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## Sensitivity energy analysis for the Saudi residential buildings envelope codes under future climate change scenarios: the case for the hot and humid region in Jeddah

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# Sensitivity energy analysis for the Saudi residential buildings envelope codes under future climate change scenarios: the case for the hot and humid region in Jeddah

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**Abstract.** The residential building sector of the Kingdom of Saudi Arabia (KSA) is the primary consumer of energy consumption, using around 50% of the total amount of electricity KSA generates. Much of this is caused by the heavy demand for air conditioning due to the extremely high temperatures in the country. On the basis of KSA's government initiatives, it is compulsory that new residential buildings adhere to strict energy codes. This study places its focus on analysing the ability of KSA's new residential building envelope codes to successfully function according to the climate at present and in the future. In Jeddah, KSA, two single-family villas were examined with DesignBuilder simulation software and impacts of the new codes that were applied were assessed. Achieving the validation of the energy model requires the measurement of temperature indoors and outdoors. In addition, a long-term financial study was conducted to analyse the economic feasibility of the codes under the current and future climate change periods. Although the study shows the new codes produce a reduction in energy consumption by 14% to 40 % from the current cases, with the inclusion of wall and roof insulation being the most effective features of the new requirements of the codes. However, these codes cannot nullify the effect of future climate change.

## 1. Introduction

### 1.1. Background and context.

The Kingdom of Saudi Arabia (KSA) exclusively depends on natural gas and oil as primary sources of energy, as over half a million barrels of oil are used on a daily basis to provide electricity for the country [1]. In just the space of the year 2014, KSA saw an increase of 7.3% in oil consumption, and their rank changed to the eighth largest consumer of oil in the world because it domestically uses 25% of the crude oil and natural gas that it produces [2]. KSA has a population of 30.7 million people, 2 million km<sup>2</sup> in area and 15.3 persons per square km density. It is also one of the fastest growing countries in the world and has 6.8% economic rate of growth per year [3]. There is therefore speedy expansion, urbanization and developmental growth within the construction industry allowing the standard of living to be fulfilled in a population that is growing alongside its demand.

Owing to its dependence on air conditioning, as well as the hot and dry climate of KSA, the building sector has been a significant contributor to the demand for energy. The building sector use up to 75% of the entire provision of electricity in KSA, and this grows every year at a rate of 7% [4]. Between the various type of buildings, 50% of the total use of electricity in the country is by the residential building sector, 70% of the entire national electrical demand is consumed by air conditioning [5].



In light of this issue, various researchers have shown that implementing an energy code and standard can perform a significant role in improving the energy efficiency in [1]. To respond to the issue of high consumption of energy caused by the building sector's expansion, the government in Saudi Arabia initiated Royal Decree No.6927 in 2012. This stated that thermal insulation is required throughout the building sector and was introduced to improve the energy efficiency of buildings. The analysis and description of the Saudi residential buildings envelope codes were described in an earlier paper [6].

### 1.2. Climate change in KSA.

In relation to KSA, one study suggested that owing to current trends, by 2041 Saudi's average warming will grow higher than the global average of [7]. Moreover, according to the study by Almazroui et al. (2012), Saudi Arabia's temperature will grow at a 0.72°C rate in mean temperature every decade. By 2050, a rise in temperature at a rate between 2.0–2.75°C was predicted [8]. The domestic building sector will therefore need to tackle substantial challenges regarding climate change in the future.

### 1.3. Research Objectives.

The main objectives of this study are following:

- To assess the capability of existing air-conditioned houses and newly built to the new residential building's envelope codes in the hot climate of KSA to perform under the current and the future climate change with the focus on energy usage.
- To examine how financially feasible the codes are for the long term with regards to the uncertain nature of climate change in the future.

## 2. Methodology

### 2.1. Case studies.

To assess the performance of the envelope codes for residential buildings, two detached single-family houses (villas) located in Jeddah city were chosen for this research, as shown in figure 1. These houses were chosen as a representation of Jeddah's mainstream domestic buildings. To ensure an acceptable level of representation of Saudi Arabia's typical, middle class residential buildings, both houses are in different locations and have varying building forms, architectural designs, building orientations, opening sizes, thermal insulation levels and number of inhabitants. This type of housing (villa) represents 20% of the number of total housing in KSA [9]. The house built first in 2008 before the code's announcement will be recognized as House A within this study. House B was built in 2015 after the code introduced. However, House B did not meet the requirements of the code because the code was not fully enforced. The full analysis of the study of House A can be seen in a previous paper [6] and an identical approach was conducted for House B. The general information and construction details of House B are shown in table 1.

**Table 1.** Characteristics of House B

	Construction
Total area	327.92 m <sup>2</sup>
External walls	Mortar (20 mm) + Siporex block (200 mm) + mortar (20 mm)
Roofs	Terrazzo tiles (25 mm) + mortar (25 mm) + bitumen layer (4 mm) + expanded polystyrene (50 mm) + reinforced concrete (150 mm) + mortar (20 mm)
Window glazing	6mm/6mm Air double clear glazing, with 5.01 % window to wall ratio
Occupancy	0.0183 person/m <sup>2</sup>

## 2.2. Modelling.

The use of DesignBuilder simulation software as investigatory method is to principally assess the performance of the residential buildings' envelope code under future climate change. Three-dimensional models for the two buildings were constructed based on the architectural drawings using DesignBuilder simulation software. Based on physical site visits and survey, the buildings characteristics including construction materials, cooling system types, lights and installed appliances of the physical villas were applied and modelled in DesignBuilder with occupancy behaviour and activity profile.

## 2.3. Models validations.

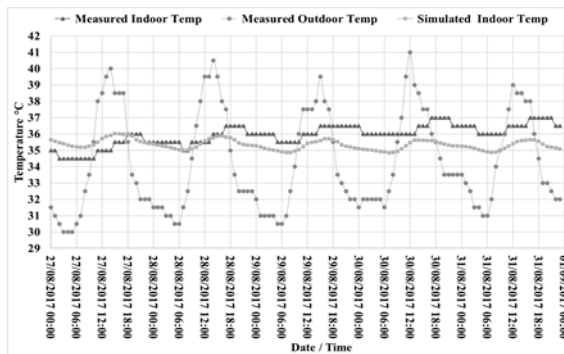
The DesignBuilder models were validated with real measurements from the buildings using iButton dataloggers (DS1921H-F5 Thermochron) for interior rooms and ibutton dataloggers (DS1923-F5# Hygrochron) for exterior conditions, as described by Abuhussain et al. [6]. The procedure of taking field measurements was initiated in June 2017 and concluded in August 2017. The research's intention behind using this period of time was due to the fact that these three months in summer are the hottest of the year, therefore air conditioner use is at its peak. In addition to the replicated buildings characteristics in the models for the empirical validation, the monthly average ground temperature was inserted in DesignBuilder and this was obtained from a previous study which conducted field measurements to record the actual ground temperatures at various depths in Jeddah city [10]. The monitoring process also aimed to observe and extract the schedule and the occupancy of the house within this three-month period. The weather data files that were used for calibration derived from hourly observations recorded at each location for each building. Depicted by figure 2 is the hourly comparison of actual measured data and results calculated by the DesignBuilder of the living room in House B for five days whilst building was free running.



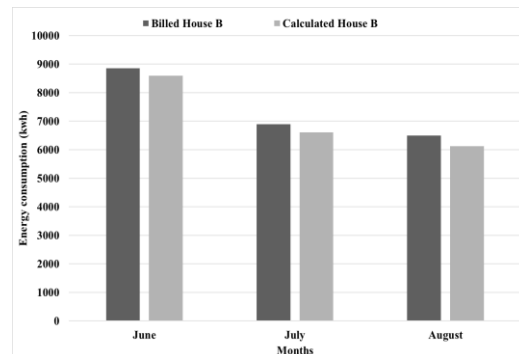
**Figure 1.** Buildings under study.

Additionally, the bill for electricity consumption per month and the villa's reports were acquired from the Saudi Electricity Company. The daily schedule of lighting, air conditioning, equipment, and occupant habits were observed and obtained from the monitoring process throughout the three-month period. A comparison of actual energy usage and that calculated by DesignBuilder are shown in figure 3 for House B. The highest energy consumption for the two houses is occurred due to requiring more energy to cool the interior through the summer. However, although House B is smaller and is better insulated than House A, House B uses as much energy as House A. The reason for this, observed through the monitoring process, was that the actual behaviour of the occupants of House B differs from the

behaviour of the occupants of House A leading to more usage of energy. Moreover, House B was fully occupied but there are some rooms were not used in House A. Having validated the software made it possible to investigate how the Saudi codes might perform in different current and future climate scenarios.



**Figure 2.** Hourly calibration between on-site measured temperature and calculated temperature for living room in house B.



**Figure 3.** Comparison between utility bills consumption and DesignBuilder results for the three months for house B.

#### 2.4. Assessments and simulations process.

To guarantee the constancy of the results of annual simulation analysis, typical daily schedules in KSA for lighting, equipment, cooling, and occupancy were specified from a prior study on energy conservation in residential buildings that exist in the country [11]. Weather data files for the current and future during the periods current, 2050 and 2080, as well as scenarios related to greenhouse gas emission, the A2, A1B and B1 of Jeddah were acquired from Meteonorm 7[12]. Table 2 draws a comparison between U-values of house A, B and the current codes which have been studied in this research.

**Table 2.** U-values (W/m<sup>2</sup>K) for existing houses and the envelope codes (code1 and 2).

U-Value (W /m <sup>2</sup> K)	House A	House B	Code1	Code2
Roofs	3.40	0.58	0.31	0.20
External walls	1.82	0.68	0.53	0.34
Window glazing	5.71 – SHGC 0.81	3.09 – SHGC 0.7	2.67 – SHGC 0.25	2.67 – SHGC 0.25
WWR %	14.5 %	5.01 %	maximum 25 % of wall for both codes	

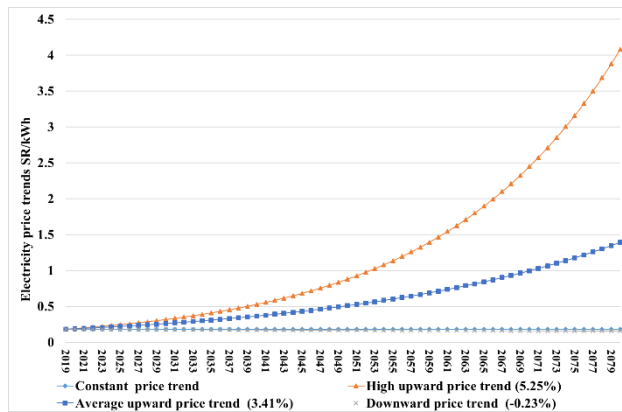
#### 2.5. Financial analysis.

Financial feasibility is among the most important concerns. The initial investment and running cost acted as the primary focus on completion of testing the residential building envelope codes in KSA under present and future climates, because they are of utmost significance when decision makers or people invest and inhabit the buildings. Thus, the emphasis has been placed on energy costs and economic feasibility of the codes for conserving energy in buildings as well as related costs varying from construction to running expenditures. The investigation goes beyond energy use and economic feasibility at present, however it reflects on scenarios in the future and consumption in the long term, due to economic assessment and long-term financial returns.

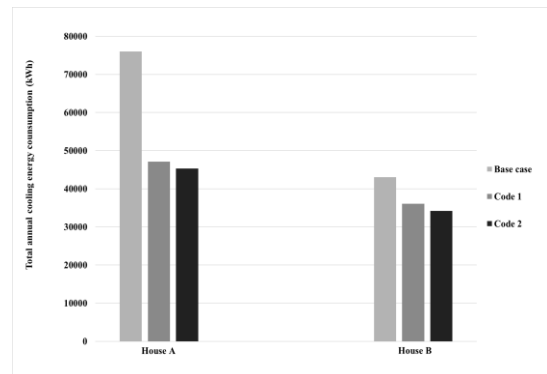
**Table 3.** Total initial costs for existing houses and the retrofitted houses.

Building	Base case initial cost	Code1 initial cost	Code 2 initial cost
House A	SR 81245	SR 124800	SR 136205
House B	SR 74590	SR 91186	SR 107942

**2.5.1. Total initial costs.** For the purpose of this study, the initial costs of the base cases (house A and B) were calculated by Saudi Riyal (SR). Also, the initial costs of improving walls insulation, roofs insulation and window glazing to achieve the codes requirements were calculated. Because of the fluctuation in the prices of thermal insulation and construction materials in KSA to predict the actual cost of constructing buildings, the research evaluated the cost of the construction labour and materials in the present market on the basis of the construction market survey. Table 3 presents the initial total cost of House A and House B, the base case buildings, and retrofitted villas to code 1 and code 2.



**Figure 4.** Predicted possible prices trends for electricity.



**Figure 5.** Total annual cooling energy consumption for the existing houses and retrofitted houses to code 1 and 2.

**2.5.2. Energy running cost.** An electricity consumption tariff was used for the calculation of actual running cost for buildings in the current year. The Saudi Electricity Company's average tariff used for residential buildings is 0.18 SR/kWh of electricity currently [13]. However, to study the financial feasibility of the Saudi codes in the long term over 61 years period from 2019 to 2080, the inflation rate of the energy price is considered in this study since electricity was the only running cost considered in this study, taking into consideration that, the increase in the electricity tariffs (the removal of subsidies by the government) will reflect increased financial benefits from applying code 1 and 2 in favour of this research. The escalation in energy prices is a significant factor to be considered when evaluating energy retrofit projects, as the energy price increase can be deemed an example of the rate of inflation.[14]. Four scenarios were chosen for future electricity prices to depict the uncertainty around the cost of electricity during the forecasting period on the basis of prior historical data provided by the Saudi Arabian Monetary Authority on the yearly percentage fluctuation of inflation rate over the previous 9 years between 2009-2018 in KSA [15]. In relation to prior data on inflation rates during these years,, this study considered high upward price scenario referred to the highest annual percentage variation of inflation with a rate of 5.25%, and the average upward price trend referred to annual percentage variation with a rate of 3.41%, and downward price trend referred to the lowest annual percentage variation of inflation with a rate of -0.23%. In addition, this study also considered a fourth scenario in which the price of electricity would be constant. Figure 4 illustrates the prediction of different electricity prices scenarios in each year up to 2080. To calculate the future yearly electricity price (FC), the present cost of electricity (PC) and the inflation rate ( $\lambda$ ) over a life time (N) are required for the equation as follows [14]:  $FC = PC (1 + \lambda)^N$

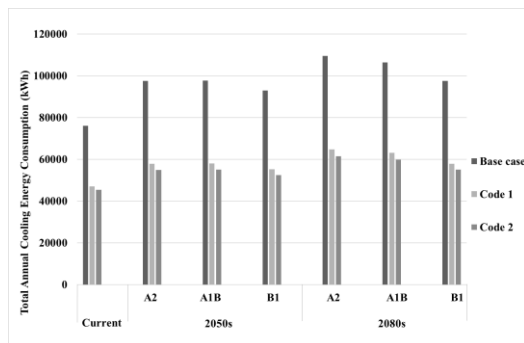
### 3. Results and discussion

#### 3.1. Effect of applying the Saudi residential building envelope codes to the villas for current climate conditions.

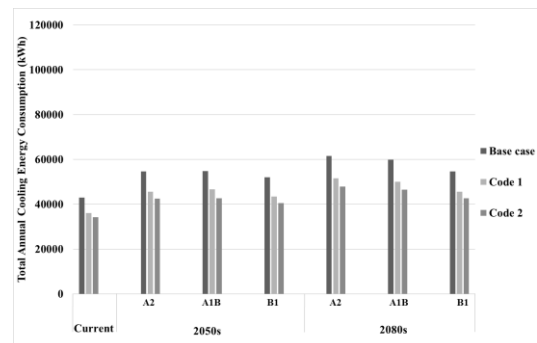
Figure 5 shows the total annual cooling energy consumption for the existing Houses A and B and the retrofitted houses to code 1 and code 2 under the current climate of Jeddah. It has been demonstrated

that applying code 1 and 2 to House A accomplished a significantly high reduction in the total annual cooling demands at respective rates of 38% and 40%. Meanwhile implementing code 1 and code 2 to House B as it stands meant that saving rates seen by reduction of total annual cooling requirements at just 16% and 20%. As has been shown, the difference of 2-4% in energy savings from code 1 and code 2 in both houses is negligible.

As mentioned by SEEC (Saudi Energy Efficiency Centre), this code has an expectation to deliver a reduction in energy of around 30-40% when implemented in the residential sector [4]. This estimation fulfils the results of this research which presents a reduction of 40% in the total annual cooling loads in base case A with the implementation of code 2. This finding is attributed to the fact that low insulation levels for walls and roofs and single glazed windows with high window to wall ratio of 14.5 %. However, the low rate of energy savings in the total cooling of 17% by applying code 2 to the base case B is due to relatively low window to wall ratio of 5%, double glazed windows and relatively low U-Values for external walls and roofs. As a result, implementing both codes to house B has a lower effect. based on the simulations performed, considerable reductions in energy seem to be accomplished already by retrofitting the villas to the standard of the new code. This shows how the standard for this type of housing in KSA can enhance the energy performance as well as minimize energy consumption in new builds of the residential building sector in the country.



**Figure 6.** The total annual cooling energy consumption in the current and future climate periods under different climate change scenarios for the base case villa A, retrofitted villa A to code 1 and 2.



**Figure 7.** The total annual cooling energy consumption in the current and future climate periods under different climate change scenarios for the base case villa B, retrofitted villa B to code 1 and 2.

### 3.2. The potential impacts of the future climate change scenarios on the base case villas and retrofitted villas to the Saudi Residential codes.

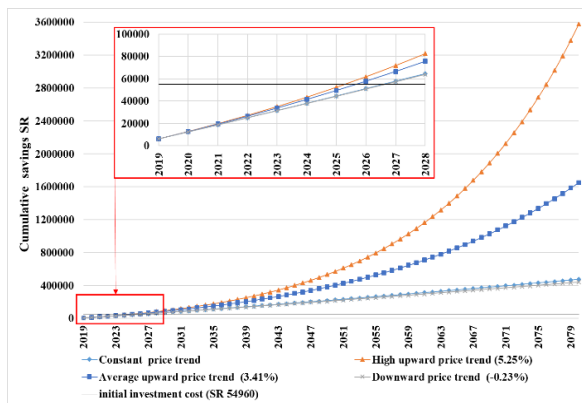
Figures 6 and 7 show the total annual cooling energy consumption for house A and B in the current and future climate periods (2050s and 2080s) under different climate change scenarios (A1, A2 and B1) for the base case villas, retrofitted villas to code 1 and retrofitted villas to the standard of the code 2. With the future climate data, the cooling demand for the base A rises sharply at a rate between 28% to 44% in 2080s depending on the future scenarios, whereas, for the retrofitted building A to code 2, this increase percentage falls in 2080s to 22-36%. Similarly, for base B but less severe increase of cooling energy consumption could reach 27% to 43%, and for the retrofitted B to code 2 to 24-40%. It can be seen that the total cooling energy consumption for the retrofitted houses to code 1 and 2 in the 2080s will still be lower than the levels of cooling consumption with existing houses under the current climate.

### 3.3. Payback Analysis and Feasibility Study

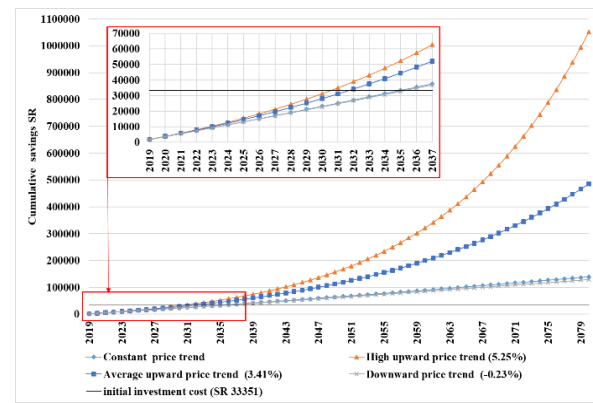
3.3.1. *House A.* Figure 8 showing the cumulative cash flow that results from the electricity saving and the time required to recover initial costs of investment of applying code 2 to house A with constant, growing and decreasing electricity prices over 61 years for A2 climate scenario. The figure of (SR 54960) shows the initial investment cost of applying code 2 construction with corresponding accumulated saving in the electricity cost yearly. The cumulative saving flow of the retrofitted house to

code 2 for various electricity prices trends shows that the payback time from electricity bill saving by improving wall and roof insulation and glazing to the standard of code 2 will be 7 to 8 years with all electricity future prices scenarios.

3.3.2. *House B.* The same assumptions for different electricity prices were made to observe the cost benefits of applying code 2 to the house B. By applying code 2 to the base case of house B, figure 9 shows that for this case the number of years needed to regain the investment on construction (SR 33351) will be 11 to 12 years alongside high and average upward prices and realistically may pay back after 16 years if the prices of electricity fall or remain constant. As a result, there will be a positive effect on the annual savings of electricity bill after 11 years, which will be even more beneficial due to the high upward price trend of electricity.



**Figure 8.** Cumulative yearly saving of applying code 2 to house A for current and future A2 climate scenario for different electricity prices.



**Figure 9.** Cumulative yearly saving of applying code 2 to house B for current and future A2 climate scenario for different electricity prices.

#### 4. Conclusions

This paper investigated the effectiveness of applying the Saudi residential buildings envelope codes for two detached single-family houses (villas) located in hot and humid climate Jeddah, KSA. Also, this paper has examined the potential impacts of future climate change scenarios on the existing houses and the retrofitted houses to the codes. DesignBuilder was the software used as the tool for investigating primarily the energy performance of the two buildings and that of the residential building envelope code in KSA under scenarios in the future climate change. Additionally, a financial assessment on the basis of results by the simulation was conducted in order to examine the financial feasibility of the codes in the long term while considering the uncertainty around climate change in the future. It becomes evident that the base case villas that were studied will not be able to tackle the impact of global warming in the future, with cooling being the main concern owing to the severe weather conditions in the country. Applying the standards by codes for residential buildings in existing villas caused a decrease in the total yearly consumption of cooling energy by a rate of 40 and 17% and can also reduce the impact of climate change in the future. However, there is still a rise in demand for cooling energy because of climate change. It is likely that global warming will cause an increase in the amount of electricity used in residential buildings for cooling in 2080s by 22-36%. Further research is necessary to enhance the current code by using codes 1 and 2 as a base case. A more thorough and passive strategy needs to be considered in future analysis, as they are not a part of the residential building envelope codes in KSA for various climate zones to neutralize the effects of climate change in the future.

Comparing the initial cost construction of applying code 1 and 2 to the base cases of house A and B was undertaken. Accordingly, based on the different future electricity prices, energy costs were calculated for the base case houses and for the retrofitted houses. It can be concluded that the payback periods to recover the initial investment and the financial benefits of applying the codes is very dependent on the growth of the energy prices and that energy prices are unpredictable. The most favourable electricity bill savings occurred by imposing the high upward rising prices which this gave a



payback time of less than 13 years for all houses. There are low electricity bills, seeing as the current average price of electricity is low, thus there is no motivation towards consumption habits becoming more rationalize. Furthermore, the low cost of bills does not encourage higher investment into the efficiency of energy, and new houses are seen as more favourable to renovating old ones. As a result of this, this study explains that if the cost of electricity rapidly increases further, over the period of study, the payback time to regain earlier investment of implementing the code in residential building envelopes will be lower and the economic benefits reaped from savings on electricity cost will be deemed more favourable.

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