Overview of Green Roof Technology as a Prospective Energy Preservation Technique in Arid Regions

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Abstract-Concerns about climate change and rising energy demands have grown as a result of fast population rise and global industrialization. The construction industry has a huge impact on the energy and environmental sectors, accounting for about 40% of global energy consumption and a large portion of overall territorial emissions. There is a need for a shift in mindset when it comes to energy usage, as well as enhanced energy efficiency approaches and radical energy efficiency initiatives. As an energy-saving solution, the green roof, also known as the living roof has suitability and environmental benefits on many levels, while also strengthening aesthetic features and provoking structural innovation. Moreover, drought-prone areas, e.g. Saudi Arabia, have significant household energy demands. The Saudi building sector consumes more than 76% of the country's total electric power generation. As a result, the purpose of this study is to provide a general overview of living roof technology and its potential in Saudi Arabia as an energy-saving strategy. An overview of the building envelope, the impact of cladding design considerations on power usage, the benefits of a living roof, cost-benefit analysis, green policies, and examples from other countries are included in the paper. Other environmental benefits, besides the energy-saving potential of living roofs, were shown to boost the quantitative benefits of the living roof idea. A more detailed study is needed, among other things, to evaluate the energy-saving potential of living roofs based on the weather of various locations.

Keywords-sustainability; energy performance; living roof; energy saving potential; building insulation

I. INTRODUCTION

The world's growing economy has inevitably resulted in increased energy demands for corporate, industrial, residential, and transportation purposes [1], while concerns regarding the environmental impact of increased energy demands have surfaced. Some climate-related issues, such as zero-energy buildings, global warming, and greenhouse gas emissions, are gaining increasing attention [2-3] According to [4], energy consumption went up drastically from 4,674 Mton in 1971 to 8,918 Mton in 2011, with non-renewable fuels including oil, natural gas, and coal accounting for the majority of this increase [5]. According to statistics, the Middle East consumes the most energy, with 33 of 4,674 million tons of oil equivalent (0.7%) in 1971 and 224 million tons of oil equivalent (4.8%) in 2011. Fossil fuels are the region's principal energy source. In 2015, almost 200 countries signed a climate deal in Paris under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC) in a serious effort to phase out the use of fossil fuels. As a result, it is vital that the rapidly developing GCC countries invest what they have in order to develop energy sources that will be sufficient in the long-term. When it comes to overall development and economic size, the Kingdom of Saudi Arabia is the largest country in the Middle East, and its housing sector has seen an increase in energy demand from 2000 to 2014, that is estimated to be over 100%. According to [6], buildings that are used for residential purposes consume almost half of the total energy output. As a result, the construction industry has a significant demand for energy. To satisfy this rising need for energy, better ways must be developed to lower the amount of energy consumed by buildings, which can be accomplished by utilizing living roofs to improve energy efficiency [7]. Apart from the positive effects on the environment and its long-term viability, the usage of living roofs improves the architectural and aesthetic appeal of buildings. This approach of energy saving has been recognized internationally [8, 9].

The living roof offers the advantage of maintaining a balanced environment and temperature stability [10]. However, despite its benefits in terms of energy saving, it is not as extensively used in the high-energy-demanding Middle East as one might expect. This could be due to the lack of scholarship and high upkeep costs [11]. The living roof has received commercial interest because it offers answers to some of the most pressing issues regarding energy and the environment. Furthermore, an architectural model of a structure in the Middle East has not been developed with a clear plan on how to apply a living roof [5]. It is clear that the Middle East has not received adequate empirical research on this topic. As a result, a full study through research is required in order to investigate the possibilities of the living roof technology in relation to the hot Saudi weather in order to have a strong grasp of the living roof as a response to the topic of energy consumption.

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II. METHODOLOGY

To achieve the purpose of this paper, extended literature review was conducted that looked into the use of living roof technology around the world and the long-term viability of its use in the desert climate of Saudi Arabia. The study would be of tremendous importance to the arid regions because it attempts to examine solutions to reduce high energy usage and its hazardous environmental consequences on structures.

An assessment is provided that contains a broad description of the building envelope system and the effects of envelope design considerations on the structure's energy consumption. The advantages of a living roof, the estimated costs, and the green regulations from sampled countries are provided. Finally, the article draws some conclusions and offers some recommendations regarding the arid regions.

III. THE BUILDING ENVELOPE

A. *Overview*

Buildings consume roughly one third of global energy and nearly 40% of all assets used [13, 14]. The bad and good ecological effects of the technology on buildings have been discussed. Authors in [11] indicated that the yearly direct and indirect ecological effects of the industry of building comprise 42% energy use, 40% emissions to the atmosphere, 30% unprocessed use of materials, and 25% water consumption. In addition, the energy supplied is less than the demanded energy due to population growth and globalization. Therefore, efforts are ongoing to conserve and maximize energy [15]. The reduction of the overall energy use in the course of buildings' life span through good use of the building envelope is one of the efforts employed [16]. A building envelope shields a building's interior environment from the outside hostile environment. Thermal comfort (temperature and humidity control), visual comfort (natural light regulation), and acoustic comfort (noise control to acceptable levels) are a few of the building envelope's tasks [3]. The building envelope's responses to heating, cooling, ventilation, and regular lighting requirements are critical in evaluating the envelope's efficiency in reducing energy usage. In this context, building envelope materials with high evapotranspiration and thermal emissivity are good passive cooling energy demand reduction solutions. The overall thermal gain to a building is governed by the U-value, which is controlled by the materials used and the design of various elements of the building envelope, and can range from 40 to 45% of the total heat load [17]. The primary goal is to reduce transmission of heat loads in order to save considerable amounts of energy. Authors in [16] looked into the impact of construction materials, thermal insulation, and envelope layer layout as solutions for lowering building energy usage. The heat resistance of a roof can be increased by $0.4m^2K/W$ for every 10cm increase in thickness when the substrate layer is made of clay [18]. In [19], the effects of different thicknesses of building insulation on thermal performance in hot, dry areas, were evaluated. When thermal shielding is installed on the exterior of the building envelope, the study found that significant energy savings can be achieved. In their investigations of level roof surfaces in the harsh weather of the Kingdom of Saudi Arabia, authors in [6] advised the use of lighter surface colors for roofs. Authors in [20] assessed up to 6 distinct types of roof structures, in Riyadh, Saudi Arabia. To improve heat efficiency, the insulating layer should be placed closer to the inside surface of the roof structure, according to this study.

B. *Variables in Envelope Design and their Effect on Energy Consumption*

1) *Insulation*

The most significant aspect in decreasing building energy use and ensuring acceptable indoor environmental quality is heat insulation [18]. Due to its thermal qualities, the exterior of the building envelope is vulnerable to the outside environment, posing a significant danger of heat gain or loss [21]. Thermal insulation reduces the need for heating and cooling and the risk of fire [22]. With walls and roofs forming practically a unitary portion of the building's envelope, the probability of absorbing or losing heat increases, thus, the envelope should have some heat insulation [5]. Thermal insulation prevents heat from moving through channels of conduction, convection, and/or radiation. Climate, environmental impact, Indoor Air Quality (IAQ), thermal conductivity of the components, economic implications, specific heat capacity, fire resistance, sound impacts, density, and other factors are all taken into account when selecting the appropriate insulating materials [23].

2) *Thermal Mass*

Thermal mass is essential for reducing building energy costs, which can be accomplished by making HVAC systems smaller. Thermal mass also reduces peak load shift conditions and total heat yield or loss, resulting in a smaller HVAC system and lower overall building energy expenditures [2]. The absorption and subsequent release of heat as needed is characterized by the thermal mass (also known as thermal lag). This is because the materials need time to absorb, store, and then release heat [24]. Thermal mass is best placed on the first floor for easy heat release and absorption since it absorbs and then releases heat effortlessly [25].

3) *Lighting*

Climate consideration in eco-friendly design has numerous advantages. Regarding lighting, orientation is important. The requirement for electric lighting can be considerably reduced by using proper building architecture and orientation while also boosting occupant satisfaction, which can be achieved by varying the direction of apertures [26]. The planned space use, the lighting equipment required, the occupants' living style, and window placement in relation to the sun's path, are all important considerations in lighting design. Energy-saving bulbs, smart technologies, dimmer switches, automation techniques, motion detectors, and Compact Fluorescent Lights (CFLs) can all help minimize lighting energy use [27].

4) *Orientation*

Orientation is an important consideration in building design, because it ensures the optimum use of solar energy depending on a site's geographical axes and the earth's axis. When the envelope's thermal performance needs to be improved, the conductive heat flow must be restricted. To do so, the building's form factor, also known as the building shape

[28], is taken into account. Because of the forms' intricacy, they may produce leaks by exposing a portion of the structure to the outside environment. As a result, compatibility must be established in order to reduce surface area and thus reduce the risk of heat absorption or loss. Corners should be avoided as much as possible by maintaining tight compactness [25]. The window-to-wall area ratio should be examined in order to create a window that is suited for a specific orientation. The floor-to-envelope area ratio should also be investigated in order to increase floor area relative to the envelope area. To fit the windows, the best elevation must be chosen. When compared to heights in the east and west, a rising window-to-wall area ratio can favor the southern elevation [6]. Outside, shading mechanisms should also be built to minimize solar gain during the summer and ensuring it during the winter when the sun is low [6]. To reduce solar energy acquisition in the summer, minimum window-to-wall area ratio could be situated on the eastern and western elevations. Because it is not exposed to direct sunlight, the north elevation is important for daylighting [29].

5) Occupants' Contribution

Depending on the type and intensity of occupant activities, vapor discharge has a significant impact on the energy usage of a residential building [30]. Occupant actions, according to a study conducted in the Netherlands, can result in a 4.2% increase in power use, whereas individual residents' behaviors may have a significant impact on overall energy usage [2].

IV. THE LIVING ROOF

A. Overview

According to [31, 32], living roofs are becoming more popular globally. The living roof is a construction made of composite materials [18]. Soil is transported onto a roof coated with a waterproofing layer [23]. The inner source (root) obstacles are above them, accompanied by a runoff cover (with adaptable profile element) that directs excess release to roof drains and provides water storage for planting during dry periods. A living roof can also be built by hoisting previously established plants with mechanical means. The growing medium has the benefit of being easily removed in the event of leaching or maintenance work due to its off-site prefabrication [33]. Living roofs have specific sections designed to keep the roof drainage system in good working order. Roots and natural materials must be kept out of the drainage pathway to ensure that it functions properly [34]. Living roof frameworks also improve the total insulating value of the roof system because they are used in conjunction with the basic material used in traditional roof systems. Living roofs have many advantages, including cost saving, energy conservation, and aesthetic appeal [11]. The substratum layer of the living roof plays a big role in this [35]. The plant layer, for example, has some aesthetic value and might also be used as a green product source [36]. Physical qualities of plants have an impact on their contribution to the environment [37]. A study of the ability of 5 plant species (sedum pachyphyllum, sedum clavatum, sedum spurium, disphyma crassifolium, and carpobrotus modestus) to withstand multiple dry period treatments (wet and non-wet) discovered that a living roof layer of diverse plant species was more effective in terms of its capacity to withstand multiple dry period treatments (wet and non-wet) [38].

B. Advantages of the Living Roof Technology

1) Energy Saving Potential

Living roofs are designed to reduce the amount of direct and dispersed radiation striking the roof, saving large amounts of energy [23, 39]. Incorporating living roof technology into buildings resulted in a total energy decrease of 17%, according to a research conducted in Jordan [1]. Similarly, based on the soil density and thermal pressure, a study comparing the energy saving potential of living roofs with typical roof systems in Egypt's desert climate indicated that yearly power savings of 15-32% can be reached [40]. Energy savings of 48% for retrofitted/insulated roofs (U-value of $1.99 W/m^2.K$) and 7% for moderated insulation (U-value of $0.8 W/m^2.K$) were discovered in an analysis conducted in Athens using TRNSYS software [41]. In schools and buildings with living roofs in Mediterranean climates, significant energy savings between 6 and 49% have been seen [42, 43].

2) Influence of Living Roofs on Indoor Environmental Quality

The energy savings from a living roof contribute directly to lower interior temperature maintenance cost [44]. According to a study in Germany that compared living roof technology to a common roofing structure, living roofs improve the internal climate of buildings [45]. It was found that living roofs reduce the temperature of the roof top and improve the inside environment of building structures.

3) Environmental Benefits of the Living Roof

Authors in [25] revealed that storm water management is one of the environmental advantages of living roofs. Rainwater runoff from vegetated roofs could be reduced by up to 40%. According to a study conducted in Singapore [5], living roof technology was able to lower the maximum flow by 65%, while saving overall runoff by 11.6% during peak strength rainfall (1mm/min). The study also found that living roofs can reduce surface heat by 7.3 degrees, extending the life of roof membranes. When factory and car emissions travel through the plant foliage/leaf index, air pollution is minimized, particularly for extensive living roof systems (trees and shrubs) [37]. Living roof technology may be used to enrich urban areas, giving a home for birds and insects while also maintaining indigenous species. Living roofs also have the benefit of reducing the heat island effect. On the temperature differential between position roofing and traditional roof surfaces, a medium of 20°C was recorded in [34]. Vegetated envelopes are more favorable in hot and sunny locations, according to [17], because the temperature of urban heat can be reduced.

4) Cost-Effectiveness Analysis

Without a cost-benefit analysis, the benefits of the proposed sustainable measures cannot be assured. A plan that has a higher cost than its benefit cannot be considered feasible. The cost-benefit analysis is a method for weighing the benefits of various solutions while accounting for the total cost of implementation. It is the basis for making decisions that benefit the economy [12]. The Net Present Value (NPV) is a common method for determining a system's current benefit after it has been constructed and utilized for a period of time [46]. If the NPV of an investment is greater than zero, it could be realized. When making a comparison of various options, choose the one that has the largest NPV. The following equation is used to calculate the NPV [47, 48]:

$$NPV = -C_0 + \sum_{t=1}^{n} \frac{F_t}{(1+P)^t} \quad (1)$$

where *t* refers to the time period, which is commonly calculated annually, F_t is the net cash flow for year *t*, calculated using the formula $F_t = B_t\ C_t$. The advantages or benefits accumulated for the year *t* are represented by B_t. The cost outflows for year *t* are represented by C_t. C_0 denotes the initial investment (including all funds spent on items as well as installations). The cost of capital is denoted by the letter *P*. The number *n* denotes the number of years for which a financial evaluation needs to be done.

5) Cost of Green Roof Installation

The value of a living roof system is determined by several elements, including the growing medium, material layer, seepage structure, barrier or palings use, and the quantity of plants. According to [49], the low-cost, largest living roof costs \$10 per square foot (0.09m^2), whereas in-depth living roofs cost \$25 per square foot [50, 51]. In Germany, living roof prices range from \$8 to \$15 per m^2. Because of the manufacturers' business interests and experience, the cost in the United States may be higher [52]. Local sources in Saudi Arabia estimate the cost to be \$9 per square foot. As a result, it is possible to estimate that the prices will range from \$8 to \$25 per square foot.

6) Maintenance Cost

The maintenance cost makes up a major amount of the total cost of such a system. The type of vegetation utilized determines the cost of maintaining living roofs, which is higher in the first year of operation as the living roofs mature. These prices might range from \$0.75 to \$1.50 per square foot [48]. Local costs are expected to be roughly \$0.23 per square foot in Saudi Arabia.

7) Cost Due to Increased Property Value

Property and company owners gain from regular landscaping since their properties' market values rise, although no direct link has been shown between the presence of green rooftops and the property value. Anyhow, if a structure is located near a forest spread, its market value could be improved by 7.1% [53]. The purchase of trees/greenery could improve the overall value of properties by 15% to 25% [53].

8) Cost Due to Longevity Benefit

Green rooftops have an average lifespan of 40 to 55 years [12], while regular rooftops have an average lifespan of just approximately 20 years [25]. The cost of re-roofing a conventional roof is projected to be up to \$160 per m^2 [5]. Furthermore, the ability of diverse plants to convert oxygen to carbon dioxide varies. Previous studies have found that 1 hectare of living roofs may remove up to 72kg to 85kg of pollutants [55]. The cost of reducing carbon emissions can be as high as \$20 per ton [54].

9) Reduced Cost as a Result of Better Air Quality Reducing the Effects of Urban Heat Islands

Green rooftops are viewed as both an air pollution remover and a source of innovation [55]. The quality of the air is defined by measuring dust, particles, and nitrates (NO_2), with a cost of \$3375/ton gained owing to NO_x gas losses in the atmosphere [56]. In addition, natural habitat creation and protection are critical in reducing the negative effects of urban environments [57]. Green rooftops use plants and soil to replace traditional rooftops, attracting insects such as butterflies, birds, bugs, and honey bees [58]. In the summer, the combination of dull surfaces and the lack of vegetation cause increase in urban air temperature [59]. Because of the use of HVAC systems, an increase in temperature causes an increase in energy demand [59]. Authors in [60] discovered that for every 1°C increase in temperature, power demand increases by 2% to 4% in 6 U.S. metropolitan areas. Heat island effect increases power consumption by up to 1GW - 1.5GW annually in the Los Angeles Basin [44].

10) Global Policies on Living Roofs (Case Studies)

Several cities give incentives in the form of grants to property owners who want to establish green spaces on their roofs, in order to encourage both commercial and residential owners to undertake arrangements for more green spaces on their roofs. Singapore, for example, has developed a thorough program to promote rooftop greening in order to fulfill a target of 50 hectares of new Skyrise Greenery Area by 2030. The creation of a roof floor incentive program, the allocation of city gardens, and technical consultation are all part of this [61]. The program also includes a monetary recompense for sustainable landscaping of current building structures in regions with a higher need for green spaces, and remuneration for new construction project designation of living roofs [49]. Portland, located in the northwest of the USA, favors living roof strategies due to the benefits of sustainably managing rainfall [11]. Germany discovered that light modifications of green rooftops can assist energy conservation. Green roofing is now used in many German cities. This strategy is backed up by accepted design standards and legal backing. As of 2005, Germany had planted 13.5 million m^2 of roof spaces [54, 62]. Munich, the Bavarian regional capital (Germany), is implementing a variety of living roof-related initiatives [63]. Such approaches include land use management rules, start-up grants for voluntary living roof construction, and a reduction in storm water levies [64]. Living roofs are particularly well-known in Munich. Thanks to a 14-year-old legislation requiring all appropriate roofs of any flat with a surface area greater than 100m^2 to be landscaped. Japan began with a light-hearted stimulus program that included free consultancy services. Following that, a subsidy program was implemented, resulting in the installation of 7000m^2 of living roofs. Worries about the environment's impact on buildings led the authorities to enact a regulation requiring construction works greater than 10,000 square feet or government buildings bigger than 25,000 square feet to landscape the 20% of the roof surface, or risk annual fines [24]. From these instances, it is clear that many cities are employing a variety of hybrid strategies to promote living roofs, even though there are differences in nature and equipment, as well as institutional inequities. The ultimate purpose of city living roof initiatives is to maximize any positive impact by utilizing human and financial resources as efficiently as possible.

11) Building Energy Modeling Programs (BEMPs)

Computer simulation is a highly valuable and cost-effective technique for estimating and analyzing energy usage and overall building efficiency [65]. Since 1960, hundreds of Building Energy Modeling Programs (BEMPs) have been developed and implemented all over the world [66]. Well-known BEMPs include ESP-r, TAS, TRNSYS, BEopt, ECOTECT, IES Virtual Environment, eQUEST, and Design Builder [67, 68]. AED is becoming increasingly reliant on technologies that can answer particular queries during the design phase. Furthermore, AED can predict a building's thermal behavior before it is constructed [65]. It can model energy costs in new and old buildings in their existing state, determining the best way to use energy. A non-technical profession would benefit from an essay detailing how to use software interface. It should include enough depth to conduct research [69]. To take advantage of the benefits of other programs via data-sharing file formats, inter-software operability is also required [70]. It is vital for credibility to demonstrate conformance with criteria used in similar building performance studies. It is vital to utilize an appropriate instrument in performance analysis to ensure the functioning and capabilities of software [14]. There are a variety of software options available, each with its own set of features. The researcher's user choice condition suggests its capabilities to be toned down [68].

12) Software Package Comparison

Many simulation programs have been developed over the few previous decades. This is evident from the US Department of Energy's homepage dedicated to generating energy simulation software tools, which lists over 240 such programs. The tools on the site range from research-grade software to commercial versions. Many studies and comparative assessments were conducted to analyze the elements and capabilities of some of the instruments in this group. Authors in [71] proposed evidence-based validation, comparative study, and analytical verification as methods for ensuring the accuracy of construction energy devices. Following a series of testing and validations, Energy Plus was found to work with the DOE-2.IE, ESP-r, and BLAST simulation tools. Authors in [66] used Energy Plus to construct and test a VRV air conditioning system that is empirically connected to a new simulation unit. The monitored simulation data revealed a total energy cooling and utilization range of 25.19 to 28.3%. By comparing the building energy performance simulation program to other readily available building energy programs, a complete assessment of the program's capabilities may be established [72]. The comparison is based on general modeling descriptions, zone loads, building envelopes, HVAC systems, economic analysis, emissions, electrical systems, and electrical equipment. Some of the most commonly used comparison programs include Bsim, BLAST, DeST, Ener-Win, Energy – 10, EnergyPlus, eQuest, IDA ICE, ESP-r, IES VE>, TRACE, TRNSYS, Tas, SUNREL, HEED, PowerDomus, and HAP. Authors in [72] investigated 6 building performance simulation tools in order to provide early design support to architects. A set of criteria was used to evaluate the simplicity of use of numerous tools. Furthermore, none of the tools were deemed appropriate for use by architects. According to them, DesignBuilder stood out because it provides a graphical user interface for EnergyPlus, a well-known energy modeling program. Authors in [67] used an online poll to assess the usability of 10 distinct architectural tools. HEED, eQuest, IES /VE, GreenBuilding Studio, ECOTECT, Design Builder, Energy – 10, DOE 2. IE, Sketch up plug-ins, and EnergyPlus each had 249 valid results when these tools were considered. The program was evaluated on its usability, information management (UIM), and connection with the Intelligent Design Knowledge Base (IIKB). The study found that IIKB had a stronger preference for tool interfaces than UIM.

V. CONCLUSIONS

A description of living roof technology as a means of energy preservation is provided in this paper. The goal of the literature review is to emphasize the theoretical foundations for the subject as well as the potential benefits and economic implications of green roofing solutions. The literature review demonstrated that one of the most important benefits is determining the level of sustainability required by the construction industry in hot and arid climates. Furthermore, when alternative software was examined, it was found that DesignBuilder and Energy Plus have greater capability for analyzing various energy conservation measures, including the green roofing model. The proper paradigm for living roof implementation is in the design of buildings with decked roofs, as is the case in Saudi Arabia. Hot weather and energy cost may pose challenges for the implementation of sustainable techniques such as living roofs, but a gradual and steady shift is underway. According to Saudi Vision 2030, a recently created strategic policy framework, attempts are being made to eliminate more than 200 billion Saudi Riyals in energy subsidies by 2030. However, the advancement of living roof technology depends on a number of factors, one of which is the importance of living roof policies. Results and case studies from various cities around the world show that a lot of work was put into advocating ideas for adapting and modifying green roofing to meet local conditions.

Aside from the energy saving potential of living roofs, there are other, environmental advantages in their utilization, such as heat island abatement, habitat creation, increased property value, improved air quality, increased roof membrane longevity, and reduced carbon emissions.

VI. RECOMMENDATIONS

The following suggestions are provided to guide future research:

- Comprehensive investigation into the energy-saving possibilities based on meteorological data from diverse places will go a long way toward proving the claim of the prospective advantages this technology could provide.

- It is necessary to perform natural plant and horticultural studies on native species, as well as their ability to live in hot, humid situations. This will aid in determining the dependability of various plant species in terms of their ability to survive.
- The adoption of such sustainable techniques will be aided by establishing living roof design and construction guidelines for new buildings and retrofits.
- Policies should be developed to accelerate the adoption of such sustainable techniques, particularly for large-scale construction projects.

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