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Energy Conservation Potential of an Extensive Green Roof in Iran for One Year Duration

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Abstract

The temperature of cities continues to increase because of the heat island phenomenon and the undeniable climatic change. The observed high ambient temperatures intensify energy problems in cities, deteriorates comfort conditions, put in danger the vulnerable population and amplify the pollution problems. There are some suggested ways to reduce these issues, among them vegetated roofs are shown to be promising. This study describes energy consumption performance of an extensive modular type green roof with different plant selections using a randomized complete design in Mashhad, Iran. Nine species from three major taxonomic and functional plant groups (grasses, ground covers and sedums) namely (*Agropyron cristatum, Festuca aurundinacea, Festuca ovina, Potentilla* sp.*, Frankenia thymifolia, Vinca minor, Sedum acre, Sedum spectabile, Carpoboratus edulis*) were selected. Temperature fluctuations during four seasons were recorded with three replicates. Experimental trials with growing beds without plants (bare roofs) were also used as controls. Small hand manual thermometers were placed in each module (box) and air temperature was also recorded. The results showed very significant temperature differences between the green and bare roof modules. Larger plants with higher biomasses kept temperatures more stable. Thermal comfort and energy saving was achieved using green roofs in this research and it could be well used in a large scale for growing cities and population energy requirements.

Keywords: Green roof, Plant variation, Season, Temperature fluctuation, Thermal performance.

INTRODUCTION

Green roof development is increasing in cities across the world because it is an important strategy that addresses some key urban environmental issues. Green roofs can reduce surface water runoff, provide habitats for wildlife, moderate urban heat island effects, improve building insulation and energy efficiency, improve air quality, create aesthetic and amenity values, provide opportunities for urban food production and preserve the roof's waterproofing (English Nature, 2003; Dunnett and Kingsbury, 2008).

The temperature of cities continues to increase because of the heat island phenomenon and the undeniable climatic change. The observed high ambient temperatures intensify the energy problem of cities, deteriorates comfort conditions, put in danger the vulnerable population and amplify the pollution problems. To counter balance the phenomenon, important mitigation technologies have been proposed and developed. Two of which that are more important mitigation technologies are associated to roofs: (a) Those aiming to increase the albedo of the roofs, known as cool or reflective roofs (Zinzi, 2010; Akbari *et al*., 2005) and those that propose roofs partially or completely covered with vegetation, known as green roofs or living roofs (Theodosiou, 2009; Santamouris *et al*., 2007; Sfakianaki *et al*., 2009). Both technologies can lower the surface temperatures of roofs, thus, decrease the corresponding sensible heat flux to the atmosphere and pass through indoors. Increasing green spaces in cities contribute to decrease the urban surface and ambient temperatures and mitigate heat island effects. Studies reported by Gill *et al*. (2007) show that an increase by 10% of the urban green in Manchester, UK, could amortize the predicted increase by 4 K, of the ambient temperature over the next 80 years. Several experimental and theoritical studies have been performed to identify the energy conservation potential of green roofs (Kumar and Kaushik, 2005; Alexandri and Jones, 2008; Wong *et al*., 2003; Theodosiou, 2003; Eumorfopoulou and Aravantinos, 1998; Jaffal *et al*., 2012; Spala *et al.,* 2008; Takakura *et al*., 2000; Castleton *et al*., 2010). The specific energy benefits depend on the local climate, the green roof design and more importantly on the specific building characteristics. Given that heat transfer benefits in green roofs are mainly provided through latent heat processes, performance of these systems are higher in dry climates. Climate change and scarcity of natural energy resources (Bahgat, 2010) are topics of current interest (Solomon and Krishna, 2011) and building accounts for 33% of global green gas emission (Wan *et al.,* 2011; Levermore, 2008).

Energy saving benefit of a green roof could be considered and discussed for warm and cold seasons of the year while most research so far have focused on warm seasons only. Therefore, this experiment was planned to quantify the energy saving potential of an extensive green roof on a year basis in Mashhad, Iran.

MATERIALS AND METHODS

This experiment was established on a roof top (3 meters above ground level) of an agriculture faculty building at Ferdowsi University of Mashhad, Iran in four seasons during 2014-2015. Nine species from the three major taxonomic and functional plant groups that are commonly used for extensive green roofs (grasses, groundcovers and sedums). *Agropyron cristatum, Festuca aurundinacea, Festuca ovina, Potentilla* sp., *Frankenia thymifolia, Vinca minor, Sedum acre, Sedum spurium* and *Carpoboratus edulis* were selected (Table 1) for a green roof design and imposed to local natural temperatures during all four seasons of 2015. In addition a non-planted trial was also considered as the control treatment. The experiment was a complete randomized design with 3 replicates. A mixture of soil, sand, pumice and perlite (40, 20, 20 and 20 w/w %) was considered as the media composition. The soil weight for each box was approximately 20 Kg. According to the climatic and environmental properties of a green roof in Mashhad, a mixture is needed to provide good support as well as suitable water retaining with a light weight.

Different plant genera used for this experiment are shown in Table 1. Accordingly, fully grown transplants were provided from a local farm near the experimental site, 6-8 leaves and 20-

Table 1. The nine species used in this study and their characteristics.

Scientific name	Family	Growth habit
Agropyron cristatum	Poaceae	Grass
Festuca arundinacea	Poaceae	Grass
Festuca ovina	Poaceae	Grass
Frankenia thymifolia	Frankeniaceae	Groundcover
Vinca minor	Apocynaceae	Groundcover
Potentilla sp.	Rosaceae	Groundcover
Sedum acre	Crassulaceae	Succulent
Sedum spurium	Crassulaceae	Succulent
Carpoboratus edulis	Aizoaceae	Succulent

30 centimeters height (except groundcovers which are spreading) (Fig. 1.). Temperature recording was performed when the plant canopy covered the box surface completely. Experimental trials were exposed to full sun during the recording duration (January-December) and irrigation was sufficiently planned constant and equal for all boxes.

For recording the temperatures in four seasons of autumn, winter, spring and summer, experimental manual thermometers were placed in trial boxes (both planted and non-planted). The thermometers were placed in the boxes as which half of it (thermal bulb) was under the media so that it can show accurate values. Air temperature of the period of the experiment was collected from Ferdowsi University of Mashhad weather station (Table 2). The thermodynamic performance of the green roofs will be the highest if they can mitigate temperature fluctuations during the extreme temperature events. Therefore, to investigate thermal performance of the green roof modules in extreme temperature conditions, temperature of the green roof modules in hottest days of April-September as representative of the months of warm seasons and temperature of the green roof modules in coldest days of October-March as representative of the months of cold seasons, respectively were selected. To test for significant differences between the treatments and the interactions, JMP8 software was used. When there were significant differences among the means, comparison between the means were performed by Duncan test ($P < 0.05$).

Table 2. Meteorological properties of Mashhad during the course of this study.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.
Temp. (ºC)	12.83	10.82	22.71	29.91	35.71	40.68	42.12	33.56	23.84	15.72	11.66	13.89
RH (%)	61.31	67.21	70.82	48.61	43.5	21.48	23.35	23.59	30.64	52.1	57.58	62.25

Source: Ferdowsi University of Mashhad Weather Station.

Heating and cooling load prediction

The heat induced by radiation on a roof in warm seasons is then passed through the roof indoors and a cooling or heating load calculation will be required to either reduce or increase the indoor temperature to the optimum level required depending on the season. The heat gained in each month of the year can be calculated. The amount of heat energy gained or lost by a substance is calculated using the following equation:

$q=mc\Delta T$ (1)

Where m is the mass, c is the specific heat, delta T is change in temperature and q is the heat energy gained or lost by a substance. The above equation for this green roof experiment can be modified as below (q1, green roof and q2, non-planted bare roof):

$q^1=mc\Delta T1$ $q^2=mc(\Delta T1+x)$ (2)

$q^1-q^2=mc\ (\Delta T1-\Delta T1+x)$ (3)

$\Delta q=mcx/hr$ (4)

Fig. 1. Experimental trials planned for this study in a four season glance along with control treatment, a) Autumn, b) Winter, c) Spring, d) Summer and e) Control.

where m is the mass of soil, c is the soil specific heat (wet soil, 14.8 J/Kg ºC), ΔT is change in temperature and x depends on the type of vegetation and q (Joule) is the heat energy gained or lost by a substance (q^1, green roof and q^2, non-planted bare roof). The differences in heat gain or lose (Δq) Kcal h^{-1} of each roof type will be achieved in this way.

RESULTS AND DISCUSSION

Temperature differences and its yearly fluctuations are shown in Table 4. Results showed very significant differences between green and bare roofs (non-planted boxes) for cold and warm seasons (Table 3). As expected, larger plants and higher biomasses kept temperatures more stable so that lower temperature fluctuations were observed in these boxes. Season changes affect plant performances in response to temperature differences and energy saving according to their survival and resistance.

Table 3. Analysis of variance from temperature differences measured for year duration (hottest and coldest days), warm and cool seasons in the studied green roof.

S.o.V	df	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.
Block	3	0.97^{ns}	1.22^{ns}	0.63^{ns}	12.16^{*}	4.76^{*}	2.27^{*}	3.57^{*}	5.2^{*}	5.16^{*}	3.58^{*}	5.72^{*}	1.13^{ns}
Species	9	20.75^{**}	12.06^{**}	4.09^{*}	44.09^{**}	44.06^{**}	54.42^{**}	57.79^{**}	42.38^{**}	16.32^{**}	30.64^{**}	5.82^{**}	27.57^{**}
Error	27	0.98	0.84	1.11	7.53	1.53	1.46	1.31	1.24	1.97	1.13	0.89	1.14
CV (%)		23.38	11.19	11.90	19.41	11.55	10.74	10.06	8.97	10.56	11.95	12.26	28.46

*,** and ns indicate significance at $P < 0.05$, $P < 0.01$ levels and non- significance, respectively.

Table 4. Mean comparison for temperature differences measured in the green roof for a year duration.

	Carpoboratus edulis	*Sedum spurium*	*Sedum acre*	*Potentila sp.*	*Vinca minor*	*Frankenia thymifolia*	*Festuca ovina*	*Festuca arundinacea*	*Agropyron cristatum*	Control
January	12.66 ^{bcd}	13.66 ^{ab}	13.33 ^{abc}	13.33 ^{abc}	12.66 ^{bcd}	12.66 ^{bcd}	12.33 ^{cd}	11.66 ^{d}	14.00 ^{a}	9.00 ^{e}
February	13.33 ^{ab}	13.33 ^{ab}	14.66 ^{a}	13.33 ^{ab}	11.66 ^{bc}	11.66 ^{bc}	13.33 ^{ab}	11.00 ^{cd}	14.66 ^{a}	9.33 ^{d}
March	3.33 ^{cd}	5.00 ^{b}	6.33 ^{a}	2.66 ^{d}	4.33 ^{bc}	5.33 ^{ab}	4.33 ^{bc}	3.66 ^{cd}	5.33 ^{ab}	0.33 ^{e}
April	27.00 ^{d}	27.00 ^{d}	29.66 ^{c}	26.00 ^{de}	26.33 ^{de}	26.33 ^{de}	23.33 ^{f}	25.33 ^{e}	31.33 ^{b}	39.33 ^{a}
May	30.33 ^{d}	34.66 ^{bc}	40.00 ^{a}	31.33 ^{d}	36.66 ^{b}	31.00 ^{d}	32.00 ^{cd}	25.66 ^{e}	31.00 ^{d}	41.00 ^{a}
June	38.00 ^{cd}	38.66 ^{bcd}	42.66 ^{b}	42.00 ^{bc}	43.00 ^{ab}	34.66 ^{d}	39.66 ^{bc}	38.00 ^{cd}	39.00 ^{bcd}	47.33 ^{a}
July	41.33 ^{bcd}	36.66 ^{de}	44.00 ^{b}	42.33 ^{bc}	43.33 ^{bc}	33.66 ^{e}	40.33 ^{bcd}	38.66 ^{cde}	40.33 ^{bcd}	53.00 ^{a}
August	40.66 ^{bcde}	38.33 ^{e}	42.66 ^{bc}	43.00 ^{bc}	43.33 ^{b}	33.66 ^{f}	40.00 ^{cde}	39.33 ^{de}	42.33 ^{bcd}	51.66 ^{a}
September	35.66 ^{cd}	33.66 ^{d}	41.33 ^{a}	39.66 ^{ab}	40.00 ^{ab}	34.00 ^{d}	36.00 ^{cd}	33.33 ^{d}	37.33 ^{bc}	42.00 ^{a}
October	7.33 ^{abc}	7.33 ^{abc}	8.66 ^{a}	7.66 ^{abc}	8.33 ^{ab}	6.33 ^{bc}	7.00 ^{abc}	7.66 ^{abc}	6.00 ^{c}	3.33 ^{d}
November	5.00 ^{bc}	4.33 ^{bc}	8.33 ^{a}	4.66 ^{bc}	7.00 ^{ab}	4.00 ^{bc}	4.00 ^{bc}	3.33 ^{c}	3.00 ^{cd}	1.55 ^{d}
December	4.66 ^{bc}	6.00 ^{b}	9.66 ^{a}	3.33 ^{cd}	5.66 ^{b}	9.33 ^{a}	4.66 ^{bc}	2.66 ^{d}	9.00 ^{a}	1.00 ^{e}

*In each line means with the same letter are not significantly different.

Warm season (spring and summer)

The results showed that experimental plant genera appeared to be significantly different by means of media temperature differences in response to warm season ($P < 0.01$) (Table 3). Non-planted boxes showed higher temperatures compared to green roof boxes (Table 3). Highest temperatures were observed in non-planted control boxes and the lowest values were observed for *Festuca aurundinacea, Carpoboratus edulis* and *Frankenia thymifolia* from April to September, which shows an approximately 30-35% temperature decrease over the control. At the start of the warm season (April and May), succulent plants began to grow but they were very small in size and grass type plants also were highly effective at this time. But from then on, grass type plants were faced with hot and dry weather conditions, their growth was considerably reduced. At this stage, succulent and groundcovers were dominated and showed to be very efficient. Succulent plants appears to be very suitable for summer seasons and *Frankenia thymifolia*, because of its spreading habit and covering growth type, tend to have a very efficient impose on temperature control and energy aspects (Table 4).

According to equation 4, regarding warm season performance of the green roof from an energy point of view, *Festuca ovina* (April), *Festuca arundinacea* (May), *Frankenia thymifolia* (June, July and August) and *Sedum spurium* (September) were the most effective plants in reducing media temperatures compared to non-planted boxes, respectively (Table 5). This actually reveals that plants with higher biomass and maximum survival at each stage showed better effects and were more efficient (Table 5; Fig. 2a).

Table 5. Cooling energy differences in a warm season of a green roof compared to non-planted bare roof (Kilo Joule).

	Carpoboratus edulis	*Sedum spurium*	*Sedum acre*	*Potentila sp.*	*Vinca minor*	*Frankenia thymifolia*	*Festuca ovina*	*Festuca arundinacea*	*Agropyron cristatum*
April	3649.68 ^{c}	3649.68 ^{c}	2862.32 ^{d}	3945.68 ^{b}	3848 ^{bc}	3848 ^{bc}	4736 ^{a}	4144 ^{a}	2368 ^{d}
May	3155.36 ^{b}	1876.64 ^{d}	296 ^{e}	2859.36 ^{c}	1284.64 ^{d}	2960 ^{c}	2664 ^{c}	4540.64 ^{a}	2960 ^{c}
June	2761.68 ^{b}	2563.36 ^{b}	1379.36 ^{c}	1577.68 ^{c}	1281.68 ^{c}	3750.32 ^{a}	2267.36 ^{b}	2761.68 ^{b}	2465.68 ^{b}
July	3454.32 ^{c}	4836.64 ^{b}	2664 ^{d}	3155.36 ^{c}	2862.32 ^{d}	5721.68 ^{a}	3750.32 ^{c}	4244.64 ^{b}	3750.32 ^{c}
August	3256 ^{b}	3945.68 ^{b}	2664 ^{c}	2563.36 ^{c}	2465.68 ^{c}	5328 ^{a}	3451.36 ^{b}	3649.68 ^{b}	2761.68 ^{c}
September	1873.68 ^{b}	2465.68 ^{a}	195.36 ^{d}	689.68 ^{c}	592 ^{c}	2368 ^{a}	1776 ^{b}	2563.36 ^{a}	1379.36 ^{b}

In each line means with the same letters are not significantly different.

Table 6. Heating energy differences in a warm season of a green roof compared to non-planted bare roof (Kilo Joule).

	Carpobroratus edulis	***Sedum spurium***	***Sedum acre***	***Poten-tila sp.***	***Vinca minor***	***Frankenia thymifolia***	***Festuca ovina***	***Festuca arundinacea***	***Agropyron cristatum***
January	1083.36 ^{a}	1379.36 ^{a}	1281.68 ^{a}	1281.68 ^{a}	1083.36 ^{a}	1083.36 ^{a}	985.68 ^{ab}	878.36 ^{b}	1480 ^{a}
February	1184 ^{a}	1184 ^{a}	1577.68 ^{a}	1184 ^{a}	689.68 ^{b}	689.68 ^{b}	1184 ^{a}	491.36 ^{b}	1577.68 ^{a}
March	888 ^{b}	1379.36 ^{a}	1776 ^{a}	689.68 ^{b}	1184 ab	1480 ^{a}	1184 ^{ab}	985.68 ^{b}	1480 ^{a}
October	1184 ^{a}	1184 ^{a}	1577.68 ^{a}	1281.68 ^{a}	1480 ^{a}	888 ^{b}	1083.36 ^{a}	1281.68 ^{a}	787.36 ^{b}
November	1021.2 ^{b}	822.88 ^{c}	2006.88 ^{a}	920.56 ^{c}	1613.2 ^{a}	725.2 ^{c}	725.2 ^{c}	526.88 ^{c}	429.2 ^{d}
December	1083.36 ^{b}	1480 ^{b}	2563.36 ^{a}	689.68 ^{c}	1379.36 ^{b}	2465.68 ^{a}	1083.36 ^{b}	491.36 ^{c}	2368 ^{a}

In each line means with the same letters are not significantly different.

Cold season (autumn and winter)

The results showed that experimental plant genera appeared to be significantly different by means of media temperature differences in response to cold seasons ($P < 0.01$) (Table 3). Non-planted boxes showed lower temperatures compared to green roof boxes (Table 3). Unlike warm season, non-planted control boxes showed the lowest temperatures during the cold season and highest values were observed for *Sedum acre, Festuca aurundinacea* and *Agropyron cristatum* (Table 4). Succulent plants were observed effective for autumn and after that they were faced with low temperatures which imposed aerial part of the plants to die. By this time, grass type plants became dominant and showed the most effective temperature control. Sedum acre again became alive and active by tend of winter in March when season moved toward warming (Table 4). Temperature control using green roof showed a nearly 35-40% stability in comparison with the control.

According to equation 4, regarding cold season performance of a green roof from an energy point of view, *Agropyron cristatum* (January and February), *Sedum acre, Agropyron cristatum* and *Frankenia thymifolia* (March), *Sedum acre* and *Vinca minor* along with *Frankenia thymifolia* (October, November and December) were observed the most effective choices for this time of the year in keeping the heat gained in the green roof compared to non-planted roof boxes (Table 6). Cold season plants performed better in this time of the year, and therefore, optimum results were mainly observed through them (Fig. 2b).

These results pointed out that survival and biomass are main factors for achieving green roof energy conservation potentials throughout the year and by the time of the year (season); different plant selection exhibits different effects.

Higher urban temperatures increase the energy consumption for cooling and raise the peak electricity demand (Hassid *et al.*, 2000; Cartalis *et al.*, 2001; Santamouris *et al.*, 2001; Kolokotroni *et al.*, 2012; Akbari and Konopacki, 2004; Akbari *et al.*, 1992). Several experimental and theoretical studies have been performed to identify the energy conservation potential of green roofs (Kumar and Kaushik, 2005; Alexandri and Jones, 2007; Wong *et al.*, 2003; Theodosiou, 2003; Eumor-

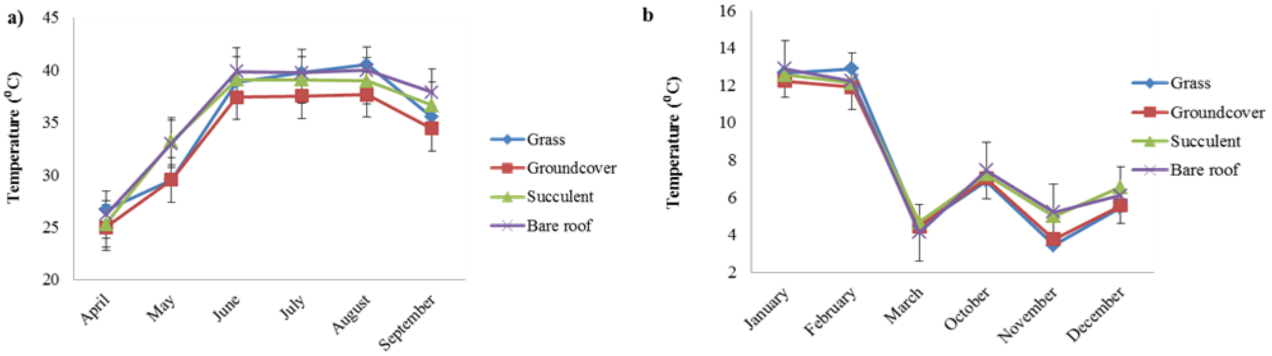

Fig. 2. Temperature fluctuations in warm (a) and cold (b) seasons through different plant covering.

fopoulou and Aravantinos, 1998; Jaffal *et al.,* 2012; Spala *et al.,* 2008; Takakura *et al.*, 2000; Castleton *et al.*, 2010). The specific energy benefits depend on the local climate, the green roof design and more importantly on the specific building characteristics. Given that in green roofs heat transfer benefits are mainly provided through latent heat processes, the performance of the systems are higher in dry climates.

The main function of green roofs is to prevent the solar radiation to heat up building's interior spaces. Green roofs are able to reflect 27% of solar radiations and absorb 60% through photosynthesis and transmit the remainder as much as 13% to the growing medium (Wong *et al.*, 2003). Direct shading of roof surfaces and cooling down the ambient air are two important phenomena that provide more thermal comfort within the building. This thermal benefit is the results of consuming solar heat gained for transpiration and photosynthesis (Wong *et al.*, 2003). Further, green roofs absorb lower radiative temperature in comparison to other types of roofs (Wong *et al.*, 2003). Green roofs combat urban heat island effects and contribute to the thermal benefits of urban areas (Shashua-Bar *et al.*, 2009). According to a study conducted in Japan, green roofs can decrease the surface temperature of the roofs to an approximate of 30 to 60 ºC (Wong *et al.*, 2003).

The results of this experiment were in agreement with other studies. For example, a 37.11% reduction in energy consumption was observed in a roof lawn garden with 0.2 m depth (Permpituck and Namprakai, 2012). They also mentioned that placing plants on a roof surface can significantly reduce building surface temperatures by up to 20º C and can save the amount of air conditioning energy used by up to 80%, although 25-50% was more common. In addition, the media temperature of the planted roof was higher by 7-8 ºC in comparison to convectional roof.

Green roofs save energy and, consequently, save money (Yan, 2011). The amount of savings depends on different factors such as type of green roofs, depth and composition of the growing media, climates, plant selection, type of irrigations and insulation specifications (Getter *et al.*, 2009). The characteristics of the vegetation have been regarded as one of the most significant parameters of the green roof heat transfers (Wolf and Lundholm, 2008; Dvorak and Volder, 2010). The outcome indicated that green roofs in Canada could reduce the heat gain by an average of 70–90% in summers and could prevent heat loss by 10–30% during winters (Liu and Minor, 2005).

CONCLUSION

The results showed very significant differences between green and bare roof considering temperature. As expected, larger plant and higher biomass kept temperatures more stable. The presence of plants in green roofs on top of a building showed major beneficial temperature reduction. This can help to reduce energy use in both cold and warm seasons and consequently save money. This effect is also very useful for heat island phenomenon and provides thermal comfort and air pollution reduction for big studies in widespread use. Increasing every degree centigrade in a cold season (warm load) or decreasing it for warm seasons (cool load) needs finance. Therefore, in general, considering the best treatment for both seasons a meaningful quantity of charge will be saved which is a great deal for growing cities and population requirements. This is even beside other benefits known for green roofs such as air pollution removal and urban greening. Thermal comfort and energy saving can be maintained with application of green roofs in a large scale for growing cities and population energy requirements.

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