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A PROPOSED METHODOLOGY FOR GREEN ROOF DESIGN STANDARDS FOR ENERGY SAVING IN HIGHER EDUCATION BUILDINGS

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Abstract

This study focuses on the question of inadequate warm comfort in the Faculty Spaces inside university constructions, which is generally from the weak efficiency of the construction wrapper. Based on the idea of energy sustainability, the study aims to investigate the material part of green roofs in reconstructing energy efficiency and lifting warm comfort in these vital scopes. The significance concerning this research lies in obtaining the academy's tenable aims while ensuring the comfort and raised output of ability members in their rooms, as they show the foundation of the educational process. The study used depended on an all-inclusive approach utilizing the simulation program Design Builder v 6.0, that proves the magnitude to which strength adeptness was worked out with green roofs in skill rooms in university constructions on the 6th of October City in Greater Cairo. The study highlighted the difference of green roofs, their talent to specify thermal covering for interior rooms, and their offering to reducing the heat peninsula wonder encircling houses. The results indicated that green roofs are a main beautiful part and a highly persuasive tenable method for enhancing strength effectiveness in constructions. The study again indicated that setting green roofs above skill scopes, along with the adding of 8 cm of polystyrene warm lining, could help reconstruct strength effectiveness by at least 30% distinguished to the base case.

Keywords Green roofs - Thermal insulation - Energy saving - Faculty Spaces - Thermal comfort

1- Introduction:

Climate change issues are among ultimate main preference of the current century; cause witnesses have altered the realm's idea of the environment and habits of maintaining it. The flags for adopting sustainable design in academy constructions have gained overwhelming

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impetus, and exertions are ongoing to implement them, directing on administering situations that preserve the surroundings and weaken strength consumption, that constructs within rooms free of contaminants and strength exhaustion. It has become inevitable to follow creative environmental and structural situations that may be used in university constructions in a necessary conduct. One of the most main of these situations is the use of green roofs of differing types according to the needs of each creator, as green roofs are thought-out a tenable tangible solution, as they offer important business-related, material and social benefits and show a useful and inspiring blueprint for crafty tenable academy buildings (Saadatian and others., 2013) [1]. Green roofs show ultimate effective alternative for reconstructing strength performance in constructions. They help weaken the element footmark, improve air value in houses, defeat urban heat reefs, and support rooms that improve and improve the welfare of consumers and increase ability productivity in university houses (Vijayaraghavan, K., 2016) [2]. They more contribute to obtaining warm comfort inside these spaces. Faculty scopes inside university houses play an important part, as they demand extreme levels of quiet and comfort to support academic productivity. They strengthen casual social interplay and unification and supply a rich environment for planning and entertainment in middle of academic hustle and bustle. This projected method delineates a method for plotting, executing, and judging the acting efficiency of green roofs in university constructions. It focal points the importance of modernizing mechanics methods, implementing progressive facilities, and realizing beautiful elements to guarantee the favorable acceptance of architectural situations in tenable academic surroundings.

2- literature review

Interest in green roofs as a tenable blueprint is firmly growing, given their capability to embellish construction performance and uplift the condition of city surroundings. This review explores far-reaching research underscoring the versatile benefits of green ceiling adoption, accompanying a devoted effort to strength performance and reconstructing the Ultra High Heat Island (UHI) effect., and mixed displaying processes. Green roofs have demonstrated to be a valuable measure proposed at threatening strength consumption in constructions, (Santamouris, 2014), [3], in welcome all-inclusive review, green roofs identified in addition to thoughtful sciences as fault-finding approaches for alleviating heat isle belongings and reconstructing indoor warm environments, with reducing reliance on air cooling plans. Similarly, (Ascione and others. ,2013) [4] found that green roofs have showed large happiness in achieving significant reductions in chilling strength consumption inside European climates. In Egypt, (Kamel and others. 2012) [5] secondhand simulations to judge the performance of a dwelling's construction in Cairo. (Terés-Zubiaga and others., 2015) Green roofs improve strength use [6] and the need for construction envelopes expected remodelled to help effectiveness. (Radwana et al., 2016) [7], defined procedures for reconstructing building conduct. Green roofs present image of a vital element in improving the warm possessions of constructions. (Pianella and others., 2016) [8], green roofs improve strength effectiveness and are a tenable solution when executed indifferent surroundings. They are also a key answer for lowering the impact of the city heat isle phenomenon. (Santamouris, 2014) [3], (Alexandri and

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Jones, 2008) [9] likewise pointed out an bettering in temperatures by way of administering green roofs and green divider in different critical domains. (Smith and Roeber, 2011) [10] likewise pointed out the possibility of utilizing green roofs as an material situation to reduce hotnesses in Chicago. Many studies have determined the benefits of city plants, especially shrubs, bushes, and green divider (Nasir and others., 2015; De Abreu-Harbich et al., 2015; Hong & Lin, 2015; Vailshery and others., 2013; Shashua-Bar and others., 2010) (Susorova and others., 2013; Chen et al., 2013; Wong and others., 2009; Cameron and others., 2014), [11],[12],[13],[14],[15],[16],[17],[18],[19], on their significance and cooling belongings realized through darkening, happening, and evaporation. Researchers have grown progressive imitation models to evaluate the act of green roofs in constructions. (Sailor., 2008) [20] grown a simulation finish that integrates accompanying construction strength analysis spreadsheet. This approach was further extended together with containing supplementary visage such as surface reflectivity (Scherba, Adam, and others., 2008) [21], photovoltaic (PV) arrangements, and reasonable heat flow assessment in city surroundings through the impact of green ceiling installations. (Moody and Sailor2013) [22] further grown these lineaments, suggesting an index to measure the energy act of constructions accompanying green roofs as a tenable environmental approach. (Terés-Zubiaga and others., 2015) [6] stressed the significance of using posing and imitation methods to measure the effectiveness of green ceiling exercise in constructions indifferent regions. (Djedjig and others. 2015) [23] still grown a concept by mixing a ratified warm model of the vegetation cover into construction strength simulations. Green roofs support many benefits, not only energy effectiveness and warm comfort, but further, (Francis and Jensen 2017) [24], highlighting their significance as a tenable expenditure in environmental preservation. They are likewise deliberate appropriate and widespread electronics to better and stimulate sustainable construction blueprints that enhance addressing worldwide tangible questions (HBRC, 2009; Sjöström, 2000) [25],[26].

3- Research Problem:

The inefficiency of the building envelopes of faculty spaces in higher education buildings in the Greater Cairo region contributes to the failure to achieve thermal comfort within these spaces and consequently reduces the quality of the internal environment in faculty spaces, which contributes to increased energy consumption to improve the efficiency of these spaces.

4- Research Objectives:

The study objects to explore the effect of using green roofs and thermal insulation on the roofs of faculty members' spaces in higher education buildings to improve energy efficiency and achieve thermal comfort within these spaces using the simulation program design builder v 6.0.

5- Research Questions:

A- How can thermal comfort be achieved within the Faculty Spaces in higher education buildings using green roofs in the hot climate of Greater Cairo?

B- How can energy efficiency for Faculty Spaces in higher education buildings be improved by treating the building envelope?

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6- Research Hypothesis:

Growing roofs, choosing the appropriate building orientation, and thermal insulation of the ceilings are among the most important solutions that can be proposed to improve energy efficiency within the Faculty Spaces in higher education buildings. They are also one of the solutions to reduce the use of mechanical cooling and heating methods.

7- Method:

To reach the study aims, a theoretical method is seen, based on a review of previous studies, their findings, their impact on the current study, the need for the current study, and an examination of the concepts used. An analytical approach is used to derive a typical model. The typical model of Faculty Spaces in higher education buildings was studied. An applied approach uses computer simulation using the Design BuilderV6.0 simulation tool, and prevailing patterns were studied. This was done using green roofs, changing the orientation, and varying the thickness of the thermal insulation of the ceilings. The simulation results are then presented for each case separately, followed by clarifying and assessing the results, thus achieving the study goals and previous studies and their findings, As Figure (1)shows.

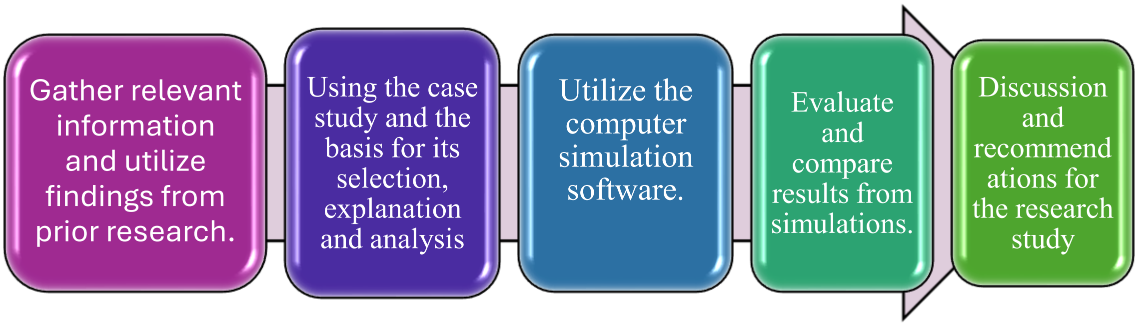

Figure (1) shows: The methodology followed in the study

8- Green roofs:

A green roof system is an extension of the existing roof which involves, at a minimum, high quality waterproofing, root repellent system, drainage system, filter cloth, a lightweight growing medium, and plants, As Figure (2)shows

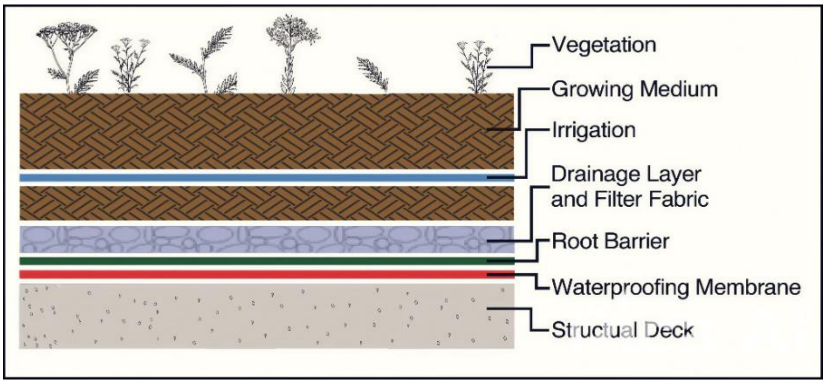

Figure (2) shows: A green roof section, showing the layers of a green roof. This section shows an optional irrigation system.[38]

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This concept is an innovation that combines architectural design with environmental awareness, aiming to transform underutilized urban spaces into green areas with diverse functions functions (Mentens et al., 2006) [27]. Green roofs are mainly classified into three types based on their characteristics and requirements.

1- Intensive green roofs can change boring roofs into cool spots. You can be creative and grow all sorts of plants, from small flowers to trees. While grass roofs work, these gardens are easier to care for than you might think, depending on what you plant. Since they use soil that's at least 15 cm deep, it gives trees and bigger plants enough space to grow. These gardens work just like regular people chill, relax, and enjoy the plants. Plus, they help keep buildings warm or cool (Sailor, 2008) [20]. Just make sure your building can hold the extra weight, especially if you want a space that everyone can enjoy, like the one in Figure 3.

Figure (3) shows the intensive green roofs [29]

1. **Extensive Green roofs** look great mixed with plants and are super eco-friendly. They're not too pricey, help the environment, and soak up rainwater well. They might not completely overhaul a building's eco-impact, but they do a lot for green design. These roofs feature a thin soil layer, typically no more than 15 cm deep, As Figure (4)shows, on which drought-tolerant, low-maintenance plants, such as sedum and grasses, are planted. This type of green roof is characterized by its low cost, economical nature, light weight and low load on buildings. It also achieves great environmental and thermal benefits (Whittinghill et al., 2013) [28].

Figure (4) shows the expanded green roofs [29]

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1- **Semi-intensive green roofs**: This type embodies the gap between extensive and intensive systems and offers a more sophisticated approach to natural vegetation. It focuses on self-sustainability and continuous development. It features moderate soil depth and can support a wider variety of plant species than extensive roofs but requires less maintenance than intensive roofs. These roofs offer a balanced approach, providing biodiversity and moderate aesthetic benefits, while remaining relatively lightweight and easy to maintain, As Figure (5)shows.

Figure (5) shows semi-intensive green roofs [29]

9- Proposed Design Methodology for Green Roofs:

A proposed approach to green roof design to improve energy efficiency in higher education buildings, As Figure (6)shows , and See Table (1):

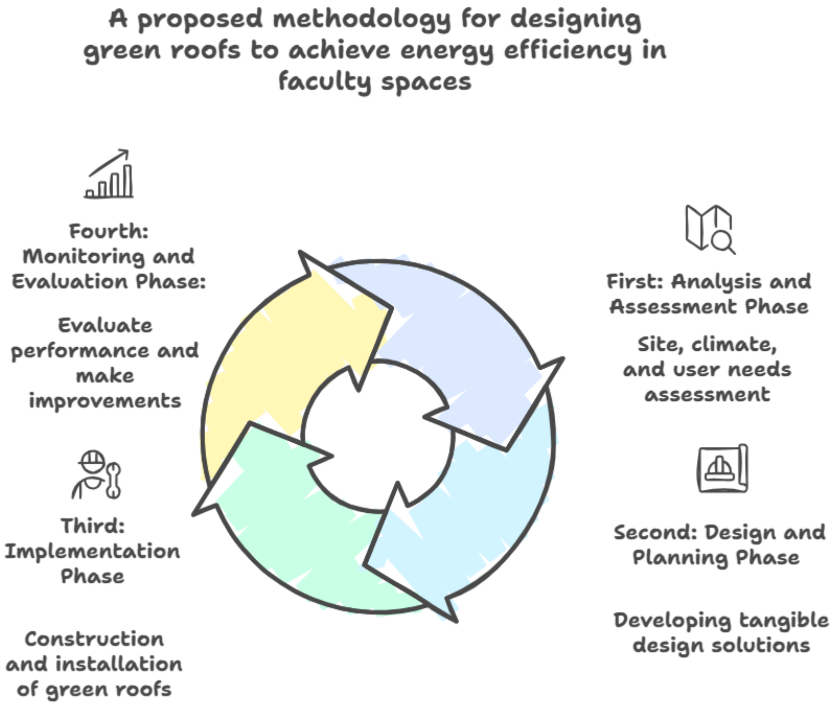

Figure (6) shows a proposed methodology for designing green roofs to improve the energy efficiency of higher education buildings for Faculty Spaces

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Table (1) shows a proposed methodology for designing green roofs to improve the energy performance for Faculty Spaces	
First: Analysis and Assessment Phase	
1- Site and Climate Analysis:	**Studying sun and wind patterns**: Analyzing the sun's trajectory throughout the day and across the seasons, as well as understanding local wind patterns, plays a vital role in optimizing environmental design (Givoni, 1994) [30]. Keep a close eye on humidity and temp daily—highs, lows, the whole deal. That way, you can pick plants that will do great (Firanj et al., 2021) [31]. Rain is also key. Know how much falls, when it falls, and how often. That helps you set up drainage that actually works, so no floods or damage. Plus, you can grab rainwater for your plants instead of using tap water. It saves water and helps the planet (Mentens et al., 2006) [27].
2. Existing Building Assessment for Faculty Spaces:	• **Checking the Structure:** First off, structural engineers make sure the building's roof can support a green roof's load. That means soil, plants, water, gear, snow, and even people working up there. Schmidt and team (2009) [32] figured a simple green roof adds around 60 to 150 kg per square meter, but a fancy one can add 300 to even 1,000 kg per square meter. If the roof isn't tough enough, they can strengthen it or use lighter materials. • **How Well the Building is Insulated**: Next, they look at how well the building holds heat, targeting the roof, walls, and windows where staff spend lots of time. This helps give insight into how much energy a green roof could save. Green roofs act like an extra layer of insulation, holding heat in and keeping it out, which helps the building's energy performance (Whittinghill et al., 2013).[28] • **Heating and Cooling Check:** Then, engineers check out the current heating and cooling systems and look at past energy bills to get a starting point. This helps measure how energy use changes after putting in the green roof. The aim is to lower heating costs in winter and cool things down better in summer. • **Where the Staff Hangs Out**: The best spots for green roofs are above faculty offices, meeting rooms, and lounges—anywhere staff spends a lot of time. These spots should be easy to reach for upkeep. Saving energy and keeping the indoor temperature comfy benefits the staff in those spaces the most.
3. Study the needs of users for faculty members	**Surveys and Questionnaires:** These play a crucial role in ensuring that the design is tailored to the needs and desires of actual users. Through questionnaires, faculty members can share their views on various aspects, including: - Find out what people want from the green roof. Some may just want a chill spot to read or hang with friends. Others might care more about

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		the look – like which plants to use, the right colors, or even the seating. Timing is also key. When you ask in a survey, you get good info and make folks feel involved. This makes them more interested in the project's result, which research supports (Manso et al., 2021).[33] * Then, figure out what activities the roof has to support. Field studies help see the important ones – like if people want quiet reading spots, places to hang out, or just paths to walk. If lots of people want reading spots, create calm, shaded areas to chill with a book.	
Second: Design and Planning Phase Insights and analyses gathered during the initial phase are transformed into actionable design strategies and solutions.			
	1. Green Roof Type Selection:	**Intensive green roofs**? These have soil deeper than 15 cm. Think full-on gardens up on the roof! You can grow almost anything, even trees. It changes wasted space into something pretty useful and insulates well, too (Sailor, 2008) [20]. Just keep in mind they're heavy, so your building needs to be able to handle the weight. These are cool for places where people want nice green areas. **Extensive green roofs?** These are different. The soil's not as deep – less than 15 cm. You plant hardy stuff that doesn't need much care, like sedum and grasses. They're easier to deal with and lighter, but your plant choices are limited (Whittinghill et al., 2013) [28]. **Semi-intensive green roofs** split the difference. The soil depth is in between the other two, so you get more plant options, but without too much weight or work.	
	2. Green Roof Layer Design:	you start with a root barrier and drainage (Shaharudin et al., 2019) [34]. Then you put the filter and growing stuff on top (Getter et al., 2007) [35]. When picking plants, don't just think about looks. Think about the local weather, how much work they will need, and if they will help the environment. Also, make sure they don't cause allergies, give good shade, and keep things comfy so people will like hanging out there.	
	3- Irrigation System Design:	**Drip irrigation** delivers water directly to plant roots, giving them precisely what they need and cutting down on waste. Almost no water evaporates, so you use much less overall. **Rainwater harvesting** involves collecting rain from roofs and storing it to water your garden or lawn. It's basic, but it really lowers your tap water use and helps save natural resources (Mentens et al., 2006) [27]. **Smart irrigation** goes a step further. These systems use soil sensors and weather info to decide when and how much water is needed. They adjust themselves, so you don't have to guess if are giving the plants	

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	right amount. It’s a big leap for saving water and keeping everything healthy.
4- **Integration of Monitoring and Control Systems:**	• **Sensor Installation:** Temperature and humidity sensors are thoughtfully placed inside faculty rooms and directly on the green roof. These devices play a key role in monitoring the green roof's effect on temperatures both inside and outside the building. • **Building Management System (BMS) Integration:** Sensor data is collected and integrated with the central building management system, enabling continuous monitoring of the building's thermal performance (Kontoleon et al., 2010) [36].
Third: Implementation Phase: This stage is considered the main transition from planning to action.	
1- **Roof Preparation:**	**Cleaning the roof from any impurities - Preparing the waterproofing layer - Installing the protection layer.**
2- **Installation of Structural Layers:**	• **Installation of a root protection layer - Installation of a tight drainage system - Installation of a filter layer:** to trap soil and prevent blockage of drainage systems. **- Installation of a soil layer:** Specially prepared soil is spread in an even thickness according to engineering needs.
3- **Planting Vegetation:**	**Plants are selected according to the climate and planted according to approved plans.** **This section shows which categorizes various plants and trees for the green roof** • **Trees:** • Includes mango, guava, orange, pomegranate, peach, mandarin, papaya, grapes, banana, apricot, lemon, loquat, plum, and olive. • **Shrubs and Vegetables:** • Features eggplant, pepper, carrots, cabbage, cauliflower, onions, and tomatoes. • **Leafy Plants:** • Comprises parsley, dill, coriander, molokhia, thyme, mint, and basil. • **Flowers and Ornamental Plants:** • Lists of jasmine, narcissus, and night-blooming jasmine (Abd Elkader et al., 2020) [40]
4- **Irrigation System Installation:**	**A drip irrigation system** connected to valves and control units to distribute water efficiently according to the approved plan. **The system must be tested** to verify its performance and identify any potential leaks. **A rainwater harvesting system** must be integrated with the irrigation system to reduce water consumption.
Fourth: Evaluation and Monitoring Phase: It is the basic stage for evaluating the sustainability of the project. It also generates baseline data that forms the basis for continuous improvement.	

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	1-Energy Performance Monitoring:	• **Measuring building energy consumption:** Periodic data collection on the building's electrical energy consumption (Niachou et al., 2020) [37]. • **We monitor the temperature in user areas at all times.** • **We dig into the energy data**, running stats to see how putting in a green roof changes temperatures and energy use.	
	2- **Green Roof Maintenance:**	• **We keep things running smoothly with regular watering,** feeding, and weeding. We check the drainage to be sure it's working right. We also look at root protection to be sure the roots aren't causing problems. Basically, we handle everything to keep the green roof in top condition.	
	3-**User Satisfaction Evaluation:**	• **Getting regular feedback** is important to see if the green roof idea is working. Surveys or focus groups can help since you just need people to share what's working and what's not. These chats don't just show opinions; they help see how the green roof changes people's mood and how they use the space. • **That info helps make better plans**. Happy users are the best sign after implementing the green roof. • **When people are satisfied**, it means things are going well. The green roof is not just a cool idea, but it is improving the workplace, which is what Manso, and team wrote in 2021. [33].	

10- Case Study:

We monitored and explored faculty spaces at the October Higher Institute of Engineering and Technology (OHI) in Greater Cairo. The standard rectangular room design was identified as characteristic of this institution.

General Information:

Project: October Higher Institute of Engineering and Technology (OHI)

Climate: Hot then dry

Location: Giza

Renovation Completion Date: 2008

The facility comprises a ground floor, first floor, second floor, specialized electrical and security rooms, service areas, and landscaped surroundings. Each floor is designated for specific functional purposes:

-Ground Floor: Primarily accommodates student and alumni services, accounting offices, public library, offices spaces, teaching space, research laboratory, and lecture halls.

- First Floor: Dedicated to offices, teaching halls, computer laboratories, senior management offices, and additional classrooms.

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-Second Floor:Reserved for remaining teaching halls,classrooms, laboratories, and control rooms.

The case study centers on analyzing the placement and functionality of Faculty Spaces within the building, as visualized in the accompanying figure (7) ,(8) ,(9) .

Figure (7) illustrations October Higher Institute of Engineering and Technology.

10-1- Thermal Performance Evaluation of the Case Study:

valuating the thermal performance of faculty spaces serves as a measure of how effectively these areas achieve thermal comfort, which primarily depends on the collection of materials and the strategy of the building envelope. After digging into green design ideas for the building and taking a close look at the materials, I compared how well the building's envelope holds up when it comes to keeping faculty spaces comfortable. I looked at things like what the walls are made of, the types of glass, and how many windows or openings there are. The whole point is to see what actually helps save energy and makes these spaces more comfortable to work in.

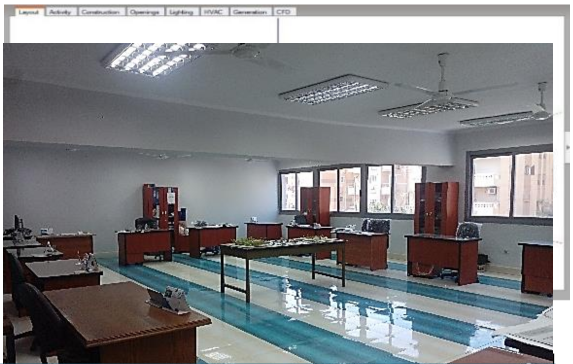

Figure (8.3) showing the interior of the model of Faculty. Source: The researcher.

Figure (8.4) showing the entrance to the model of Faculty Spaces in the case study. Source: The researcher.

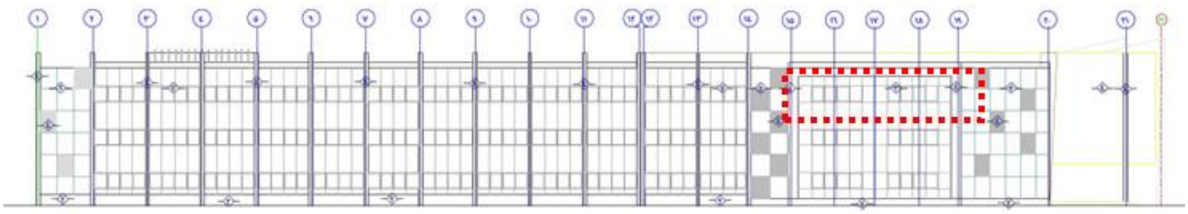

Figure (9.) illustrations the facade of the Faculty Spaces under study. Source: The researcher

7-2 - Basis for Selecting the Case Study

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Living in Greater Cairo means dealing with a hot, dry climate, which isn't great for the faculty buildings. They're not really set up to be green or comfy, meaning people are stuck with bad temperatures inside. That's what this study is all about fixing.

Here's our plan:

- We're keeping in mind Cairo's specific climate.

- We're going to need real data to make sure our tests are accurate.

- The study will check out different buildings and see how well they do in terms of being efficient and good for the environment.

- We'll also create models to see how these things change indoor comfort and energy use.

7-3 - Case Study Assessment: For Faculty Spaces in OHI:

So, to get a handle on this, we took a good look at the weather in Greater Cairo. We checked how temp and humidity play together using the Climate Consultant 6.0 program to figure out what the weather's really doing to how comfy people feel inside.

-The psychrometric chart that we used plots temperature along the bottom edge and humidity up the side. It shows you a good look at Greater Cairo's climate. To find the comfy spot and you can see it in Figure 10 We looked at stuff like the hot and humid weather, clothes people wear, how active they are, and how packed these places get. The result of considering these things give you an idea how comfortable people feel.

Psychometric map of thermal comfort

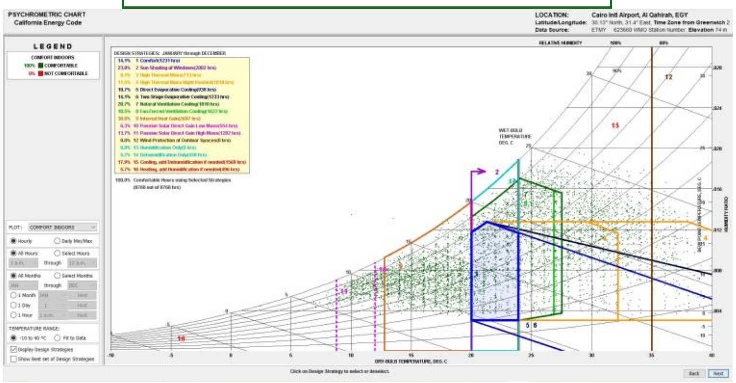

Figure (10) shows the psychometric map of thermal comfort for the study case using the Climate Consultant 6.0 program. [39]

B. The Faculty Spaces Model Data:

- Architectural Design Data:

We're checking out the faculty area, seeing what's up before and after some tweaks. We want to know how different materials mess with the temperature, the layout, and how open it feels. So, yeah, we're matching space as is, with future designs. We're watching overhangs; window and door sizes; walls, and the materials for all this stuff.

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- Heat Gain:

Heat gets into place in two main ways: from the inside and from the outside. Inside, you have people, lights, and machines that are giving off heat. From outside, the sun pushes through the walls and windows.

7-4. Evaluating the Faculty Spaces Models Using Simulation:

I used simulation tools to check how the faculty space works. I created a digital model of the building and checked out how it works.

- A. Simulation Methodology:

We put the building's specs and size into a simulation program to make a virtual model that looks just like the real thing. This model helps us play out how the building uses energy, and we use software like Design Builder 7.0 for this. The program spits out a detailed analysis based on what we feed it and gives us some thoughts on the case study.

- B. Building Operation Data:

Operational Activities:

- The building is open daily from 8 AM to 4 PM, except for Fridays and Saturdays. Here are a couple of important things:

- The occupant density is 0.55.

- People inside usually have a burn rate of 1.0 MET because they're usually standing or walking.. Computers are the main equipment everyone uses.

As for the daily schedule, things really get going from 9 a.m. to 3 p.m., again skipping Fridays and Saturdays.

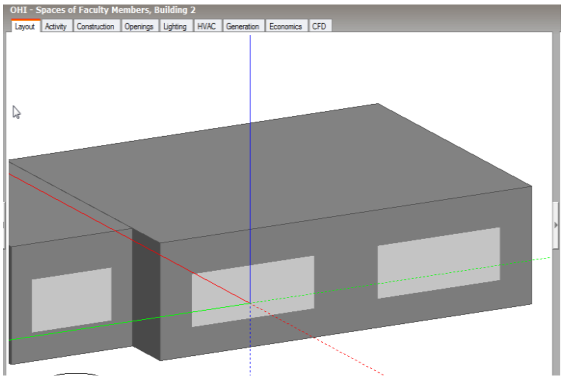

Figure (11) shows a model of the case study in the Design Builder 6.0 program.
Source: https://designbuilder.co.uk/ 7-12-2024

7-5- Discussion of the results:

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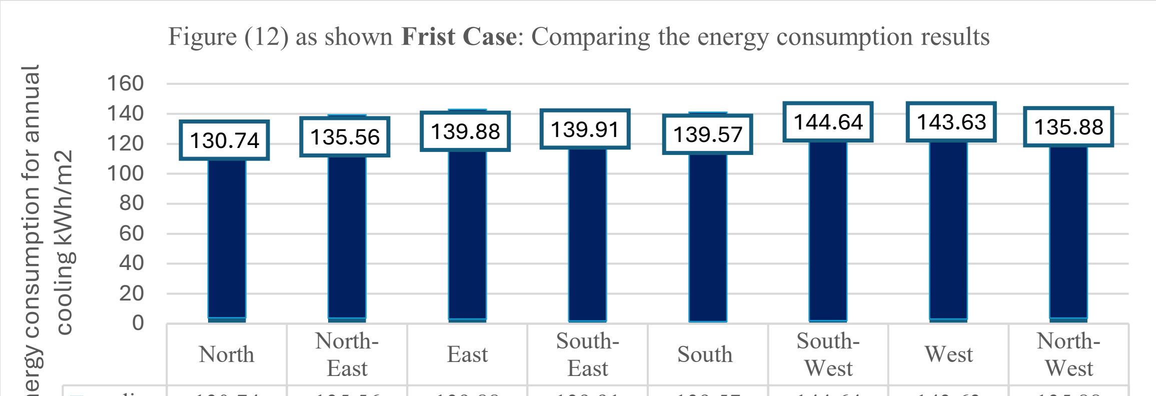
- **Frist Case**: Comparing the energy consumption results, as shown in Figure (12):



	North	North-East	East	South-East	South	South-West	West	North-West
cooling	130.74	135.56	139.88	139.91	139.57	144.64	143.63	135.88
heating	3.93	3.83	3.02	1.85	1.48	2.02	3.03	3.78

Figure (12) illustrates the variations in energy consumption rates based on building orientation.

In the first case, the model results reveal that the Faculty Spaces model for the Greater Cairo region exhibits the highest energy consumption rate when oriented south-west. Under this configuration, involving a 25 cm thick red brick wall, 6 mm single dark glass, and a 20 cm UV-reinforced concrete surface, the annual energy consumption rate reaches 144.64 kWh per square meter—a peak value of 3.303. This is the highest energy demand out of all the orientations we looked at. On the other hand, the north-facing side uses the least energy each year just 130.74 kWh per square meter. That's 9.6% less than the south-west orientation. Other orientations follow, with varying consumption rates: west (143.63 kWh/m² annually), south-east (139.91 kWh/m² annually), east (139.88 kWh/m² annually), and south (139.57 kWh/m² annually). The north-west orientation registers an annual rate of 135.88 kWh/m², while the north-east orientation achieves the second-lowest consumption at 135.56 kWh/m² per year, second only to the north-facing configuration.

- **The second case**: Comparing the energy consumption results, as shown in Figure (13):

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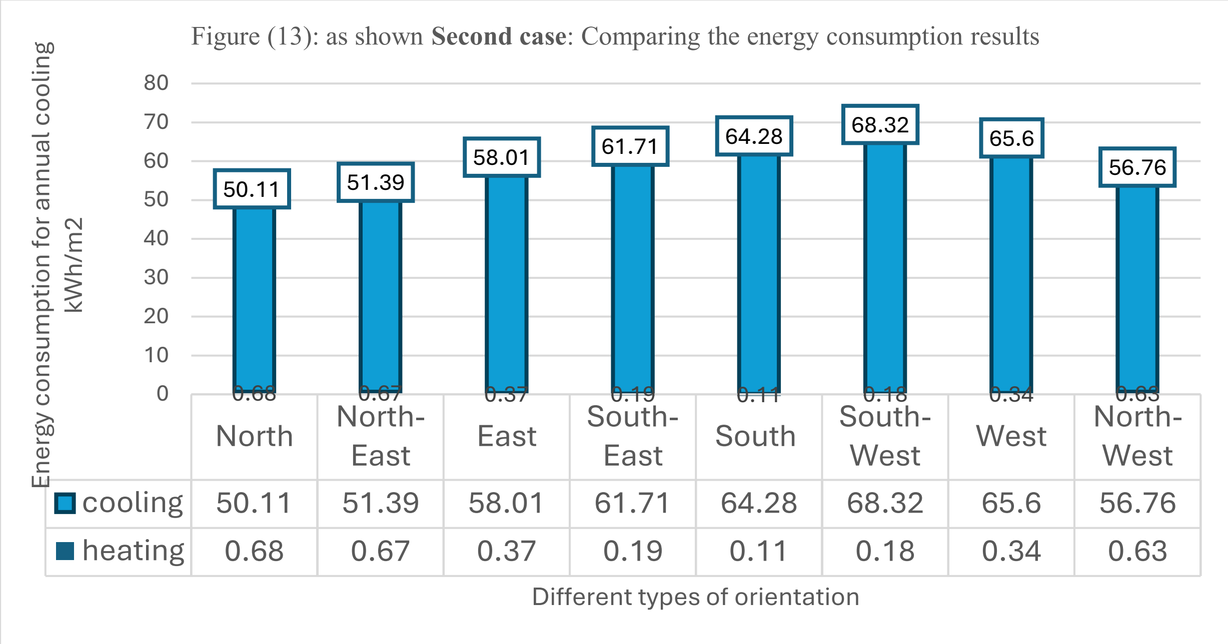

Figure (13): as shown **Second case**: Comparing the energy consumption results

Figure (13) in the second case illustrates how energy consumption rates are influenced by building orientation.

Simulation results reveal that, for faculty members' spaces in the Greater Cairo region, spaces oriented toward the southwest consume the most energy annually under the basic scenario. This scenario involves a 25 cm thick red brick wall, 6 mm single glass, a green roof, a 20 cm reinforced concrete ceiling, and 2 cm thermal insulation, leading to an energy consumption rate of 68.32 kWh per m² annually making it the highest among all orientations.

Energy consumption significantly decreases with a northward orientation, which records the lowest annual energy usage of 50.11 kWh per m² a 26.65% reduction compared to the southwest orientation. The next highest consumption is observed with a west orientation, at 65.6 kWh per m² annually, followed by south (64.28 kWh per m²), southeast (61.71 kWh per m²), and east (58.01 kWh per m²). If your building faces northwest, you're looking at using around 56.76 kWh per square meter. Facing northeast is a little better, at 51.39 kWh per square meter. North-facing buildings use the least energy. So, where your building faces really makes a difference in how energy-efficient it is, especially for those faculty buildings that all have the same design.

- The third case: Comparing the energy consumption results, as shown in Figure (14):

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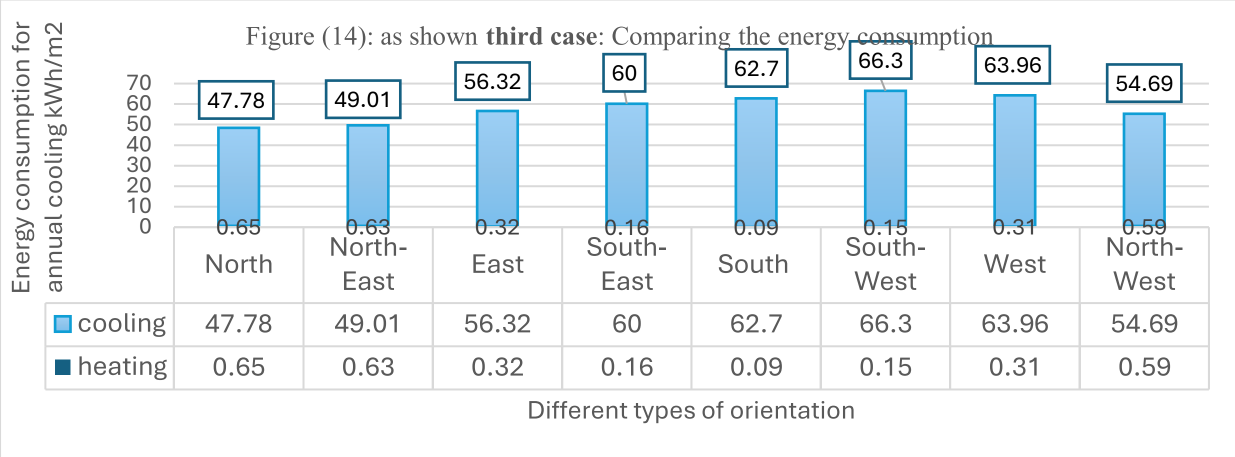

Figure (14): as shown **third case**: Comparing the energy consumption

Look at Figure 14 in Case Study 3. It's clear that energy consumption varies depending on the building's orientation.

in Greater Cairo, the models say faculty offices eat up the most power when the building faces southwest which is standard around here. The usual setup is a 25 cm red brick wall, thin 6 mm window glass, a green roof, a 20 cm reinforced concrete ceiling, and 4 cm of insulation. With all of that, the building uses 66.3 kWh /m^2. This represents the highest consumption rate among all orientations. In contrast, the lowest energy consumption is observed with the (north) orientation, which records an annual rate of 47.78 kWh / m² a reduction of 27.93% compared to the (south-west) orientation. Following this, the energy consumption rates for other orientations are as follows: (west) at 63.96 kWh/m² annually, (south) at 62.7 kWh/m² annually, (south-east) at 60 kWh/m² annually, (east) at 56.32 kWh/m² annually, and (north-west) at 54.69 kWh/m² annually. The (north-east) orientation has the second-lowest energy consumption rate after (north), at 49.01 kWh / m² annually.

-Fourth case: Comparing the energy consumption results. As shown in Figure (15):

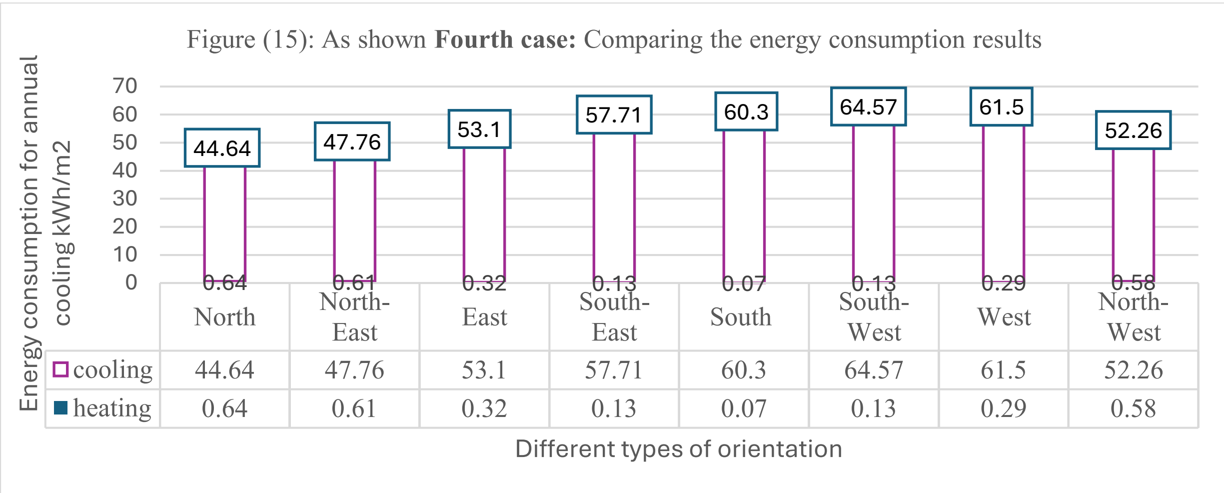

Figure (15): As shown **Fourth case:** Comparing the energy consumption results

Figure 15, presenting the results of the Fourth case, highlights how energy consumption rates fluctuate based on orientation.

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According to the simulation, the highest annual energy consumption rate for the faculty members' spaces model in the Greater Cairo region occurs with the (south-west) orientation under specific conditions: a 25 cm thick red brick wall, 6 mm single glass, a green roof, a 20 cm reinforced concrete ceiling, and 8 cm of thermal insulation. This setup uses 64.57 kWh of energy per square meter.annually. In contrast, the lowest rate is observed with the (north) orientation, achieving an energy usage of 44.64 kWh/m² annually a 30.86% reduction compared to the (south-west) orientation. Following this, energy consumption decreases across other orientations in the following order: the (west) orientation records 61.5 kWh/m² annually, the (south) orientation at 60.3 kWh/m², the (south-east) orientation at 57.71 kWh/m², and the (east) orientation at 53.1 kWh/m². The (north-west) orientation shows a rate of 52.26 kWh/m² annually, while the (north-east) orientation comes close to the north but features the second-lowest rate at 47.76 kWh/m² per year.

8- Economic Feasibility Analysis for green roofs for Higher Education Buildings

Table (2) shows Cost-Benefit Analysis for Green Roofs (Financial Analysis)

Table (2): Cost-Benefit Analysis for Green Roofs (Financial Analysis)

Item	Cost / Benefit (EGP per Square Meter)	Description and Explanation
first. Costs		
1. Capital Investment (Initial Cost)		
• Ceramic Tiling (Traditional Alternative)	**285**	The baseline cost for comparison includes essential elements such as insulation, slopes, and finishing.
• Grassy Green Surface	**210**	It offers a lower initial cost compared to the traditional alternative, incorporating insulation, a drainage layer, soil, and turf.
• Trees and Shrubs (Productive Garden)	**270**	The cost is slightly higher than a grassy surface due to the added expense of saplings, fruit trees, and more complex irrigation systems. Additional components include irrigation systems
2. Annual Operation & Maintenance (O&M) Costs	**50 - 100 / m²/annually**	fertilizers, replacement of certain plants, and seasonal labor for maintenance—costs not associated with a traditional roof.
Second. Returns and Savings		

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1. Immediate Capital Cost Savings	**+ 75 (Savings difference)**	Opting for a grassy surface (210 EGP per square meter) results in an immediate saving of 75 EGP compared to ceramic tiling (285 EGP per square meter).
2. Energy Cost Savings (Air Conditioning)	**~ 15% - 25% savings in electricity consumption**	Green roofs do a great job keeping buildings cool. Top-floor rooms stay comfortable without blasting the air conditioning, and that cuts down on yearly maintenance bills in a big way.
3. Food Production (Fruits & Vegetables)	**Market value + Intangible value**	You can harvest the crops that grow there, too. Sell them or use them in the university cafeteria either way, you save money or bring in extra cash.
4. Extended Roof Lifespan	**200% - 300% increase in lifespan**	With this setup, you're looking at about 64.57 kWh/m² for energy use. Plus, that green layer helps protect the roof's waterproofing from sun and temp changes. This little bit of protection can seriously extend your roof's life, like double or even triple the lifespan, saving you big bucks on replacements down the road.
5. Indirect Benefits (Hard to quantify monetarily but valuable)		
• Stormwater Management	-	A green roof helps reduce rainwater runoff, easing strain on local drainage systems and lowering flood risks in areas like Cairo.
• Improved Air Quality	-	It enhances air quality by absorbing CO2, producing oxygen, and capturing particulate matter—improvements that contribute to better work environments and public health.
• Aesthetic and Recreational Value	-	The creation of a green space for faculty relaxation can also boost productivity and job satisfaction.
• University Branding	-	The implementation of green roofs positions the university as an environmentally conscious and innovative institution, strengthening its reputation and attracting prospective students and researchers.
Third. Financial Feasibility Metrics		
• Payback Period	**3 - 7 years**	From a financial feasibility perspective, green roofs offer compelling metrics. For surfaces like grass, the capital savings result in almost immediate payback. When factoring in energy savings,

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• Return on Investment (ROI)	**High in the long term**	prolonged roof maintenance intervals, and food production benefits, the return on investment (ROI) grows steadily over 15–20 years.
• Life Cycle Cost Analysis (LCCA)	**Lower total cost**	Green roofs might seem pricier at first, but they can save you cash in the long run like, over 30 or 40 years. Regular roofs need constant fixes and new waterproofing, which adds up. Green roofs? Not so much. Less maintenance equals more money in your pocket over time.

9- Conclusion:

Green roofs aren't just for looks; they seriously cut down on energy and boost sustainability, which is great news, especially in harsh climates and on college campuses.

First: In Greater Cairo, the Faculty Spaces model used the most energy when the building faced southwest. We're talking about a setup with 25 cm red brick walls, 6 mm single dark glass, and a 20 cm concrete roof (UV-protected). That burned 144.64 kWh per square meter each year, hitting a peak demand of 3.303. That's the most out of all the directions they looked at.

Next, orientation was key again. Southwest-facing faculty offices in Greater Cairo sucked up the most energy annually. This setup had similar walls (25 cm red brick), 6 mm single glass, but with a green roof, a 20 cm concrete ceiling, and 2 cm of insulation. This combo used 68.32 kWh per square meter a year, which was the highest.

It's the same story in the third test. Southwest rooms, with the same walls (25 cm red brick), 6 mm single glazing, a green roof, a 20 cm concrete ceiling, but this time with 4 cm of insulation, hit the top again at 66.3 kWh per square meter.

The fourth one really shows things. Southwest rooms, with the usual walls (25 cm red brick), 6 mm single glass, a green roof, a 20 cm concrete ceiling, plus 8 cm of insulation, used 64.57 kWh per square meter each year. But the north-facing rooms? Only 44.64 kWh per square meters, that's almost 31% less than the southwest ones!

So, the long and short of it? Green roofs and some good insulation (like the 8 cm used here) can cut faculty spaces' energy use by at least 30% compared to the basic building. And that's great for saving energy.

10- Recommendations:

1. Colleges should really work on making their buildings use less energy. Green roofs? Great idea. They not only lower energy costs but also improve indoor air.

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2. Here's the main thing to remember: green roofs paired with really good insulation (at least 8 cm thick) makes a huge difference. You could save over 30% on energy compared to what you're used to.
3. But don't just pick any green roof. You gotta think about what the building can handle, how much money you have, and what you want to use the space for. If you do it right, you can change staff areas into cool places where people want to chill and hang out.
4. Also, you need a good plan to keep those green roofs in tip-top shape. That means regular stuff like watering, fertilizing, trimming, weeding, and making sure the water drains right and roots don't cause trouble. If you keep up with it, your green roof will stay helpful and look great.

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