Research Article

Greening Strategies for Improving Existing Residential Buildings' Performance in Bahrain's Tropical Desert Climate

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Abstract: *Bahrain's tropical desert climate significantly challenges existing buildings' energy efficiency and indoor comfort. The residential sector in Bahrain consumes up to 48% of national energy production. Cooling accounts for up to 80% of domestic energy use. Moreover, existing buildings require envelope renovation, and one of the least intrusive methods is greening strategies. The study's main objective is to assess the impact of retrofitting greening strategies on energy consumption and specify its optimum configuration. Simulations through DesignBuilder were conducted to model a typical housing unit in Bahrain. Results indicated that greening provides effective protection from solar radiation and reduces solar heat gains through building envelopes. Furthermore, the configuration of the green roof combined with the South and West green walls offered the best results in limiting indoor cooling energy demand. Findings suggest that retrofitting existing residential units could significantly reduce cooling loads and, therefore, reduce energy consumption.*

Keywords: *Building performance, Energy efficiency, Greening Strategies, Sustainable Building, Retrofitting.*

Bahreyn'in Tropikal Çöl İkliminde Mevcut Konut Binalarının Performansını İyileştirmek İçin Yeşillendirme Stratejileri

Özet: *Bahreyn'in tropikal çöl iklimi, mevcut binaların enerji verimliliğini ve iç mekan konforunu önemli ölçüde zorlamaktadır. Bahreyn'deki konut sektörü, ulusal enerji üretiminin %48'ine kadarını tüketmektedir. Soğutma, evsel enerji kullanımının %80'ine kadarını oluşturmaktadır. Ayrıca, mevcut binalar zarf yenilemesi gerektirmektedir ve en az müdahaleci yöntemlerden biri yeşillendirme stratejileridir. Çalışmanın temel amacı, yeşillendirme stratejilerinin enerji tüketimi üzerindeki etkisini değerlendirmek ve optimum yapılandırmasını belirlemektir. Bahreyn'deki tipik bir konut birimini modellemek için DesignBuilder aracılığıyla simülasyonlar yürütülmüştür. Sonuçlar, yeşillendirmenin güneş radyasyonuna karşı etkili koruma sağladığını ve bina zarfları yoluyla güneş ısısı kazanımlarını azalttığını göstermiştir. Dahası, yeşil çatının Güney ve Batı yeşil duvarlarıyla birleştirilmesi, iç mekân soğutma enerjisi talebini sınırlamada en iyi sonuçları sunmuştur. Bulgular, mevcut konut birimlerinin yeniden donatılmasının soğutma yüklerini önemli ölçüde azaltabileceğini ve dolayısıyla enerji tüketimini azaltabileceğini göstermektedir.*

Anahtar kelimeler: *Bina performansı, Enerji verimliliği, Yeşillendirme stratejileri, Sürdürülebilir bina, Yenileme.*

1.INTRODUCTION

Energy consumption for buildings has become more relevant due to the increase in population. With the increase of average temperature of about 1.1 ºC, this could lead to increased cooling demand in buildings. The main driver for the increase in average air temperature is the rate of Green House Gas (GHG) Emissions, mainly CO_2 [1] the reliance on fossil fuels for energy generation is a main contributor to CO_2 emissions and therefore, emissions would be limited if energy generation is reduced. Currently, buildings consume up to 40% of total global energy generated, specifically in the MENA region where energy is generated from fossil fuels this leads to increased CO_2 Emissions. Moreover, several studies have noted that the average energy consumption in the MENA region is higher than average [2, 3, 4] or when compared with buildings in Europe. In the GCC region the demand for cooling load is the main contributor for elevated energy consumption [5]. This could be addressed by improving the efficiency of buildings but then even with reduced consumption relying on fossil fuel energy would still contribute to CO_2 Emissions and therefore energy generation should be implemented. Recently, Net Zero Energy Buildings has been gaining interest in literature and seems like a strategy that might improve both building efficiency and buildings' reliance on fossil fuels for energy [3, 4, 6].

Passive Strategies

Buildings' envelope determines the ability or the extent to which a building is able to resist the harsh atmosphere conditions surrounding it without requiring any energy or mechanical instruments. for example [3] discusses the potential for NZEB and near Zero Energy Buildings (nZEB) in the MENA region and discovered that the regulations and standards for buildings require an overhaul in order to improve the buildings' efficiency, for example air infiltration rates should be limited to 1.2ACH, walls should have a U-value of 0.17 $W/m^2.C$ to reach nZEB standard. Moreover, building envelope resistance to heat exchange (U-value) is a main factor in its efficiency and therefore should be carefully considered. The building envelope includes Walls, Roofs and Windows. The efficiency of the materials is measured by their rate of heat exchange (U-value) [7], [8]. In a recent study in Riyadh, KSA, [4] studied an existing 3 story 597m^2 residential unit and found that walls have a U-value of 0.8 $W/m^2.K$, Windows have a U-value of 1.7 $W/m^2.K$ with window to wall ratio (WWR) of 5% and roof and were able to achieve net zero energy through changing the HVAC system and relying on solar power generation. On the other hand, [3] discovered that walls and roofs would require a minimum U-value of 0.17 $W/m^2.C$ and 0.11 $W/m^2.C$ for a building to reach the status of a near Zero Energy Building (nZEB). In addition to construction materials, other methods can be employed to improve the passive abilities of buildings, for example through increasing the albedo, i.e the solar reflection of the buildings' exterior. This can be achieved through using cool materials, green walls, green roofs or even utilising shading [9]. Moreover, cool materials offer a reflectivity of 50% or higher, allowing for lower absorption of solar energy, in comparison to typical building materials might have a reflectivity of 5%, introducing cool materials could reduce surface temperatures by 10ºC [10]. Green walls and roofs also serve as a great solution for passive insulation, when compared to typical roofs covered with bitumen and have a potential to reduce solar energy absorption due to its high reflectivity 70-85%[11], however, green roofs and walls should be carefully planned and studied to ensure its effective with present climate, [12] demonstrated that green roofs and walls effectiveness is more significant in hot and dry conditions. Another study displayed high potential using green walls with reductions in heat gains up to 97% (west orientation) and a reduction in heat loss about 30% [13]. However, greening for both walls and roofs has shown an increase of relative humidity for both indoors and outdoors, [14] investigated the impacts of green walls in a tropical climate setting and discovered that even though it resulted in a reduction in the air and surface temperatures, the green wall cased an elevation in indoor humidity by approx. 43%. On the contrary, in Daemei's experiment [15], they tested a green wall and measured data for both indoors and outdoors, while outdoors experienced an incremental increase in relative humidity, the indoors experience a 32% reduction in relative humidity. This most likely means that the results could depend on the climate of the location. Although passive strategies massively improve buildings' abilities to withstand weather conditions, indoor climate systems are essential for creating a pleasant environment for residents and users, that is why mechanical cooling/heating is important for every building since around 60-70% of building energy [5] consumption goes for HVAC, mainly efficient systems are able to provide a higher output compared to its energy input.

Active Strategies

Maintaining a pleasant indoor environment is essential and therefore, heating, air ventilation and conditioning (HVAC) is utilised. In colder climates heating is the main requirement for pleasant indoors while in warmer climates cooling through air conditioning is provided. The term active strategies are quite broad and include numerous mechanical systems and instruments and since the focus here is on the GCC region, only cooling systems will be discussed in this review. Several studies explored the potential colling instrument appropriate in terms of efficiency in the GCC region, [4] compared a ground heat pump (GHP) to a one package HVAC system and found that even though a GHP costs twice as much it offers savings up to 52% in input power. Also, the GHP shows potential in reducing CO_2 emissions to about half, reducing noise, it seems the only downside is the initial cost of the system. Moreover, other systems were explored by [3] for MENA region and concluded that a Heat Pump System. Split Air Conditioning and High Package Terminal Acs all pose as a potential solution towards NZEB and nZEB buildings.

Energy Generation

In the kingdom of Bahrain, Photovoltaics (PV) are the best option due to the abundance of solar radiation. Moreover, other methods such as wind turbines were considered, but are not fully feasible in Bahrain due to low wind speeds, vibrations generated on site [16]. Moreover, PV panels with a size of 7.8kW would be feasible and can produce up to 12,500 kWh annually [17]. Lastly, other literature also tested the potential of the T8 unit for solar power generation and also concluded that covering the roof of the residential unit would produce up to 12,500kWh per year [18].

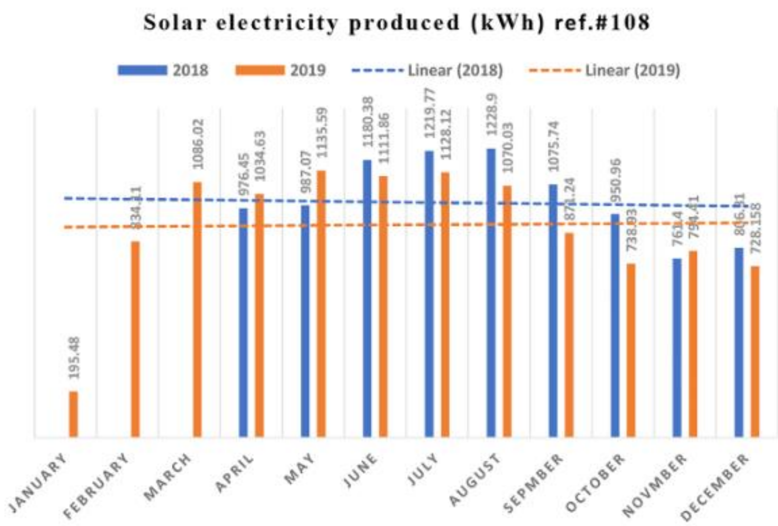

Figure 1. Energy Generation for two years of a 7.8kW solar PV system in Bahrain [17]

Energy Consumption

Currently about 50% of the total global population are living in urban areas and this is projected to increase in 2050 to 68%, the increase in population also leads to an increased demand for energy and more specifically in economies relying on fossil fuels this also leads to elevated GHG emissions [19]. Moreover, oil and gas account for 80% in terms of energy generation further increasing the need for alternatives [20].

The residential and commercial sectors, both account for 50 – 65% of total energy consumption globally while also contributing to about 60% of CO_2 emissions [21] and from the global GHG emissions this accounted for 28%, almost a third of global emissions from other sectors such as industry, transport and construction [22]. Furthermore, [3] estimated the normalized residential building consumption and found that in Bahrain a residential building would require 281 kWh/m^2 annually and this is considered high when compared to the Association of Heating, Ventilation and Refrigeration Engineers (ASHRAE) 90.1 code for efficient energy which for Bahrain would be 87 kWh/m^2 annually. On the other hand, in another study it was found that residential units in the kingdom of Bahrain reach an annual normalized consumption between 70-85 kWh/m^2 [5], this could indicate that some data available may not be very accurate and requires more investigation. Moreover, in Europe, countries introduced targets in order to limit energy consumption for example, Spain with 120 kWh/m^2 annually, Romania 120-140 kWh/m^2 annually with the intent to even reduce these values more in the future for nZEB implementation [23].

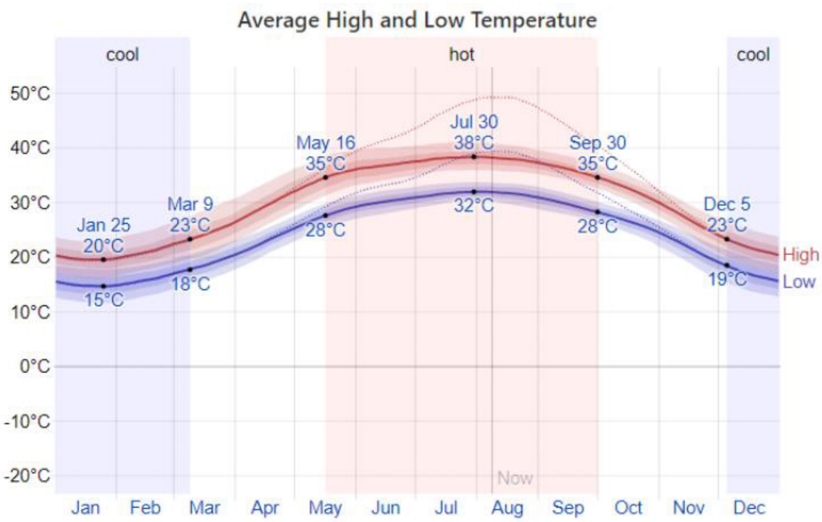

Figure 2. Bahrain annual weather [26]

Bahrain Climate

The Kingdom of Bahrain is an archipelago of 51 natural islands and 33 artificial islands, with Bahrain being the largest island, the total area of the kingdom is 780 km^2 [24]. The Kingdom of Bahrain is situated near the east coast of the Kingdom of Saudi Arabia between a Latitude and longitude of 25° 30' 26° 20' N and 50° 20' – 50° 50' E, respectively. On average the warm season lasts for 4.5 months from the month of May to September with the average high temperature reaching 35°C and average low being 32°C. The cool season only lasts for 3 months with an average daily high under 23°C. Rainfall is often recorded to occur between October and April with most of the rainy days taking place during January with a high rainfall average of 11mm. Humidity levels are high on average with the muggier period lasting up to 7.5 months, from April to November reaching above 75% on some days during August [25]. The warmest month during the year is July, with the average high being 38°C and average low at 32°C [26].

Energy Consumption in Bahrain

For the case of the Kingdom of Bahrain, most of the energy is consumed by the residential sector, according to the pie chart below (Figure 3) [27], 48% of total energy consumption in the Kingdom, including the industrial sector [28]. These numbers are also supported by the annual Electricity and Water Authority (EWA) report, with the latest consumption by sector indicates that domestic consumption in 2022 accounted for 8,733 GWh out of total consumption by all sectors of 18,293 GWh which equals 47.7% (Figure 4), [29]. Furthermore, Energy consumption in the residential sector is mainly the result of high cooling demand, with cooling degree days (CDD) value of between 3,200 – 3,600ºC annually [5],[27]. This indicates that cooling is essential, and therefore a considerable portion of domestic energy consumption could be attributed to cooling demand. Moreover, in two studies it was found that the cooling demand and reliance on air conditioning for residential buildings in Bahrain accounted between 71-80% of total energy consumption [27], [5], both simulations and collected energy bills has shown very similar data, more importantly the peak in energy demand is reached during the summer season which further indicates that cooling is main the contributor to high energy consumption. Figure 4 below shows consumption by sector has increased by 6.5% between 2018 and 2022 1.8% annually.

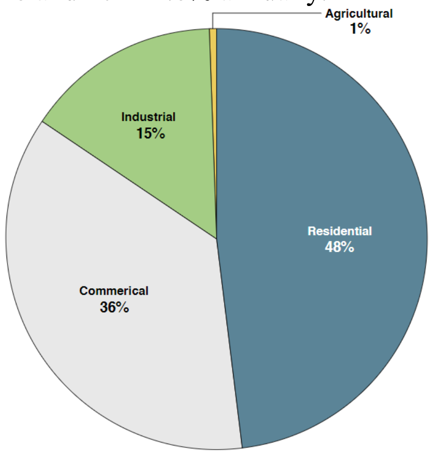

Figure 3. Energy consumption of different sectors in Bahrain [27]

Net Zero Energy Buildings (NZEB)

According to [30] net zero energy is achieved by reaching the highest energy efficiency via implanting renewable energy generation on site. Therefore, this process is done on two levels, first, through the reduction of energy consumption (passive strategies) and second by offsetting the energy consumed through site generated energy (active strategies). Moreover, NZEB encapsulates many challenges that have to be addressed in order to achieve the desired outcome, first, the building envelope, second, indoor climate control systems for cooling and heating (HVAC), third, energy generation systems, and fourth, automation systems for buildings [31]. Furthermore, NZEB is beneficial on three main levels, economic, environmental and social. Economically, it can offer better efficiency and therefore offer savings in energy consumption, reduce maintenance costs due to high efficiency and offer better resale value due to the aforementioned benefits [32]. Environmentally, NZE buildings offer superior insulation and air tightness, better indoor air quality and improved heat gain/loss and a reduced carbon footprint by reducing its loads and therefore reduces its reliance on fossil fuel generated electricity [33]. Lastly, on a social level, NZEB has potential to involve residents in the decision-making process and have the residents completely aware of the maintenance process [34]. Potentially, NZEB buildings could pose as a solution for energy consumption, however, it is important to optimize buildings' performance through passive strategies as much as possible and therefore such strategies should be studied. Achieving NZE for residential buildings in the region has been shown to be feasible [4]. However, the suggested values for walls and roofs in the studies do not seem to be feasible or might prove to be very expensive to implement, currently, the Kingdom of Bahrain regulations suggest walls and roofs to have a U-value of 0.57 W/m^{2}C and 0.3 W/m^{2}C. Furthermore, the energy generation seems to be much more feasible with estimated generation of 12,500 kWh for a single story house in Bahrain. This review aims to shed light on the potential of NZEB buildings in Bahrain of which data shows it can pose as an effective strategy in limiting the domestic energy consumption while achieving to reach Bahrain's 2060 carbon neutrality goals [2]. According to reviewed literature, many factors dictate the efficiency of building performance, more specifically the potential of greening strategies in reducing cooling demand in the region is limited but shows a lot of promise in other international studies. In theory green walls and roofs might greatly reduce solar loads on building envelopes while offering a cost effective solution for new and existing buildings [35]. points out that energy retrofitting existing buildings could be the best approach in reducing energy consumption.

المجموع Total	زراعي Agricultural	صناعي Industrial	تجاري Commercial	منزلي Domestic	السنة Year
17,321	62	2,786	6,307	8,166	2018
17,027	60	2,769	6,515	7,683	2019
16,520	74	2,354	5,631	8,461	2020
18,019	64	2,891	6,487	8,577	2021
18,293	56	2,919	6,585	8,733	2022

Figure 4. Annual Energy Consumption report from 2018 - 2022 [29]

Figure 5. Requirements for NZEB Residential Building [6]

2.METHOD

2.1. Study Design and Setting

For this study, a typical residential unit called the T8 unit was selected. The unit selected for the study is a typical housing unit offered the Ministry of Housing in the Kingdom of Bahrain, called the T8 Unit. This unit has been used in various residential cities such as Arad, AlBusaiteen, Askar, AlBurhama, West Riffa and 9 more cities. This residential unit was designed to house a family of 5 members. The villa's area is 209m^2 and includes two living rooms, kitchen, 3 bedrooms and 4 bathrooms [36]. Such residential units finished in 2015, follows thermal insulation regulations pre 2019, which states that maximum allowed u-values for walls and roofs are 0.75 and 0.6 W/m^{2}C, respectively. These values concerning the building envelope directly impacts cooling demand of indoor spaces and therefore amending the envelope with greening strategies might offer benefits for reducing cooling demand of existing buildings in the Kingdom of Bahrain. A common method for studying buildings' performance is through running computer simulations on a 3D model of said building. Through the reviewed literature, methods were summarized along with applicable parameters from each software. Moreover, Designbuilder was selected mainly for its reliance on EnergyPlus calculations and high level of detail when it comes to modifying material properties, occupancy schedules, HVAC systems efficiency, lighting loads and more. Table 1 below shows a summary of similar studies methods. The building digital 3D model will be created based on the provided technical plans. Then, the building envelope material properties are entered into the simulation in addition to the weather data file for the climate. Data for power generation for the same model is gathered and validated from available literature. The simulation will be broken into two phases. First phase will provide information regarding the typical housing unit (T8) and establish a base line for the comparative analysis. The second phase will include several simulations for different configurations of green strategies for walls. Finally, data is comparatively analysed to evaluate the benefits of green walls. Below (Figure 6) is an illustration for the process and integration of data. Regarding energy consumption, a schedule was placed for the occupancy of the residential unit. Specific times for sleeping, using the living room and kitchen. It is worth noting that many appliances were not accounted for and the schedule proposed is based on personal experiences with family life in the Kingdom of Bahrain. moreover, the proposed schedule took into account workdays and weekends, for example, accounting for extra sleep hours, late hours in the living rooms or additional hours for the majlis where family visit occur during weekends. These schedules are essential in terms of determining cooling demand, since every occupied space is air conditioned except for Bathrooms. HVAC in the residential unit is present in the form of Split Air Conditioning units, installed wherever needed (Bedrooms, Living rooms and Kitchen). For this model, the efficiency of Acs was considered, based on the year the units were built Electricity and Water Authority (EWA) had not enforced any regulations in terms of power consumption. Therefore, the coefficient of performance (COP) for the units were kept as default in the software at 1.8. It is worth noting that COP of split air conditioning units are available in the kingdom with a higher COP after enforcing new laws in 2017 [37]. Greening solutions offer the ability to cover existing structures and according to available literature provides protection against solar radiation and heat, specifically in regions with high global solar radiation due to its shading ability and evapotranspiration [38], [39]. Due to the limited time to conduct this study, the best performing solutions from available literature were selected for this study. It was decided to select an extensive green roof system and for walls a modular green wall system due to its ability to be applied on top of the outer layer of the walls and high insulation properties [40], [41]. Table 2 in the next page summarizes each configuration with corresponding model properties. Baseline is a typical residential unit without any alterations, while others will have some level of treatment either for roof only, walls only, or both walls and roofs.

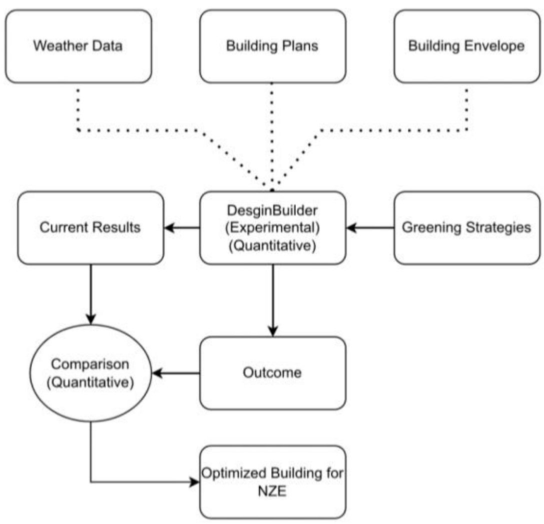

Figure 6. Simulation process for the T8 unit.

Table 1. Analysis of Methods, tools and outcomes for the reviewed literature.

Author	Method	Tool	Parameters	Outcome	Research Methodology
(Al-Saeed and Ahmed, 2018)	Simulation	• BIM Revit via Insight 360	• Building Envelope • WWR • Window type • Potential PV gen • HVAC System & Operation • Appliance Efficiency • Air Infiltration	• Guidelines for future regulations and values for insulation based on normalized consumption	• Experimental • Quantitative
(Ismaeil and Sobaih, 2023)	Simulation	• Hourly Analysis Program (HAP) Pvsyst V7.1.0 Software	• Building Envelope • WWR • Window type • Potential PV gen • HVAC System & Operation for a GHP system. • Appliance Efficiency • Air Infiltration	• Guidelines for installing dual renewable energy systems (GHP and PV) for residential units in KSA.	• Experimental • Quantitative
(Daemei, et al., 2021)	Field Measurement Simulation	• EnergyPlus • Artificial Neural Network • Envi-met • Data Logger	• Outdoor Air Temperature for green and non-green walls • Indoor Air Temperature for green and non-green walls • Indoor Relative Humidity • Outdoor Relative Humidity	• Established a predictive model for predicting air temperature around the green wall and validated it.	• Empirical • Quantitative
(Ratih, et al., 2018)	Miniature Model Field Measurement	• Hygrothermo meter (AT, RH) • IR Surface Thermometer. • Environment Tester for Windspeed.	• Surface Temperature (Indoor & Outdoor) • Air Temperature (Indoor & Outdoor) • Relative Humidity (Indoor & Outdoor) • Wind Speed.	• Established the impact of a green system in terms of air temperature, surface temperature and relative humidity in a tropical climate.	• Experimental Quantitative

Table 2. Different configurations for the simulation of green strategies.

Configuration	Walls	Treatment	Roof	Treatment
Baseline	Typical Concrete Wall Sandwich o.75W/m2C	Non	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	None
R	Typical Concrete Wall Sandwich o.75W/m2C	Non	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	Extensive Green Roof 0.57 W/m2C
WR	Typical Concrete Wall Sandwich o.75W/m2C	Modular Green Wall 0.4W/m2C	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	Extensive Green Roof 0.57 W/m2C
SR	Typical Concrete Wall Sandwich o.75W/m2C	Modular Green Wall 0.4W/m2C	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	Extensive Green Roof 0.57 W/m2C
SWR	Typical Concrete Wall Sandwich o.75W/m2C	Modular Green Wall 0.4W/m2C	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	Extensive Green Roof 0.57 W/m2C
NESWR	Typical Concrete Wall Sandwich o.75W/m2C	Modular Green Wall 0.4W/m2C	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	Extensive Green Roof 0.57 W/m2C
NESW	Typical Concrete Wall Sandwich o.75W/m2C	Modular Green Wall 0.4W/m2C	Typical Concrete with Insulation + Water Proofing 0.6W/m2C	None

3.RESULTS & DISCUSSION

Results show that the configuration for greening strategies directly affected its efficiency in reducing the cooling demand. Interestingly, reductions in cooling demand are more noticeable during the summer season. The graph in figure 8 illustrates changes in cooling energy demand of the different scenarios. In the "Roof Only" configuration, cooling demand is almost identical for cool months (Oct-Apr), however, during the summer changes become more apparent but are still negligible with a reduction in cooling demand approximately 0.4%. Moving on, it is obvious that coupling roof and walls yields better results in terms of cooling demand reduction. Even by only combining greening strategies for the roof and the west wall resulted in an 11% reduction in annual cooling demand. Moreover, covering the south wall resulted in even more reductions in cooling demand, up to 14%. Lastly, combining roof with south and west wall resulted in the highest reduction in annual cooling demand with 23% less energy for cooling when compared to the baseline and 10% when compared to roof and south wall configuration.

Furthermore, it seems that the impact of green strategies is amplified during the summer months, table 3 below shows the monthly change in cooling demand for all configurations compared to baseline. The warmest months of the year experience the most reductions. However, during the winter months, the simulation shows negative values, indicating that the models required slightly more cooling (2 to 13%) compared to less insulated configurations. Usually, simulation tends to slightly overestimate cooling for winter months and underestimate cooling in summer which could also indicate higher reductions in a real scenario.

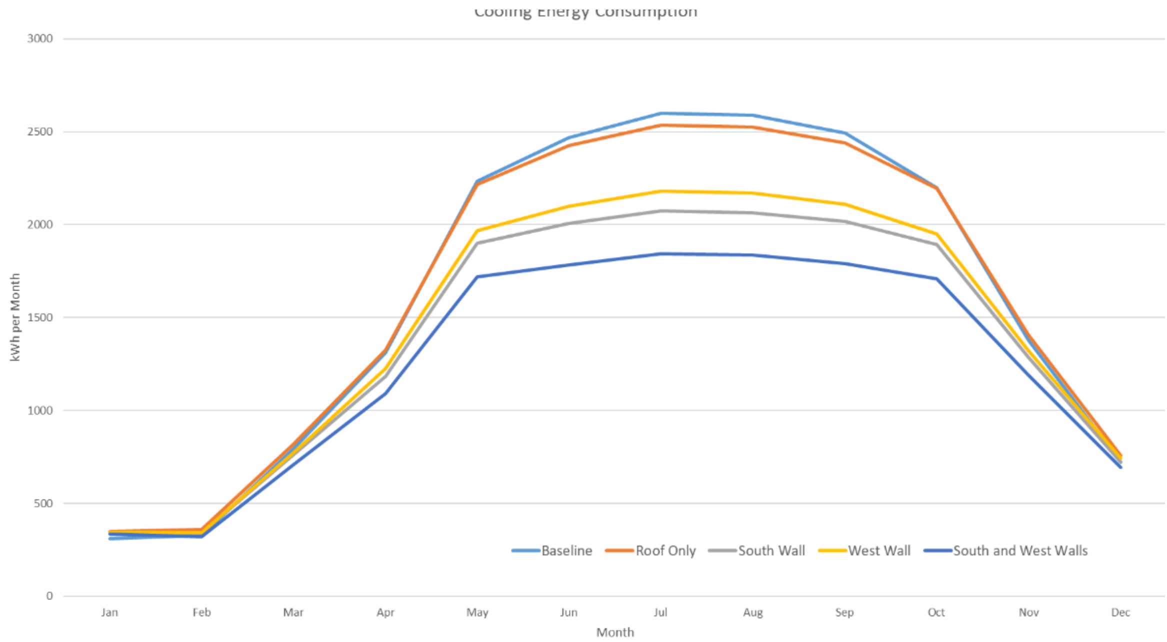

Figure 7. Changes in cooling consumption based on configuration.

The strength of green strategies be it for roofs, walls or both, is that they can be retrofitted onto existing buildings' envelopes. Building envelope is the protective shell separating indoor environment from outdoor climate conditions. Furthermore, greening could be a solution for future improvement of existing buildings, with the goal being reduction in cooling loads. Results have shown that an extensive green roof coupled with a modular green wall covering two orientations could result in 24% savings in terms of cooling energy demand. On the other hand, it must be mentioned that green roof solution may not be the best solution for retrofitting the roof area. Currently, thermal insulation regulations for building roofs in Bahrain require a maximum u-value of 0.3 W/m^2.C, which is much lower than an extensive green roof and should be explored as an option for future studies. Furthermore, for this case, reflective and shading strategies could potentially be more beneficial in terms of roof area, keeping the roof accessible also reserves the potential for future solar PV installation. This aspect should be studied to find the optimal configuration of insulation and green strategies for retrofitting. Also, in terms of greening, numerous benefits were not covered in this study, such as carbon sequestration, contribution to air quality, ability for shading and maintenance could be further explored. Additionally, some literature is available for utilizing artificial green strategies in order to avoid maintenance requirements, but this also nullifies any other environmental benefits [42].

Table 3. Monthly cooling demand for every configuration.

	Config.	Change in cooling load for every configuration compared to Baseline							
Month	**Baseline**		**Change%**	**West Wall kWh**	**Change%**	**South Wall**	**Change%**	**S&W walls**	**Change %**
kWh	Roof		-13%	344.6456	-12%	345.4182	-12%	335.2085	-9%
kWh	Change%	West Wall	-9%	343.4102	-5%	342.3937	-4%	321.0647	2%
kWh	Change%	South Wall	-3%	772.5141	2%	759.1381	4%	707.9501	11%
Jan	308.2658	349.3409	-1%	1224.585	7%	1184.047	10%	1089.224	17%
Feb	328.2057	358.0864	1%	1966.207	12%	1900.37	15%	1719.745	23%
Mar	791.7454	816.4457	2%	2099.537	15%	2005.939	19%	1782.684	28%
Apr	1310.964	1325.004	2%	2180.836	16%	2073.912	20%	1842.484	29%
May	2234.2	2217.535	2%	2171.425	16%	2063.946	20%	1836.73	29%
Jun	2469.649	2425.133	2%	2110.92	15%	2017.467	19%	1789.36	28%
Jul	2600.515	2537.225	0%	1950.122	11%	1891.472	14%	1707.606	22%
Aug	2588.301	2525.85	-2%	1320.376	4%	1287.931	7%	1190.556	14%
Sep	2492.507	2441.63	-5%	741.866	-3%	720.5879	0%	692.3079	4%

Moreover, Configuration SWR shows the best promise offering only three surfaces to be covered while showing low cooling demand relatively. For example, when all walls are treated except for the roof, cooling demand increased by only 9% compared to SWR. Consequently, treating all walls and roof only reduced cooling loads by an additional 1.7% compared to SWR configuration. Figure 8 above illustrates cooling energy consumption for different configurations. Moving on, greening strategies proposed in this study have shown potential for reducing cooling loads. The goal of this study was to evaluate the ability of such strategies in assisting existing residential buildings achieve NZE or nZE. Solar PV system for a similar unit would generate up to 12,500 kWh annually, when this is compared to the best configuration (SWR), solar energy generated annually could cover up to 83% of annual cooling energy demand and 66% of total energy demand. It is worth noting that the model included did not account for retrofitting lighting and new efficient cooling systems, further improving the building cooling system efficiency could immensely reduce energy consumption, it will be definitely explored in the future [39].

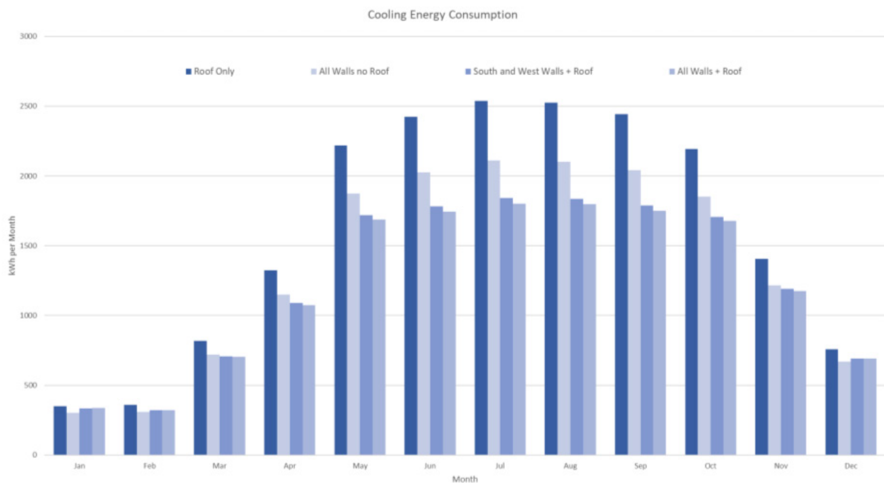

Figure 8. Comparison between monthly cooling energy consumption for worst and best performing configurations.

Table 4. percentage of total energy consumption covered by solar energy generated for every configuration.

Configuration	Annual Cooling Energy kWh	Change %	Generated Power kWh	Energy Offset kWh	Renewable Energy %
Baseline	19422	-	12,500	6922	44.6%
W	19353	0.36%	12,500	6853	45.2%
WR	17226	11.3%	12,500	4726	62.2%
SR	16593	14.6%	12,500	4093	67.3%
SWR	15015	22.7%	12,500	2515	79.9%
NESWR	14759	24.0%	12,500	2259	81.9%
NESW	16368	15.7%	12,500	3868	69.1%

5.CONCLUSION

This study explored the potential for retrofitting green strategies for Bahrain's tropical desert climate, it can be concluded from this study that coupling roof and wall strategies yields better results, specifically when focusing on south and west facades. The study found that when green roofs are coupled with green walls offer benefits in terms of reducing building cooling loads up to 23% which is aligned with findings from similar literature [43]. Such reductions in terms of cooling could prove beneficial in the future for reducing carbon emissions and transitioning into nZE buildings but greening strategies alone does not seem to be sufficient, treatment of other envelope elements like windows and AC systems could elevate the benefits of retrofitting green strategies. On the other hand, maintenance, plant species and environmental impact of greening strategies must be studied for the context of Bahrain, more specifically its impact on outdoor and indoor humidity level. Besides, this study has faced several limitations, such as time frame for running simulations and tests was not sufficient and this study will pose as preliminary research with the ultimate goal being finding the optimum configuration for greening strategies for the Kingdom of Bahrain. Also, this study covered one type of residential unit and more should be explored in the future. Going on, after this study, more comprehensive solutions would be studied, potential of reflective insulation and shading would be explored alongside green strategies.

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