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# The Energy-Saving Potential of a Green Roof on Existing Residential Buildings. A Case Study of Jubail Industrial City, Saudi Arabia.

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**Abstract-**Residential buildings are the major sector in the construction industry that consume energy and affect the whole environment. Controlling these effects has always been the foremost concern, especially the existing ones. This paper addresses a case study of existing residential buildings at Jubail Industrial City in the Kingdom of Saudi Arabia, where the units are reproduced all over the districts.

With proper design and maintenance, green roofs can provide cost-effective and sustainable solutions for existing residential buildings. The best set of strategies through the Climate Consultant software have been studied where the strategy of adding the green roof comes as a priority for the selected city. Green roofs, also known as vegetated roofs or rooftop gardens, offer a wide range of benefits for existing residential buildings. These benefits include improved insulation, reduction of stormwater runoff, increased biodiversity, and improved air quality. In addition, green roofs can also provide aesthetic and recreational benefits for residents. Green roofs can reduce a building's energy consumption, lower urban heat island effects, and extend the roof's life. By using the green roofs suitable type for the existing buildings and simulating the two scenarios for the existing and the proposed cases using the Design Builder software, while using Climate Consultant software recommends strategies, results revealed that the green roof option could reduce the total energy consumption by at least 8.8 %. Besides benefiting the building's users, this approach will provide an economical solution to protect the environment in terms of reducing power consumption and environmental pollution.

**Keywords-** Green roofs, Energy Consumption, Built Environment, Eastern Province, Kingdom of Saudi Arabia.

## I. INTRODUCTION

At the present surging industrial revolution, the exponential rise in population, and consumption of energy resulting in significant damage to the environment. Global rise in the temperature is one of the issues, which results from increased consumption of energy [1]. As a result, researchers are striving to reduce energy consumption and protect the fragile environment. Residential buildings are the major contributor to energy consumption and environmental perturbation globally [2, 3]. Studies were performed to quantify the direct and indirect environmental effects of the operation of various buildings. It is estimated that buildings, in general, consume about 42% of energy and are responsible for 40% of atmospheric emissions [4, 5]. The commercial and residential buildings alone in the USA represent 40% of the annual energy consumption [6]. With the increasing population and rapid urbanization, most of the countries are not able to fulfill the demand of electricity. Therefore, the most popular

scenario is to reduce and conserve energy resources to optimize the utilization of energy and reduce the carbon footprints [7]. The building envelope is one of the major contributors to energy efficiency, which may control the amount of energy required for heating, cooling, ventilation, and natural lighting needs. It is reported that the electricity consumption for air conditioning in the top 20 developed countries are augmented by around 400 TWH during the year 2015 to 2018 [8, 9]. The cumulative impacts of energy consumption in heating and cooling of buildings during their life cycle are appearing in the form of global environmental perturbation. As we generate and consume energy almost for everything during building operations, energy conservation could be one of the smart strategies to reduce global environmental problems [10].

Saudi Arabia is one of the fast-growing countries in the Middle East in terms of its population, economy, and energy structure. In order to fulfill the needs of a rapidly growing population, the Kingdom is investing substantial capital to develop infrastructure and provide needed energy. As a result, the country is facing challenges related to energy, environment, and economic sustainability [11].

Due to the existence in hot and arid region, building sector in Saudi Arabia consumes significant amount of energy for cooling. Saudi Arabia is having higher global per capita energy consumption and carbon dioxide (CO<sub>2</sub>) emission index [12]. In the building sector of Saudi Arabia the air-conditioning consumes roughly 65% of the electrical energy used [13]. Being situated in hot climate region, Saudi Arabia is facing even hotter environment with time. Studies predicting extreme temperature events more frequent in the future [14]. Researchers indicated an increase of 0.65 °C per decade [15]. According to a recent study by Collins et al., Saudi Arabia is likely to encounter an increase in temperature of between 5 and 7 degrees Celsius by the end of the current century [16]. Recent studies reported that the Saudi Arabian's climate is warming up at a rate which is 50% higher than the rest of the continent in the Northern Hemisphere [17].

More than 80% of the total electricity use goes to residential buildings in Saudi Arabia [18]. In general, the building sector in Saudi Arabia classified as less energy efficient which may be attributed to the availability of cheaper electricity, boom in construction area, inadequate awareness of energy-efficient stratagems, and lack of relevant policies as compared to most advanced countries. With the advent of Saudi vision 2030, benefits in the reduction of energy consumption have been incorporated in the countries

plans. It is a promising option as the building sector has the most competency of plummeting energy demand as compared to other sectors. In order to achieve this objective, it is very important to provide efficient design to the building insulations to reduce energy consumption. Particularly the roof of the building is the major component in heat transfer and generally the main source of energy loss. Effective insulation requires appropriate material, suitable design, and skilled workmanship, which ultimately increases the cost of construction.

Applying rooftops with plantation, known as a Green Roof, is an innovative approach, which can improve the energy efficiency of buildings. There are extensive range of sustainability and ecological benefits while adopting green roof options in addition to escalation in the aesthetic value and architectural inspiration of buildings. Therefore, implementation of green roof rather than a conventional roof could improve the energy efficiency of residential buildings [19]. Robustness of green roof and essential need of improving energy efficiency in the country, more research is required to demonstrate the potential and feasibility of green roof implementations in Saudi Arabia especially for residential buildings, which are major part of constructed buildings in the kingdom.

Green roofs research is still limited to a few countries. Almost 66% of total research is done in the USA [20]. Hence, there is a need to study the suitability of this passive technique in other countries like the kingdom of Saudi Arabia (KSA). Prior research is done for a case study for faculty homes built in the university in the eastern province [21]. The outcomes of the investigation indicated that the green roof could reduce energy consumption by 6.7% to 6.8% according to the climatic conditions of Dhahran and Riyadh respectively. Meanwhile, projects are prepared to have a lot of residential buildings all over the Kingdom while adopting typically approved buildings' layouts. These buildings should be treated in a different way to reduce energy consumption and stop global warming as well as the Ozon depletion effects. With the expectation to reach 66% of urban spaces worldwide, due to the population increase, passive strategies including green roofs should extensively studied and applied for current and future buildings [22].

#### A. Green roofs history in Saudi Arabia

Some studies investigated the use of the green rooftop with relation to the type of the final slab and the type of vegetation in residential buildings in different cities of KSA, whether there is air inside it or in case of air absence [23]. Other studies examined the benefits of the green roof existence in mosques allocated in the kingdom [24]. Further studies are still needed, especially for the residential sector.

#### B. Green roofs advantages for climate

There are numerous benefits for using green roofs include storm water retention, reduction of the urban heat island effect, water quality enhancement, energy cost saving, air cleaning, noise drop, ecological benefits, social and economic advantages [20]. All these items are being neglected or not efficiently used in most of the areas in the kingdom. In

addition, vertical farming requires lesser amount of water for growing crops [25, 26]. Although, vertical farms can be established on roofs with larger space employment and efficiency, the rooftop farms are more economical in construction [27]. Schade et al., evaluated the energy performance of a green roof in a sub-arctic climate. Results of the study revealed that the energy benefit of a green roof on a highly insulated building in a subarctic climate is low [28].

One study estimated the reduction of energy in urban built environment and reported that green roofs can reduce a building's cooling energy consumption by 25-50% and heating energy consumption by 10-15% [22]. Another study found that green roofs can reduce summertime cooling energy consumption by up to 75% [29].

#### C. Connection with 2030 vision

Vision 2030 of Saudi Arabia, which is aligned with the United Nations (UN) Agenda 2030, targets the enhancement of the quality of life for everyone. landscaped areas will be developed further, to meet the recreational needs of individuals and families. This will not happen unless the usage of the existing resources including buildings' roofs as essential part for greenery, which eventually can be used as a recreational area for building users [30, 31].

#### D. Problems facing green roofs in the existing residential buildings.

There are many problems concerning the green roofs including, green roof awareness among all stakeholders, a special provision in building regulations for green roofs, long-term environmental consciousness, and subsidized green roof materials cost [32]. All these problems need to be addressed, meanwhile they are connected in a way that user awareness might be the key to starting using such a strategy in the existing and upcoming buildings. Castleton and colleagues in their study concluded that there is strong potential for green roof retrofit in the United Kingdom. Their study confirmed that older buildings with insufficient existing insulation are having lower to benefit from a green roof as present building regulations require higher levels of insulation that green roofs are providing insignificant effect on annual building energy consumption [33]. However, the effect of energy saving increase significantly in the higher temperature climate regions such as in Saudi Arabia.

#### E. Suitable green roof for existing building structure

One of the challenges facing the green roofs implementation is the collaboration between architectural and structural fields where both should cooperate in solving and adopting this passive technique in all building types wherever appropriate. This paper will fill in this gap.

At the residential area of Jubail Industrial city. Various types of residential units are being used. These units are designed based on specifications set by the government and the Saudi building code (SBC). Data was collected for the construction types used in those selected buildings.

The specifications of all exiting construction materials are used as per the requirements of Royal Commission (RC)

engineering department which follows and aligns with the International Building Code (IBC) as shown in Figure 1& Figure 2.

**F. Study aim**

The primary objective of the present study is to evaluate and analyze the effectiveness and potential benefits of incorporating green roofs onto pre-existing residential buildings. The study seeks to investigate the impact of green roofs on various aspects such as energy efficiency, stormwater management, air quality, biodiversity, and overall environmental sustainability. By conducting an in-depth analysis of the data collected from the study, the researchers aim to provide insights and recommendations on the feasibility and implementation of green roofs as a sustainable and eco-friendly solution for urban development.



Figure 3: Residential buildings at Jubail Industrial City selected for present study. Source: researchers

**II. METHODOLOGY**

**A. Building specifications and Simulation Software:**

The objective of current work is to measure the effectiveness of green roofs if added to the existing residential buildings. Hence, a particular residential building, with an area of 1163.89-meter square, in a carefully chosen district of Jubail industrial city, KSA utilized as a case study. The building is repetitive and approved by the royal commission engineering department to be used in all residential districts. The research methodology is qualitative in which, typical residential building is simulated in Design Builder software as a base case and the energy consumption is measured. The two scenarios are implemented and measured after adding the green roof materials to the base case. The results were compared and analyzed accordingly.

Design Builder is a program which can perform building energy simulation and can be used to model the performance of a green roof at various selection of choices. The software allows users to input the specifications of the green roof, such as the type of plants, growing medium, and irrigation system, and then simulates the thermal, lighting, and energy performance of the building with the green roof. The software can also be used to evaluate diverse green roof configurations to conclude the most energy-efficient design. Additionally, it can also simulate and evaluate other sustainable design features such as solar panels, geothermal systems, and more.

In the present work green roof categorized by Morakinvo and coworkers [34] is adopted as it considered the single as well as multi-course extensive layers. In addition to that, it does not require maintenance and regular irrigation. They categorized green roofs in four types, which are intensive with a depth greater than 12 inches, semi-intensive with a depth between 6 and 12 inches, multi-course extensive consist of 4–6 inches substrate thickness, and single-course extensive with substrate thickness 3–4 inches [34]. The last type requires no maintenance and no irrigation as proofed by the report of the United States General Services Administration [35, 36].

An extensive green roof is an example of a naturally occurring, mainly self-sustaining type of vegetation. Clearly, reducing stormwater runoff from buildings at the source is the most cost-effective and sustainable construction [33]. Plants with specialized adaptation to harsh site conditions and

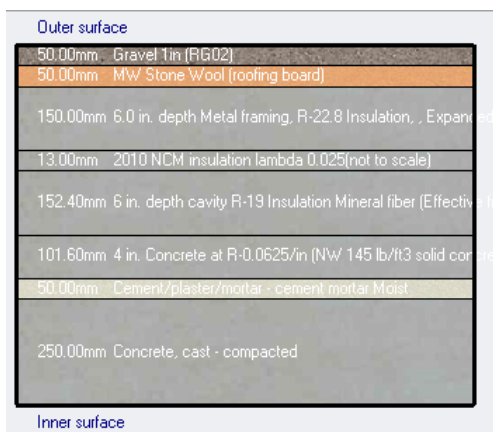


Figure 1: Layers of approved roof top. Source: researchers

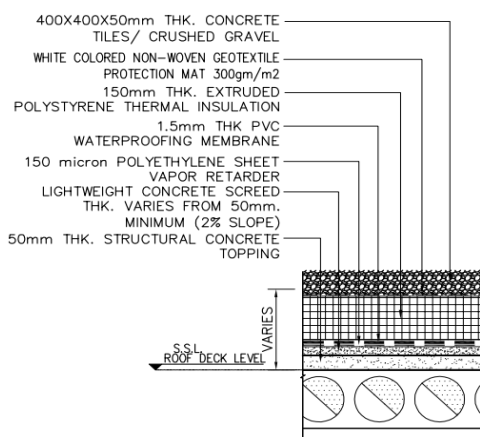


Figure 2: section of roof layers. Source: researchers

As per the International Building Code IBC 2009 section 503 general building heights and area limitation: type IB occupancy group R2 maximum of eleven stories and area per story is unlimited. As per the existing design of buildings in this area, the requirements are met. The building area is 1163.89-meter square, and the building consists of seven floors including the ground floor, refer to Figure 3.

great regeneration potential can be found on a large green roof, refer to Figure 4. Moos, succulents (Sedum), and small herbaceous plants, such as drought-tolerant grasses, are further characteristics. Large-scale green roofs like this one require little upkeep and don't have an irrigation system that is permanently installed because that would be counterproductive. Additionally, extensive green roofs have lesser weight than deeper systems because of the shallow profile they have. The weight ranges from 60-150 kg/m<sup>2</sup> [37].

Extensive green roof is adopted in the simulation model to set the comparison between the base case (existing building) without having a green roof and the model with the green roof existence. The energy consumption in both cases is calculated and compared accordingly. Then the multi-course extensive with 5 inches substrate is simulated as a second scenario.



Figure 4: Zero-Runoff, Sponge City, Green Residential Living: built from 1998-2000 [38].

### B. Simulation Model

The selected building is replicated using Design Builder software with all related information for the base case as mentioned in section 1.5. Then, the two scenarios applied with all needed parameters. Finally, for selected case study Climate Consultant application utilized to come up with the appropriate design strategies considering the climate conditions of Jubail Industrial city throughout the year (January to December).

## III. DISCUSSION/ANALYSIS

This section describes the parameters and data input used in the study including existing material and dimensions. Each building consists of six floors and a ground floor, four residential units on each level where only one entrance exists. The building information is simulated in the program with all the dimensions and the existing data. The ratio of the opening is set to 25% as an average recommended by Qiaoxia Yang [39] for the openings in the residential units in order to get the best energy saving. All the exterior walls are made up of 60 mm-thick precast concrete walls and 100 mm-thick walls at the inner side of exterior walls. A 60 mm-thick thermal insulation material having thermal conductivity of 13 m<sup>2</sup>-K/W is sandwiched between them as per the existing building specifications. The interior walls are painted with emulsion

paint finishes. The wall requirements used in the software as input data are depicted in Figure 5 with needed insulation and existing materials. Details of the wall layers simulated in the Design Builder software also presented in Figure 6. The roof of the building is reinforced cement concrete (RCC) slab.

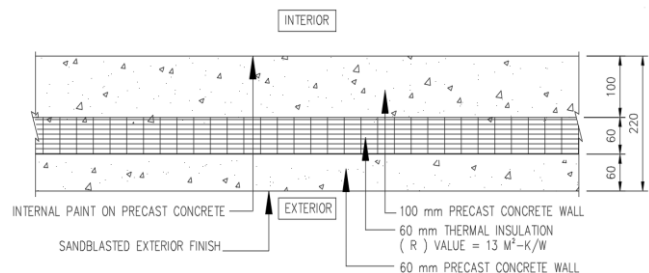


Figure 5: wall layers as per royal commission specifications.

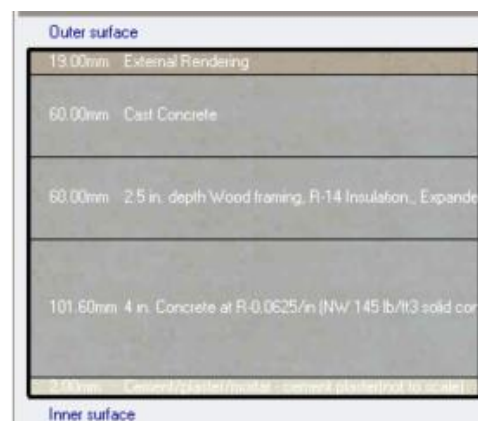


Figure 6: Wall layers simulated in Design Builder. Source: researchers

### A. Analysis with Design Builder

Design Builder is a core 3-D modeler software which provides robust alternative building for comparing designs by using function and performance-based method of comparison. It can perform a variety of analysis via the combination of three-dimensional building modeling and dynamic energy simulations in a user-friendly environment. It is interfaced with user friendly and compatible software such as SBEM and CFD modules provides conceptual design [40, 41].

Analysis done on seven story residential building having a total covered area of 1163.89 m<sup>2</sup>. The details of building's floor plan are shown in Figure 8. According to the United States Energy Information Administration (US-EIA), the average energy consumption of residential building in the US varies, depending on the type of building, and the region. According to US-EIA, in 2019, the average annual electricity consumption per household was about 10,908 kilowatt hours (kWh).

In the European Union, according to a 2019 report from the European Commission, the average energy consumption per square meter of residential buildings is around 150 kWh/m<sup>2</sup> per year[42]. In Canada, according to Natural Resources Canada, the average energy consumption per household was about 113 GJ (gigajoules) in 2017 [43]. It's worth mentioning that these numbers may vary depending on the region. In the present study the overall energy consumption including

heating and cooling of studied building determined and the energy consumption estimated without and with green roof having various specifications. The obtained results will help the user to decide the type and configuration of green roof best suited for that environment.

In the present analysis, first the base case of existing building model was performed as shown in Figure 7. The building material specifications are taken according to the approvals by both the Saudi Building Code and the Royal commission regulations. All the available specifications including the openings and material types are applied to simulate the base case. Simulation results estimated the energy consumption of the building as 139.14 kWh/m<sup>2</sup>.

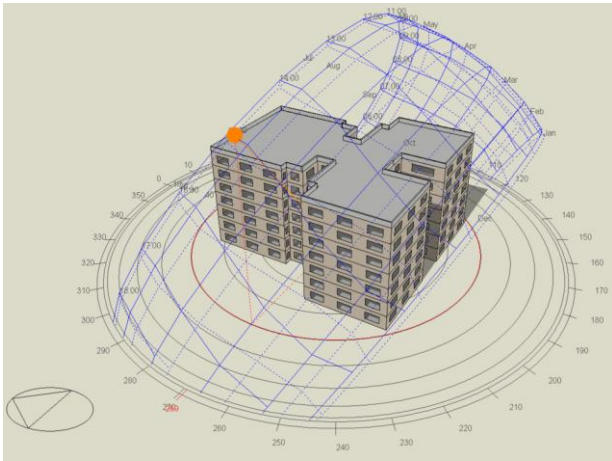


Figure 7: Existing building simulation. Source: researchers.

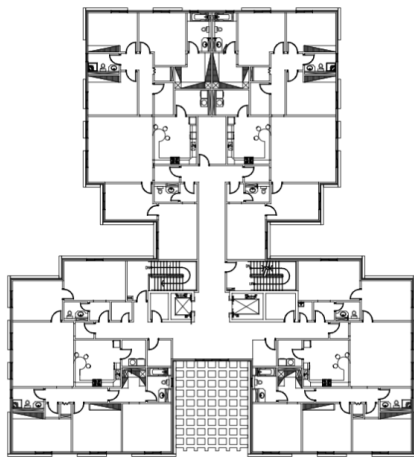


Figure 8: Existing building floor plan. Source: researchers.

Climate Consultant is a computer simulation tool which uses the climate data of whole year provided by Department of Energy [44] from thousands of weather stations installed around the world. Climate Consultant used to simulate the selected climate and the building specifications while using the local climate data into meaningful graphic displays to analyses the effect of variables such as green roof parameters. In the current simulation the annual characteristics of the Jubail industrial city such as solar radiation, precipitation, temperature, relative humidity, natural ventilation, and cloud cover, considered and analyzed to see how it influences the

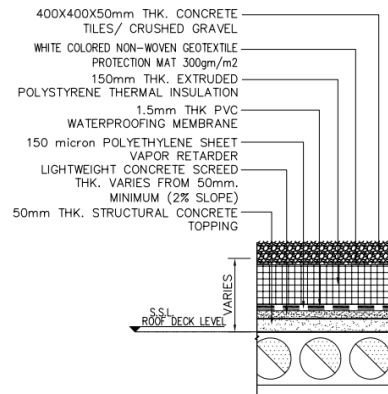
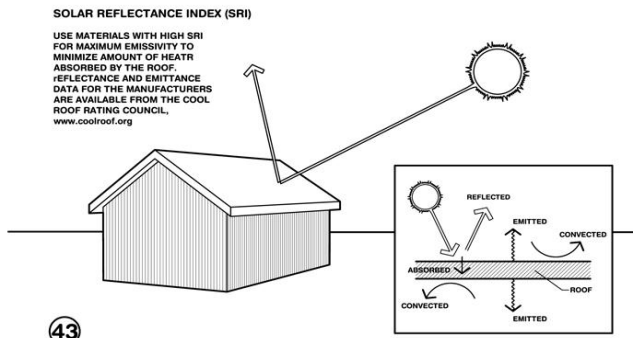
energy consumption of the studied building. Climate Consultant is very helpful to optimize energy efficiency, reduce the operating cost and at the most reduce the carbon footprint of residential building.

The output of the simulation is a Psychrometric Chart in which each dot represents the humidity and temperature of each of the 8760 hours annually. Various selected design strategies are characterized by explicit zones on the psychrometric chart. Climate Consultant evaluates the distribution of this psychrometric data in individual Design Strategy zone in order to generate a unique list of Design Guidelines for a particular location. The **Error! Reference source not found.** depicted the result of the simulation for the selected study.

Result of this application can play an important role in developing the building design strategies that respond to the specific climate conditions of a site with and without green roof option. Climate Consultant provides data and analysis on factors such as temperature, humidity, wind, solar radiation, and precipitation, to be used and design buildings that are energy-efficient, comfortable, and resilient to extreme weather events. As shown in **Error! Reference source not found.**, the best set of strategies that might be used for saving the building's energy consumption as well as increasing the users' comfort with at least 16.4 % by reducing the total used energy with a regular building. One of the most important tactics is to utilize materials having higher SRI (Solar Reflectance Index) to minimize the heat absorption by the roof, refer to **Error! Reference source not found.**

Analysis shows that the energy consumption could vary depending on the location, type of building, and the year. Furthermore, it's worth mentioning that energy consumption also depends on the specific building characteristics and how the building is operated and maintained.

In the simulation case of green roof mounted building various layers of the green roof are added as shown in **Figure 11: Details of green roof layers adopted in the study.** Figure 11. Layers mainly consist of a waterproof membrane to protect the building structure from water damage, a drainage layer to move water away from the building, a growing medium, such as soil or a soil-substitute, to support plant growth, plants, which can include a variety of grasses, flowers, and small shrubs or trees. The roof thickness is 4 inches with all related layers and.



Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain

Figure 9: Design guideline for the selected city

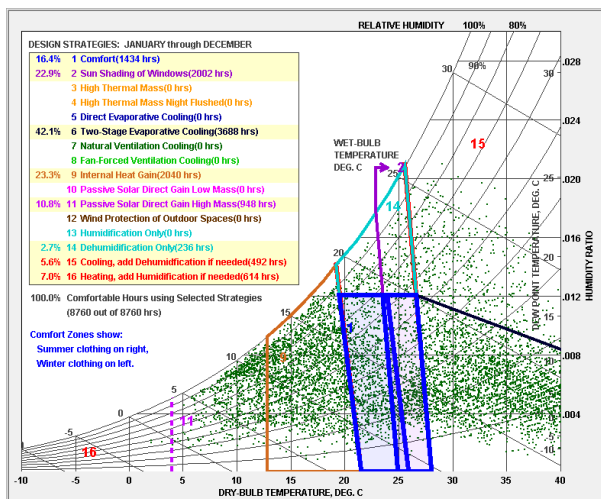


Figure 10: Best set of design strategies to be used.

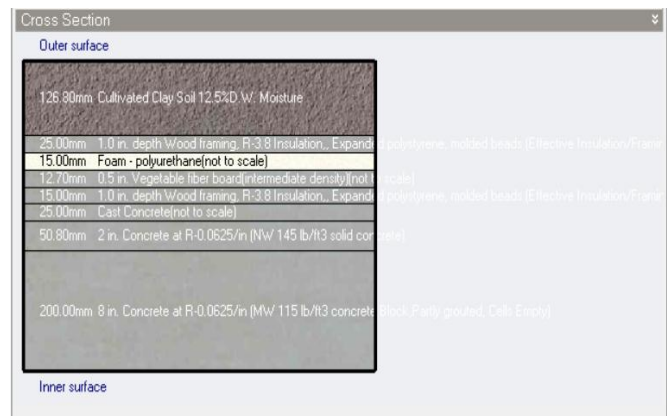
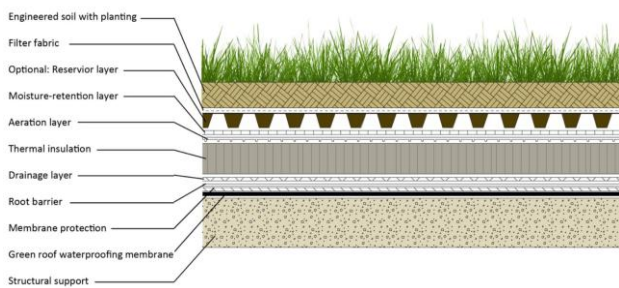


Figure 11: Details of green roof layers adopted in the study.

Therefore, the added layers contain a moisture-retention layer, reservoir layer, filter fabric, and engineered soil with plants. When compared with the energy consumption of the base case it is noticed to be away less, which is equivalent to 126.89 kWh/m<sup>2</sup>. Which gives a reduction of about 8.8% in energy consumption. However, based on current consumption of energy in the existing buildings a reduction of 15.4% can be achieved.

#### IV. RESULTS

As shown in the previous section, the green roof existence in the building reduced the energy consumption by approximately 8.80%. This result can benefit not only the user, but also the revenues which can extend to reach the country level and the whole environment. Based on the specification applied in the proposed scenario, the usage of the green roof materials with thickness of 4 inches is the most beneficial scenario to be used. This outcome coincide the results of similar studies done elsewhere [34, 45].

A climate consultant application can use data on temperature and humidity to inform the design of a building's HVAC system or use data on solar radiation to optimize the orientation, shading, and glazing of the building. It can also help to identify opportunities to use passive design strategies, such as natural ventilation and daylighting, to reduce the energy needs of the building. Climate consultants can also help to estimate the potential impacts of climate change on a building or site and make recommendations for design strategies that can help to mitigate these impacts. This can include incorporating green infrastructure such as green roofs,

rain gardens, and other features that can help to manage stormwater, reduce urban heat island effects, and provide other environmental benefits. Using a climate consultant as part of the building design process can help to ensure that a building is well-suited to its specific location, and that it is able to adapt to the changing climate conditions over time.

It has been noticed also that buildings constructed in the selected city have high standards for walls and other building elements. While adding the green roof can enhance the building's quality in different directions. This strategy can also have an added value from the social point of view, as this new rooftop can work as a gathering area for residents.

## V. CONCLUSION/LIMITATION

Green roofs are an innovative solution to help mitigate some of the negative environmental impacts of buildings, such as energy consumption and stormwater runoff. They consist of a layer of vegetation and soil, installed on top of a building's roof, which provides a range of environmental benefits. However, to fully realize the potential of green roofs, they need to be integrated into building regulations in similar climatic conditions.

By integrating green roofs into building regulations, it would become mandatory for new buildings to include green roofs in their design. Additionally, existing buildings could be retrofitted with green roofs to help reduce their energy consumption and stormwater runoff. The layers required for green roofs would need to be carefully selected to ensure they do not affect the structural integrity of the building as shown in the previous case study.

It's worth noting that the energy savings from green roofs depend on the specific design and materials used, as well as the climate in which the building is located. However, green roofs also offer a range of additional benefits beyond energy savings, such as improving air quality and providing habitat for flora and fauna.

The paper suggests that buildings constructed in a specific city already have high standards for walls and other building elements could have benefits. However, there is an opportunity to further enhance the building's quality by adding a green roof. A green roof can provide a range of benefits for the building and its surroundings.

From an environmental perspective, a green roof can enhance air quality by capturing pollutants, reduce the urban heat island effect by lowering the temperature of the building and the surrounding area, and promote biodiversity by providing habitat for plants. It can also reduce stormwater runoff by absorbing rainwater, which can help to prevent flooding and reduce the strain on the city's drainage system.

In addition to these environmental benefits, a green roof can also have social benefits. By providing a gathering area for residents, the green roof can become a community space where people can connect with nature and each other. This can help to foster a sense of community and improve social cohesion.

Overall, adding a green roof to a building can enhance its quality in multiple directions, including environmentally, socially, and aesthetically. It can also contribute to the sustainability and resilience of the city as a whole.

While the paper presented one building with one solution, the research could be extended to a larger number of buildings and other scenarios in different climate conditions. This would help to better understand the potential benefits of green roofs and how they can be applied to different building types and environments.

In conclusion, green roofs have the potential to significantly improve the environmental performance of buildings. By integrating them into building regulations and retrofitting existing buildings, we can help to reduce energy consumption and stormwater runoff while also providing additional environmental benefits. However, careful consideration is needed when selecting the specific design and materials for green roofs to ensure they are effective and do not compromise the building's structural integrity.

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