Thermal Performance of the Extensive Green Roofs in Hot Dry Climate

Ashraf Muharam, ElSayed Amer, Nasser Al-Hemiddi

King Saud University, Dubai

Abstract—*Green roofs have been used as an environmentally friendly product to encourage sustainable construction. Green roofs have a variety of advantages, such as reducing the energy consumption for cooling systems. The performance of these systems depends on the climates.*
The energy consumption for heating and cooling inside the residential and commercial buildings reach to 70% in hot dry climates such as Riyadh city which the temperature reached 50°C. So, the study aim to examine the efficiency of Extensive Green Roof system for reducing energy consumption of cooling in buildings in hot dry regions by compared it is performance with concrete roof system. The experimental validations were applied on residential building in Riyadh city during the summer season in 2014. The study used two rooms for testing thermal performance - the first room with extensive green roof system and the second room with concrete roof system. The results showed that using environmentally friendly insulation (Extensive Green Roof System) could reduce 12% to 33% for energy consumption of air conditioning in hot dry climates.

Keywords— Thermal Performance, Green Roof System, Concrete Roof System, Hot Dry Climate, Internal Temperatures.

I. INTRODUCTION

Green roofs (ecoroofs , sky gardens or sky-rise gardens) are simply vegetated roofs that covering building's roofs. Green roofs are one of the green design practices that aim at protecting our environment (sustainable life) by reducing the developmental impacts on our communities. Germany is the oldest country that introduced the true modern green roofs in the early 1970s. After that, when green roofs systems were enhanced to ensure safety and long life span, the acceptance of green roofs in the European marketplace came in the 1980s, [41].

In Riyadh city buildings consume about 70 % of the total energy used in the building for cooling and heating because of the Riyadh's harsh and tropical climate. This percentage is higher than the standard percentage of energy consumption in other countries which is from 35% to 55 %. However, several studies found out that green roofs is an energy efficient solution compared to conventional roofs. Because of the benefits of green roofs, many governments encouraged the use of green roofs in the houses by reducing taxation for land owners as in the New York city [3]. In Saudi Arabia, the government improved the laws of the building process to link the process of getting license for building with the insulation efficiency [42]. From this point of view, the importance of green roofs will emerge because it is one alternative technologies and environmental-friendly insulation.

The study aims at examining the efficiency of Extensive Green Roof system for reducing the indoor temperature which, in turn, will reduce the energy consumption of cooling in buildings during the summer seasons in Riyadh city. The research method depends on the mixed scanning approach by reviewing the research problem in the available literature and comparing the theoretical finding with experimental validations. The experimental validations were applied on residential building in Riyadh city during the summer season in 2014. The study used two rooms for testing thermal performance - the first room with extensive green roof system and the second room with concrete roof system.

II. LITERATURE REVIEW

Green roofs are classified as intensive roofs and extensive roofs, according to their purposes and characteristics. Intensive roofs are associated with roof gardens ; requiring a reasonable depth of soil from 150mm to 1200mm, which will support larger plant life and require constant maintenance. Extensive roofs have a relatively thin layer of soil between 50 and 150mm of growing medium to support plant life. They are designed to be virtually self-sustaining ,therefore they require low maintenance [15]–[32]. Also, there is a significant difference between green roof weight. The typical weight of extensive green roofs is from 20 kg/m2 to 169 kg/m2 while the weight of intensive green roofs is from 290 kg/m2 to 968 kg/m2 [34]–[35]. Also, the cost of intensive green roofs is more expensive than extensive green roofs. However, the probability of profits being earned from green roofs is much higher than the potential financial losses [4]–[5]–[6].

The systems of Green roofs: There are three systems or technologies that can be used for green roofs. The first one is the Complete System. This type of system can be added to the roof either during or after construction. Although this system does contribute to the highest structural loading, it increases the building cost. The second one is the Modular System, the plants in this type are typically grown inside trays offsite, so it does not built into the roof. The third one is the Pre-cultivated System (Vegetative Blanket). This type typically come in rolled that can be placed on any roof [11].

A. The Benefits of Extensive Green Roofs

Green roofs have been used as an environmentally-friendly product to encourage sustainable construction. Green roofs have a variety of advantages, as following:

Runoff Management: The storm water runoff reduction achieved by green roofs is strongly related to local climate conditions. The total relative retention was significantly higher in the summer season than in the winter season [33]. This result was supported by the study of [38] which found that under the baseline climate, extensive green roofs were demonstrated to be efficient tools for decreasing storm water runoff (61–75%) in summer and (6–18%) in winter.

Removing Air Pollutants: Many studies found out that extensive green roofs are reducing air pollution and are still playing a supplementary role in regards to air quality. It is estimated that 2000 m2 of the uncut grass on a green roof can remove up to 4000 kg of particulate matter. An amount of 19 m2 of extensive green roofs can remove the same quantity of pollutants as a medium sized tree[28].

Reducing Noise: Green roofs reduce the noise and have important parameters for the acoustical quality of housings. According to the study of [28], the results indicated that green roof improvement exceeding 10 dB was found in sound frequencies between 400 Hz and 1250 Hz.

The Urban Wildlife and the Materials Durability: Extensive green roofs enhances urban wildlife diversity and materials durability. According to [8], it was found out that green roof could mitigate the loss of ecosystem services in urban areas, and diverse green roof plantings may support more abundant and diverse fauna. In addition, the expected lifespan of green roofs ranges from 40 to 55 years, while the life of conventional roofs is about 20 years [3]–[31].

The Urban Heat Island Mitigation: The green roof can mitigate urban heat island effect. According to [4], Rosenzweig et al. suggested that if New York city covers 50% of roof tops with green roofs, the temperature difference between the city and its surrounding may decrease by 0.8 °C. That explains why urban areas have higher temperature than rural areas because of density of trees in rural areas. So, with a low percentage of plant cover, green roofs can reduce the overheating of air in cities [38].

Saving Energy: The higher urban temperatures increase the energy consumption for cooling and raise the peak electricity demand. For example, the peak electricity load will increase 1.5– 2% for every 1° F increase in temperature in US cities with population larger than 100,000 [32]. The specific energy benefits of green roof depend on the local climate, the components of green roofs and the characteristics of building. According to [1]–[2]–[26] found out that green roofs can reduce the energy consumption of cooling from 1% to 73%, such as 1% and 11% for Tenerife, 0% and 11% for Sevilla, 2% and 8% for Rome, and 60% of external energy contributions in a tropical climate in Singapore. And in Toronto, the building overall energy consumption was reduced by 73%, 29%, and 18% for a building top floor, first, and second floors below.

According to [9]–[12]–[27]–[32]–[36]–[37]–[38], Green roofs are better than conventional roofs (concrete slab, bituminous roof, ceramic and metallic roofs, and conventional gravel ballast roof) and green roof are as much as cool roofs in reducing energy consumption in the buildings. When considering the benefits of green roofs, the net present value may be 30–40% less than that of conventional roofs.

B. Thermal Performance of Extensive Green Roof

The thermal capacity defines the thermal performance of the green roofs. Increased thermal capacity of the roofs leads to a maximization of the stored heat, reducing peak surface temperatures, and decreasing the sensible heat flux period [32].

According to the studies of [6]–[14]–[17]–[20], the green roofs are more effective in reducing heat gain than heat loss. The measurement found that the heat gain through the green roof was reduced by an average of 70–90% in the summer and heat loss by 10–30% in the winter. Extensive planted roofs lower indoor air temperature from 1°C to 10°C in summer during the warmest daytime hours, and they can reduce air temperature at 10 cm height by 0.7 ◦C, with no significant effect at 160 cm.

Climate plays a very important role in the mitigation of the potential of green roofs. In sunny climates, reflective roofs have an important advantage. While in moderate and cold climates, green roofs seem to present higher benefits [32]–[39].

Many studies have investigated the impact of green roofs characteristics (green canopy, soil and roof support) on the temperature of the building surface temperatures, on the amount of heat fluxes in a building, and on the amount of the used energy when using the system of green roofs. The experimental results of [10] confirm that the plant canopy reflects 13% of incident global solar radiation and absorbs 56%, so that the solar radiation entering the system can be then estimated as 31% of the incident global solar radiation. The thermal behavior of a green roof is a complex phenomenon (such as shading, evapotranspiration, conductivity and absorption) and involves combined heat and mass transfer exchanges.

According to [2]–[16]–[18], different plants have different results at the levels of effectiveness. As the amount of the coverage increased, the magnitude of the temperature changed (decreased). Furthermore, the results being drawn from the study of [21] showed that the effects of temperature reduction decrease with plant height. According to [34], the water requirements of the plant species is from 2.6 to 9.0 L/m2per day, depending on the plant kind and the surrounding conditions. However, the study of [7] indicated that gray water and roof runoff can be recycled for household uses such as toilet flushing, laundry water, and outdoor irrigation. A residential home can reduce its typical potable water consumption by 31% when using gray water for irrigation and toilet flushing.

Soil acts as an inertial mass with a high heat thermal capacity, high time lag effect, and low dynamic thermal transmittance. The thermal performance of the soil depends on some variables: soil depth, water balance, and organic matter [2]–[25]. First soil depth: the experiment of [13] showed that the thermal insulation performance does not require a thick soil. A thin soil layer of about 10 cm is sufficient to reduce substantially heat penetration into the building. Furthermore, the study of [30] found that deeper media depths allow for greater diversity in plant material, generally encourage healthier plants with greater biomass, increase water holding capacity, and act as a buffer in changing winter temperatures. Second, water blance: The study of [14] indicated that soil thermal property is largely depending on its water content. Water could enhance soil thermal conductivity and heat capacity, facilitating downward heat transmission, storing heat and suppressing soil temperature fluctuation. In contrary, the studies of [25]–[26] found out that the thermal conductivity increases with the water content of the substrate and thus reduces their thermal performance. The average error without the water balance is 2.9 °C. Then it is 0.8 including the water balance. Third organic materials: According to the literature review of [24], the main benefits of using organic matter are that it maintains good soil structure. Although using organic matter has advantages, the guidelines of green roofs in German recommends to use 4–8% organic matter for extensive green roofs because of organic matter breaks down over time and causes the substrate to shrink.

An extensive green roof system usually consists of: plants, a light substrate, and an optional filter and drainage layer [35]. Although green roofs have become a sustainable construction that offers interesting environmental advantages over traditional roofing solutions, green roofs design is still based on conventional materials such as (Filter layer) which used Polyethylene or other artificial materials. The green roof's thermal behavior impacted due to the materials properties. For example, the temperature of the green roofs that containing a plastic layer in the drainage material was higher as if stones was used in the drainage layer. Around 2-3 °C higher in a wet state, and 1-2 °C higher in a dry state [42]. In addition, the study of [22] indicated that the use of recycled construction waste for green roof construction has wider environmental implications in terms of reducing the amount of landfill waste.

III. METHODOLOGY

The method [23] being adopted in this research depends on the mixed scanning approach which involves reviewing the research problem in the literature and compare the theoretical findings with the experimental validations in order to achieve the research aims and objectives.

Application Study

In order to obtain an experimental data regarding the thermal behavior of extensive green roofs and their interactions with the energy performance of buildings, an experimental platform with green roofs system was constructed in the Deraib region which is located in the north of Riyadh city. The experimental platform is a simple repetition of residential rooms being built by similar materials. The platform consists of two rooms which are used for the study of treatment of the energy efficiency of buildings by using a selective standard for extensive green roof properties, and conventional roofs (concrete roof with depth of 15cm), see Figure (1). Also, the facades of these rooms will be painted with the Paige color, see Figure (2). To reflect a real urban setting, the experiment was conducted on the residential building that could simulate both physical and geometrical similarities in reality.

The application study consists of three stages: the stage of experiment preparation, the stage of data collection, and the stage of data analysis and discussion.

Heat Measurement Equipment

The normality of temperature and the relative humidity data was checked by using (The EL-USB-2-LCD+) which measured the air temperature and the relative humidity inside the rooms and outside the rooms every five minutes. Thermocouples sensors (ANRITSU Digital handheld thermometer - ANRITSU MTER CO.,LTD) were arranged in different levels within the model to include the components of the empirical model so as to measure the covariance of temperature. Heat flux sensors were placed on the surface of the plants, walls, and at the ceiling layer in order to assess the amount of the heat conduction of those components. The results of the experiment were analyzed by using the statistical analysis program of Microsoft Excel.

Description of Models

1- Model Direction: The main elevation that increases the indoor air temperature was the south and the west elevation, see Figure (1).
2- Model Geometry: The experiment model has one floor, and it is built with a conventional method of construction being applied to a residential building in Riyadh city, see Figure (3).
3- Model Plans: Figures (4 and 5) show the schematics o the rooms being tested.

4- The Model Materials: The test model was constructed by using traditional materials. Figure (2) show the materials being used:

Concrete hollow bricks were used to construct the exterior and indoor walls.

The exterior walls were painted by Yellow colors.

Transparent white glass type (4mm) was used for windows.

Reinforced concrete (15 cm) was used for the ceiling of the rooms.

Steel doors were used with brown paints.

Ceramic tiles were used in the floors, and the internal walls were painted by white paint.

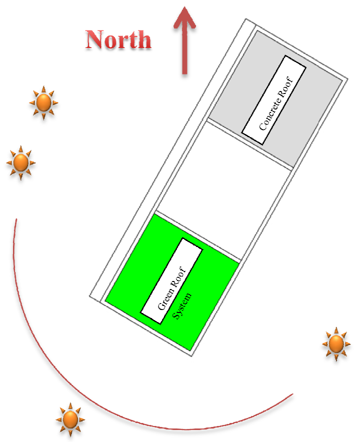

Figure: (1) A plan's view showing the model direction.

Figure: (2) shows the exterior finishes in test rooms.

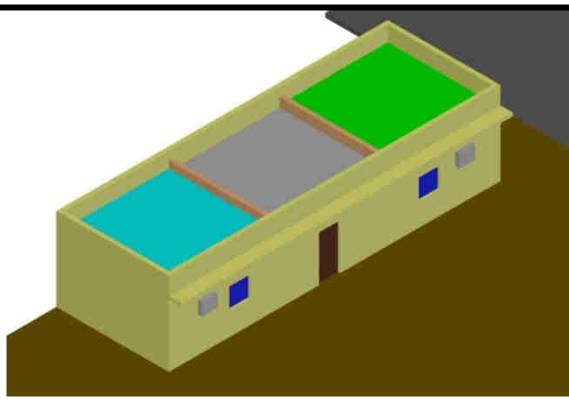

Figure: (3) A perspective view of a residential building being used for the experiment.

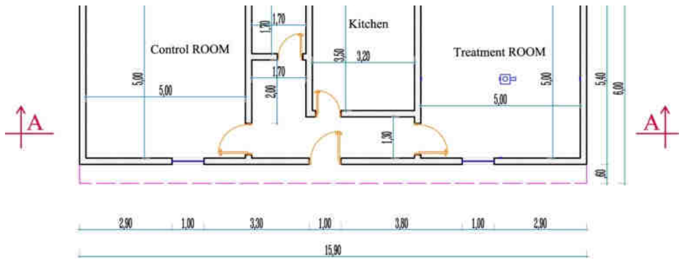

Figure: (4) A Plan's view of the rooms being tested.

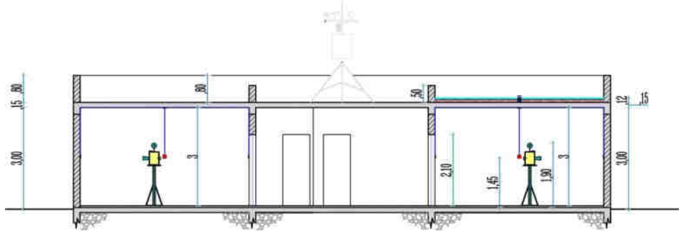

Figure: (5) The vertical section view of the rooms being tested.

Construction of Representative Extensive Green Roof Systems

A Pre-cultivated system (Vegetative Blanket) was used in this experiment. This type typically comes in rolled that can be placed on any roof and be grown off-site. Also, this type has a good advantage ; namely, it is very thin (very lightweight option) compared to the other types.

An extensive green roof system consists of following matter Figure (6):

Plants that are drought resistant.

A light substrate or engineered soil that holds enough nutrients and water.

An optional filter and drainage layer to transport the excess rainwater off the roof.

Extensive green roofing components are installed on the top of the concrete slab. To begin constructing 12 cm nominal thick of substrate, first construct it in the site of the experiment on the roof of the testing room. The green roof substrate, that is designed by Prof. Fahd Al Mana who is a member at Department of Plants Production, Agriculture

College, king Saud university, is constructed by collaboration with agricultural engineers. Substrate has six layers, and the components of installation have many steps.

First of all, the roof was cleaned. After that, the substrate layers was installed consecutively, see Figure (6).

A5 mm thick styrene butadiene rubber (SBR) waterproofing membrane (preventing water from reaching the roof decking in an actual field installation) Figure (7).

A 0.1 mm thick polyethylene slip sheet allowed any moisture in the waterproofing membrane to exit the system and saving water for irrigation, see Figure (8).

A 3 cm thick gravels which is as drainage layer and saving soil from erosion, as shown in Figure (9).

A 2 cm thick sand that acts as a filter layer for drainage, see Figure (10).

A 4 cm thick soil which consists of mixed ratio (1:1:3) – (batamos: clay soil: soft sand) with organic materials, see Figure (11).

A 3 cm thick vegetative roll layer with Cynodondactylon (Bermuda- Tifway - 419) grass, see Figure (12).

Drainage pipes of excess water from the growing medium were channeled and installed in the corners of the green roof substrate to allow water to drain freely from the system.

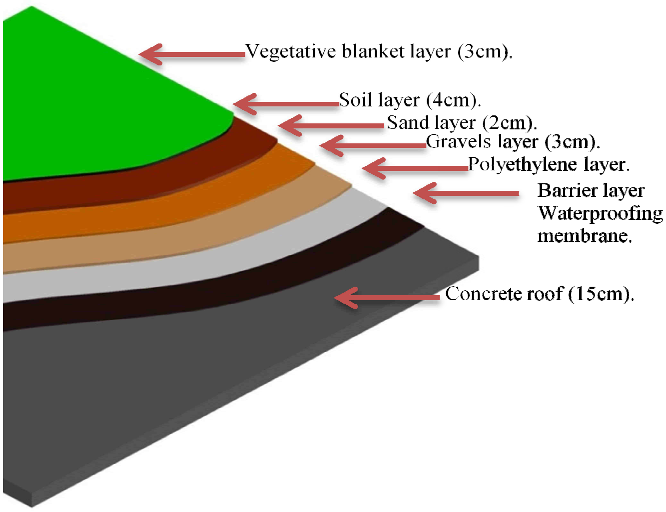

Figure: (6) The various components of the extensive green roofing system.

Figure: (7) Shows installation of (SBR) waterproofing membrane on14-3-2014.

Figure: (8) Shows installation of polyethylene slip sheet on

Figure: (9) Shows gravels layer 3cm (drainage layer) on 14-3-2014.

Figure: (10) Shows sand layer (drainage layer) 2cm on 14-3-2014.

Figure: (11) Shows final layer beneath grass layer on 14-3-2014.

Figure: (12) Shows installation of final layer grass rolls (Bermuda 419 or Tifway).

Installation of Measuring devices

There are 24 sensors that are used in this test. Eight sensors are in the green roof system, see Figures (13, 14 and 15), two sensors are in the concrete roof system, six sensors are in the treatment room walls, six sensors control room and two sensor out test rooms.

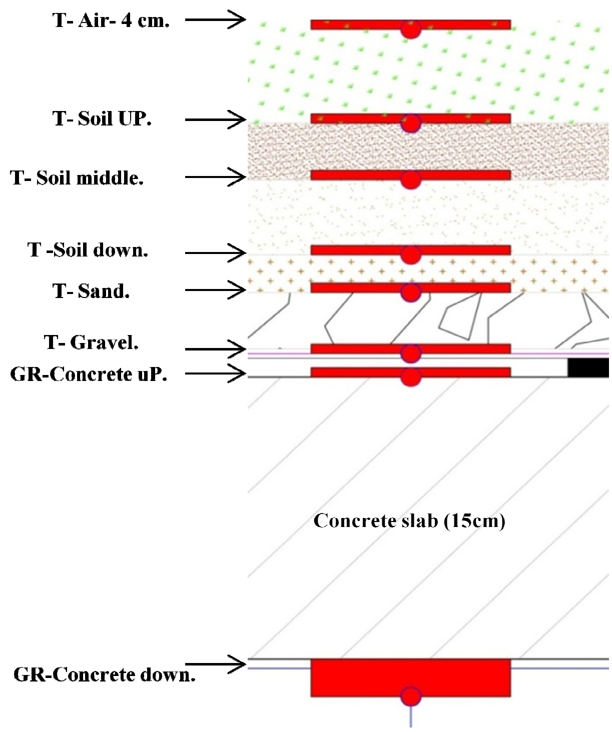

Figure: (13) The vertical section shows the sensors' places in the extensive green roof system.

Figure: (14) Shows the installation of thermocouples sensors in substrate.

Figure: (15) Shows the name of thermocouples sensors on14-3-2014.

Periods of Grass Growth

Grass (Bermuda 419 or Tifway) experienced significant growth during a period of two months. First, the grass wilted during the first two weeks after the grass roll was installed in the site on 14-3-2104, because the grass roll was grown offsite, see Figure (16). Then during the next three weeks, grass started to grow and the density of foliage increased, see Figure (17). After that, some fertilizer was added (that contains nitrogen and potassium) to improve the vegetative growth and the plant density, see Figure (18). Finally, the grass growth was completed and was ready to tests on two months and half, see Figure (19).

Figure: (16) Shows grass growth (Bermuda 419 or Tifway) on 22-3-2014.

Figure: (17) Shows grass growth (Bermuda 419 or Tifway) on 22-4-2014.

Figure: (18) Shows grass growth on 5-5-2014.

Figure: (19) Shows grass growth on 26-5-2014.

Data Collection and Analysis

Thermal performance of extensive green roofs was during the warm period. The warm period chosen for the analysis was in June 2014 from (06-June to 23-June), which is a representative of a typical summer season in Riyadh city. The daytime is characterized by high loads of solar radiation with an average air temperature of 42◦C and an average relative humidity of 15.1%. Days presented winds with daily average and max value from 4.0 km/h to17.0 km/h.

The conventional roof system (concrete roof) was used for comparison against the performance of the extensive green roof system. The following matters present the results from the testing room in terms of the temperature variation and relative humidity variation.

A. Temperature Variation

As shown in Figure (20), plant roofs were better than concrete roofs for their ability to decrease temperature fluctuations. The average values of internal air temperature differences were of 5.5±2°C for the extensive green roof system compared to concrete roof system. Furthermore, as shown in Figure (21), the internal ceiling surface temperature differences were of 7±.05°C.

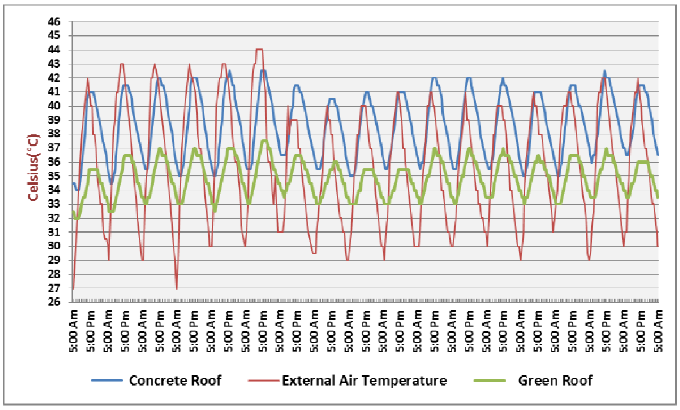

Figure: (20) Temperature variation of the internal air temperature in the treatment room and the control room during the time period from 6-6-2014 at 5:Am to 23-6-2014 at 5:Am.

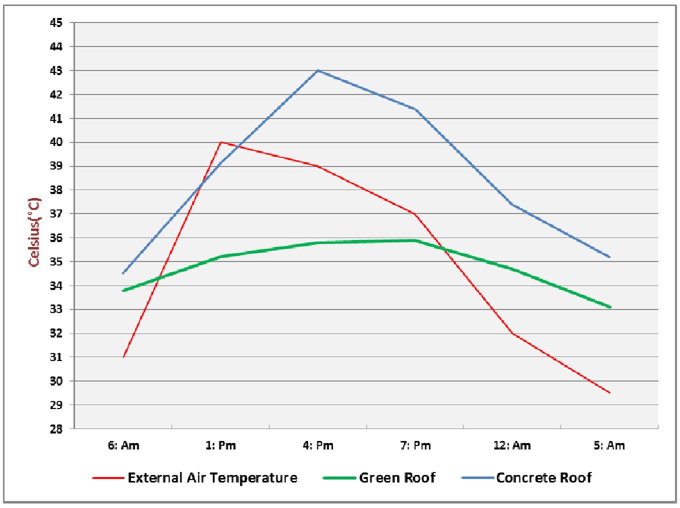

Figure: (21) Temperature variation of the internal ceiling temperature in treatment room and control room during the time period from 12-6-2014 at 6:Am to 13-6-2014 at 5:Am.

Figure (22) shows the temperature of thermocouples in substrate layer of extensive green roof system. The average values of substrate layers temperature differences were of

1±.01°C during the testing time period. The maximum temperature of substrate layers reached to 50°C when the external air temperature was 43°C and the minimum temperature of substrate layers reached to 34°C when the external air temperature was 28°C. However, the internal ceiling temperature was lower than the top layer of substrate (grass layer) up from 4°C to 14°C. While the air temperature at 4cm in the grass layer reached 58°C because of the evapotranspiration phenomenon. Also, Figure (22) shows that the performance of substrate layers were different during the time period of day. During the night period, the lower layers of temperature were lower than the uppers layers of temperature. While during daylight period, the lower layers of temperature were higher than the uppers layers of temperature.

B. Relative Humidity Variation

Figure (23) shows that the internal relative humidity in the treatment room (green roof system) was lower than the internal relative humidity in the control room (concrete roof system) of about 9±1%. This means that treatment room was more comfortable, while people in the control room started to sweat quickly.

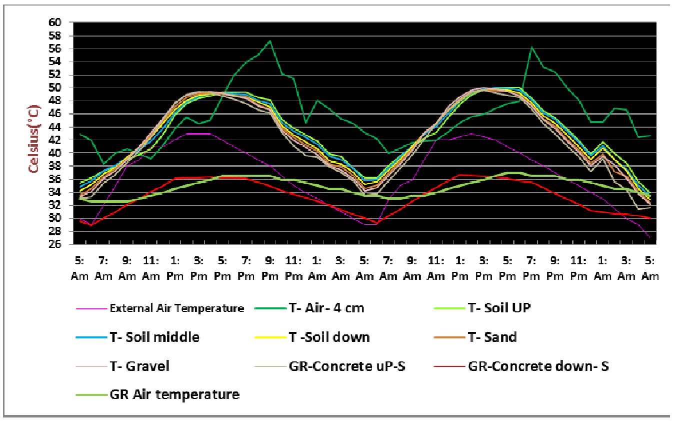

Figure: (22) Temperature variation of substrate layers temperature in extensive green roof system with tall grass (regular irrigation) during the time period from 7-6-2014 at 5: Am to 9-6-2014 at 5:Am.

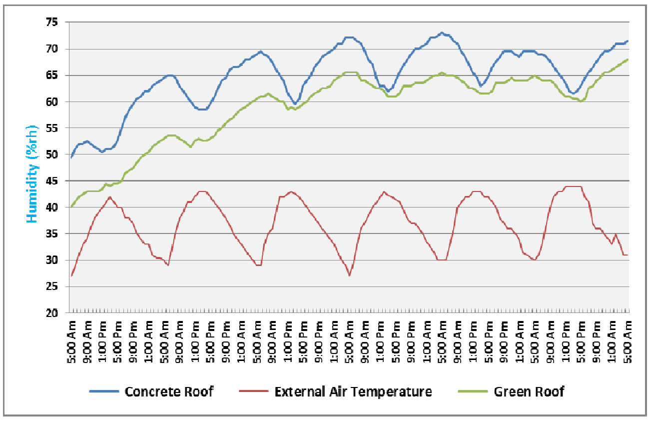

Figure: (23) Internal relative humidity variation of the treatment room and control room during the time period from 6-6-2014 at 5:Am to 12-6-2014 at 5:Am.

IV. DISCUSSIONS

The discussion of the results focuses on the thermal performance of the extensive green roof system and the thermal performance of the concrete roof system during the testing period. The discussion includes the temperature variation of the internal air, internal ceiling and Internal Walls.

A. Internal Air Temperature Variation

As shown in Table (1), the first evaluation was achieved through making a comparison between air temperatures of the rooms showing the final impact of the extensive green roof system and the concrete roof system on the indoor thermal comfort conditions. In the treatment room, the temperature of internal air varied from 37.5 to 32.5°C, while in the control room, the temperature of internal air varied from 42.5 to 34.5°C when the external air temperature varied from 44 to 27°C in the recorded period from 6-6-2014 at 5: a.m. to 23-6-2014 at 5:a.m. Internal air temperatures in the treatment room with the green roof system stay 2–5.5°C cooler than that in the control room with the concrete roof system during the testing period. It is obvious that thermal insulation by using the extensive green roof system is better than the thermal insulation by using the concrete roof system. Furthermore, the temperature of internal air variation in the treatment room was up to 5°C, while in the control room it was up to 8°C. This means that green roof system could regulate the temperature fluctuations and heat fluxes.

Table: (1) Temperature variation of the internal air temperature in treatment room and control room.

Celsius	External Air Temperature	Internal Air Temperature Time period from 6-6-2014 at 5: Am to 23-6-2014 at 5:Am Treatment Room (Green Roof)	Internal Air Temperature Time period from 6-6-2014 at 5: Am to 23-6-2014 at 5:Am Control Room (Concrete Roof)
Maximum	44°C	37.5°C	42.5°C
Minimum	27°C	32.5°C	34.5°C
Difference	17°C	5°C	8°C

B. Internal Ceiling Temperature Variation

During the daytime, in moments of maximum air temperature, the internal ceiling surface temperature of the extensive green roof system was substantially lower than that of the concrete roof system. While the maximum temperature of internal ceiling was 43°C for concrete roof, the maximum value that was recorded for the green roof was 36°C. The temperature difference for the internal ceiling between the green and concrete roofs was up to 7°C during the daytime. Also, during the nighttime, the internal ceiling temperature of green roofs was lower than internal ceiling of the concrete roof system and was up to 1.5°C, see Table (2).

C. Internal Walls Temperature Variation

Since the focus of this research is to evaluate the potential thermal benefits of the extensive green roof system in hot climates, it is important to make a comparison between the various components of the testing rooms.

As shown in Table (3), the maximum temperature of internal walls during the daylight in the treatment room (green roof) was higher than that in the control room (concrete roof), up to 4.5- 4- 3.4-2°C for the north-east wall, the north-west wall, the south-east , and the south-west wall respectively during the testing time. Also, the minimum temperature of internal walls during the night day in the treatment room (green roof) was higher than that in the control room (concrete roof), up to 2.5- 1.4- 2.6-2.7 °C for the north-east wall, the north-west wall, the south-east and the south-west walls respectively during the testing time. These temperature variations are because of the testing room has different directions. The treatment room has an exterior south-west wall, while the control room has an internal south-west wall. However, the temperature of the internal air in the treatment room was lower than that in the control room due to using the extensive green roof system.

Table: (2) Temperature variation of the internal ceiling surface temperature in treatment room and control room.

Celsius	External Air Temperature	Internal Ceiling Temperature Time period from12-6-2014 at 6: Am to 13-6-2014 at 5:Am. Treatment Room (Green Roof)	Control Room (Concrete Roof)
Maximum	40°C	36°C	43°C
Minimum	29.5°C	33°C	34.5°C
Difference	10.5°C	3°C	8.5°C

Table: (3) Temperature variation for internal walls surface temperature in treatment room and control room.

Celsius	External Air Temperature	Internal Walls Temperature Variation Time period from 6-6-2014 at 6: Am to 14-6-2014 at 6:Pm Treatment Room (Green Roof) North - east	North - west	South - east	South - west	Control Room (Concrete Roof) North - east	North - west	South - east	South - west
Maximum	44 °C	47 °C	45 .2 °C	40 .2 °C	45 .9 °C	42 .5 °C	41 .2 °C	36 .8 °C	4 3. 9 ° C
Minimum	29 °C	27 °C	27 .2 °C	30 °C	26 .9 °C	24 .5 °C	25 .8 °C	27 .4 °C	2 4. 2 ° C
Difference	15 °C	20 °C	18 °C	10 .2 °C	19 °C	18 °C	15 .4 °C	9. 4 °C	1 9. 7 ° C

D. Energy Saving Discussion

According to the study of (Lin et al. 2011) in some tropical areas, the electric consumption of air conditioning systems can be cut down by 6% when the temperature is reduced by1 °C. But in our study, the extensive green roof could reduce the internal air temperature up to 5.5±°C. So, the extensive green roof system can reduce 33% to 12% for energy consumption of air conditioning in Riyadh city during the summer seasons.

V. CONCLUSION

A number of conclusions can be drawn from the experimental study presented and discussed in this study. The conclusions are the main results of this study.

The results of this study indicate that:

The maximum temperature of internal air in the treatment room (Extensive Green Roof System) reached 37.5 °C,

while in the control room (Concrete Roof System) it reached 42.5 °C. The temperature difference was 5.5 °C during the testing period in summer seasons in Riyadh city.
The minimum temperature of internal air in the treatment room (Extensive Green Roof System) reached 32.5 °C, while in the control room (Concrete Roof System) it reached 34.5 °C. The temperature difference was 2 °C during the testing period in summer seasons in Riyadh city.
Temperature variation of internal air in the treatment room was 5 °C, while in the control room was 8 °C. This means that the green roof system was better than the concrete roof system for regulating the temperature fluctuations and heat fluxes.
The (Extensive Green Roof System) could reduce 12% to 33% for energy consumption of air conditioning in Riyadh city during summer seasons by using environmentally friendly insulation.
The internal ceiling temperature of the extensive green roof system was substantially lower than the internal ceiling of the concrete roof system. The temperature difference was up to 7°C during the daytime.

VI. ACKNOWLEDGMENTS

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