Future Cities and Environment

TECHNICAL ARTICLE

ubiquity press

Using Green Roofs for Social Housing to Improve Energy Consumption in New Cities. (An Applied Study of Social Housing in Egypt's New Cairo City)

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ABSTRACT

Green roofs are an effective way to solve many environmental problems. New cities in Egypt have recently suffered from increasing energy consumption as a result of increasing construction density resulting from population growth, which has decreased green spaces in Egyptian cities. This paper aims to improve the energy consumption of cooling and heating energy in social housing in new urban cities in Egypt, reduce high temperatures inside and outside building, and decrease the urban heat island effect. To achieve these aims, the study suggests a method that is based on modifying the traditional roof of residential construction in Egypt by converting it to a green roof. An integrated analysis model including a strategy shows the environmental and climatic benefits of using green roofs to provide the external outdoor temperature of social housing buildings. The result revealed that green roofs, which are used by 50% of green roofs in traditional buildings, were shown to be efficient in reducing annual energy consumption by 12% and decreasing the average temperature inside buildings by 2.44°C, whereas the average temperature outside was reduced by 3°C.

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KEYWORDS:

Energy consumption; heat island; green roof; ENVI-met program; Design-builder program; cooling and heating energy

TO CITE THIS ARTICLE:

Goda, ZMA, Foda, MAM and Elsayyad, NAE. 2023. Using Green Roofs for Social Housing to Improve Energy Consumption in New Cities. (An Applied Study of Social Housing in Egypt's New Cairo City). *Future Cities and Environment,* 9(1): 2, 1–11. DOI: https://doi.org/10.5334/fce.165

1 INTRODUCTION

Egypt's cities face great challenges such as overcrowding, transportation congestion, greenhouse gas emissions, and the urban heat island effect. The Egyptian government is concerned with road planning and neglecting green spaces, and this leads to ignoring the achievement of the community's sustainability goals (Kamel et al., 2012). New Cairo is one of the new cities that is suffering from the absence of green areas in terms of quantity and distribution. The actual amount of green areas that are available per resident in New Cairo is approximately equivalent to 0.33 square meters (Attia, S., & Amer, A, 2009), but by comparing this value to large cities around the world it is still less. The World Health Organization (WHO) suggests that every city provide a minimum of 9 square meters of urban green space for each person (Morar et al., 2014); it also suggests that an ideal amount of urban green space can be generously provided as much as 50 square meters per person (Takano et al., 2002). As shown by this viewpoint, every city in the world should try hard to have a sufficient provision of urban green spaces. Residential buildings, in general, are an efficient sector of energy consumers in Egypt, accounting for approximately 40% of total energy consumption for buildings. This paper will investigate if the green roof solution would be effective in Egypt to keep buildings cooler, use less energy and increase the percentage of green areas (Fahmy et al., 2018).

The design of an effective green roof system is a complex procedure that depends on several factors of sustainability, including social, cultural, climatic, and environmental considerations (Williams et al., 2010). Green roofs are one of several passive cooling methods that are known and used in many countries. Green roofs are classified as intensive or extensive based on plant height. The extensive type has a growing medium thickness of less than 20 cm, while the intensive type has a thickness of more than 20 cm (Jones & Alexandri, 2006). Green roofs are being considered by building owners as a means to decrease energy consumption and CO_2 emissions. Green roofs are effective at reducing urban air temperatures and have a sufficient effect on air quality by improving the absorption of pollutants (Theodosiou, 2003).

The purpose of this paper is to study the impact of green roofs on the electricity consumption of social housing by analyzing their impact on annual energy usage and air temperature in a typical New Cairo neighborhood by using a Design-builder simulation program and ENVI-met program. This research's empirical studies are based on computer simulation and the evaluation of software products. The first software used in this project is Design-builder 4.5, which is one of the building performance simulation tools that includes over 389 different tools (Attia et al., 2012). Design-builder can be utilized at any stage of the design process. It also has a visually oriented interface that is used by architects. The case study was created and edited with the Design-builder software to measure the cooling and heating consumption of a traditional roof and a green roof. Finally, the results were entered into Microsoft Excel software and displayed as tables and charts. The second software used in this project is ENVI-met, which is a critical tool for analyzing micro-scale thermal exchanges in urban environments. It is a three-dimensional simulation model for top-layer interactions throughout urban environments (Sharmin et al., 2017). This encourages a detailed evaluation of microclimatic changes, which are especially relevant to urban geometry and significant for comfort considerations and the analysis of small-scale interactions between plants, specific buildings, and surfaces.

2 PREVIOUS STUDIES

Many studies have been conducted on the use of green roofs in different locations (Radwan, 2017), which revealed that the huge rooftop areas of buildings in Egypt were neglected for storing furniture, building materials, and food waste. These areas could be utilized to create green areas or social spaces that can be used by people in a better way. Green roofs are an idea that could be easily applied in Egypt to solve the problem of the absence of green spaces. Ragab, Ayman, and Ahmed Abdelrady discussed the impact of several types of green roofing with varying thermal conductivity on energy consumption for cooling school buildings in Egypt (Ragab & Abdelrady, 2020). The results showed that the proposed green roof types saved between 31.61 and 39.74% of energy. Green roofs were shown to be more efficient at reducing energy consumption as compared with traditional roofs, especially in hot climates. Andrews revealed that California State University San Marcos completed a new university student union in 2014 that included a 223 m^2 live roof system on its upper terrace. The green roof met the university's goals for aesthetic design, energy efficiency, and stormwater management through its selection of materials and local flora. This project demonstrates the successful implementation of a green roof in an arid climate (Andrews III, 2016).

As seen above, green roofs play an invaluable role in the environment. This paper focuses on the use of green roofs in social housing buildings in Egypt, which has not previously been addressed to decrease electricity consumption and improve temperatures.

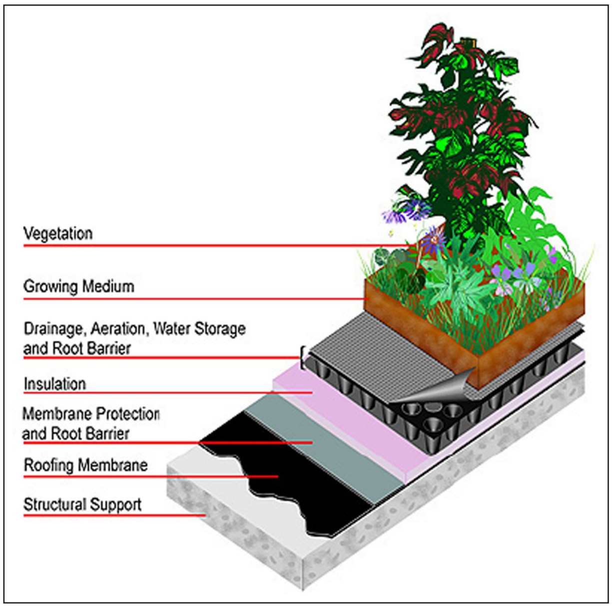


Figure 1 Depicts the various components of a living roof system (Latshaw et al., 2009).

3 MATERIALS AND METHODS

This study includes two parts: the first presents the theoretical framework for green roofs. It describes the layers that transform a traditional roof into an environmentally green roof. It will also present the definition of green roofs, their benefits, their types, and the goal of their use. The second explores a case study in New Cairo city by examining energy consumption and the indoor comfort temperature of residential units using the Design-Builder simulation program, while the ENVI-met program will investigate outdoor comfort temperatures.

3.1 THEORETICAL FRAMEWORK OF GREEN ROOFS

- Items for green roofs
  Green roofs consist of agricultural components and construction roofing systems. A green roof has three layers, starting at the bottom with structural elements, a growing reservoir (which always includes soil); and plant shade (components chosen for the particular application), as shown in Figure 1 (Peck et al., 1999).

- Types of green roofs
  The first type of green roof system is an extensive green roof system, which requires minimal maintenance techniques and may not require any irrigation at all. This type has less weight and less soil, which helps reduce costs and roof loads. The second type of green roof system is the semi-intensive living roof, which is also known as a simple living roof, and it is planted with horizontal cover plants. The third type of green roof is the intensive green roof, as shown in Figure 2, which includes growth medium, plantation, and irrigation and must be implemented above a concrete floor base (Karachaliou et al., 2016).

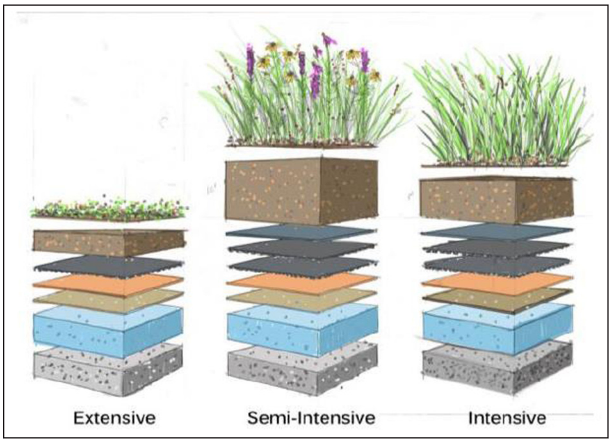


Figure 2 Intensive, semi-intensive and extensive types (Mohamed et al., 2019).

- Advantages of green roofs
  1. Air Quality Improvements: Plants on green roofs are an effective environmental filter. A green roof not only reduces the temperature but also filters the air that passes over it. In addition, it removes up to 95% of heavy metals such as cadmium, copper, and lead (Peck et al., 1999).
  2. Benefit from the produce: A green roof can produce a variety of flowers, vegetables, and herbs. On your green roof, you can also grow a variety of herbs with medical potential. Additionally, you have the option of using or selling these herbs. On your green roof, you can produce fruits and vegetables. You can live an exceptional lifestyle and spend less money if you use the vegetables and fruits that your green roof can provide (He & Jim, 2010).
  3. Mitigation of the heat island effect: Green roofs absorb solar radiation that would strike dark roof surfaces, improving energy conservation. They deflect solar radiation so that it does not generate heat. It also reduces the amount of electricity used by air conditioners and the rate at which chemical processes produce pollutants like ground-level ozone (He & Jim, 2010).

- Disadvantages of green roofs
  1. More expensive than traditional roofs: Green roofs tend to be slightly more expensive than standard roof options. This is due to the added weight of the plants which need more support.
  2. Require extra maintenance: Your green roof should be maintained in the same manner as a garden, which includes regular watering, fertilizing, and weeding.

3. Green roofs require more weight than traditional roofs because they need more structural support. Therefore, some roofs need to be retrofitted to handle the increased pressure.

3.2 CASE STUDY

The case study method relies on simulation software from the Design-builder program and ENVI-met to compare two buildings. One of them has a traditional roof, whereas the other has a green roof. The Design-Builder will show how much energy is consumed each year and how comfortable the temperature is inside. The ENVI-MET program will show how comfortable the outdoor temperature is and how fast the wind is.

This case study is located in New Cairo, Cairo Governorate, Sakan Misr Serial 14, at latitude 29.98035 N and longitude 31.44269 E, northeast of Greater Cairo, as shown in Figure 3. A residential building consists of five floors. Each floor has four units with an area of approximately 95 m^2. Each unit contains three bedrooms, a kitchen, a bathroom, and a living room, as shown in Figure 4.

The simulation in the Design-builder program includes modeling building performance for cooling and heating consumption, then identifying the green layer, which reduces energy use and could improve the indoor thermal comfort of the building.

An ENVI-met program is a critical tool for analyzing micro-scale thermal exchanges in urban environments. The ENVI-met was selected to evaluate the outdoor thermal comfort simulation for a traditional building without a green roof (case A) and a traditional building with a 50% green roof (case B), which is measured on June 21 at 2 p.m. Air temperature values range between 34.45°C and 37.65°C for case A, and air temperature values range between 32°C and 35.5°C for case B.

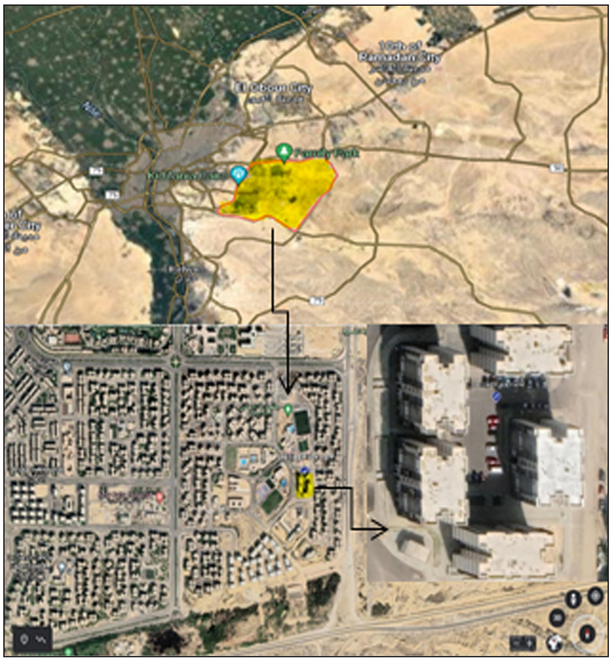


Figure 3 Residential buildings in New Cairo (via Google Earth).

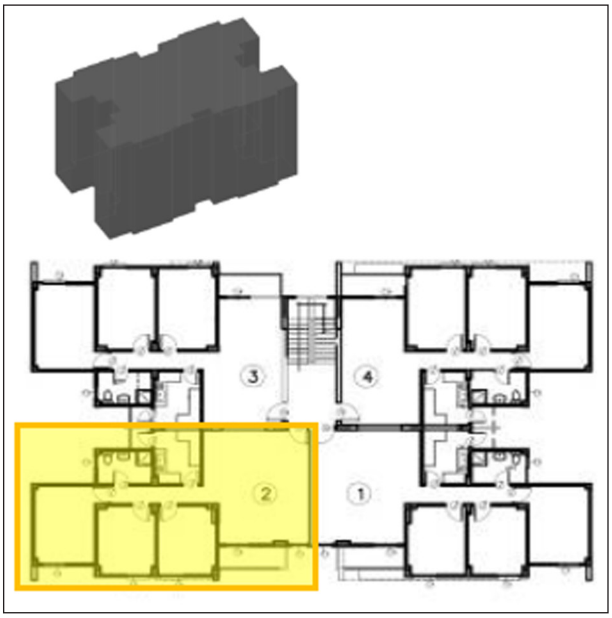


Figure 4 Unit of residential building (By Author).

4 DATA ANALYSIS AND RESULTS

4.1 SIMULATION INPUT DATA IN THE DESIGN-BUILDER PROGRAM

For this study, unit number 2 of the residential building was selected, as shown in Figure 4. Simulation results in the Design-Builder program are divided into two sections. The first section discusses the annual energy consumption of roof layers for a traditional building as shown in Figure 5 and green-roof layers for a building as shown in Figure 6. The second section identifies the indoor thermal comfort temperature of a traditional building and a green roof building. The paper will replace 50% of a standard roof with a green roof and compare the rooftop before and after using a green roof. The 50% with a green roof has been chosen to use the other part of the building for some other services, such as using it to put a water tank or satellite dish. The energy consumption per year was analyzed from January to December. The results of the building model were used to compare a traditional building without a green roof (case A) and a traditional building with a 50% green roof (case B).

4.1.1 Annual Energy Consumption Analysis

Table 1 shows the cooling consumption, heating consumption, and total energy consumption of a traditional building without a green roof (case A) and a traditional building with a 50% green roof (case B) to compare the two cases.

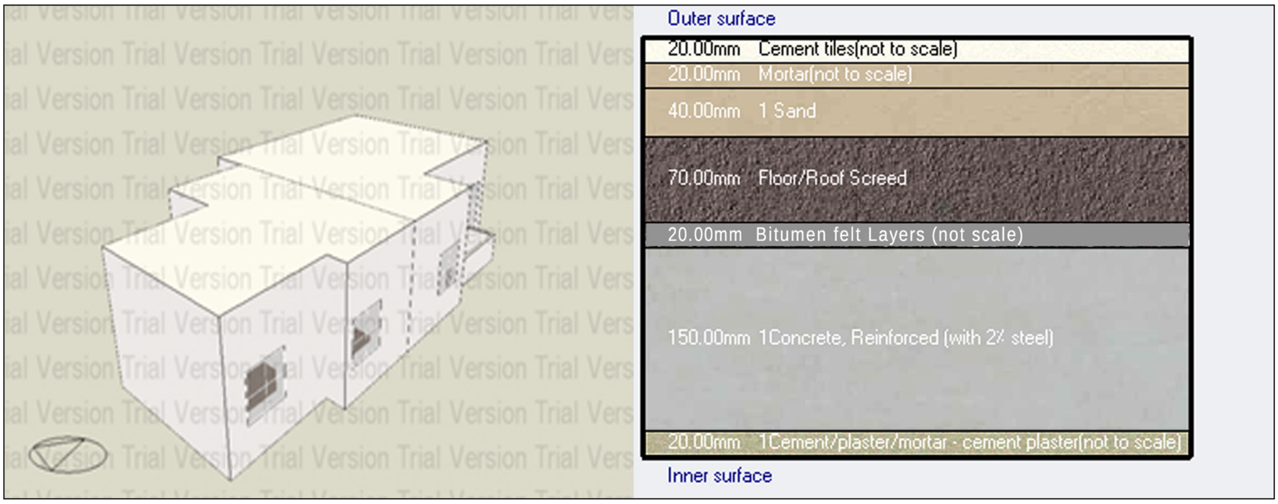


Figure 5 The layers material roof of traditional case (Design-builder Screen shoot).

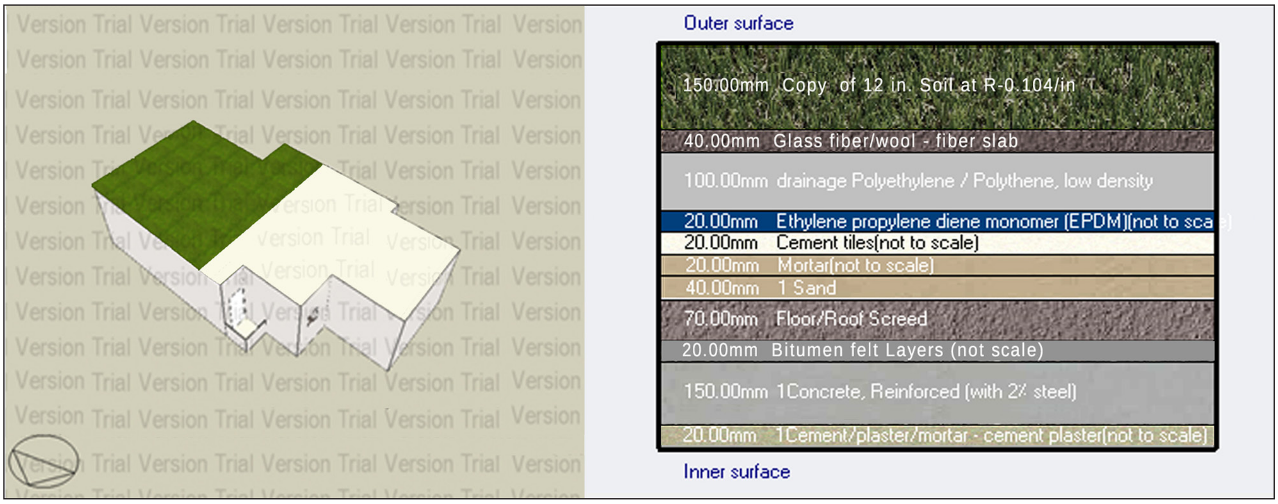


Figure 6 The layers material roof of 50% green roof case (Design-builder Screen shoot).

ENERGY CONSUMPTION	CASE A (TRADITIONAL ROOF)	CASE B (50% GREEN ROOF)
Cooling Consumption	8367.32 k.w.h	7365.43 k.w.h
Heating Consumption	2078.91 k.w.h	1817.51 k.w.h
Total energy Consumption	10,446.23 k.w.h	9,182.94 k.w.h
Total energy Saving	10,446.23 – 9,182.94 = 1,263.29 k.w.h	

Table 1 A comparison between the traditional case and the case with an incorporated green roof.
Source: The researcher based on the data outputted from Design Builder (version 6.1.3.008).

The simulation results as shown in Figure 7 showed that the green roof reduced the annual energy consumption for cooling and heating as compared to the traditional roof, as shown in Table 1. For green roofs, annual energy consumption is reduced by 12%. The average cooling energy savings decreased from 8367.32 k.w.h to 7365.43 k.w.h by 11.9%, whereas the average heating energy savings decreased from 2078.91 k.w.h to 1817.51 k.w.h by 12.5%. So, the green roof method decreases annual energy consumption better than the traditional roof.

4.1.2 Indoor thermal temperature Analysis

Table 2 shows the air temperature, operative temperature, and outside dry bulb temperature of a traditional building without a green roof (case A) as shown in Figure 8, and a traditional building with a 50% green roof (case B) as shown in Figure 9 to compare the two cases. The meaning of operative temperature is the combined effects of the mean radiant temperature and air temperature (Tdb). But the outside dry bulb temperature is the temperature of air that does not take into consideration any moisture content. An ordinary thermometer placed indoors or

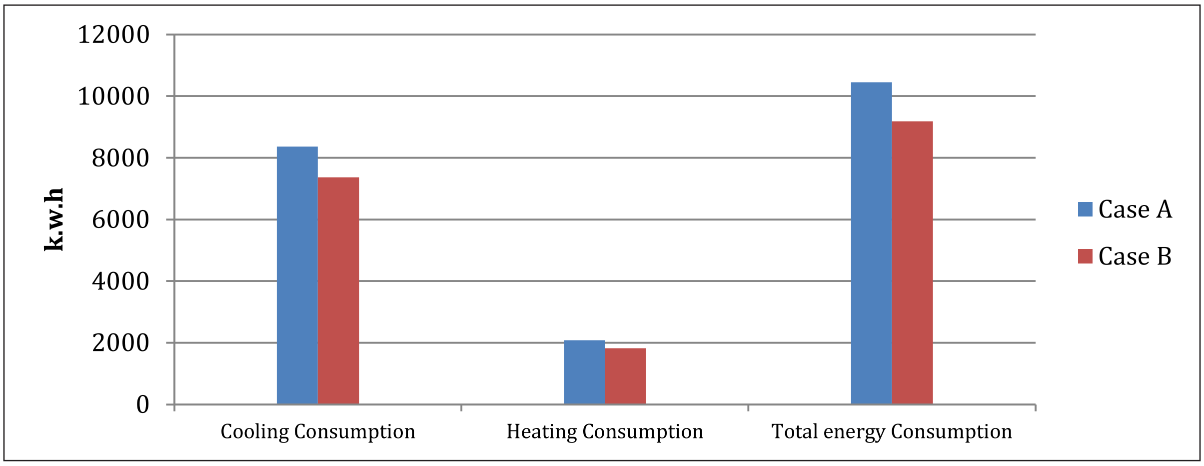


Figure 7 Annual cooling, heating, and total energy consumption for case A and case B (By Author).

THERMAL TEMPERATURE	CASE A (TRADITIONAL ROOF)	CASE B (50% GREEN ROOF)
Air Temperature	27.35°C	25.46°C
Operative Temperature	28.31°C	25.87°C
Out Side Dry Bulb Temperature	30.18°C	27.21°C
Discomfort hours	1.53	0.00

Table 2 Comparative between thermal temperature between case A (traditional roof) and case B (50% green roof) on June 21. Source: The researcher based on the data outputted from Design Builder (version 6.1.3.008).

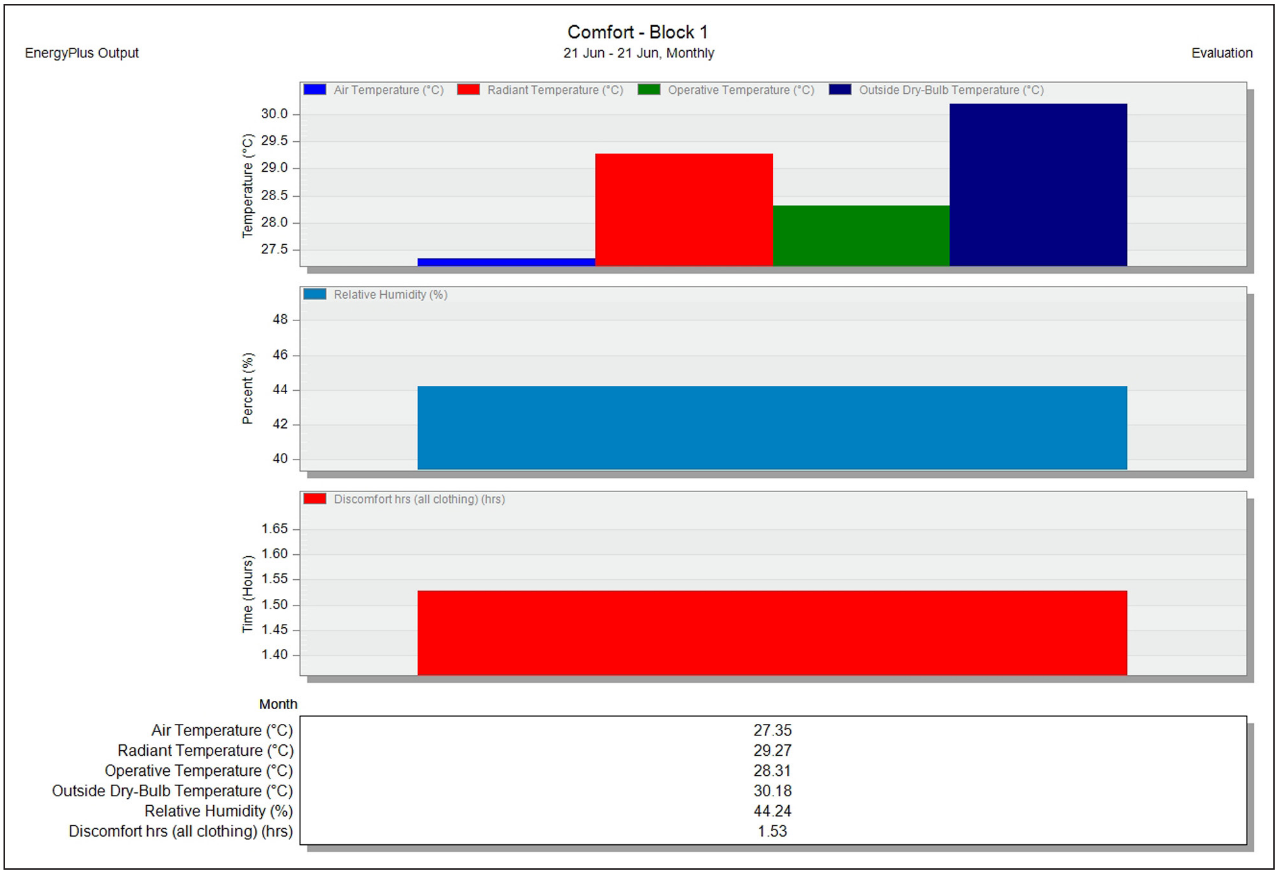


Figure 8 Air temperature, operative temperature, and outside temperature for case A without a green roof (Design-builder Screen shoot).

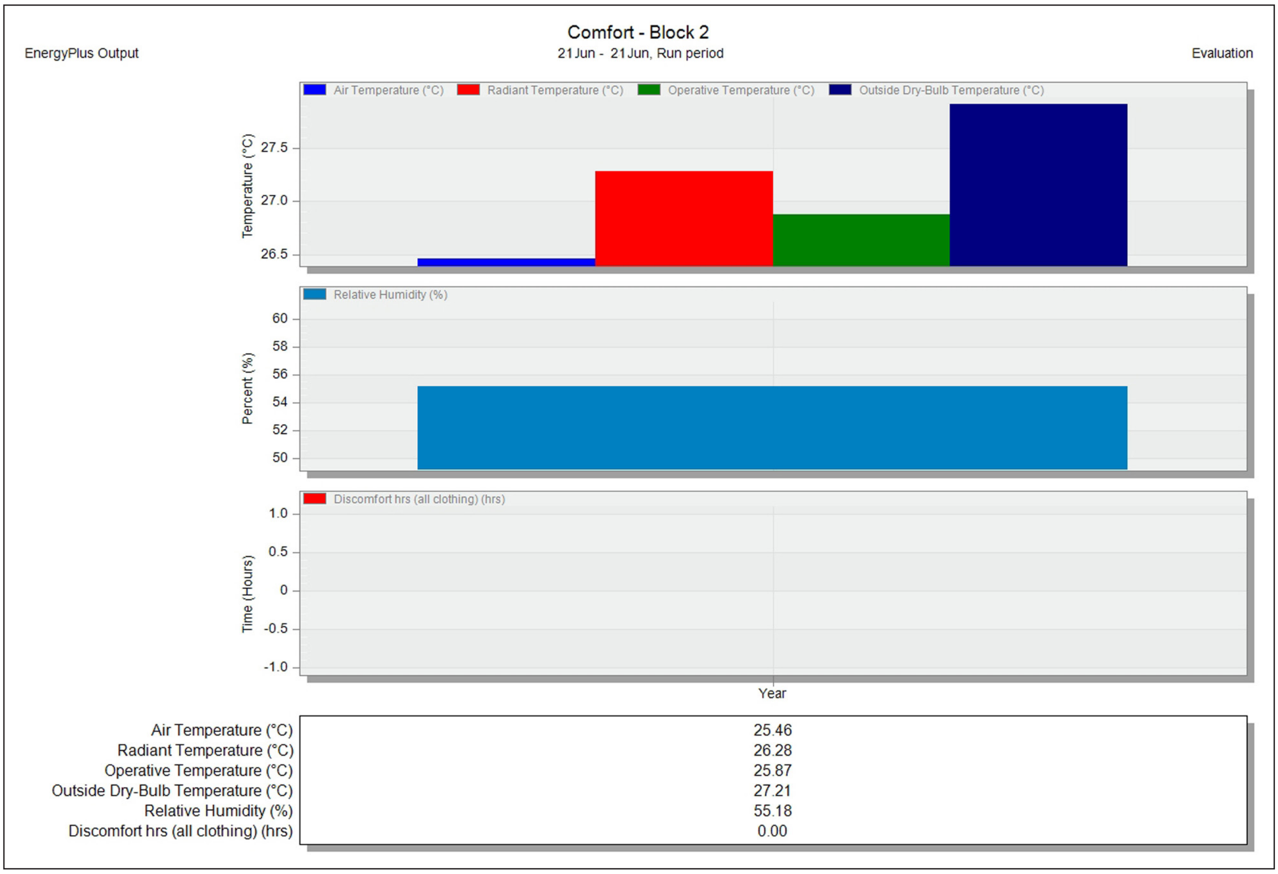
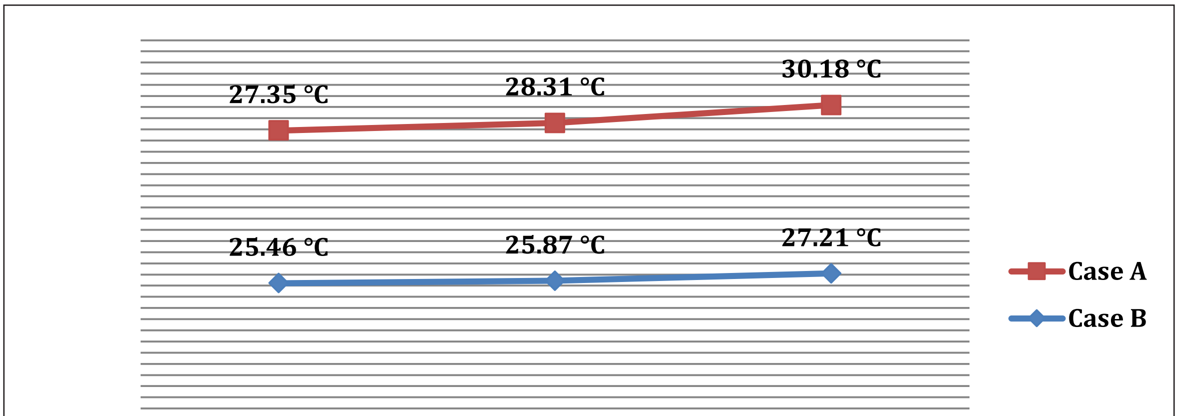


Figure 9 Air temperature, operative temperature and outside temperature for case B with a green roof (Design-builder Screen shoot).



	Air Temperature (°C)	Operative Temperature (°C)	Out Side Dry Bulb Temperature (°C)
Case A	27.35	28.31	30.18
Case B	25.46	25.87	27.21

Figure 10 Air temperature, operative temperature, and outside temperature for case A and case B (By Author).

outdoors will measure the dry bulb temperature. The amount of moisture in the air, called relative humidity, cannot be determined from the dry bulb temperature alone.

According to the program results, on June 21, the operative temperatures were examined for a traditional roof and a green roof model. Results showed that the operative temperature for case A without a green roof achieved 28.31°C on June 21, as shown in Figure 8, while case B with a green roof achieved 25.87°C on the same day, as shown in Figure 9. The difference between the traditional roof and the green roof model was 2.44°C, as shown in Table 2 and Figure 10. These results reflected the effectiveness of green roofs on hot buildings.

4.2 SIMULATION INPUT DATA IN THE ENVI-MET PROGRAM

In this part, the simulation software tool of the ENVI-met program examines a cluster of residential buildings in New Cairo City. A cluster consists of five buildings and a general service parking area, as shown in Figure 11. The simulation sequence goes as follows: First, the base case will be modeled in ENVI-met with min. air temperature 28°C, max. air temperature 38°C and windspeed 3.5 m/s as shown in Figure 12. After that, the green roof will be added with selected material in the ENVI-met program as shown in Figure 13 to compare the effects of adding vegetation to 50% of traditional roofs to clarify the impact of green roof buildings on temperature reduction. The simulation was measured at 2 p.m. on June 21.

The simulation results indicated that the green roof effectively reduced the outdoor air temperature, as shown in Table 3 and Figure 16. The air temperature

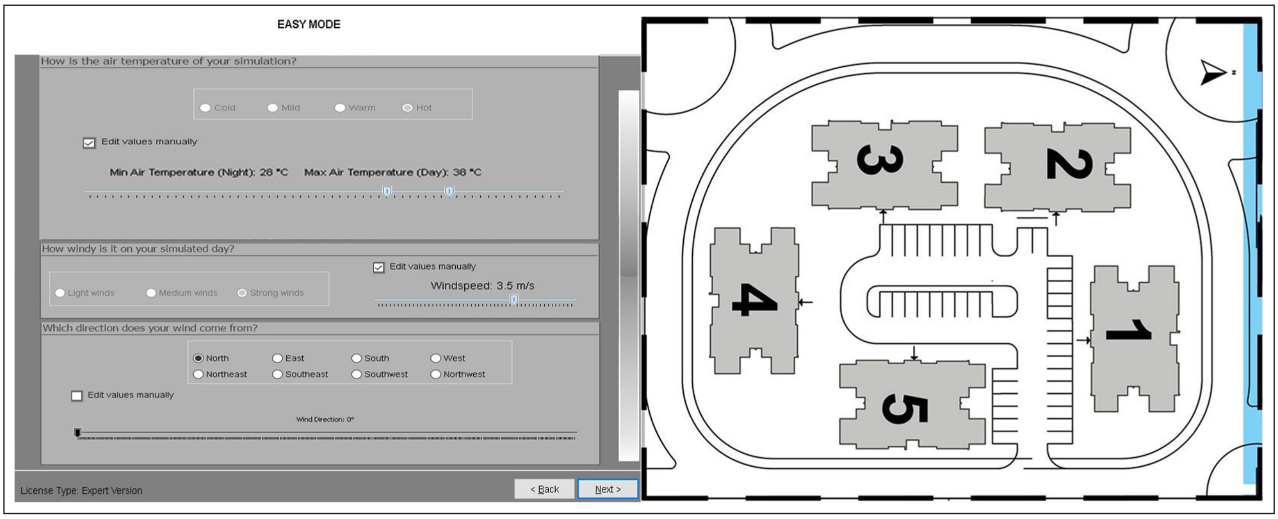


Figure 11 A cluster of residential buildings in New Cairo City (By Author).

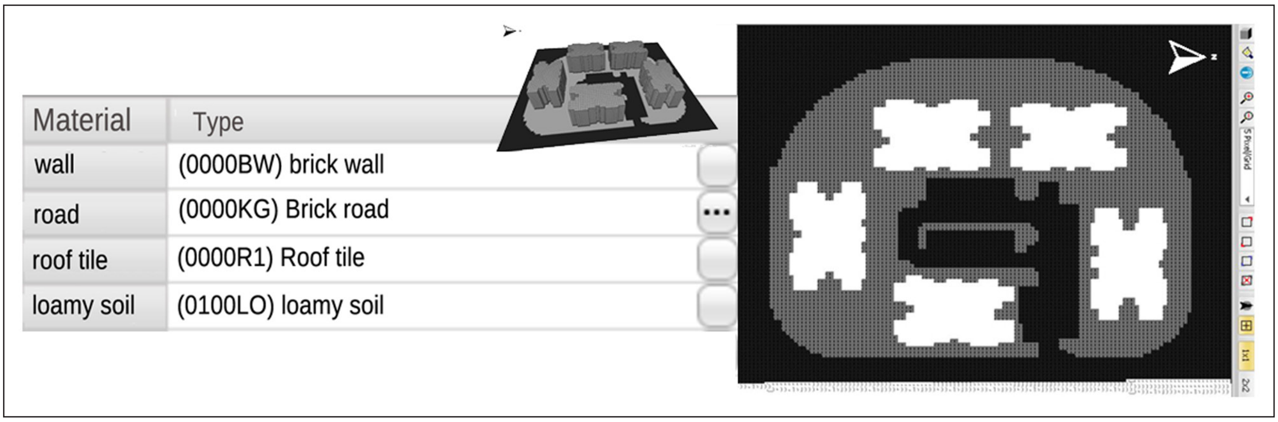


Figure 12 A base case cluster modeling of residential buildings (ENVI-met Screen shoot).

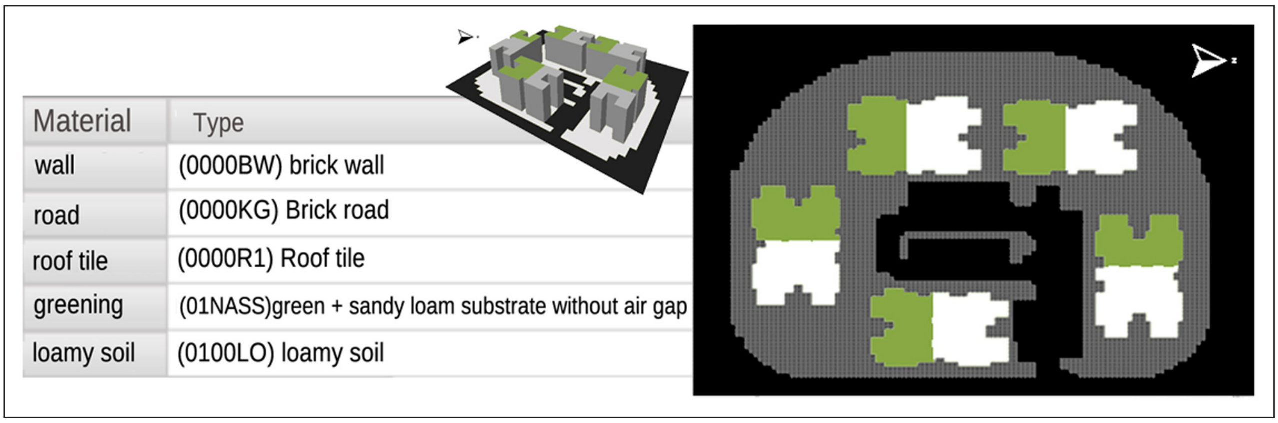


Figure 13 A green roof cluster modeling of residential buildings (ENVI-met Screen shoot).

OUTDOOR AIR TEMPERATURE	CASE A (TRADITIONAL ROOF)	CASE B (50% GREEN ROOF)
Min. Air Temperature	34.45°C	32°C
Max. Air Temperature	37.65°C	35.50°C

Table 3 Comparative between the air temperature between case A (traditional roof) and case B (50% green roof) on June 21. Source: The researcher based on the data outputted from ENVI-met (version 4.4.4).

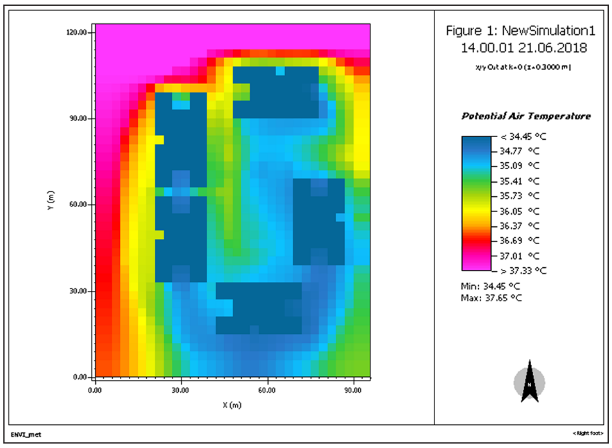


Figure 14 ENVI-met result of air temperature at 2 p.m. on June 21 for case A without a green roof (ENVI-met Screen shoot).

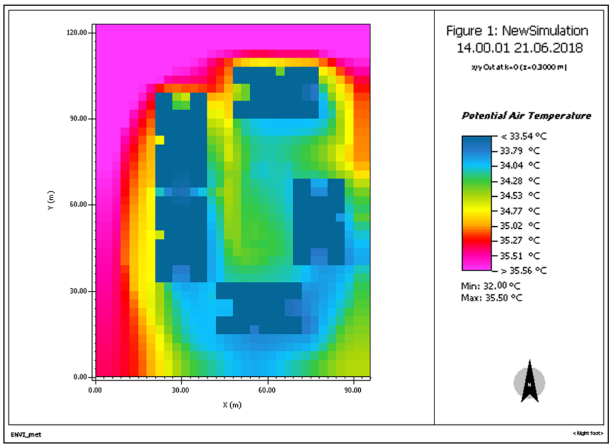


Figure 15 ENVI-met result of air temperature at 2 p.m. on June 21 for case B with a green roof (ENVI-met Screen shoot).

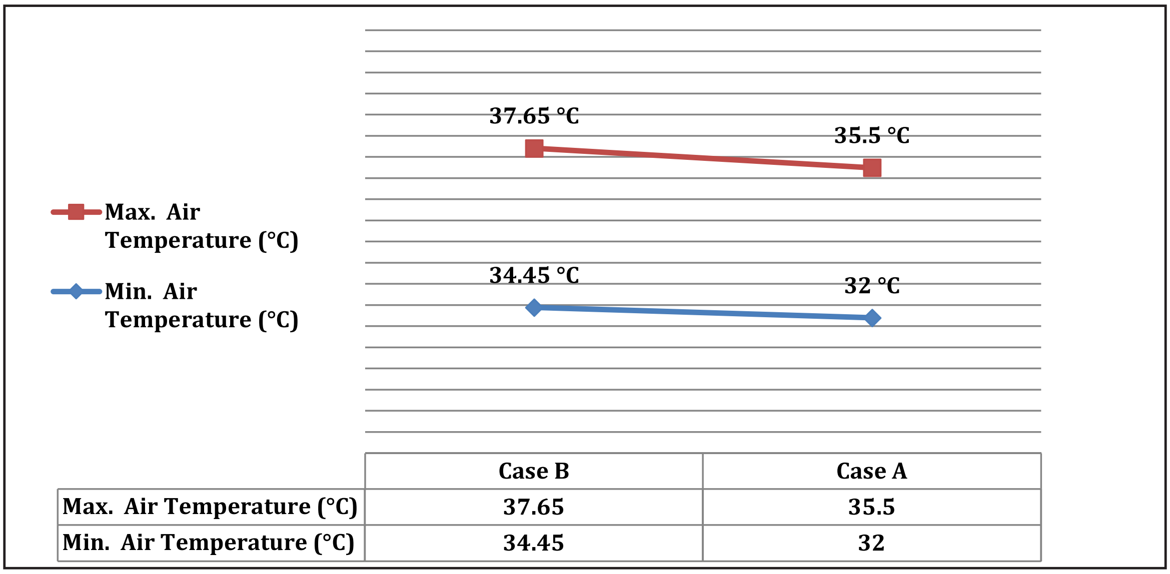


Figure 16 Min. Air Temperature and Max. Air Temperature for case A without a green roof and case B with a green roof on June 21 (By Author).

values range between 34.45°C and 37.65°C for case A, as shown in Figure 14, whereas the air temperature values for case B range from 32°C to 35.5°C, as shown in Figure 15.

5 CONCLUSION

Green roofs are an appropriate method of saving energy in hot climates. This study was conducted to improve the energy efficiency of indoor areas, the air quality of indoor buildings, and the air temperature of outdoor buildings. The results of this study show that green roofs can reduce energy consumption in hot climates. The case study showed that the energy consumption for the base case was 10,446.23 K.W.H., while the energy consumption for using 50 percent of the green roof was 9,182.94 K.W.H. The energy savings for the investigated green roof method are estimated to be in the range of 12%. Additionally, green roofs are efficient at reducing and improving air quality and microclimate performance. The average temperature inside buildings was decreased by 2.44°C, whereas the average temperature outside was decreased by 3°C.

COMPETING INTERESTS

The authors have no competing interests to declare.

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TO CITE THIS ARTICLE:
Goda, ZMA, Foda, MAM and Elsayyad, NAE. 2023. Using Green Roofs for Social Housing to Improve Energy Consumption in New Cities. (An Applied Study of Social Housing in Egypt's New Cairo City). *Future Cities and Environment,* 9(1): 2, 1–11. DOI: https://doi.org/10.5334/fce.165

Submitted: 23 August 2022 **Accepted:** 20 December 2022 **Published:** 12 January 2023

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