Adapting Traditional Passive Strategies within Contemporary House to Decrease High energy consumption Impact in Nejd Region, Saudi Arabia

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Abstract. Saudi Arabia has been identified by the Intergovernmental Panel on Climate Change (IPCC) as one of the strongest warming projected regions which indicates a serious future impact if no radical change is made in energy consumption [1]. The Saudi Electricity Company indicated that electricity consumption for 2017 is 204,597 GW [2]. Residential buildings have used 55% of the annual energy consumed in Saudi Arabia [3]. Therefore, this research aims to investigate the efforts that can be made to reduce this extreme consumption of energy by using simple traditional design techniques that were used in traditional buildings in the Nejd region, Saudi Arabia. The Nejd region was chosen because it represents the majority of Saudi’s topography and weather, and is recognized as the largest region in the country with the biggest population size [4]. Two houses were monitored during the summer of 2018. One represents a traditional old house while the other represents a contemporary house built by the Ministry of Housing (M.of.H) in Riyadh City. The two case studies provided valuable data for further analysis as the architectural design for the houses were analysed to distinguish the architectural features and weaknesses. Two models for the two cases were created using DesignBuilder and validated against measured data. The computational models were then used for dynamic thermal simulation, and used to estimate the energy consumption for the selected cases. The integrated passive strategies in traditional house were analysed, and compared it with a contemporary house. The result shows a 52.3% differences in annual energy consumption between the traditional house with contemporary house. In addition, the simulation result illustrates a 24.3% reduction in the annual energy consumption for the contemporary house is achieved by applying the passive strategies to the house design.

1. Introduction
Saudi Arabia recognises the issues surrounding energy sustainability caused by the drastic rise in energy demand over the last ten years. There has been an increasing in electricity demand in Saudi Arabia leading to a consumption of approximately 9.2 kilowatt hours per year per capita in 2015, while it was approximately 7.7 kilowatt hours per year in 2010. Currently, residential buildings consume 55% of the total national energy consumption [3]. The residential building sector’s energy consumption will continue to increase, and statistics imply that 70% of current construction projects being carried out currently are linked to housing [6], Saudi Arabia’s residential buildings use an excessive amount of electrical energy, even more so throughout summer when approximately 60% of energy consumed is due to air conditioning [7]. Adding to the seriousness of this problem the Ministry of Housing in KSA is working to establish 781,636 residential units which will be completed in 2020 [8]. To fulfill increasing demands, the Saudi government is planning to expand the capacity of electric generation from 55GW to 120GW by 2020. This will be the Middle East’s greatest increase of electricity generation [9]. Responding to the high energy consumption crisis causing the building
sector’s substantial growth, another initiative was introduced in 2012, the Royal Decree no.6927 and it introduced a minimal standard for thermal insulation in every building sector, to enhance the efficiency of energy in buildings. In 2017, the building code in Saudi was designed to be more efficient[10].

The rapid increase in usage of heating and cooling systems in buildings had numerous disadvantages as well as higher consumption of energy, including a growth in peak electricity demand, indoor air quality problems and more significantly, environmental problems like ozone depletion and global warming [7]. Consequently, alternative solutions were presented to eliminate or lower usage of systems for conventional mechanical heating and cooling. For the study presented in this paper, five traditional passive strategies were investigated to assess their effectiveness in reducing the energy consumption in a traditional house, and evaluated their negative and positive impact on the energy consumption for contemporary houses in Saudi Arabia. The five strategies are: window to wall ratio, exterior wall thermal mass, shading device, ceiling height, and the inclusion of greenery spaces.

2. Literature Review
Many researchers have shown that implementing an energy code and standard can perform a significant role in improving the energy efficiency in buildings. The Saudi government recent initiative has been the basis of an obligatory building code for new build residential buildings. It was established to minimise energy consumption as of January 2017. According to the SEEC (Saudi Energy Efficiency Centre), a reduction of 30-40% of energy has been expected to be accomplished in the residential sector [12].

Table 1 explains the building code requirements for the thermal building envelope. The building code’s effect on energy consumption was tested by Mohammed Abuhussain on a typical house in the city of Jeddah [10]. The study concluded that by adhering to the building code, the existing villa accomplished a significant calculated reduction of 40% from the annual total of cooling demand. Abuhussain advised that further passive strategies to be included in the energy code for residential buildings in varying climate zones of Saudi so that the effects of potential climate change can be neutralised.

Table 1: Building code requirement for the thermal transmittance (U-Values) for low-rise / residential buildings

| Opaque Elements          | Climate Zone 1 (Riyadh, Jeddah, Dammam cities) | Climate Zone 2 (Ha’il, Tabuk cities) | Climate Zone 3 (Asir City) |
|--------------------------|-----------------------------------------------|-------------------------------------|---------------------------|
| Roof                     | 0.31                                          | 0.37                                | 0.42                      |
| Exterior Walls           | 0.53                                          | 0.61                                | 0.7                       |
| Opaque Doors – All       | 2.84                                          | 2.84                                | 2.84                      |
| Assemblies               |                                               |                                     |                           |
| Vertical Glazing, 25% of wall |                                               |                                     |                           |
| All Assemblies           | 2.67                                          | 2.67                                | 2.67                      |
| SHGC - 0.25              |                                               | SHGC - 0.25                         | SHGC - 0.25               |
| SHGC - 0.35              |                                               | SHGC - 0.35                         | SHGC - 0.35               |

Other studies concentrated on the theoretical aspect of traditional building characteristics. For example, Farzaneh Soflaei studied architectural features in the Iranian traditional central courtyard [14]. The study illustrated the analysis of the environmental physics for central courtyards which cover four important aspects. The dimension and orientation of the courtyard perform a significant role for maximising radiation during the cold seasons towards passive heating as well as daylighting, including maximum amiable airflow for natural ventilation and passive cooling for indoor areas were possible throughout the warmer seasons. On the other hand, Albert Malama studied the thermal performance of traditional and contemporary housing in the cool season of Zambia. The statistics of the research on the traditional house show they are more uncomfortable in the cooler seasons as compared to the contemporary house.
Traditional buildings with passive strategies in Saudi Arabia were not involved in saving energy consumption strategies, and there is no study that researches the difference between the energy consumption in traditional and contemporary building. Therefore, this paper aims to bridge this gap and take advantage of traditional passive strategies in new contemporary houses.

3. Methodology
In order to distinguish the traditional passive strategies and draw comparisons between traditional and contemporary houses, two typical traditional and contemporary houses located in Riyadh city were selected for this study. Riyadh city is the capital of Saudi Arabia, and it has the highest population in the country, which increases the demand on the residential facilities [4]. The first case study is on a traditional house located in the Aldhoo neighbourhood, one of the most traditional areas in the centre of Riyadh city which received special attention from the Riyadh Development Authority. The second case is a contemporary house that was built by M.of.H in Al-Uyaynah, Riyadh city, and it was completed in April 2018. On-site measurements for both cases were collected including exterior and interior temperature, exterior and interior humidity, wind speed and direction, and solar radiation. It is important to mention that data collection was based on climate analysis that was conducted in August, which is a favourable period as the hottest month in 2018. This data was validated by using a simulation software program, DesignBuilder. 3D models were built based on architectural and constructional drawings for both houses. The drawings and data were obtained from three sources: (i) review of building drawing filed with projects’ consulters, (ii) site visits to buildings under construction, (iii) informal interviews with contractors. The energy consumption for cooling and heating systems was calculated using the temperature data collected. In addition, standard Saudi family occupancy was taken into consideration for energy analysis[16].

Traditional passive strategies have been investigated in order to see the negative and positive impact on energy consumption in the traditional and M.of.H houses. This study applies to the contemporary house features and compares them to the traditional building to investigate the size of the negative impact. Five passive strategies were investigated in the two types of houses. The passive strategies include window to wall ratio, walls and window shading device, height ceiling, thermal mass, and outside green area.

3.1. Case Studies

3.1.1. Contemporary House (M.of.H House)
In 2018, 12161 houses were built by M.of.H in Saudi Arabia which represent the typical contemporary house for a single Saudi family. According to Opoku and Abdul-Muhmin, 40% of the residential building stock is classified as single family house [17]. As a result, enhancing the energy performance in this form of residential buildings can positively reduce the overall energy consumption in Saudi Arabia’s building sector.

The total land area for this house is 500 m², and it comprises of two storeys with 272 m² total building area. This house was designed to inhabit 6 people. M.of.H projects were built by using a concrete construction system with adherence to the minimum standard amount of thermal insulation. Ground floor, intermediate floor, roof, interior walls, and exterior walls construction and thermal insulation details were illustrated in Table 2. However, the architectural drawing clarifies that environmental effects have not been taken in to consideration when buildings are designed.

3.1.2. Traditional House
The traditional house with one central courtyard is the most popular traditional house type in the Middle East. The courtyard is the main element that all spaces connect with directly. Therefore, most of the house opens (windows and doors) are directed to the courtyard which contains 15.1% of the total land area. The total land area is 155 m2, and the total building area is 270 m².

The Riyadh Development Authority and the General Authority for Tourism and National Heritage (SAUDI) are very careful about the architectural sensitivity of traditional houses. Therefore,
the house has been renovated with the same original natural materials that were used in the original building with minor additions of artificial material used to protect and preserve the natural materials and the building’s construction (Table 2). Clay block, mud plaster, and Athl joist (local tree trunk) are the main construction element that distinguished the traditional house in Saudi Arabia. Interestingly, the building property of traditional house is compatible with the new Saudi Building Code requirements. The building envelope insulation fulfils the new Saudi building code requirements which has a significant impact on the current and future climate [10].

Table 2: Specification of M.of.H and traditional Buildings’ Materials and Their Thermal Properties.

| Categories       | M.of.H House (Contemporary House) | Traditional House |
|------------------|-----------------------------------|------------------|
| Thickness (m)    | U-value (W/m²-K)                  | Thickness (m)    | U-value (W/m²-K) |
| Ground floor     | 0.29                              | 0.30             |
| Exterior walls   | 0.25                              | 0.57             |
| Interior walls   | 0.25                              | 0.42             |
| Intermediate floor | 0.36                           | 0.50             |
| Roof             | 0.48                              | 0.67             |

3.2. Modeling validation

3.2.1. On site measurement & Simulation tools
In order to collect weather data for the selected case, iButtons data loggers (DS1921H-F5 Thermochron) were used in 5-6 of the most important spaces such as bedrooms, living room, and kitchen for collecting hourly interior temperature data. The loggers were installed in constant positions that were distant from any heat source. Davis weather station (Pro2) was used to collect hourly exterior weather data. Weather stations rose 2m from the rooftop with a custom stainless steel stand to prevent any outside climate obstacles (Figure 1). It’s important to mention that all data loggers were tested in closed room in the basement of the architecture school building at university of Liverpool to calibrate the accuracy of the loggers’ reading. The result illustrated a good agreement between the data loggers’ records.

3.2.2. Validation
To examine the different options for energy efficiency, baseline energy for the traditional house and the M.of.H house were developed, to identify the passive strategies which could be implemented on the residential building in Saudi Arabia. Using the architectural drawings with DesignBuilder software (version 5.0.1) a 3D model for a standard villa was developed as depicted in Figure 2. A validated computer model has been used to principally assess the energy consumption for different types of residential building in Riyadh.

Figure 1: Equipment used for on-site measurements

Figure 2: 3D model for selected cases

Figure 3 depicts the result of hourly temperature calibrations between the actual interior temperature affected by architectural characteristics for measured rooms. The software temperature calibration gave near identical result with a 1.02% average difference for five spaces during a one-month period.
According to Abuhussain the researcher can consider the model to be valid as long as the difference between simulated and measured results is less than 5% [10].

Figure 4 illustrated the hourly temperature calibration between the on-site measured and DesignBuilder simulation results for room 2 in the traditional house. The validation result gave a 3.16% average difference for six spaces during a one-month period. The actual reading for interior temperature was affected by airflow inside the room because the windows and doors were open. The airflow is fluctuated from room to other, and this was caused by opening size and direction. That means the interior temperature was affected by the exterior temperature when the natural wind passes through the building’s openings which increases the amount of airflow’s velocity.

3.3. Energy consumption evaluation

In order to calculate the cooling and heating annual energy consumption, EnergyPlus has been chosen to demonstrate the analysis for the whole-building energy simulation. EnergyPlus is a relatively straightforward simulation program which does not require extensive time to perform simulations. It has a user-friendly interface. For this study, four aspects were considered to assume a close result of actual energy consumption which are: building occupancy, energy use, HVAC system, and AC set point. The first aspect is the building’s occupancy information which describes Saudi’s standard number of family members and behaviour. Jubran Alshahrani found that 45% of Saudi families have up to 5-6 members [16]. In addition, Alshahrani described Saudi family behaviour and energy use which are important aspects of energy consumption. Six different zones are examined to study the energy used and people’s habits of consumption in the sleeping zone, kitchen zone, dining zone, living zone, family zone, and guest zone. The third aspect is the HVAC system, which is the window AC, and is requested by the Ministry of Housing for such houses in the specification sheet for M.of.H projects. Significantly, the AC has a cooling set point of 25.5°C and a heating set point of 20°C base on the minimum requirement in the new Saudi building code [18].

3.4. Assessment process for traditional passive strategies

3.4.1. Assessment of passive strategies in contemporary house

The traditional construction and design techniques applied to the contemporary house were inspired form the traditional house. The additional design characteristics are described in the following:

- Window to wall ratio is an important variable affecting energy performance in residential buildings in a hot, dry climate. The ratio was decreased from 6.5% to 2.5%, and the window size became 0.5m X 1m.
- The overhang shading was added to shade the windows and solid walls. The vertical shading extends 1.6m overhang which is 50% of the ceiling height. This percentage was determined from the traditional cloister extension into the courtyard. In the traditional house, the cloister overhangs 1.85m, which is 50% of ceiling height.
Contemporary materials were used on the basis of an Al-Sanea study which advises using melded polystyrene and heavyweight concrete blocks [19], the exterior walls are to be of thermal mass, and the wall thickness should be increased from 0.25 m to 0.4 m. This suggestion gave the contemporary house similar thermal mass properties to the traditional house.

The green area covered all of the threshold between the edges of the house and the fence. This addition was inspired by the main function of courtyard, which is expected to have a direct impact into the ground temperature. A recent study conducted by Limor Shashua demonstrated that landscape decreased 4°C of the ground temperature [20].

4. Result and Discussion

4.1. Energy consumption

4.1.1. Contemporary House (M.of.H House)
The study results indicate that the average annual energy consumption of the typical M.of.H House is approximately 31800 kWh. It is axiomatic that cooling accounts for 93.8% of total energy consumption especially in a hot dry city like the Alyuaynah region. An extremely hot summer requires 5655 kWh in August alone when the outside temperature reaches 43.7°C. On the other hand, the heating system needs 1960 kWh a year which is 6.2% of the of annual total energy consumption.

4.1.2. Traditional House
The study results indicate that the average annual energy consumption of the typical traditional house is approximately 15155 KWh, despite the temperatures in the Riyadh region reaching 48.7°C, which is 5°C more than the Alyuaynah region. The cooling system requires about 13215 Kwh, which is 87.2% of the total energy consumption, and heating takes up 12.8% of total annual energy consumption which is around 1940 KWh.

4.2. traditional passive Strategies
As can be seen in Figure 10, during hot summer months, the traditional house requires less cooling energy than the contemporary house. It is apparent that passive cooling strategies reduced the cooling loads for the traditional building in comparison to the modern building, which has been built without consideration for passive techniques. By referring to the simulation results, the traditional passive cooling strategies can provide significant reduction to cooling energy consumption for M.of.H housing in Riyadh. The M.of.H Houses consume approximately 52.3% more energy than the traditional house, although the traditional house is located in a relatively hotter climate (Figure 5). Furthermore, the research established the impact of passive strategies on the traditional house design by including characteristics of the contemporary house in the design. A rise of 85.7% total cooling energy use and total annual cooling compared to the base case was shown in the results (Figure 6).
Since the construction and design concepts of traditional and modern houses are completely different, the energy consumption in these houses are also different. The objective of this research is to demonstrate the significant impact of traditional passive cooling strategies into M.of.H contemporary houses. The energy saving that were achieved by additional traditional design technique, is explained in the following:

- The simulation result shows roughly 5.4% saving of the total annual cooling energy consumption by decreasing 4% of base case’s window to wall ratio.
- The overhang shading for windows and solid walls, achieved 4.8% reduction in cooling annual loads.
- The thermal mass technique saved approximately 7.4% of the annual cooling and heating energy consumption.
- The exploitation of the open green areas around the house has a significant impact on annual energy demand with a reduction of 12.4% of total annual cooling energy demand.

Traditional passive strategies improved the energy efficiency for the contemporary house by reducing the total annual cooling energy demand by approximately 29%. Figure 7 shows that 24.3% reduction in the annual cooling and heating energy consumption for the contemporary house is achieved by adding the traditional passive techniques to the house design.

The effectiveness of applying passive cooling techniques was negative on the performance of the improved case during the winter season, where the total annual heating energy consumption was increased by 58%. This is linked to two main reasons including minimizing direct solar radiation, and decreasing the ground temperature. However, this only represents 5.7% of total annual energy consumption for improved case.

High ceiling technique was neglected of traditional passive techniques included in the analysis of this study. It was found that raising the height of the ceiling will increase cooling loads by roughly 23% due to the increase of the space volume. However, this strategy could provide further energy reduction during natural ventilation modes.

**Figure 7:** the different between the annual cooling and heating energy consumption for M.of.H house with five passive strategies.

**Key:** BC (Base case), HC (Ceiling Height), WW (Window to wall ratio), shading (shading device), T.M (thermal mass), G.A (Green area), PS (Passive strategies case)

**5. Conclusion and recommendation**

In Saudi Arabia, contemporary residential buildings significantly contribute to high demands of electrical energy. Specifically, energy consumption is caused by space cooling, with summer time being a major cause of peak demand and therefore high levels of electricity consumption. In this paper, five traditional passive strategies are investigated to assess their effectiveness in reducing the
energy consumption in contemporary Saudi houses. The simulation results show that traditional houses without passive strategies request double energy consumption. In addition, the effectiveness of these strategies has been investigated and analysed to reduce the cooling and heating energy demand of M.of.H residential buildings. The five evaluated traditional passive techniques include window to wall ratio, walls and window shading device, height ceiling, thermal mass, and outside green area. These five techniques are attempted in traditional and contemporary houses. It was found that traditional passive techniques can achieve a significant reduction in cooling and heating energy use for a typical residential building located in Riyadh with a rate of 28.7% for the annual cooling demand and with 24.3% from the total annual energy consumption. The results of this study fulfil the aim of the new 2030 vision of Saudi Arabia by reducing the total energy demand for the residential sector in the country.

One of the limitations of this study is the parametric analysis for traditional passive strategies to distinguish the optimum design solution that is compatible with a contemporary house in Saudi Arabia. In addition, other design principles in a traditional house such as central courtyard should be studied to investigate their ability to implement these techniques in a future version of contemporary houses in Saudi Arabia.

6. References

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