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Investigation of thermal benefits of an extensive green roof in Istanbul climate

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Green roofs have become an ecological solution in cities with the environmental problems that have increased in recent years. Green roofs are used as aesthetic elements as well as their ecological benefits for the city and urban environment. Comparative measurements were performed through field study in Landscape Architecture Department, Faculty of Forestry, Istanbul University, Green Roof Research Station (IUGRRS), to produce quantitative data on this subject and investigate the thermal properties of a typical extensive green roof. This paper analyses the thermal properties of a typical extensive green roof in comparison with a bituminous membrane roof (reference roof). During measurement period, it has been confirmed that a typical extensive green roof with 50 mm-thick growing media provided a thermal protection to the building envelope against extreme temperature effects. Impacts of extreme temperature fluctuations on the surface of the green roof to the building envelope were reduced by the green roof system by 79%. Results obtained from the field measurements show that green roofs are a sustainable choice in Istanbul climate conditions.

Key words: Green roofs, field measurement, thermal benefits, urban environment, Istanbul climate.

INTRODUCTION

Roof gardens, more commonly known as green roofs in European countries, are gaining foothold in North America while widely popular and established in European countries especially Germany, France, Austria, Norway and Switzerland (Wong et al., 2003). In the early 1960's green roof technology was developed in Switzerland and enhanced in many countries, particularly Germany (Bass and Baskaran, 2003). After 1980, many green roofs were constructed with the idea of bringing vegetation back into urban areas (Köhler, 2005).

In present day ecological functions of green roofs became more important rather than their aesthetical properties. Green roofs are used for energy efficiency, thermal insulation, preventing overheating of building surfaces, protecting the waterproofing membrane and reducing the micro urban heat island effect, which is produced by roof surfaces.

Research studies show that green roofs have thermal benefits in building and urban scale (Kumar and Kaushik, 2005; Santamouris et al., 2007; Fioretti et al., 2010; Susca et al., 2011; Liu, 2004; Lazzarin et al., 2005). This natural solution contributes to the thermal benefits in buildings and their surrounding environments (Wong et al., 2003). The shade provided by the plants reduces the cooling load of the building and to that extent, also helps to reduce the building's contribution to the urban heat-island effect (Ong, 2003). In addition, green roofs can significantly reduce energy use in buildings with poor

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insulation values, both in summer cooling and winter heating (Castleton et al., 2010).

In recent years, green roof market show signs of development in Turkey. Especially with the momentum of environmental awareness and green building certification programs, green roofs are being frequently used in new commercial and residential projects. According to market size survey of Turkish Association of Roofing Industrialists and Businessman, market rate of green roof systems have risen 237% in 2009 compared to past two years (Turkish Association of Roofing Industrialists and Businessman Market Size Survey, 2009).

With a population of nearly twelve millions, Istanbul is the biggest and the most crowded city in Turkey. Therefore, environmental problems have emerged with the urbanization. There are a few research studies and insufficient information about the performance and environmental benefits of the green roofs in Istanbul climate. Understanding the thermal properties of green roofs is important to explore the sustainability and benefits of green roofs in climate conditions of Istanbul.

Green roof research in Istanbul University has started in 2006. After five years of research, with the support of Istanbul University Scientific Research Projects Department, Istanbul University Faculty of Forestry Landscape Architecture Department Green Roof Research Station (IUGRRS) was developed in Istanbul University Faculty of Forestry Campus in 2010.

This paper aims to investigate the thermal properties of a typical extensive green roof in climate conditions of Istanbul through comparative field measurements in IUGRRS. Assessment of temperature distributions in roof layers and defining the role of extensive green roofs in terms of sustainability were investigated within the scope of this research.

MATERIALS AND METHODS

Site description

Istanbul expresses characteristics of a Mediterranean climate (Csa, Csb climate zone), according to updated Köppen-Geiger Climate Zone Classification System (Kottek et.al. 2006), especially the southern parts of Istanbul, show the general characteristics of the Mediterranean climate. However, in northern parts, the Mediterranean type climate is modified by the cooler Black Sea and northerly colder air masses of maritime and continental origins. This type is locally called 'the Black Sea Climate' (Cfb) and described as having cooler temperatures in both winter and summer, and usually experiences more rains compared to the climate of the Mediterranean coasts of Turkey (Ezber et al., 2007).

IUGRRS is located at the North of Istanbul, Bahçeköy – Sariyer Region, 41.10°N, 28.59°E. It is situated in suburban area of Istanbul in a neighborhood of Belgrad Forest and 100 m above the sea level. IUGRRS surrounded by open spaces in the north and south sides with a parking lot in the west. Except the wooded slope in the east, the surrounding terrain is flat. Nearest building is the sports hall which is located 20 m away from the southwest side of the research area. Research station has an area of 24 m^2 with a height of 3.20 m. It contains indoor and outdoor measurement instruments to evaluate the performance of roof systems comparatively.

Experimental design

Roof of IUGRRS is a low-sloped roof and divided width-wise into two equal parts with an area of 10.2 m^2. A typical extensive green roof (GR) and a reference roof (bituminous roof) (RR) were installed on these roof parts to perform comparative measurements. Roof slab of building is constructed with 15 cm cement slabs with a slope of 1% and covered with two layers of waterproofing membrane. There are identical interior rooms under roof systems to monitor indoor conditions. There is not a HVAC system available in the research building. Ventilation is provided by two windows which are operated simultaneously.

Climatic conditions affect the layer arrangement and thickness of green roof system. Deeper substrates are beneficial for increased water-holding capacity; however increases loads to the building. Shallower substrates are subject to temperature fluctuations and rapid drought. Various green roof systems are available in different research sites in the world. In BCIT Green Roof Research Program 75 – 100 mm substrate depth was used. In Michigan State Green Roof Research Program, substrate depth of test modules varies between 25-100 mm. In addition, determined substrate depth in Neubrandenburg Green Roof Centre of Excellence – Germany were between 50 – 100 mm.

Green roof system used in this research is a typical extensive green roof, which has a thickness of 90 – 95 mm; consists of two layers of waterproofing membrane, water retention mat(4,5mm), drainage layer (Zinco FD25, 25mm), filter cloth, substrate (Zincolit, ZinCo GmbH, Unterensingen/Germany) and plants respectively. There is no irrigation system or fertilization available in green roof system. Reference roof system consists of two layers of waterproofing membrane. Upper layer of waterproofing membrane is finished with mineral-coated waterproofing membrane.

Plants were established directly via plugs upon the 50 mm-thick substrate. Mixture ratio of the substrate is determined with the field studies, due to lack of information in product brochure. Estimated mixture ratio of the substrate is; crushed clay – brick (50 to 55%), pumice (40 to 45%) and organic material (sandy loam, compost 10%).

Succulent plants have been identified as being well adapted to extreme conditions, because of their ability to store excess water. The genus *Sedum* is a popular choice among extensive green roofing projects due to its tolerance for drought and shallow substrate adaptability (Getter and Rowe, 2006). Plant selection was made according to several research studies (VanWoert et al., 2005; Getter and Rowe, 2008; Durhman et al., 2007). Three *Sedum* species; *Sedum reflexum (covers 45%), Sedum spurium* "Album" (*covers* 30%) and *Sedum spurium* "Atropurpureum" (covers, 25%) were planted in the roof.

Data collection

A set of sensors and measuring instruments were installed to measure interior and exterior conditions during measurement period between 11.11.2010 to 09.12.2011;

(i) Outdoor temperature values recorded from 200 cm above the roof with the automated weather station (DeltaOhm HD2003 Three axis Ultrasonic Anemometer, Delta OHM S.r.L., Padova/Italy, measurement accuracy of ±1°C).
(ii) Infrared surface thermometers (Optris CSmicro 2W, Optris GmbH, Berlin/Germany, measurement accuracy of ±0,2°C.) were installed on stainless steel weather pole, 100 cm above the roof to measure surface temperatures of roof systems.
(iii) Thermocouples (Comet PT1000 sensors, Comet System s.r.o., Roznov pod Radhostem/Czech Republic, ±0,25 to ±0,5°C accuracy) were installed into roof layers to measure temperature profiles in the roof layers.

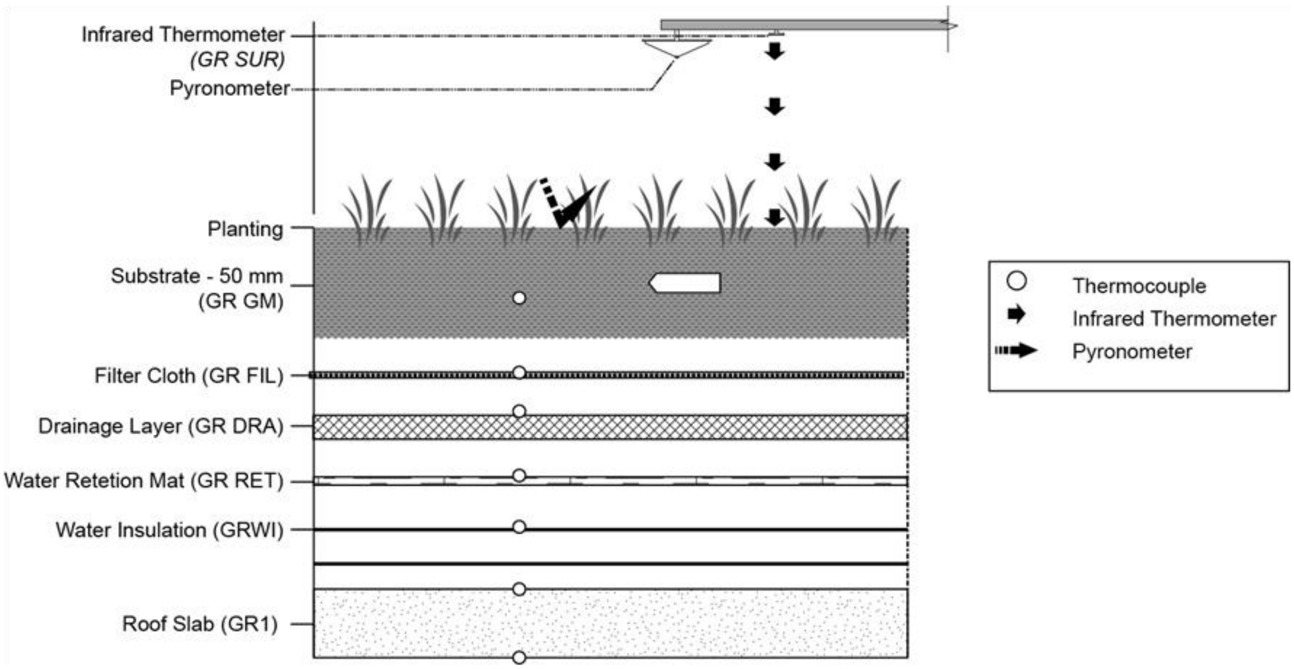

Figure 1. Location of sensors in green roof layers.

Table 1. Descriptive statistics of measured temperature values.

Abbreviation	Days	Daily average	Standard error mean	Standard deviation	Minimum	Maximum
GR INT	382	15.7	0.4	7.3	3.4	28.7
GR1	382	15.2	0.4	8.2	2.2	30.2
GR WI	382	15.0	0.4	8.4	1.9	30.3
GR RET	382	15.0	0.4	8.5	1.7	31.1
GR DRA	382	14.7	0.5	9.1	1.0	33.2
GR FIL	382	14.6	0.5	9.1	0.8	33.1
GR GM	382	14.9	0.5	9.8	0.4	35.5
GR SUR	382	12.9	0.5	9.6	-2.7	33.1
RR INT	382	15.5	0.4	7.7	2.9	29.2
RR 1	382	16.8	0.5	10.3	0.4	37.0
RR SUR	382	14.3	0.5	10.7	-3.6	35.5
AIR	382	14.7	0.3	6.5	0.5	25.9

(iv) To obtain indoor temperature values, digital thermometers mounted inside research station (Comet T3110, Comet System s.r.o., Roznov pod Radhostem-Czech Republic, ±0,4°C accuracy).
(v) Albedo rates of both roof systems were calculated with the obtained measurements from pyranometers on the roof (DeltaOhm LP PYRA 02, Delta OHM S.r.L., Padova – Italy, ISO 9060 certificated first-class pyranometers).

Temperature data was measured in eight places to determine the temperature distribution in green roof layers. Two sensors were used to measure temperature distribution in reference roof layers. Surface temperatures of roofs were measured at 100 cm above the roof surface with infrared thermometers. Location of sensors in roof layers is shown in Figure 1.

Performed measurements were recorded in two data loggers (Comet MS5D, Comet System s.r.o., Roznov pod Radhostem/ Czech Republic). Comparisons were performed between collected data from both roofs simultaneously. Data processing was performed using MS Excel® and MatLab® software.

RESULTS AND DISCUSSION

Measurements have started at 11 November, 2010 in IUGRRS. Statistics of temperature data obtained from the layers of roof systems are expressed in Table 1.

During research, annual average air temperature was recorded 2.0°C higher than normal climate values (12.7°C). In November and December, significant variation in temperature regime was observed. During research, monthly average temperature values of these months were recorded as 4 to 7°C distinctive from the normal climate values based on the 30 year station measurements of Bahçeköy between 1974 and 2004 by the State Meteorological Service of Turkey.

Temperature fluctuations in roof layers

Temperature values occurring on the surfaces of the roofs affect the roof layers beneath. Presence of plant canopy shades the roof and decreases temperature values occurring on roof surface. While bringing an ecological solution to the structural surfaces with green roof systems, it is also aimed to mitigate urban heat island effects in urban scale and reduce extreme temperature effects in building level. In this context, the temperature distribution in the layers of roof systems was analyzed.

In measurement period, minimum daily average temperature of green roof surface was recorded as -2.7°C, while reference roof was -3.6°C. In summer, maximum daily average surface temperature of green roof was recorded as 33.1°C while reference roof was 35.5°C. More extreme temperature differences were observed in a research in Michigan due to climatic differences (Getter et al., 2011). In this study, maximum and minimum average monthly temperatures over the course of the year were consistently more extreme for the gravel ballasted roof than the green roof and the gravel roof was up to 20°C warmer during the summer.

In diurnal cycle graphs (Figure 2), temperature fluctuations on the roof surfaces are shown. In winter and autumn, difference between roof surface temperatures were similar. In spring due to seasonal change, differences between the temperatures of roof surfaces became more visible. Plant cover ratio and presence of moisture in growing media have had an effect to reduce the green roof surface temperature in spring. However, difference in temperature values of roof surfaces was decreased in summer. Peak values of surface temperature of the green roof were lower than reference roof. Despite the rapid changes at the surface temperature of reference roof, response of green roof was much slower.

In colder period, roof surface temperatures were recorded lower than air temperature. Surface temperatures were started to increase due to change in solar radiation levels in March. As seen in diurnal cycle graphs (Figure 3), plant cover and moisture content in growing media have effect to reduce the roof surface temperature. However the temperature fluctuations on the green roof surface were higher due to rapid warming-cooling cycle of roof surface.

At the end of spring, a decrease was detected on the surface temperature of green roof in 12 to 14th hour of the day. This decrease was more apparent between May and August. Reason of this decrease could not be recognized. However, there's a possibility of this situation could be related with CAM activity of plants on the roof or with the evaporation occurs from the bottom layers of the roof.

Table 2. Temperature fluctuations in roof layers (differences between daily maximum – minimum temperatures).

Temperature differences (°C)	Minimum	Median	Average	Maximum
GRSUR	1.1	14.7	16.9	40.7
GR GM	0.2	9.3	13.3	39.9
GR1	0.2	2.1	2.4	11.4
GRINT	0.1	1.5	2.0	11.5
RRSUR	1.0	17.6	17.7	36.2
RR1	0.5	13.3	14.0	32.8
RRINT	0.2	2.2	2.6	11.6
AIR	0.6	6.3	6.3	17.5

Temperature fluctuations (differences between daily maximum and minimum temperatures) on the surface temperature of the roof systems were investigated. In drought period (from middle of May to August), temperature fluctuations on the surface of the green roof and the growing media were higher than reference roof which was an unexpected result (Figure 3 and Table 2).

In drought period, evaporation rate in the growing media was not remarkable due to low precipitation and moisture content. In a study of Jim and He (2010), it was highlighted that the substrate moisture is effective in regulating substrate thermal behavior. As a similar result, inadequate soil moisture and shallow substrate has caused overheating of the growing media and the surface of the green roof in our study. In addition, the result agrees well with some research studies as well as Jim and Peng (2012) which shows the shallow substrates allows solar energy to heat up the entire layer and increases ET due to moisture content.

In warmer period, severe temperature fluctuations were observed on the surface of green roof and substrate layer and reached up to 40°C (Table 2). This variation was even smaller on reference roof surface. However, these large intervals on temperature values didn't have an effect to the lower layers of the green roof.

Temperature measurements were made in the bottom layers of roof systems to analyze the temperature change between the surface and roof slabs. Roof slab temperature values were measured to determine the heat attenuation ability of roof systems.

Green roof protected the roof slab and waterproofing membrane from extreme temperature effects that occurred on the surface of the roof (Figure 4). Green roof system reduced the extreme temperature effects in summer by 27%. In winter, roof slab temperature of the

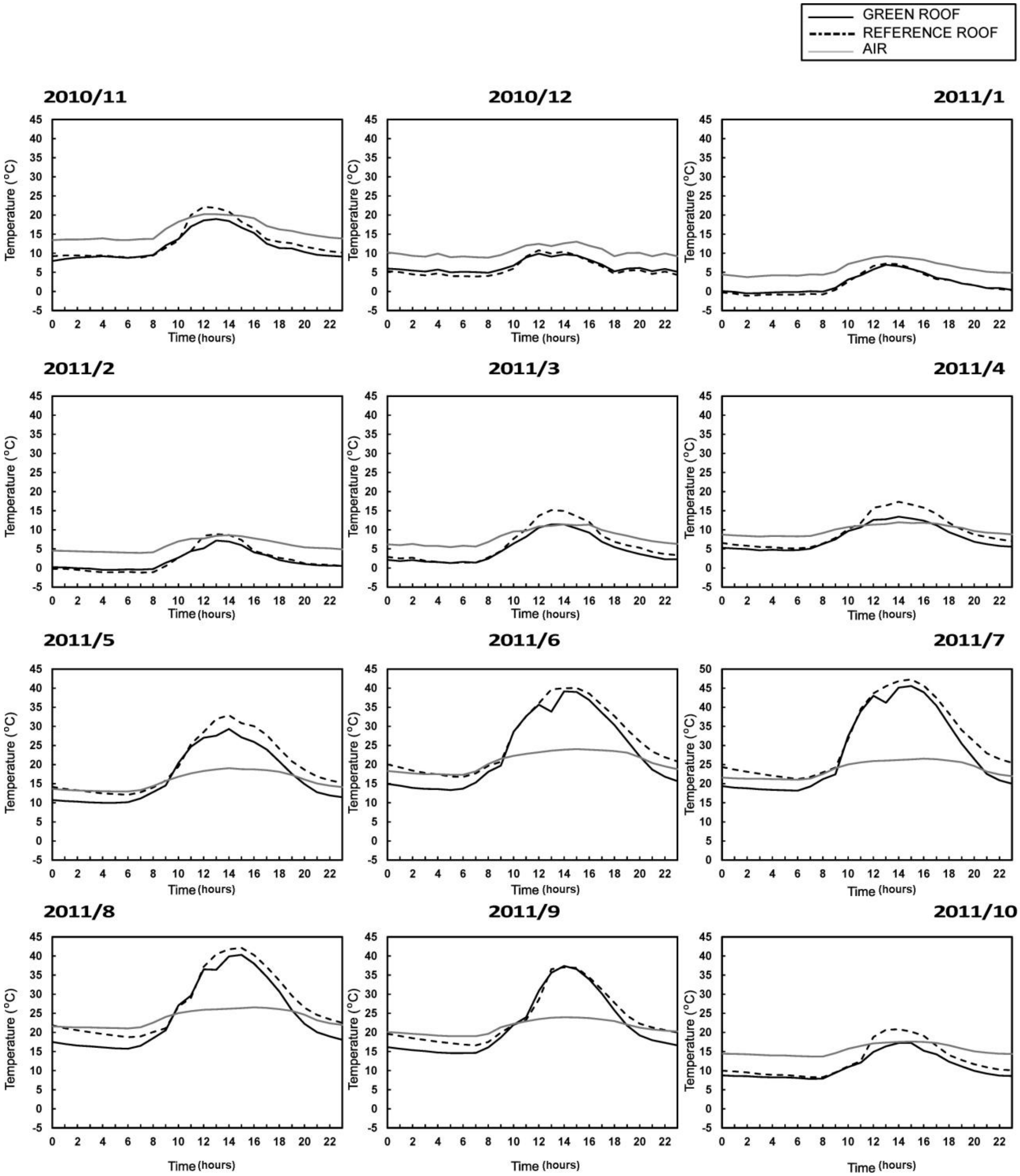

Figure 2. Diurnal cycle graphs of roof surface temperatures.

green roof was 53% higher than the surface temperature.

Extreme temperature fluctuations on the roof surface have caused rapid temperature changes on the roof slab of the reference roof (Figure 4 and Table 2). In warmer period, temperature differences between roof slabs had reached to 9°C. In colder period, it was found that roof slab under green roof was 0.7 to 2.3°C warmer than reference roof.

In the coldest day of the measurement period (10 March, 2011 to 0.5°C), roof slab temperature under the green roof was 2.7°C which was 2.2°C warmer than roof slab under the reference roof. In the hottest day of the

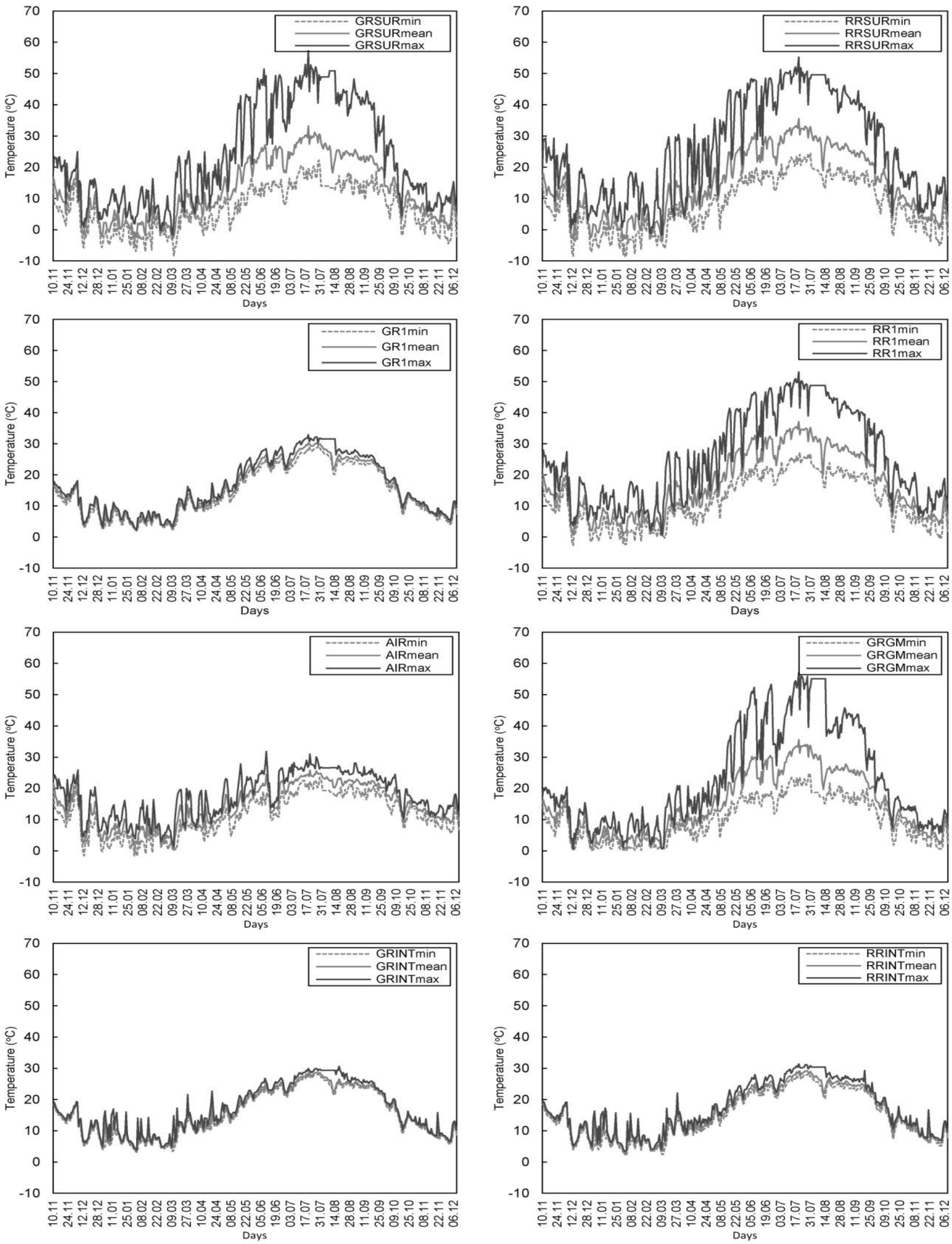

Figure 3. Daily minimum and maximum temperatures (temperature fluctuations) of the roof layers.

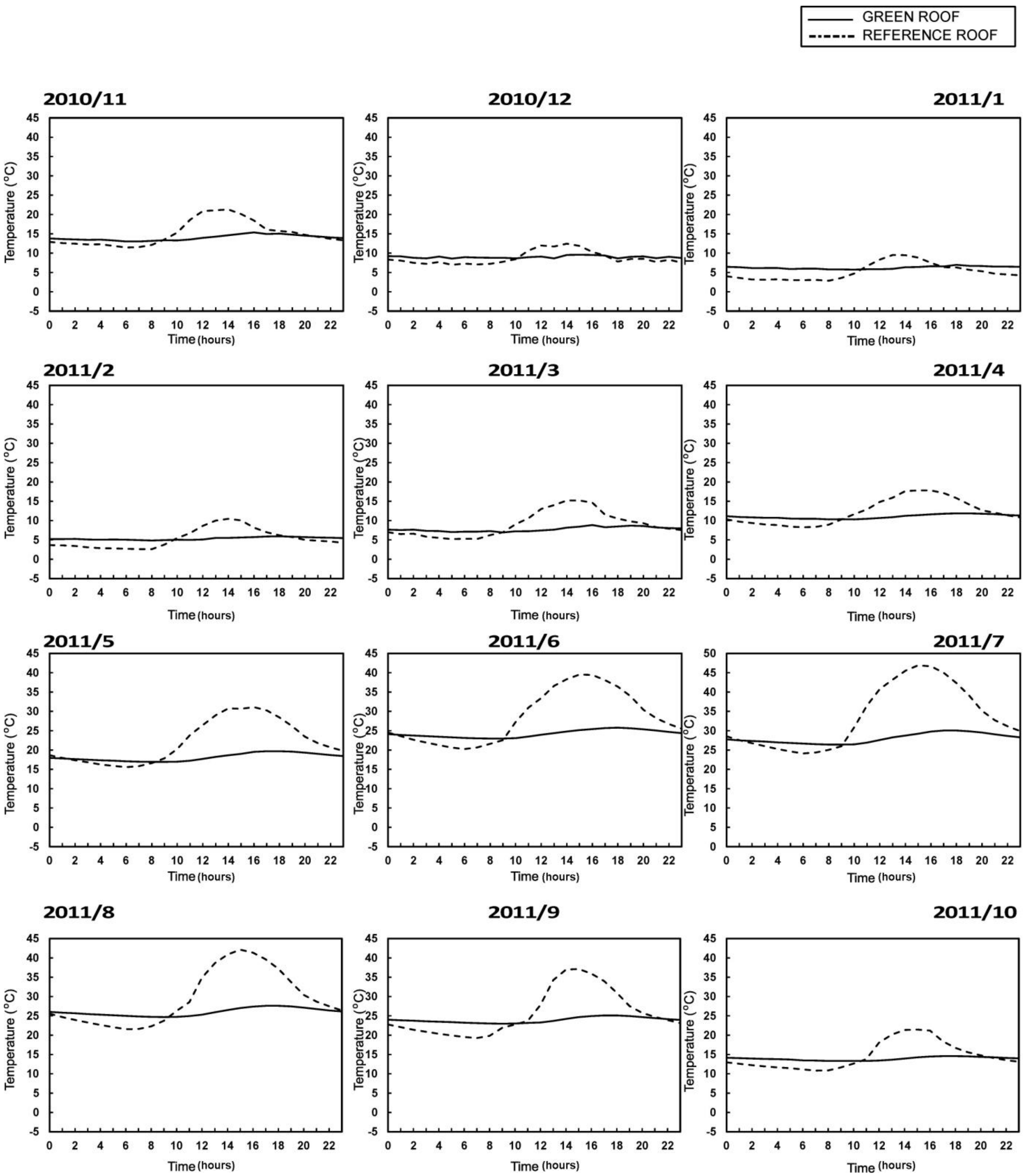

Figure 4. Diurnal cycle graphs of the roof slab temperatures.

measurement period (10 July, 2011 to 25.9°C), temperature of roof slab under reference roof reached to 37.0°C. Meantime, temperature value of roof slab under the green roof remained 30.7°C which was 6.3°C cooler than reference roof.

These effects can be seen in daily minimum and

Table 3. Number of days that roof surfaces and roof slabs exceeded various levels.

Roof slab	Day count	Percent	Roof surface	Day count	Percent
GR1<10	130	34.03	GRSUR<10	182	47.64
10<GR1<20	119	31.15	10<GRSUR<20	82	21.47
20<GR1<30	130	34.03	20<GRSUR<30	111	29.06
GR1>30	3	0.79	GRSUR>30	7	1.83
Total	**382**	**100.00**	**Total**	**382**	**100.00**
RR1<10	161	42.15	RRSUR<10	131	34.29
10<RR1<20	87	22.77	10<RRSUR<20	107	28.01
20<RR1<30	106	27.75	20<RRSUR<30	88	23.04
RR1> 30	28	7.33	RRSUR>30	56	14.66
Total	**382**	**100.00**	**Total**	**382**	**100.00**

maximum temperature differences. Temperature fluctuations on the roof slab under the green roof remained between 0.2 to 11.4°C. Temperature fluctuations on the roof slab under the reference roof were much higher than green roof which were between 0.5 to 32.8°C. Green roof reduced the temperature fluctuations by 0.3 to 21.4°C. During measurement period, we have found that a typical extensive green roof can provide a significant temperature reduction to the envelope of the building. Green roof provides stable temperature distribution on roof slabs. During measurement period, general average roof slab temperature under green roof was 1.6°C lower than reference roof.

At the beginning of the study, it was expected that green roof would provide significant heat insulation to interior rooms. But daily average room temperatures show that the green roof provided a cooling effect to the interior room in summer but this effect remained only between 0.5 to 1°C. In winter green roof provided a relatively warmer interior (1 to 3°C) than reference roof. Temperature fluctuations in interior room under the green roof were between 0.1 to 11.5°C. Similar temperature fluctuations were seen in the room under the reference roof which was between 0.2 to 11.6°C (Figure 3).

The normality of obtained temperature data was checked using the Kolmogorov-Smirnov Test. It was found that the daily average temperature values were not normally distributed. Mann-Whitney U Test were applied under level of significance of $\alpha=0.05$, to determine the significance of temperature differences of interior rooms. As a result of the test, no significant difference was found between the two data sets. This situation depends on several reasons. Major factors affecting measurements were the thickness of roof slabs and the roof surface area. Also, construction method of the roof, heat insulation properties and heating conditions of the building may have an effect. Temperature fluctuations on roof layers did not have a major effect to indoor conditions. Statistically, there is no significant difference found between the interior room temperatures.

Thermal insulation provided by green roof to the research building seems to be inadequate. But in bigger scale, insulation provided by the green roof will bring considerable amount of energy consumption to a building. This situation depends on several reasons. Major factors affecting measurements were the thickness of roof slabs and the roof surface area. Also, construction method of the roof, heat insulation properties and heating conditions of the building may have an effect. In obtained results, thermal insulation provided by green roof to the research building seems to be inadequate. But the insulation will bring energy consumption to a building in bigger scale.

Temperature profile

Various layers of a green roof perform diversely under various outdoor conditions. In entire measurement period, the temperature profile of a green roof was investigated. Temperature distributions of surface and bottom layers of roof systems were analyzed. The number of days that roof surfaces and bottom layers exceeded various levels was analyzed and expressed in Table 3.

In Table 3, temperature distribution of roof slab and roof surface temperatures can be seen as in number of days and percentages. 182 days out of the observed 382 days the surface temperature of green roof was lower than 10°C which can be expressed as surface temperature of green roof was lower than 10°C in 47.64% of days in measurement period. Surface temperature of the green roof exceeded 30°C only 7 days while surface of reference roof exceeded 56 days out of the 382 days. Roof slab temperature under reference roof exceeded 30°C in 28 days out of 352 days while roof slab temperature under green roof exceeded 30°C only 3 days.

In Canada Ottawa, Baskaran et al. (2003) analyzed temperature distributions of two roof systems (green and reference roof). In 660 days of measurement period, it was observed that the roof slab under the reference roof reached a temperature above 30°C in 342 days out of the 660 days, 219 days above 50°C and 89 days above 60°C. In same research, roof slab under the green roof reached a temperature above 30°C in 18 days out of the 660 days and never reached 40°C. Green roof reduced the temperature fluctuations on the roof slab compared to the reference roof.

Similar temperature distributions in the roof layers were observed in our study with the research studies in the world (Liu and Baskaran, 2003; Teemusk and Mander, 2009) Green roof provided a significant protection to the roof slab. Due to climate conditions, temperatures above 50°C had not been detected.

In our study, temperature distributions in the roof layers have shown similar characteristics. During seasonal change, major changes in reference roof layers are evident. Layers under the green roof have stable temperature values. Bottom layers of the green roof have similar temperature distributions (waterproofing membrane, water retention mat and filter layer). Growing media and plant canopy attenuated temperature changes through roof layers.

9 out of 12 months surface temperature of the green roof had the lowest temperature values. Rest of the 3 months, surface temperature of reference roof (2 months) and interior room temperature under green roof (1 month) had the lowest temperatures. 12 out of 6 months, maximum temperature values observed from roof slab under the reference roof (6 months) and interior room temperature under green roof (6 months).

In Greece, Spala et al. (2008) found that green roofs reduce the energy demand of a building by 40%. Similar results put forward by Sailor (2007) and Niachou et al. (2001) with mathematical models. In addition, Alexandri and Jones (2008) report that green roofs can provide energy conservation to the buildings by 32% to 100%. Similar results obtained from our study. Temperature distributions obtained from the study shows that green roof provides a significant insulation to the building.

In Estonia, Teemusk and Mander (2009) observed the rapid warming cooling cycle of the green roof surface in Estonia climate compared to the bituminous roof. In the same research, Fluctuations on the green roof surface was reached to 40°C.

In our research, temperature fluctuations on the surface of the green roof were measured between 5.0 to 27.4°C. In addition, temperature fluctuations on the surface of the reference roof were measured between 6.8 to 26.1°C. Similar to the findings of Teemusk and Mander (2009) daily temperature fluctuations on the surface of the green roof have reached up to 40°C. In summer, temperature fluctuations on the surface of the green roof and growing media reached to 40°C which were 4°C higher than reference roof which was an unexpected result.

Temperature fluctuations on the roof slabs show different distributions. Roof slab under the green roof did not affected by the fluctuations on the green roof surface and these fluctuations remained between 1.0 to 3.7°C. However, roof slab under the reference roof exposed to higher temperature fluctuations which are between 5.5 to 22.8°C. In brief, impacts of extreme temperature fluctuations on the surface of the green roof to the building envelope were reduced by the green roof system by 35 to 79% and provided a stable temperature distribution to the building envelope.

Fioretti et al. (2010) found that green roofs are sustainable choice for Mediterranean climate, where the climatology of precipitation and the general climatic conditions are less favorable to the growth of vegetation on top of the building. In milder Mediterranean climate of Istanbul, plants on the green roof were survived during our research. Plants withstand to drought periods up to 40 days and extreme weather conditions like snow and rain events. Plant growth on the roof was not remarkable in November 2010 to April 2011 because of seasonal conditions. Towards the end of April, with the increase in air temperature and seasonal change, plant coverage on the roof had reached to 85%.

Conclusion

Thermal impacts of a typical green roof in climate conditions of Istanbul have been analyzed in terms of their expected benefits for the building and the surrounding urban environment in a case study (IUGRRS).

During the monitoring and assessment period, obtained results will have an important role to a deeper analysis of thermal behavior of green roofs in Istanbul. Quantitative data obtained from this research were summarized.

Layers under the green roof had stable temperature values while the surface of green roof had the lowest values in measurement period. However, reference roof were affected directly from the changes in air temperature and solar radiation.

It can be confirmed that the green roof tolerated and attenuated the temperature changes through roof layers. Extreme fluctuations on the surface and in growing media of the green roof did not affect the roof layers beneath. While roof surface and plant canopy were exposed to negative temperature values during winter, temperature fluctuations in waterproofing membrane and roof slab were milder. Impacts of extreme temperature fluctuations on the surface of the green roof to the building envelope were reduced by the green roof system by 79%.

Difference between reflected solar energy from the surfaces of the roofs was not significant. In general, albedo rate of the green roof is 7% lower than reference roof. In addition, evaporative cooling and insulation of growing media had an effect to reduce temperature fluctuations in green roof system. But in drought periods, evaporation rate in the growing media was not remarkable due to low precipitation and moisture content. Inadequate soil moisture has caused overheating of the growing media.

Findings obtained from this study confirm that a typical extensive green roof contributes to reduce the extreme thermal effects in urban environment. Also, it can be said that a typical green roof is a sustainable choice for Istanbul climate conditions. But there are still further research studies needed to clarify water and energy related performance of green roofs in Istanbul climate conditions.

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