The Effect of Planted Roofs on the Energy Behaviour of Buildings

D.G. Aravantinos[1] and K.N. Axarli [1]

(1) *Laboratory of Building Construction and Building Physics, Aristoteles University of Thessaloniki, P.O. Box 429, 52124 Thessaloniki, Greece, Fax:+302310 263632, E-mail: axarli@civil.auth.gr*

ABSTRACT

Vegetation on the building envelope can have a marked effect on the microclimate and on the building's energy behavior as well.
In this paper, the impact of planted roofs on the thermal load of buildings is presented. Based on measurements and a series of thermal simulations, the energy behavior of buildings covered with conventional and planted roof is analyzed. The discussion is mainly focused on the evaluation of the temperatures developed at the different layers of both, a bare and a planted roof. Simulation analysis has been used in order to evaluate the impact of thermal insulation along with the type of roof (conventional or green roof) on the heating and cooling requirements of the buildings.
The analysis is based on the results of field experiments carried out in buildings in the urban context of Thessaloniki, Northern Greece, (40^0 N). A series of measurements of relative humidity, air and temperatures at the different layers of roof were performed in two identical buildings with bare and planted roof.

Keywords: planted roof, green roof, passive cooling, energy, thermal load, heat flux.

INTRODUCTION

It is a fact that dense built environment which modern cities and urban areas experience, has kept people away from nature and alienated them from it. Since big scale urban reconstruction projects aiming to increase the green in cities face both financial and social obstacles, something that makes them really hard to implement, it is preferable to look for simpler solutions.

Small scale design approaches are often effective in replacing depleted vegetation in cities and thus improving the environmental quality, as well as the quality of life in the city. Such an approach could be the development of green roofs. Planted roofs apart from providing environmental, visual, and technical benefits can also affect the thermal load of the building and the internal thermal comfort conditions.

Field measurements that were taken in Thessaloniki, Northern Greece, (40^0 N), by the Laboratory of Building Physics of Aristotle University of Thessaloniki have shown that the planting of roof affects the temperature on the roof surface and consequently its thermal performance. The measurements were carried out in two identical neighboring four-storey buildings with the same building envelope construction. The first building (building A) was covered with a conventional bare roof system, a typical construction solution for Greece, whilst the second one (building B) had a planted roof. The components, the thickness and the order of the layers in both the bare roof and the green roof are shown in the figure 1.
A measurement system has been installed in order to record the temperature and the humidity of both the internal and the external air, and the temperature at the various layers of the roof.

The fourth floor in both buildings, where the measurements were carried out, remained unoccupied during the measurement period and its ventilation was kept at low levels.

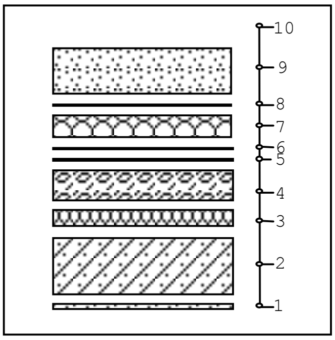

Fig. 1. Flat and planted roof construction detail

The following layers are found in both planted and bare flat roofs:
1. plaster (1.5cm), 2. reinforced concrete slab (15cm), 3. thermal insulation (expanded polysterene 5cm), 4. lightweight concrete (min 5cm), 5. asphalt waterproofing membrane (two layers: 0.7cm), with aluminium protection (in the case of bare roof)

The following layers are only found in planted roofs:
6.anti-root membrane, 7.drainage layer (6cm), 8.geotextile filter (0.3cm), 9.substrate (thickness varies: 20-12cm), 10.planting

THE RANGE OF TEMPERATURE IN THE ROOF

According to the research results, the fluctuation of temperature in the conventional bare roof appears to have a higher range than the green one. Figures 2a, 2b and 3a, 3b show the recorded temperature distribution at each layer inside both, the bare and the planted roof, through-out a winter day in January and a summer day in July.

The outside surface temperature presented the highest fluctuation with a daily range in the conventional roof about 25^{o}C during the warm period and 10^{o}C during the cool period, whereas the annual range reached 50^{o}C. The daily range in the green roof during both the warm and the cool period was nearly 5^{o}C, while the annual range was only 16^{o}C.

This difference in the recorded temperatures between the bare and the planted roof is due to the influence of the solar radiation received on the surface of the bare roof, especially during the warm period. Contrary, the foliage of the green roof shadows the surface preventing overheating. The direct solar radiation is either reflected or absorbed by the leaves of the plants. In this way the influence of the direct solar radiation is minimum and the surface temperature is affected mostly by the temperature of the air layer which is between the substrate and the foliage of plants. Transpiration tends to cool the air in the plant canopy, in turn lowering the surface temperature of the soil. This phenomenon is more intense during summer when the foliage is very dense, than during winter, when the vegetation is gravely eliminated and the soil absorbs larger amount of the solar radiation. For this reason the surface temperature of the planted roof is lower than the ambient air temperature by 2^{o}C to 4^{o}C in summer (it has been recorded a difference up to 8^{o}C) all through the 24-hours, while during the cool period the temperatures differ only about 1^{o}C.

Evaporation at the soil surface, which absorbs large amount of heat, also contributes to the maintenance of low surface temperatures. The wind influences as well, since it helps the evaporation and besides it contributes to the increase of thermal losses. The layers of substrate section (soil and drainage layer) in the green roof, decisively influence the roof performance due to their thermal capacity, which rises with the absorbed water from the soil and the drainage layer. The addition of water increases the heat capacity of the soil, which is an indication of its capacity to store energy. When the soil becomes waterlogged, as it happens during summer, the thermal capacity of the layer approaches the capacity of the water (4186 KJ /kg ^{o}C).

During summer, in the afternoon, the temperature in the substrate is 6°C lower than the temperature developed on the outside surface. In the morning, when the ambient air temperature reduces to the minimum, the two temperatures tend to coincide.
In winter, the temperature in the substrate layer is higher than the one on the outside surface by 4°C to 5°C and only in midday, when the influence of the solar radiation is high, temperatures tend to be the same.

Also, it is worth mentioning that the temperature at the water-proofing layer of the planted roof, which in fact separates the structural part from the planted one, remains almost constant on a seasonal cycle; around 11°C in winter and 27°C in summer. The thermal capacity of the substrate layer limits the temperature range at the water proofing membrane that otherwise would be very high in summer due to the solar radiation. It can been seen that on a July day with ambient air temperature approaching 31°C, the water proofing membrane of the bare roof reaches peak temperature in excess of 50°C at 14.00 hours, whereas the temperature at the water proofing membrane of the planted roof has peak below 27°C. The temperature curve in the structural part of the roof indicates that the layer which is underneath the water-proofing membrane seems to be affected thermally more by the structural part of the roof which faces the interior, and less by the planted one.
Measurements also show that all through the year, internal surface temperature in the conventional roof fluctuates around 18°C, whereas in the planted roof only 15°C. However, it is notable that in the planted roof the inside surface temperature is almost identical to the internal air temperature both during the cool and the warm period. In contrast, in the conventional bare roof the inside surface temperature shows a difference of 0.5°C to 1.0°C from the corresponding air temperature, which reaches 3°C during midday hours in summer.

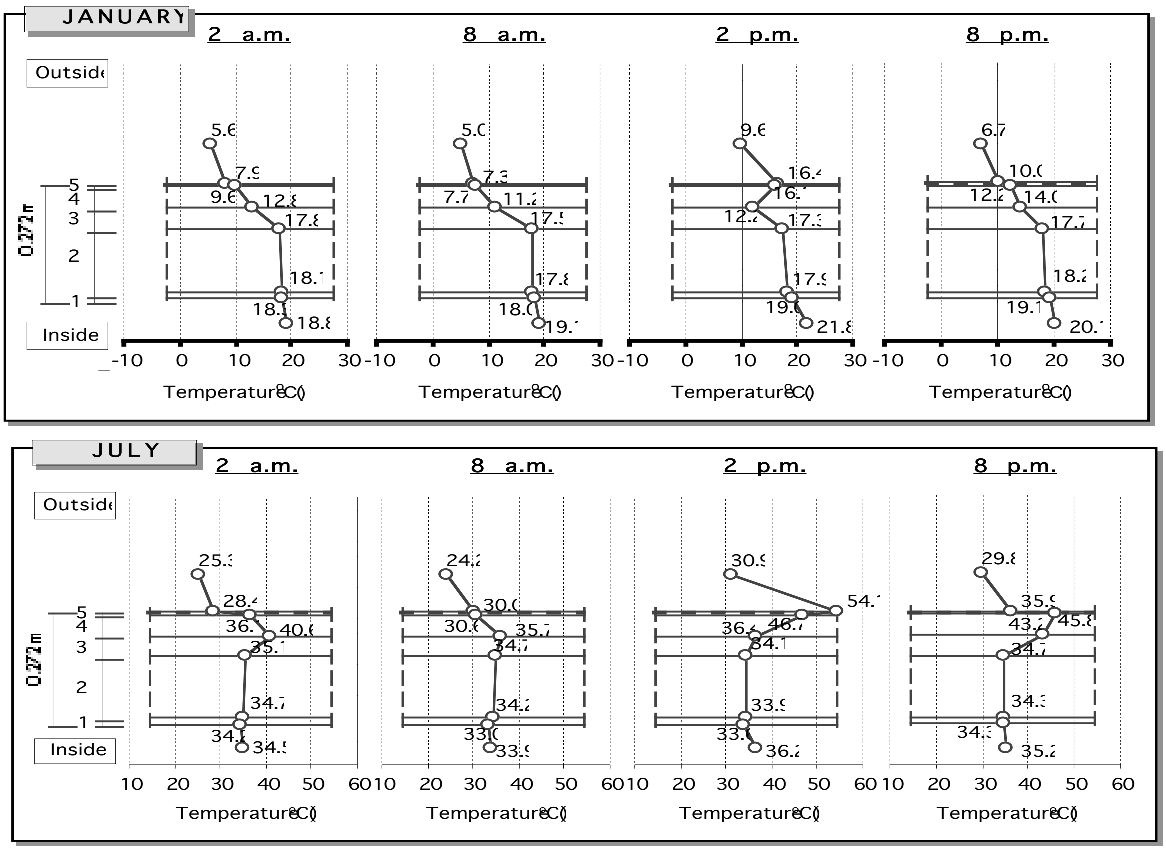

Fig. 2a, 2b. Temperature distribution at each layer inside the flat roof during winter and summer

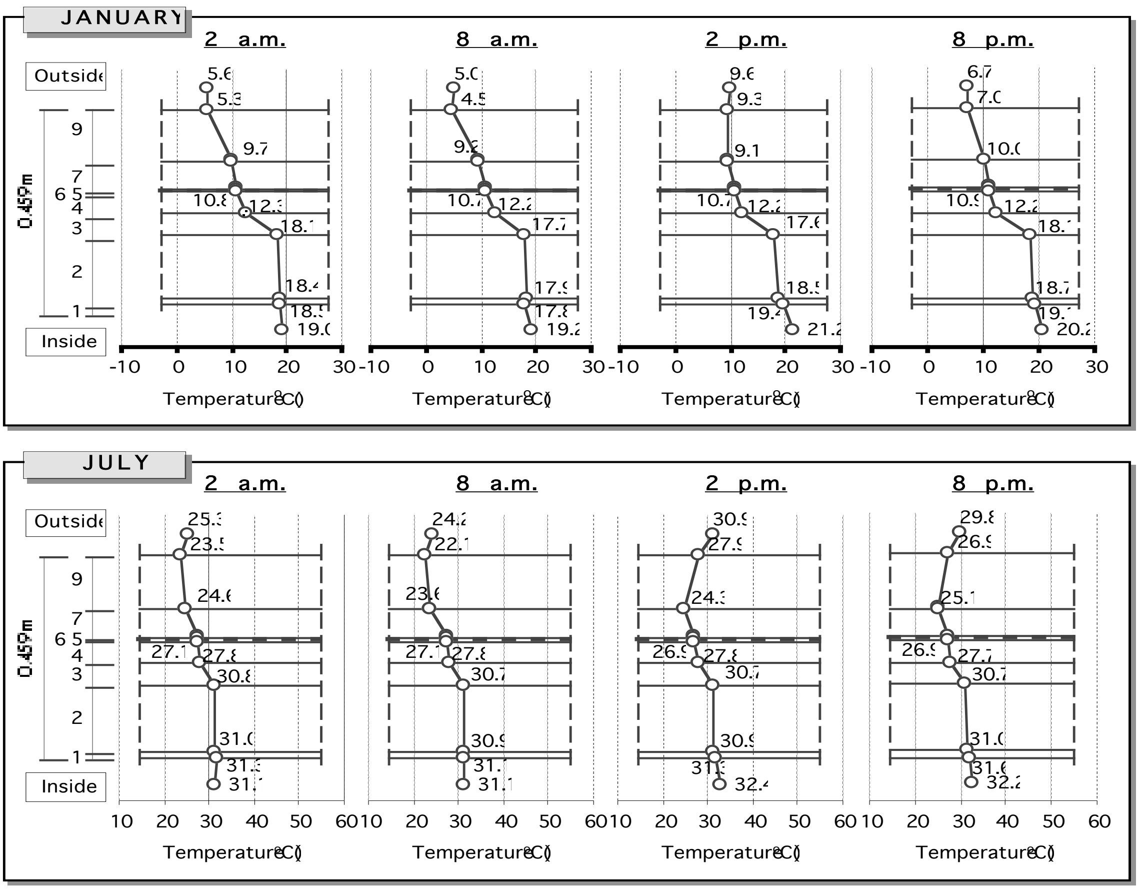

Fig.3a, 3b.Temperature distribution at each layer inside the planted roof during winter and summer

HEATING AND COOLING CONSUMPTION

Based on measurements and a series of thermal simulations, the energy behavior of the roof of both buildings covered with conventional and planted roof was analyzed. The investigation focused on the impact of the level of the roof thermal insulation along with the type of roof (conventional or green roof) on the heating and cooling requirements of the building. For the simulation purpose, varying amounts of roof thermal insulation were considered.The conventional bare roof with 5cm thermal insulation [Uvalue =0.644 W/(m^{2}K)], was used as the reference case of the comparison, as it is the most common construction in Greece.

Since the heat flux through the roof is part of the total heat fluxes (thermal losses or gains) of the building, any change in the thermal insulation capacity of the roof, has a great impact on the consumed energy for the heating or cooling.

Figure 4a,b shows the heating and cooling demand (KWh/m^2 floor area) during winter (October – April) and summer (June – August) respectively, for the building covered with flat bare roof or planted roof, when ,

- thermal insulation is high (10cm thermal insulation): Uvalue of the bare roof =0.361 W/(m^{2}K) and Uvalue of the planted roof =0.330 W/(m^{2}K), or
- thermal insulation is just sufficient to comply with Greek standards (5cm thermal insulation -existing buidings): Uvalue of the bare roof =0.644 W/(m^{2}K) and Uvalue of the planted roof=0.553 W/(m^{2}K).

According to the results of the simulation, the increase in the roof thermal insulation causes decreased heat fluxes, regardless of whether they are heat losses or heat

gains. Therefore, high level of thermal insulation affects the heating and cooling load in both types of roofs, but in a different way.
In addition, as the thermal protection of the roof increases, the differences between the conventional and the green roof eliminate, as far as their energy behavior is concerned.

During the heating period, the difference in performance between these two roofs which have the same level of thermal insulation is limited; the building with the planted roof has slightly lower heating demand than the one with the bare roof (fig. 4a). The building with planted roof requires 2.36% less heating than the building with conventional roof, when thermal insulation is 5cm and 0.5% less heating, when thermal insulation is 10cm. In multi-storey buildings, the thermal flux through the roof is a minor factor of the thermal balance equation and consequently the impact of thermal insulation is low.
Furthermore during winter, due to the small amount of solar radiation that planted roof receives, the soil substrate does not develop higher temperatures than the top cover of the bare roof. Therefore, the increase of thermal insulation in the green roof causes small decrease in the building heating demand, similar to the decrease it causes to the conventional roof (10.2% and 8.6% respectively).

On the contrary, during summer, the type of the roof gravely affects the cooling demand of the building (fig 4b). The thermal insulation layer in fact does not have a direct impact on the temperatures developed on the upper layers, but only on the heat conduction from the upper part of the roof to the internal space.

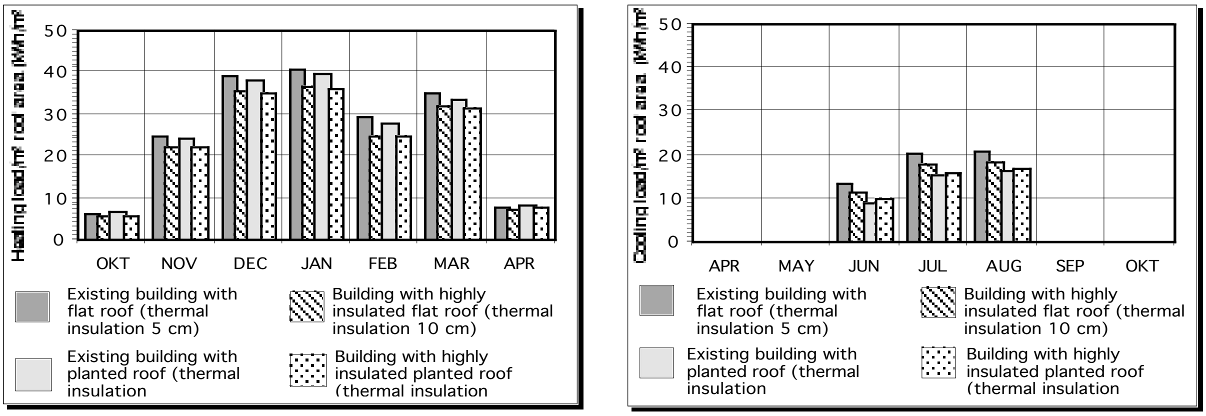

Figure 4a,b. Heating and cooling load per m² floor area, for the different buildings

The upper layers of the bare roof are overheated due to the intense solar radiation, as it has clearly shown in the figure 2b. This heat, which is stored in the upper layers of the element, is conducted to the interior of the building, meeting a resistance mainly from the thermal insulation layer. Therefore, overheating of the building that is covered with bare roof is expected and it is directly connected to the level of the roof thermal insulation layer. Overheating and/or cooling load diminishes as the thickness of the insulation increases. In the planted roof however, the maintenance of low temperatures in the planted section (as it is shown in the figure 3b) contributes to the decrease of the cooling load of the existing building. The building with planted roof needs 25.48% less energy for cooling than the building with bare roof, with the same level of thermal insulation (5cm thermal insulation).

On the contrary in the planted roof, where the temperature of the soil remains low, when thermal insulation thickness increases, the heat flux from the interior to the external air decreases. An increase in the thermal insulation causes an increase in the cooling load, since the thermal communication between the interior of the building and the cooler layers of the planted roof is eliminated. Therefore the ability of the concrete slab to cool the space by absorbing amounts of heat from the internal is limited. For the cases under examination, the addition of an extra layer of thermal insulation at the planted roof causes a 5% increase in the cooling demand.

CONCLUSIONS

Planted roofs can be an effective solution to the replacement of depleted vegetation in the constantly expanding cities and also a way in which the relationship between man and nature can be reconsidered, especially in the densely built-up areas.
Research has also shown that planted roofs are complex building elements, which can seriously alter the thermal characteristics of the building envelope.

According to the research results, planted roofs influence the thermal behavior of a building during the cool period in a different way than during the warm period.

- During the heating season, planted roofs have slightly better performance than bare roofs, regarding the reduction of thermal losses, due to the extra layers they have. This contribution however is minor and thus planted roofs cannot be considered as an effective way to decrease thermal losses through the roof structure. It has been shown that the thickness of the insulation layer is the major factor in reducing conductive heat losses through the roof structure and cannot be replaced by the extra layers of a planted roof.
- On the contrary, during the cooling season, green roofs have much greater impact on the building's thermal performance and a great cooling potential. Planted roofs are not any more the thermally weak building element, as it is the case of the bare roofs. The thermal capacity of the substrate may reduce and delay the effect of heat gains from solar radiation and high air temperature. Planted roofs act also as a natural way of cooling, as the heat from the warm interior of the building is conducted to the upper layers of the roof which are cooler, due to evapotranspiration of plants. However, increased thermal insulation may eliminate the cooling effect of the substrate and planting.

Therefore, when design aims to increase the beneficial thermal effects of a planted roof, the level of the roof thermal insulation should be such so that the total savings of energy during the cool and the warm period are maximum.

BIBLIOGRAPHY

1. Aravantinos D., Theodosiou T., Tourtoura D., (1999):"The influence of a planted roof on the passive cooling of buildings", proceedings I.S.E.S. conference,"Solar is renewable", Jerusalem, 4-9 July.
2. Axarli K., Despotidou H., (2005): "Transformation of existing roof tops into gardens: advantages-disadvantages and application difficulties", proceedings "Landscape architecture: Education, Research and Practice", School of Architecture, A.U.Th, Thessaloniki, May 11-14, p.p. 223-234
3. Eumorfopoulou E., Aravantinos D., (1998): "The contribution of a planted roof to the thermal protection of buildings in Greece", Energy and buildings 27, p.p., 29-36.
4. Givoni Baruch (ed.), 1998: "Climate Consideration in Building & Urban Design", Van Nostrand Reinhold.
5. Morais C., Rosiz M., (2005): "Thermal performance of green roof in the city of Sao Carlos (SP), Southeast of Brazil", proceedings PLEA 2005 Conference, Beirut, 13-16 November 2005, p.p.87-92
6. Research programme "The impact of planted roofs on the thermal load of buildings and the quality of life in the big urban centers", (2001): research programme funded by the Aristotle University of Thessaloniki, the Municipality of Stavroupolis and the Ministry of Development, Greece, 1997-2001
7. Yannas S., Erell E., Molina J.L.(eds), (2006) "Roof Techniques: a Design handbook", Earthscan,UK