings` energy code in KSA, a detached single-family house (villa) located in Jeddah city has been selected for this study. This villa was built in 2008 before applying the Saudi residential building`s energy code. This is becoming a typical villa and represents the dominant type of residential buildings in Jeddah city. This housing type represents 20% of the total housing number in KSA.[13] A three-dimensional model for this typical villa that was built based on the architectural drawings using DesignBuilder software (version 5.0.1) as shown in figure 3.

Figure 3: villa under study.

The use of this simulation tool as investigatory method is to principally assess the performance of the residential buildings` energy code under future climate change. The building characteristics including construction materials, cooling system types, lights and equipments of the physical villa were applied and modelled in DesignBuilder with occupancy and activity profile as shown in table 1.Current and future weather data files for the periods (2010, 2050 and 2080) also greenhouse gas emission scenarios the A2, A1B, and B1 for Jeddah city were obtained from the climate generator software Meteonorm 7. This software is a climate generator tool that provides users with weather data files for most locations world-wide. [14]

2.2 MODEL VALIDATION

Hourly temperature calibrations between the DesignBuilder model and the actual interior temperature were conducted by recording the indoor and outdoor temperature at hourly intervals. Ibutton dataloggers (DS1921H-F5 Thermochron) were placed in each single room in the house in a constant position to be away from any heat source and to record the indoor temperature. Also, Ibutton dataloggers (DS1923-F5# Hygrochron) were sheltered from direct sunlight and rainfalls and fixed on the top of the villa`s roof to record the outdoor temperature Figure 4 shows the equipment that were used for on-site measurements .The process of field measurements began in June 2017 and ended in August 2017. The study intends this period of time because this three months during summer represents the hottest weather in the year where the use of the air conditioner peaks. Monitoring process were also attempted to monitor and extract the occupancy and the schedule of the house for those three months.

Table 1: characteristics of the villa and simulation options.

Parameters	Villa
No. of floor	2 floors+ annex
Total area	439.25 m2
Building Height	9.6 m
Orientation	North
External/ Internal walls	20 mm mortar (outer surface) 200 mm Hollow red-clay brick 20 mm mortar (inner surface)
Internal floors	10 mm ceramic tiles (outer surface) 25 mm mortar 150 mm Reinforced Concrete 20 mm mortar (inner surface)
Roof	25 mm Terrazzo Tiles (outer surface) 25 mm mortar 4 mm Bitumen layer 150 mm Reinforced Concrete 20 mm mortar (inner surface)
WWR	14.5 %
Window glazing	6 mm Single clear glazing
Infiltration rate	0.7 ac/h (estimated)
HVAC system	Constant volume DX with no heating
Occupancy	0.0136 person/m2
Thermal zones	Multi zones
Cooling set point temperature	25.5 ◦C (stated in the code)

Figure 4: Equipment used for on-site measurements.

Figure 5 displays hourly comparison between the actual measured data and DesignBuilder results for the living room in the villa for five days while the building was a free-running. The calibration results show that there is no more than ±4% difference between the measured and simulated temperature. According to Taleb [15] the researcher can consider the model to be valid as long as the difference between simulated and measured results is less than 5%. In addition, billed monthly consumptions of electricity for the villa were obtained from the Saudi Electricity Company to compare with those calculated for the base case villa. Figure 6 draws a comparison between utility bills consumption and DesignBuilder results during three months .The calibration processes were employed to principally validate the calculations of the DesignBuilder model and supporting the state of being confident and certain about the simulations in order to conduct a study under the impact of climate change.

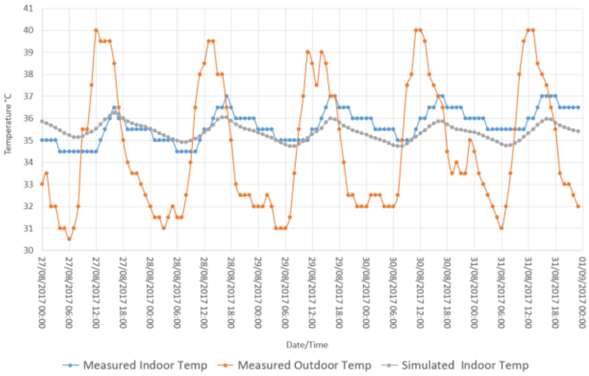


Figure 5: Hourly calibration between on-site measured data and calculated consumption for living room in the villa.

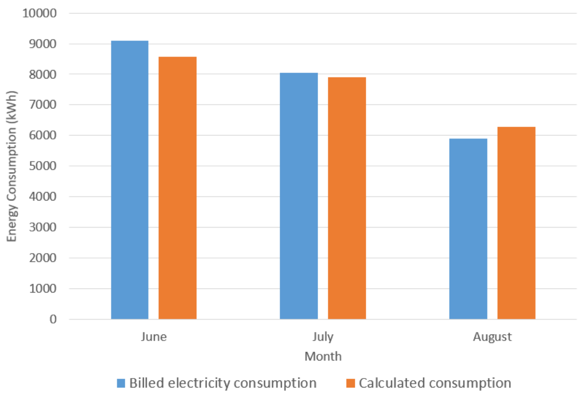


Figure 6: comparison between utility bills consumption and DesignBuilder results for the three months.

2.3 SIMULATION PROCESS

In order to ensure the constancy of the annual simulations analysis results, the typical Saudi daily schedules pattern for lighting, equipment and occupancy were specified from previous study of energy conservation in the existing residential buildings in Saudi Arabia.[16] The monthly energy DesignBuilder simulation results for the base case villa under the current climate is acquired and shown in figure 7. As expected, figure 7 shows that the space cooling represents 83% of the total annual electricity energy consumption for the villa. The next stage was to apply code 1 and code 2 to the base case villa in order to evaluate the performance of the base case villa against code 1 and against code 2 under the current climate. Table 2 draws a comparison between U-values of the typical villa and the current codes which have been studied in this research. In order to achieve the thermal transmittance U-values that are listed in the code for walls and roofs, practical construction materials and methods that are commonly used in Saudi Arabia were selected. Table 3 summarized the specifications of construction methods and materials for walls and roofs that are currently used in KSA. Finally, extensive simulations by engaging climate change scenarios were conducted to examine the requirements of the Saudi residential building's energy codes for external walls, roofs and openings specifications.

Table 2: U-values (W/m2K) for existing typical villa and the Saudi residential building`s energy codes (code1 and 2).

U-Value (W / m2 K)	Existing Building	Code1	Code 2
Roofs	3.40	0.31	0.20
Ext. Walls	1.82	0.53	0.34
Windows	5.71 SHGC - 0.81	2.67 SHGC - 0.25	2.67 SHGC - 0.25

Table 3: Construction characteristics for walls and roofs.

Parameter	Code 1	Code 2
Wall	20 mm mortar (outer surface) 100 mm Hollow red-clay brick 50 mm expanded polystyrene 150 mm Hollow red-clay brick 20 mm mortar (inner surface)	20 mm mortar (outer surface) 100 mm Hollow red-clay brick 80 mm expanded polystyrene 150 mm Hollow red-clay brick 20 mm mortar (inner surface)
Roof	25 mm Terrazzo Tiles (outer surface) 25 mm mortar 4 mm Bitumen layer 100 mm expanded polystyrene 150 mm Reinforced Concrete 20 mm mortar (inner surface)	25 mm Terrazzo Tiles (outer surface) 25 mm mortar 4 mm Bitumen layer 160 mm expanded polystyrene 150 mm Reinforced Concrete 20 mm mortar (inner surface)

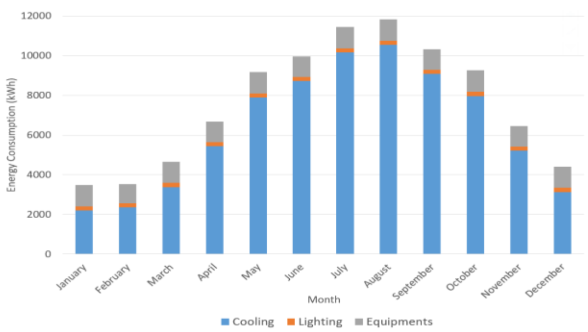
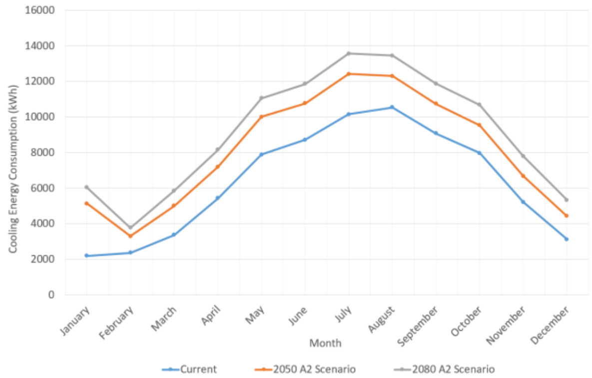


Figure 7: Monthly electricity consumption for the base case villa.

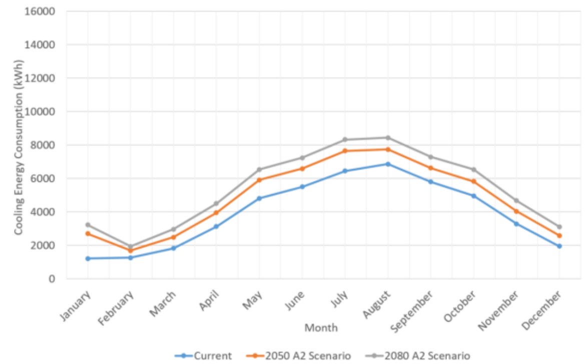
3. RESULTS AND DISCUSSION

Figure 8a shows the monthly cooling energy consumption for the existing villa under the current climate and the A2 future climate scenarios. It can be clearly seen that the yearly cooling loads with the existing villa under the current climate extend from 2000 kWh in January to a peak cooling load of 10000 kWh in July but with the future climate A2 scenario in 2080, the cooling load increases from 6000 kWh in January to 14000 kWh in July. Figure 8b shows the same 12-month time frame of cooling energy consumption for the retrofitted villa to code 1 under the current climate and the A2 future climate scenarios. The graph shows the result that the yearly cooling load with the retrofitted code 1 under the current climate range from 1200 kWh in January to a high cooling load of 6800 kWh in August but with the future climate A2 scenario in 2080, the apex cooling load of 8400 kWh is achieved in August and a trough of 2000 kWh is attained in February.

Figure 9 shows the total annual cooling energy consumption in the current and future climate periods under different climate change scenarios for the base case villa (in blue) , retrofitted villa to code 1 (in orange) and retrofitted villa to the standard of the code 2 (in grey). It is shown that applying code 1 to the existing villa has achieved a high reduction in the total annual cooling demands with a rate of 38% calculated. The saving rate in the total annual cooling requirements by applying code 2 to the base case villa is approximately the same level as applying code 2 as it achieved 40 %. As it can be seen, the 2% difference in cooling energy savings from code 2 and code 1 is negligible. As mentioned previously by Saudi Energy Efficiency Centre (SEEC), this code is expected to achieve 30-40% energy reduction in the residential sector. This prediction meets the results of this study that shows 40 % reduction in the total annual cooling loads for the base case villa by applying code 2. Therefore, applying code 2 to this housing type (villa) which represent one fifth of the overall total number of the residential buildings in KSA can improve the energy performance and reduce the consumption of energy in the building sector in Saudi Arabia. As figure 7 shows, A2 is the worst scenario. However, this is due to abnormally high temperatures. Based on the climate condition from the current climate to 2050 (A2 scenario), the most consumed energy of annual cooling for the retrofitted villa to code 1 is being increased at a rate of 23 %. While over the climate change from the current to 2080, this increase will reach at a rate of 38%.



(a)



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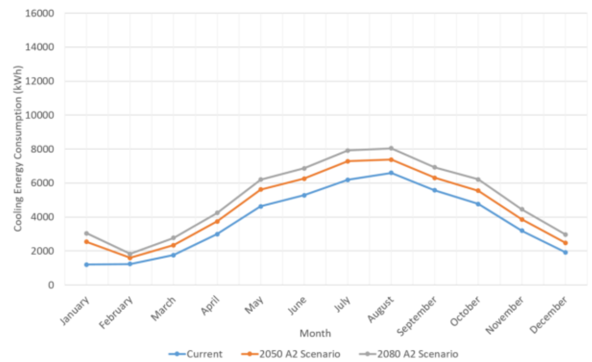

(c)

Figure 8: the changes in monthly cooling energy consumption for the base case villa (a), code 1 villa (b) and code 2 villa (c) under the current climate and future climate change (A2 scenario).

In general, the results indicate that the global warming will negatively cause an impact on the demand of the total electricity. This is based on the changing the climate producing a rise in the cooling energy demand. As a result, applying code 1 can nullify the effects of the future climate changes in the 2080s. This is so due to the total annual cooling energy consumption for the code 1 retrofitted house not being as high as the cooling energy use for the base case villa under the current climate. The outcome of applying code 1 for the base case villa is considered as a major contribution by reducing the cooling energy consumption and combating the effects climate change.

4. CONCLUSION

This study investigated the effects of applying the Saudi residential building`s energy code for a detached single-family house (villa) located in Jeddah, Saudi Arabia. Also, this study aimed to see how the code would perform under the current climate and future climate change scenarios. The software DesignBuilder was used for this study as a simulation and investigatory tool to principally assess the performance of the residential building's energy code under future climate change senarios. It is clear that the base case existing villa specification will not be able to tackle the effects of future global warming as cooling is the main worry due to the harsh weather conditions in Saudi Arabia. Administering the Saudi Residential buildings energy standards to the existing villa attained a high reduction in the total annual cooling demands equalling to 38%. Applying code 1 can minimize the effects of future climate changes. However, there is still an increase in cooling energy demand due to climate change.

Further studies are required to improve the current code by using the code 1 and code 2 as a base case. Also, more investigative and passive strategies that are not included in the Saudi Residential buildings energy code for different climate zones in Saudi Arabia in order to neutralize the effects of future climate change should be considered in future analyses.

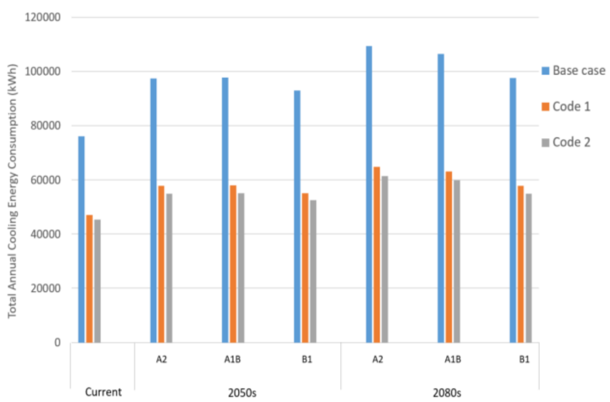

Figure 9: the total annual cooling energy consumption in the current and future climate periods under different climate change scenarios for the base case villa, retrofitted villa to code 1 and code 2.

REFERENCES

[1] M. Abdul and O. S. Alshamrani, "Prospects of energy conservation and management in buildings – The Saudi Arabian scenario versus global trends," vol. 58, pp. 1647–1663, 2016.

[2] N. Al-Tamimi, "A state-of-the-art review of the sustainability and energy efficiency of buildings in Saudi Arabia," *Energy Effic.*, 2017.

[3] Saudi Energy and Efficiency Center, "Building energy sector." [Online]. Available: http://www.seec.gov.sa/en/buildings-en. [Accessed: 19-Nov-2017].

[4] "Electricity Cogeneration Regulatory Authority, KSA ,Annual statistical booklet for electricity & seawater desalination industries," 2016.

[5] F. Alrashed and M. Asif, "Analysis of critical climate related factors for the application of zero-energy homes in Saudi Arabia," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1395–1403, 2015.

[6] M. Almazroui, M. Nazrul Islam, H. Athar, P. D. Jones, and M. A. Rahman, "Recent climate change in the Arabian Peninsula: Annual rainfall and temperature analysis of Saudi Arabia for 1978-2009," *Int. J. Climatol.*, vol. 32, no. 6, pp. 953–966, 2012.

[7] N. A. Aldossary, Y. Rezgui, and A. Kwan, "Domestic energy consumption patterns in a hot and humid climate: A multiple-case study analysis," *Appl. Energy*, vol. 114, pp. 353–365, 2014.

[8] K. T. Huang and R. L. Hwang, "Future trends of residential building cooling energy and passive adaptation measures to counteract climate change: The case of Taiwan," *Appl. Energy*, vol. 184, pp. 1230–1240, 2016.

[9] H. Radhi, "Evaluating the potential impact of global warming on the UAE residential buildings - A contribution to reduce the CO2 emissions," *Build. Environ.*, vol. 44, no. 12, pp. 2451–2462, 2009.

[10] S. L. Wong, K. K. W. Wan, D. H. W. Li, and J. C. Lam, "Impact of climate change on residential building envelope cooling loads in subtropical climates," *Energy Build.*, vol. 42, no. 11, pp. 2098–2103, 2010.

[11] X. Wang, D. Chen, and Z. Ren, "Assessment of climate change impact on residential building heating and cooling energy requirement in Australia," *Build. Environ.*, vol. 45, no. 7, pp. 1663–1682, 2010.

[12] "The General Population and Housing Census | General Authority for Statistics KSA." [Online]. Available: https://www.stats.gov.sa/en/13. [Accessed: 18-Oct-2017].

[13] M. Alhashmi *et al.*, "Energy Efficiency and Global Warming Potential in the Residential Sector : Comparative Evaluation of Canada and Saudi Arabia," vol. 23, no. 3, pp. 1–12, 2017.

[14] "Meteonorm," 2017. [Online]. Available: http://www.meteonorm.com/. [Accessed: 11-May-2017].

[15] H. M. Taleb, "Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U . A . E . buildings," *Front. Archit. Res.*, vol. 3, no. 2, pp. 154–165, 2014.

[16] A. H. Monawar, "A Study of Energy Conservation in the Existing Apartment Buildings in Makkah Region , Saudi Arabia," *PhD Thesis, Sch. Archit. Plan. Landscape, Univ. Newcastle upon Tyne, United Kingdom.*, 2001.