Investigating and analyzing the thermal behavior of the "green roof system" installed in two buildings in Athens, Greece

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ABSTRACT

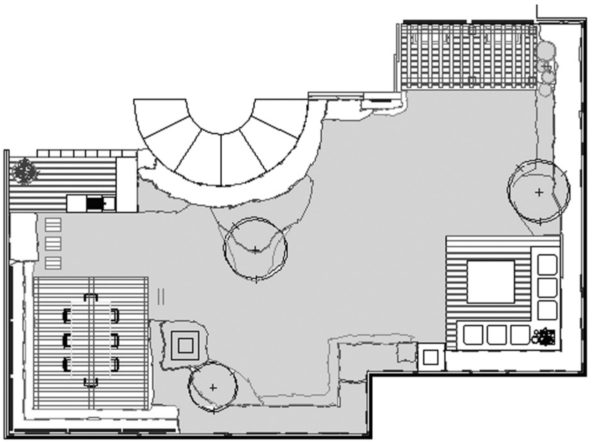
The present paper deals with the experimental analysis and monitoring of the energy and environmental performance of a green roof system installed in two residences, in the region of Athens, Greece. The one is located in municipality of Psichico and the other in municipality of Peristeri. The analysis was carried out in two phases. During the first phase, monitoring of the green roof system was performed. Extended surface and temperature measurements were taken of the indoor and outdoor environment where the green roof is installed.
During the second phase, in order to investigate the potential of energy saving the heating and cooling loads were calculated using the dynamic thermal simulation software TRNSYS.
Lower surface temperatures are measured in the spaces, which are covered by vegetation while higher in the spaces, which are not covered by vegetation. Surfaces that are covered externally with the green roof have lower U-values than conventional roofs without any vegetation, resulting in reduced heat losses from the interior of the building.
The energy performance evaluation showed a significant reduction of the cooling load in the case of the residence in Psichico (11%), while the reduction of the cooling load in the case of the residence in Peristeri is insignificant (2%). This can be justified by the fact that, in the case of the residence in Psichico, the whole roof is covered by the green roof system, while in the case of the building in Peristeri, only some parts are covered. Finally, the influence of the green roof system in the buildings' heating load was found to be insignificant.

1. INTRODUCTION

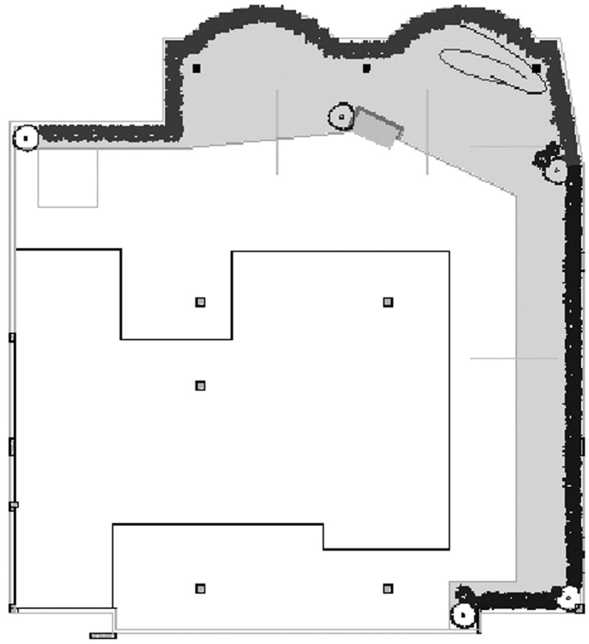
Various studies have been performed in order to analyze the energy performance of a green roof system. Apart from the attractive appearance, the installation of this system affects positively the microclimate, while evapotranspiration from plants and grass can reduce urban temperatures. Also, shading from plants protects the residence from solar radiation and reduces the temperature fluctuation during the day. The energy for cooling purposes is reduced as well, during summer.
The "green roof" system consists of a vegetation layer which is a roof planting soil, a filter sheet which prevents fine particles from being washed out of the substrate soil, a drainage layer which has special holes that ensure evaporation and the necessary ventilation, a moisture retention layer which provides mechanical protection and retains moisture and nutrients and a root barrier which prevents roots from affecting waterproofing.

Picture 1. "Green roof element"

The aim of this study is the analysis of the green roof's energy performance, in two buildings, in Psichico and in Peristeri. The study was completed in two phases. During the first phase, experimental measurements were conducted in indoor and outdoor spaces, in both buildings, while during the second phase, the energy saving was examined trough a mathematical approach by calculating both cooling and heating loads for the two buildings.



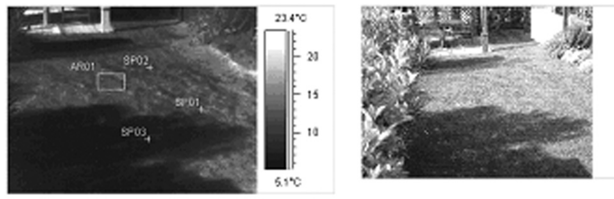
Picture 2. Architectural plan of green roof in Psichico. The light grey areas are covered by “green roof” system.



Picture 3. Architectural plan of green roof in Peristeri. The light grey areas are covered by “green roof” system.

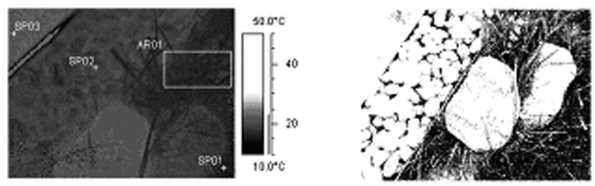
2. EXPERIMENTAL MEASUREMENTS

The two residences are located in the region of Psichico and in the region of Peristeri, in Athens. The first residence is a two-storey building and its roof is partly covered by a green roof system, while the second residence is a flat on the last floor of a multi storey building and its roof is almost full covered by a green roof system.
Surface temperature measurements are performed with a camera of infrared thermograph (Thermovision 570) (28/03/2007, 20/04/2007).
Pictures 4 and 5 show visual photos in specific places of the two buildings and their surface temperature distribution as it has been taken by the infrared camera. The gray scale on the on the right part of the thermo-photograph picture represents a different temperature range. Also, in Appendixes A and B are given tables containing surface temperature in selected points. Also, the tables contain information concerning the surface material, its shading and if the photos were taken after or before watering the green roof.



AR01	12.1°C
SP01	11.6°C
SP02	10.6°C
SP03	6.6°C

Picture 4. Surface temperature distribution on green roof in Psichico.



AR01	16.9°C
SP01	10.1°C
SP02	19.8°C
SP03	21.9°C

Picture 5. Surface temperature distribution on green roof in Peristeri.

The indoor air temperature was measured with calibrated self-recording thermometers with 1 min. timestep interval.

Accuracy	± 0.4ºC	0 – 70ºC
Analysis	0.1 C	-40 – 100ºC

3. CALCULATION RESULTS

3.1 Heating and cooling loads

The green roof system was installed, as previously mentioned, in the two residences in the region of Psichico and in the region of Peristeri in Athens. Heating and cooling loads were calculated for the preexisting situation and for the present condition after the installation of the green roof system, for each building.
Hourly values of global solar radiation, diffuse solar radiation, dry bulb temperature, relative humidity, wind speed and wind direction were necessary for the calculation of heating and cooling loads of each residence. The monthly average, maximum and minimum values of the most important meteorological parameters are shown in Appendix B.
The desirable thermal comfort conditions are given in Table 1 and are in accordance with the greek regulations.

Table 1. Desirable thermal comfort conditions during the summer and winter period.

	Temperature (^{0}C)	Schedule
heating	20	00: 00– 24:00
cooling	26	07:00 – 23:00

The internal gains are considered negligible.
The infiltration rate was considered to be equal to 0.2 to 0.5 air changes per hour, while the natural ventilation rate for the experimented time period was assumed 0.8 to 1 air changes per hour.
For the scenarios that were studied, some details are given below:
1. Preexisting situation: The roof's thermal insulation was considered 5cm thick and its thermal conductivity 0.11kJ/hmK.
2. Present situation: The main difference as regards the first scenario concerns the green roof installation. The description of the green roof has been done in accordance to the system structure and taken into account its operation. The green roof has been assumed as a non-dynamic element.
In Table 2 are given the calculated annual values of heating and cooling loads and the percentage of their reduction before and after the green roof system installation.

Table 2. Heating and cooling loads before and after the green roof system installation

	Heating loads (kWh/m²)		Cooling loads (kWh/m²)	
	Before	After	Before	After
Psichico	92.80	91.00	30.79	27.48
		-1.94%		-10.76%
Peristeri	46.16	45.40	9.95	9.88
		-1.65%		-0.62%

The monthly values of heating and cooling loads before and after the green roof installation are given in Appendix C.

3.2 Internal air temperatures

In order to estimate the thermal comfort conditions inside the buildings, the hourly internal temperatures were calculated, for one year.
In the case of the building in Psichico, the internal temperatures are lower after the installation of the green roof system, during the summer period, while they are higher during the winter period. More specifically, the internal temperature difference appears to be lower up to 0.6^{0}C, during the summer period, and higher up to 0.4^{0}C, during the winter period, after the installation of the green roof. In the case of the building in Peristeri, the temperature difference is negligible, because its roof is partly covered by the green roof system.
The cumulative frequency distribution of the internal temperatures before and after the installation of the green roof system and the cumulative distribution of the ambient temperature were calculated. According to the calculation results and for the residence in Psichico the 66% of the internal temperatures are lower than 26^{0}C, before the installation of the green roof system while 68% of the internal temperatures are lower than 26^{0}C, after its installation. In the case of the building in Peristeri, the internal temperatures are affected less as the roof is partly covered by the green roof system.

3.3 Surface temperature of internal side of the roof in residence in Psichico

Especially for the residence in Psichico where the impact of the green roof is higher, the surface temperatures of the internal side of the roof were calculated before and after the installation. In Figure 1 the alteration of the average hourly surface temperatures are shown during a summer and a winter month, after the green roof installation. The roof internal surface temperature affects significant the long wave radiation emitted by the roof and therefore the achievement of thermal comfort.

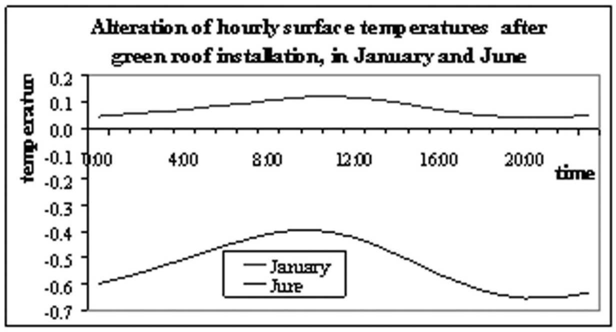


Figure 1. Alteration of hourly surface temperatures after green roof installation, in January and June.

4. CONCLUSIONS

The present study deals with the estimation of the energy performance of a green roof system installed in two residences, in Psichico and Peristeri, in Athens, Greece. Also, an estimation of hourly internal temperatures for one year, before and after the green roof installation was performed.
Lower surface temperatures of the green roof are measured in places covered by thin dense green vegetation, as grass, while higher surface temperatures of the green roof are measured in places covered by shrubs. The temperature difference ranges from 3.7^{0}C to 7^{0}C. The highest temperatures are measured in spaces covered by wood or stone. The maximum temperature difference between surfaces covered by green roof system and other surfaces, which are not covered, was estimated to 7^{0}C, in both buildings.

After the watering of the green roof system, part of the water hives in the drainage layer and so the density and the heat capacity of the green roof system is increased. The temperature differences between vegetated and non vegetated areas become higher.
According to calculation results the installation of green roof system reduces the cooling loads by 11% in the residence, in Psichico, while the reduction of cooling loads in the residence in Peristeri is negligible, since its roof is partly covered by the green roof system.
Also, a reduction of heating loads is noticed in both buildings. This is because of the reduction of heat losses through the roof element as the installation of the green roof reduces the U value of the roof.
Additionally as the roof heat capacity is increased, flattering of temperature fluctuation affected by meteorological parameters is noticed.
Finally, green areas on roof elements reduce the solar gains. Even the reduction in relative values may be the same in summer and winter period, the absolute reduction is greater in summer period as the absolute value of the incident solar radiation is much higher. So the effect of shading is higher in summer period (reduction of cooling load) and almost insignificant in the winter period.

APPENDIX A.

Residence in Psichico			
Surf. Material	Shading	Watering	Surf. Temp. (^{0}C)
Grass	-	-	12.1
	-	-	13.1
	-	-	13.3
	-	-	10.2
	-	-	10.2
	-	✓	10.6
Imperme-able film (neighbor residence)	-	-	15.2
	-	-	13.4
	-	-	15.7
	-	-	13.4

Residence in Peristeri			
Surf. material	Shading	Watering	Surf. Temp.(^{0}C)
Grass	-	✓	10.6
	-	✓	12.7
	-	-	21.2
	-	-	15.9
	-	-	16.9
	-	-	17.2
	-	✓	16.5
Tiles	-	✓	22.7
Cement	-	✓	21.0
Plaster	internal surface		20.8
Plaster			19.7

APPENDIX B. Meteorological Station: Athens (23.37E, 38.04N)

Month	Solar radiation on Horizontal (kWh/m^2)		Average value of		
	Total	Diffuse	Dry bulb temperature (ºC)	Relative humidity (%)	Wind speed (m/sec)
1	60	28	9.5	76	4.4
2	69	29	7.6	71	3.9
3	100	41	10.4	76	3.7
4	166	55	16.1	59	3.3
5	196	65	21.1	61	3.0
6	227	62	24.7	54	3.1
7	226	63	26.0	46	4.2
8	211	56	26.9	45	4.1
9	162	48	22.9	51	3.5
10	107	39	16.1	62	3.2
11	73	30	15.1	74	2.7
12	58	24	11.6	75	2.6

APPENDIX C. Heating – Cooling loads
Results are given in kWh/m^2.

	Building in Psichico			
	Heating loads (kWh/m²)		Cooling loads (kWh/m²)	
	Before the green roof installation	After the green roof installation	Before the green roof installation	After the green roof installation
January	20.18	19.53	0.00	0.00
February	22.64	22.02	0.00	0.00
March	18.05	17.81	0.00	0.00
April	3.05	3.23	0.00	0.00
May	0.00	0.00	1.41	1.07
June	0.00	0.00	6.10	5.25
July	0.00	0.00	8.99	8.06
August	0.00	0.00	11.47	10.63
September	0.00	0.00	2.83	2.46
October	5.50	5.44	0.00	0.00
November	6.85	6.85	0.00	0.00
December	16.49	16.15	0.00	0.00
Sum	92.80	91.00	30.79	27.48
		-1.94%		-10.76%

	Building in Peristeri			
	Heating loads (kWh/m²)		Cooling loads (kWh/m²)	
	Before the green roof installation	After the green roof installation	Before the green roof installation	After the green roof installation
January	9.72	9.54	0.00	0.00
February	10.95	10.76	0.00	0.00
March	9.03	8.89	0.00	0.00
April	2.22	2.13	0.00	0.00
May	0.05	0.05	0.14	0.14
June	0.00	0.00	1.88	1.87
July	0.00	0.00	3.22	3.20
August	0.00	0.00	4.12	4.10
September	0.00	0.00	0.59	0.58
October	2.99	3.01	0.00	0.00
November	3.41	3.36	0.00	0.00
December	7.77	7.64	0.00	0.00
Sum	46.16	45.40	9.95	9.88
		-1.65%		-0.62%

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