Title: **Evaluation of Vegetative Roofs' Performance on Energy Consumption in Hot and Humid Climates**

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ABSTRACT

Green roofs have been widely used in Europe proved to be beneficial. However, in the US they are not widespread. Previous studies have concluded that the main obstacle that makes architects, developers, etc. reluctant to introduce vegetative roofs is their preference for the traditional roofing since it is a tried-and-true technology. A positive feedback on the performance of vegetative roofs will encourage developers and possibly government authorities to invest more in them. Therefore, a survey was conducted to determine the performance of green roofs in existing buildings in hot and humid climates. This paper presents the results of this survey of around 40 buildings. The methodology and pertinent questions are also presented.

Due to the many parameters involved in determining the rate of energy consumption in a building, a definite conclusion regarding how much exactly they can effect on saving can not be drawn, however, the results showed that green roofs can result in saving in the annual energy consumption and using shrubs as well as increasing soil thickness were found to be most effective in reducing building energy consumption.

INTRODUCTION

The broadest description of a vegetative roof is growing plants on rooftops. Vegetative roofs are also referred to as green roofs, eco-roofs, living roofs, and roof gardens. (Osmundson, 1999)

Vegetative rooftops are not limited to flat roof buildings; they also can apply to sloped roofs, and a good number of such examples exist, particularly for residential homes. Typically, vegetative roofs include layers of planting media and drainage material on a high-quality waterproof membrane.

There are two main categories of vegetative roofs: intensive and extensive. Intensive roofs look like ordinary gardens people access at ground level, and are often open to the public. They include a variety of plants such as trees, shrubs, bulbs, and grass. In general, intensive roofs have deeper rooting substrates, greater than 15cm. They also need more maintenance, including irrigation, pruning, and fertilizing. (Osmundson, 1999) Intensive vegetative roofs may also have promenades, benches, and other hardscaped areas. The deep soils, hardscapes, and furniture in the intensive roofs add to the weight of the roof and should be considered in the structural design of buildings. (Dunnett and Kingsbury, 2004)

Extensive vegetative roofs are much lighter than intensive ones and are not intended for public access (Dunnett and Kingsbury, 2004). Plants growing on extensive roofs need relatively little maintenance after establishment. Such plants extend horizontally and often do not exceed 40cm in height. They can survive in shallow rooting substrates, 3-10cm, and usually consist of herbaceous perennials or self-propagating annuals. Most often, these plants survive with minimal irrigation, often rain-fed. Further, they require little or no fertilization, and little maintenance to sustain healthy plant growth and coverage on the roof. In addition to their use on flat rooftops, extensive vegetative roofs are often established on low degree sloped roofs on new or existing buildings. (Osmundson, 1999)

Figure 1. Typical components of a vegetative roof. (Source: Holladay, 2006; after the American Wick Drain Corporation)

Vegetative roofs have been used in the United States for around 10 years, and have grown

Vegetative roofs have been used in the United States for around 10 years, and have grown considerably over the past few years The City of Chicago was first to implement vegetative roofs in its buildings, followed by Washington, D.C. and Boston. Today, some manufacturing facilities, residential complexes, hospitals, city halls, and other urban buildings in the United States are incorporating vegetative roofs.

The development in 1998 of the Leadership in Energy and Environmental Design (LEED) Rating System, a voluntary green building standard for grading buildings for their environmental performance, has influenced government policy-making. LEED standards evaluate buildings on a point system that considers site development, material selection, energy efficiency, and indoor environmental quality. Vegetative roofs qualify for up to 3 points in LEED as "potential technologies and strategies" under the storm water management and heat island effect categories. A vegetative roof may also accumulate points indirectly under the categories on energy efficiency and water efficient landscaping. (USGBC, 2002)

Today, tax incentives in the United States are being implemented to manage storm water runoff, reduce urban heating, and minimize the negative impact of the built environment. California, Maryland, Massachusetts, New York, and Oregon are all adopting such practices. (American Council for an Efficient Economy, 2002) Here, vegetative roofs come to play a role. The city of Portland, Oregon, for example, has restricted construction of new buildings of some maximum height to a certain floor area ratio. However, a floor bonus is added if 30-60% of the roof is covered with vegetation.

Still, the use of vegetative roofs in the United States specially in a hot and humid climate is not as wide- spread as in Europe ; many are still reluctant to introduce it to their buildings preferring the conventional tried roofing system.

Benefits of Vegetative Roofs

The benefits of vegetative roofs are widely known, and have been addressed extensively. The many benefits those roofs provide include energy conservation through reducing the urban heat island effect and roof surface temperature, management of storm water runoff, creating wildlife habitat, and providing recreation places as well as beautifying the surroundings. Other benefits include protection of roofing materials and thus prolonging the life of the roofing membrane, and air filtration.

Energy conservation

Buildings' heating and cooling costs can be reduced by roof vegetation, because vegetative roofs insulate and minimize temperature extremes. Vegetative roofs protect the roof components from solar radiation, thus reducing heat flux into the building during the summer and insulating it in the winter. (Niachou et al., 2001) Stein (1990) reported that vegetative roofs decreased the inner air temperature of buildings by 5°C. A study by Hien and others (2005), in which the researchers explored roof temperatures before and after installing a vegetative roof on a building in Singapore, found out that vegetative roofs experienced lower surface temperature than original exposed roof surfaces. A maximum difference of 18°C was observed. Further, the study showed that the heat flux through the roof was greatly reduced due to the installation of the vegetative roof. Over 60% of heat gain was eliminated by using a vegetative roof that covered the whole area of the roof. The researchers found that intensive vegetative roofs would yield better results in terms of reducing ambient temperature than extensive roofs.

An experiment was done by Liu (2002) on vegetative roofs in Ottawa, Canada, in which measurements were taken from a field roofing facility where the roof was divided into two areas, one of which was covered with a vegetative roof and the other was a conventional roof. This study, showed that the vegetative roof outperformed the conventional roof in the spring and summer. Energy efficiency of the vegetative roof was slightly better than that of the conventional roof in the fall and winter. However, heat flow through both roofs was almost the same when the roof was covered with snow. This has been attributed to the fact that as the medium in the vegetative roof froze, its insulation value was greatly diminished.

In general, past research has showed that savings in energy costs through the use of vegetative roofs are dependant on the regional climates. However, it is believed that such savings may be enough to pay for the extra cost of a vegetative roof system over a certain number of years. (Niachou et al., 2001)

Management of storm water runoff,

Conventional roof systems do not retain a significant amount of storm water. Most storm water often results in overflow. In cities with combined sewer system (storm water and wastewater), the overflow of storm water reduces the efficiency of wastewater treatment. Storm water runoff also causes soil erosion, contaminating surface water bodies. For this reason, storm water management strategies - minimizing and retaining storm water runoff during rain events - are often high priorities for city planners.

Depending on vegetation type, substrate's components and depth, and roof slope, a vegetative roof system can slow the runoff from a rooftop and spread storm water runoff over a longer period of time by retaining as much as 60-100% of the rainwater. (VanWoert, 2005; Hunt et al., 2004) In a study conducted in Michigan on roof platforms, Van Woert and others (2005) reported that in evaluated combined rain events, 84 - 87% retention occurred on platforms with 4cm media depth. In addition to detaining runoff, vegetative roof systems use foliage and a lightweight soil mixture to absorb and filter rainfall.

Supporting wildlife,

Vegetative roofs can support wildlife and preserve biodiversity. They can be designed to mimic natural ecosystems, and thus help to provide a habitat for endangered species. Further, plants in vegetative roofs are less susceptible to damage by stepping on them. Therefore, easily damaged plant species can thrive on such roofs. In addition, vegetative roofs can be a home for birds that nest on the ground. Also, the soil of those roofs can be a safe habitat for insects, since it is less disturbed. It has been reported that in Germany, for instance, vegetative roofs support 10-40 insect species. ("About Green Roofs")

Providing recreation places and aesthetically pleasing environments,

Generally, incorporating green space into the built environment restores nature in urban settings. Vegetative roofs, when designed to be viewed by passersby and used by the communities they serve, can compensate for the lack of green areas in cities. Research has showed that leisure activities in natural settings including gardens help people cope with stress.

Further research in the field of psychology has showed that natural views help diverting the attention of the viewer away from himself or herself and thus reduce worrisome thoughts and improves health. Furthermore, it is believed that sounds, smells, colors, and plant movements may enhance human wellbeing significantly. Since people spend long times in buildings, it is worth to make buildings more desirable to work and live in by adding gardens to them. ("About Green Roofs"; Ralf and Lohr, 2003)

It is believed that the incorporation of vegetative roofs into buildings may help offices and residential units overlooking vegetative roofs to have higher resale and economic values. (Osmundson, 1999) In this context, Kongshaung and Bhat (2004) give the example of the Hilton Hotel in Montreal, Canada, where a rooftop garden was installed as early as 1967. Since the installation of this garden, the hotel has had a 7% higher occupancy rate than other local hotels.

Other benefits of vegetative roofs,

Vegetation also increases the lifespan of the roof membrane compared to a conventional roof. A vegetative roof will last at least twice longer than a conventional one. (Osmundson, 1999) This is because vegetation protects roof membrane from constant daily expansion and contraction due to temperature extremes, which ultimately leads to material failure on a conventional roof.

Green roofs also have the potential for improving the air quality. Mike and Witter (1983) calculated that a 1.5-square-meter grass surface produces enough oxygen for one human for one year. Liesecke and Borgwardt (1997) reported that vegetative roof filtered diesel and gasoline exhaust. Researchers have found that a 1 square meter of grass on the roof can remove about 0.20 kg of airborne particulates. ("About Green Roofs; Ralf and Lohr, 2003")

The above literature review shows that there are many benefits in vegetative roofs, the most important of which are energy conservation in the buildings they cover, control of the storm water runoff, support wildlife, and providing recreation places. But, vegetative roofs are still not widespread in the United States. In this research, we will try to get feedbacks regarding the benefits of vegetative roofs from real buildings that incorporate such roofs in the United States. Most importantly, the research concentrates on investigating the potential of vegetative roofs in the United States for conserving energy in buildings, controlling storm water runoff, supporting wildlife, and providing recreation places.

RESEARCH OBJECTIVE

The objective of this study is to provide data on the performance of green roofs in a hot and humid climate. This research aims at providing the data required to test the following hypothesis: Vegetative roofs are being used to provide four main benefits: energy conservation, control of storm water runoff, support of wildlife, and provision of recreation places. (Dunnet and Kingsbury, 2004) The benefits of these roofs are realized with no serious problems resulting from the installation of these roofs, and at affordable costs.

METHODS

In order to test our hypothesis, we need to get feedback from real buildings on the performance of their vegetative roofs, and the costs involved in these roofs.

Questionnaire as a Data Collecting Tool

There are different approaches to the investigation of vegetative roofs' performance. One approach is to interview people in charge of roof maintenance, people using those roofs, and people who are closely affected by the way such roofs perform as with people living in the floors directly covered by those roofs. Given the circumstances of this research, interviews are not the most appropriate approach.

The relatively small number of buildings with vegetative roofs in the hot and humid climates in the US is spread over a large geographical area, and thus visiting projects to carry out interviews would involve high financial costs and require more time than that given to this study.

Another approach to investigate vegetative roofs' performance is to observe real roofs over a long period of time and collect some data to analyze. Given the constraint of time, this approach has been ruled out. As for the building of experimental roof, it is also inappropriate for the purpose of this study that aims at getting feedback from real-life projects which are subject to all sorts of physical conditions, and with which people interact.

Taking into consideration the above-mentioned points, it has been concluded that the use of a questionnaire to investigate the performance of vegetative roofs will probably be the most appropriate for the purpose of this study. By using a questionnaire, we can gather data from respondents in different places with relatively low cost. Potential respondents were administrators of institutions or businesses occupying the buildings understudy.

Population and Sample

The population of the study is the buildings with vegetative roofs in hot and humid climates in the United States. In order to identify this population, we consulted online and in-print publications on vegetative roofs and sustainable architecture. In addition, we approached the U.S. Green Building Council's LEED program, since it is likely that such buildings are LEED certified, or have applied to obtaining LEED certification. Around 80 buildings with vegetative roofs in the hot and humid climates in the United States were identified. However, some of the identified roofs have a very small area, and therefore are not useful for the purpose of this study. Other roofs cover garages; those were excluded from this study since we did not expect to be able to monitor their performance. Further, the issue of energy conservation is irrelevant in this type of buildings. Other roofs that we identified to exclude belong to some small private residential homes and units, and they are unlikely to have data on their roof performance of their roofs. Only around 60 buildings with vegetative roofs that could be included in the study were identified.

The study sample consists of a group of institutional, commercial, and governmental buildings with vegetative roofs in hot and humid climates in the United States. Those buildings are of large scale and their follow-up on the roof performance is expected to be good. Furthermore, some of those buildings are investing in vegetative roofs, so it is likely that they will keep some records of the roof performance. In addition, people in charge of those buildings most probably will be interested in the results of such a study and may therefore be cooperative.

The Questionnaire

The questionnaire mainly consists of three sections: the first inquires about the building data, the second inquires about the performance of the vegetative roof, and the third inquires about the respondent(s). The significant benefits of vegetative roofs as mentioned previously are considered in part two. In other word, by asking general question we are able to reach conclusion about the performance of the green roofs. The questionnaire was sent to respondents in a Word Template format.

Responses

Respondents were given two weeks to return the filled questionnaire to us. Before the end of the second week, a reminder was sent asking them to send us their responses.

Thirty two out of sixty responded to the questionnaire. But in some responses, some of the questions were not answered. A few respondents asked that we provide them with a summary of the results. Some respondents emphasized that their names or their buildings' name should not appear in the study.

DATA ANALYSYS, FINDINGS & DISCUSSION

Benefits of Vegetative Roofs

Buildings in this study were investigated for the benefits their vegetative roofs provide. These benefits were included under four categories, which are often cited as major advantages in research on vegetative roofs (see the introduction). These benefits include energy consumption, creation of recreation places, support of wildlife, and control of storm water runoff.

The findings of the study are represented in Figure 1. As shown in the table below, the buildings are categorized in eight groups regarding the proportion of vegetative area to the total area. The vegetative roofs of all buildings from which we receive responses to our questionnaire are desirable as controlling control storm water runoff. Twenty seven out of thirty two roofs support wild life. Five of thirty two roofs serve as recreation places. Only five out of thirty two buildings have low or very low rate of energy consumption.

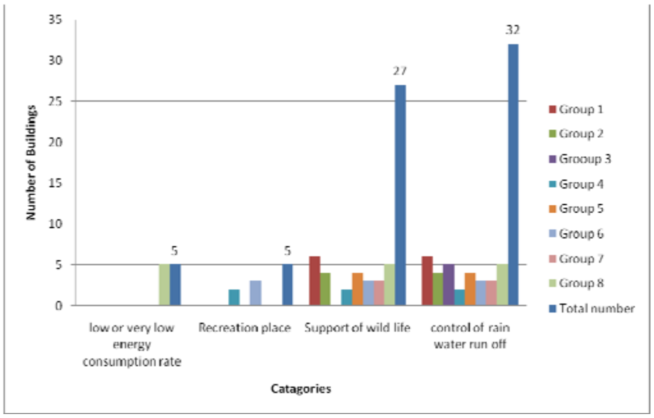

Figure 2. Benefits of vegetative roofs

Building group	Vegetative area / Total area	Total number
Group 1	20	6
Group 2	21	4
Group 3	22	5
Group 4	22-25	2
Group 5	25-30	4
Group 6	30-35	3
Group 7	35-40	3
Group 8	100	5

Table 1. Categorizing the 32 studied buildings

It is worth mentioning here that unlike other categories of vegetative roofs' benefits, the category on energy consumption is complicated as it involves many aspects. In this study, five buildings were reported to have a moderate energy consumption rate. But the rate that this study defines as moderate is the average consumption rate for office and commercial buildings in the United States in that particular climate context. One building was reported to have a high rate of energy consumption. Whether or not the rate of energy consumption in a building can reflect the real performance of the building's vegetative roof is questionable (see the discussion on energy performance below).

<u>Energy performance of buildings with vegetative roofs</u>

As shown in Figure 2, only twenty seven out of thirty two respondents to the questionnaire responded to the question on energy consumption. Only ten out of thirty two buildings was reported a low energy consumption rate, which the questionnaire defines as "less than 18 and more than 12kWh/sq ft/yr". Eleven buildings were reported a moderate energy consumption rate, which the questionnaire defines as "18-20 kWh/sq ft/yr". Six buildings was reported a high energy consumption rate, which the questionnaire defines as "more than 20 and less than 28kwh/sq ft/yr".

However, a fifth respondent commented that although he was not certain about the rate of the building's energy consumption, the building (one of the Buildings in group 3) received a certain rebate from the energy company. Further investigation of this matter revealed that the rebate is associated with the use of energy-efficient light fittings that would result in less energy consumption. But, this does not inform us about the exact rate of the building's energy consumption, and therefore we have included this building in the “do-not-know” category. This example is helpful for the purpose of this study as it shows that parameters other than the type of roofing may affect the energy consumption rate in a building.

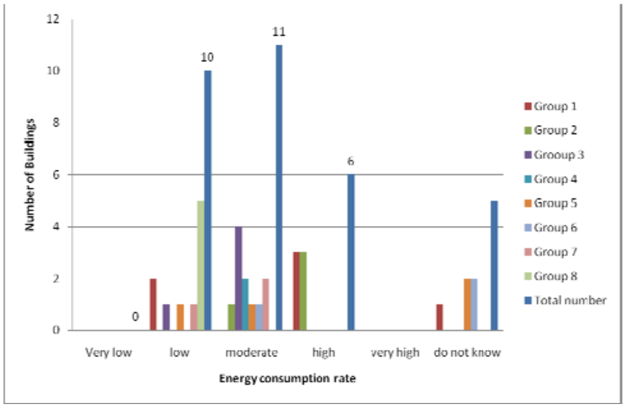

Figure 3. Energy consumption

After all, the question on energy consumption in the questionnaire does not ask for any figures; it asks respondents to select the rate of energy consumption from a list that includes a description (very low, low, moderate, etc.) as well as a kWh/sq ft/yr rate. Further, vegetative roofs are being installed in buildings for a number of benefits that include reduction of heat transfer through buildings' roofs, and therefore, if the energy consumption of the building turned out to be low, the design team and manufacturers of the roof would be happy about it and would point it out in a way that makes answering the question on energy consumption in the questionnaire very easy. Therefore, it is most probable that the four buildings from which we received a do-not-know response have moderate, high, or very high rate of energy consumption.

Since the moderate energy consumption rate in this study represents the average energy consumption in office and commercial buildings, we may argue that only eleven vegetative roofs out of thirty two perform well in terms of energy efficiency. This is an unexpected result that contradicts previous research on the thermal performance of vegetative roofs (see the theoretical background and literature review section of this study).

Still, it is possible that the eleven buildings that reported medium energy consumption rate would not have reached this rate without the use of vegetative roofs. So, even though the thermal performance of these buildings is the average for a conventional building with no vegetative roof, their vegetative roofs may still be performing well in terms of energy conservation, cutting down energy consumption from high to medium rate. One may argue that this conclusion may be extended to buildings of high energy consumption rate as well, and thus may assume that the vegetative roof of the building of high energy consumption rate performs thermally well. In order to investigate this issue, we need to take a closer look at some of the buildings' data that may have a bearing on their energy consumption and that the respondents provided in their responses to the questionnaire.

In Table 2 below, four buildings from different groups and almost the same footprints are compared with each other. Results show the different parameters that were included in the questionnaire and that may affect the energy consumption in the investigated buildings. Parameters include percentage of the vegetative roof area to roof area, kind of plants used, percentage of vegetation in the roof, percentage of glazed areas in the façades, number of stories, number of people per square foot, and function of the building.

Table 2 shows that the building with high energy consumption rate, Building (group 6), has slightly higher percentage of vegetation roof than two of the buildings with low energy consumption (group 3). Further, Building (group 3) has more than double the percentage of vegetation roof of the Building (group 6), which has low energy consumption rate, and has a higher vegetation roof than the Building (group 4). Building (group 6) has a lower percentage of glass in its façades than buildings (group 7), (group 4), and (group 3), and has the same type of planting as Building (group 7), which is bushes. In fact, previous studies found that the use of taller vegetation in vegetative roofs helps more in reducing energy consumption in buildings that have such roofs. This, however, does not seem the case in Building (group3) that has a sod roof, but has the lowest energy consumption rate (the discussion below illustrates on this point).

The difference in the percentage of vegetation in the roof makes a difference when it comes to heat transfer through slab as previous research has shown. This is probably one of the reasons why Building (group 3), which has its vegetative roof 100% covered with plantation, performs well in terms of energy conservation. This also explains the more or less similar per square foot energy consumption of Building (group 3) and Building (group 6), though the former has less percentage of vegetative roof area.

The difference in floor numbers may have some bearing on the energy consumption of the buildings. After all, it is through the roof that most of heat gain and loss occurs, and thus the per-square-foot energy consumption for a two-story building is expected to be more than that for a four-story building. This explains why Building (group 6) has a higher energy consumption rate, but does not explain the opposite in the case of Building (group 7), which is discussed in more detail later in this section.

The use of buildings affects the rate of energy consumption. In the case of these four buildings, one may argue that both buildings (group 6) and (group 7) are expected to have higher energy consumption for cooling/heating and for lighting than the other two buildings. This is due to their use as community college or university class rooms, where hours of occupation of spaces are expected to be more than in a school (Building group 4) or an office building (Building group 3).

	Building (group3) low energy consumption	Building (group4) moderate energy consumption	Building (group7) moderate energy consumption	Building (group 6) high energy consumption
Percentage of vegetative roof	22%	25%	35%	21%
Kind of plants	extensive roofing (sod)	turf	bushes	bushes
Percentage of vegetation in the vegetative roof	100%	90%	40%	50%
Percentage of glass in the facades	40% (low-e glazing)	75%	50%	15%
Number of stories	2	9	4	2
Number of people per square foot	0.003	0.007	0.002	0.03
Function of building	office	school	classes in a community college	classes in a university
location	Maryland	New York	South Texas	Florida

Table 2: Parameters affecting energy consumption in the investigated buildings.

It seems, however, that the major reason why Building (6) consumes more energy than the other buildings, particularly Building (7) which has a number of similar parameters in common with Building (6) is that it is located in (Florida), whereas the other buildings are located in cold climates (Maryland, New York, and south Texas).

In hot climates most of the energy consumption is used for the air-conditioning of the buildings, whereas in cold climates most of the energy is used for heating the buildings. However, it could be argued that it is more energy consuming to cool a space than to heat it. This is attributed to the fact that there is heat dissipation from light fittings, office equipment, and people occupying the space. In fact, it is also observed that the number of people occupying per- square-foot of the space of Building (6) is much more than those occupying the space in other buildings.

Therefore, to cool the space, one needs to overcome both the climatic conditions and heat resulting from internal loads in the space, which will result in more energy required to cool the space. On the contrary, the same internal loads will help reduce the energy needed to heat a space. In addition, the process of burning fuel to get heat is much more efficient than the process of cooling.

Both buildings (4) and (7) have similar energy consumption rates. However, the vegetative roof in Building (7) covers 10% more roof area than does Building (4), and the type of vegetation in the former is bushes and in the latter is sod. In general, the increase in the area of the roof covered with vegetation and the use of intensive kind of vegetative roofs, which incorporate taller plants such as bushes and trees, help more in reducing energy consumption in buildings. However, it should be kept in mind that other parameters affect a building's energy consumption, such as the number of stories which probably has a bearing on the thermal performance of Building (7) and the percentage of vegetation in the roof, which has been discussed above. The fact that Building (6) does not perform well even though it uses intensive type of vegetation in its roof may be attributed to its location in a very hot humid city, especially that some researchers suggest that the type of vegetation is not of great importance for the purpose of the roofs thermal performance in hot humid climates. (Hien et al., 2005)

It is worth mentioning that Building (3), one of the buildings in the study that has low energy consumption rate, has an extensive roof that covers only 22% of its roof. The performance of this vegetative roof was acknowledged in contributing one LEED point to the building (credit Landscaping / Exterior Design to Reduce Heat Islands Effect). However, the published information on this building shows that it incorporates a number of features, other than the vegetative roof, that contributes to its energy efficiency. Those include low glass, use of daylighting, which saves up to 24% in lighting energy, solar shading, and efficient air-conditioning/heating system that incorporates a run-around heat recovery loop, tied to the heat pump system, which recovers heat/cool energy from exhaust air and uses that energy to preheat or precool incoming ventilation air.

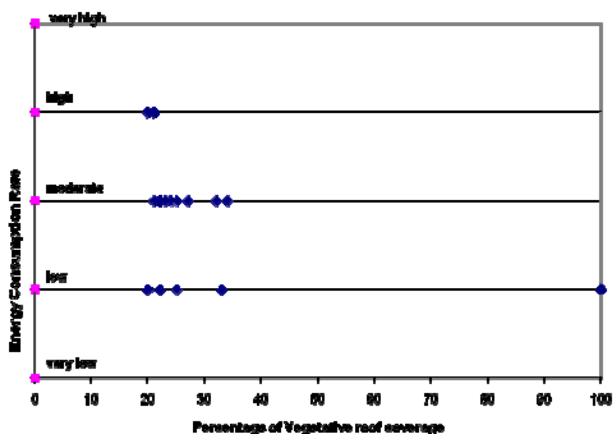

Figure 4. Relationship between percentage of vegetative roof coverage and energy consumption

If we are to judge from the data that the respondents provided, we may conclude that vegetative roofs do not help reduce energy consumption in buildings, since only nine of the buildings have a low rate of energy consumption. However, this conclusion is based on the assumption that the investigated buildings would have a moderate consumption rate even if vegetative roofs were not installed. But this is not necessarily true, as demonstrated by the building that has high energy consumption, even though it has a vegetative roof. If a building's energy consumption is still around the average or higher than the average rate, it does not necessarily mean that its vegetative roof is not protecting the roof from heat transfer. Further, other aspects may have affected the rate of energy consumption in the investigated buildings. This is obvious from the above discussion, especially the discussion of both buildings that have the minimum and maximum rates of energy consumption among buildings from which pulled out received responses.

An accurate conclusion could have been reached in this regard if we were able to compare energy consumption of the same building with and without its vegetative roof. In fact, that is why we have incorporated in our survey a number of buildings to which vegetative roofs have been added after the buildings were in operation. Although in eight out of thirty two buildings for which we got responses, the roof is not original, respondents did not answer the question that asked about energy consumption before and after the roofs were installed. With the absence of answers to this question, the accuracy of any conclusion we may reach would be specious.

The actual savings of green roofs are probably can be estimated by conducting experiments (both before and after) where a vegetative roof is added to a building after a baseline period without it. The study done in the 2005 by Sonne (2006) which showed an 18.3% heat flux reduction to the ceiling/roof in Orlando, FL under cooling conditions with a green roof for a savings of 0.7 kWh/day in a 306 m^2 building.

Storm water runoff control by vegetative roofs

As mentioned earlier, the survey showed that the vegetative roofs of all buildings investigated in the study contribute to the management of storm water on their sites. However, although the question in the questionnaire asks for explanation of how the vegetative roof controls runoff, it does not specifically ask for a percentage of runoff reduction. Figure 5 shows the results of storm water runoff control. Consequently, only sixteen out of thirty two gave the percentage of runoff reduction by the vegetative roofs of their buildings.

One of the respondents explained the patterns of runoff from the roof of his building in different rain events. In the vegetative roof of this building, which is 80% covered with vegetation, roof drains have been installed to collect rainwater that is then diverted to a cistern. According to the respondent, during a 1-inch rain event, no water running into the drains has been observed, but during larger events, water running into those drains has been observed. Unfortunately, the scale of measure given for this building is different from the ones given for the other two buildings, and therefore does not allow us to compare this building with the other two in a useful way. Still, it is most possible that the vegetative roof of this building performs well in terms of storm water management, especially that it has contributed, in addition to other features, a LEED point to the building, for its storm water management strategies.

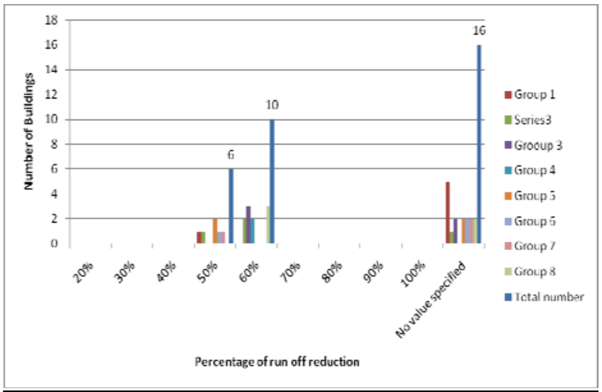

Figure 5. Storm water runoff

Figure 6 shows the relationship between the percentage of storm water runoff reduction and the percentage of planted area of the vegetative roof. Building (group8) reduces runoff by 60% and its vegetative roof is 100% covered with vegetation. Building (group2), however, reduces runoff by 50% and only 50% of its vegetative roof is covered with vegetation. A closer look at the type of plants used for both roofs shows that while the roof of Building (group4) mostly has sedum that of Building (group6) mostly has bushes.

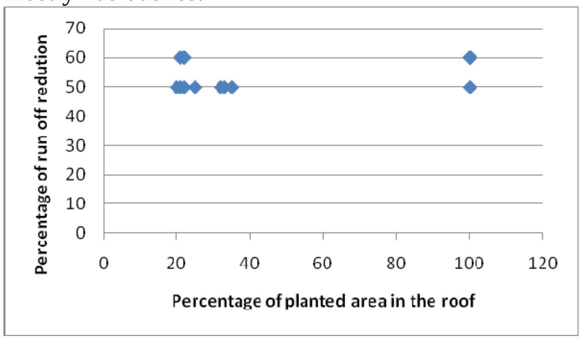

Figure 6. Relationship between percentage of vegetative roof and runoff reduction

Previous research has shown that, depending on the type of a vegetative roof, a vegetative roof may retain somewhere between 25 to 75% of storm water. Vegetative roofs reduce runoff through a number of means including storing water in the substrate, absorbing water by the roots of the plants, holding precipitation on the plants' leaves and then returning it to the atmosphere by transpiration and evaporation, and slowing the speed of runoff by infiltration through the layers of vegetation.[1] We may argue that in the case of the roof of Building (group 4), the deeper roots of the bushes and their foliage as well as the deeper substrate are responsible for the competitive percentage of runoff reduction by the roof in comparison with the vegetative roof of Building (group 6) that has more vegetation coverage that consists of sedum.

From the above analysis of the data on storm water runoff of the vegetative roofs in the study, we can conclude that vegetative roofs are being used to control runoff. Further, they seem to do well when the percentage of plantation of the roof is very high as well as when deeper media and taller plants are used. It is worth mentioning, however, that although the performance of vegetative roofs in terms of storm water runoff is only dependent on a few parameters relating to the vegetative roof (the percentage of plants in the roof, the type of plants, and the thickness of the planting medium) the data we received from the respondent to questionnaire is not enough to enable us to withdraw accurate and definite conclusions. It is possible that the question in the questionnaire was not accurate. But, as we have experienced in the section on the energy consumption where the question was very specific, only half of the respondents to the questionnaire answered this question.

Wildlife support and vegetative roofs

As mentioned earlier in this study, twenty seven out of thirty two buildings from which we received responses to the questionnaire support wildlife on their vegetative roofs. One of the buildings that reported not supporting wildlife on its roof was completed in 2006. But it seems that the respondents are not aware of the meaning of the term wild life.

In general, twenty buildings observed birds and insects on their vegetative roofs. Eight of them

1 Joanne Gerson. "Green Roofs for Stormwater Control." Available at http://ohio.sierraclub.org/miami/images/files/josgreenroofpaper.pdf (accessed December 2006).

specified the observation of butterflies, four of them specified the observation of bird nests, and four specified the observation of bees. Three of the buildings plan to do beekeeping. The interesting thing about this last building is that it uses its vegetative roof as a recreation place for school children. Having wildlife on the roof of the building definitely supports the educational process and creates awareness among children of the significance of nature and the management of storm water runoff.

No problems related to certain wildlife species have been observed. One of the buildings was reported to have leakage problems through the roof and a very high maintenance cost, but it was not attributed to the fact that the roof has wildlife on it.

Use of vegetative roofs as recreation places

As mentioned earlier in this study, five out of thirty two buildings from which we received responses to the questionnaire use their vegetative roof as a recreation place.

Previous studies have showed the significance of introducing nature to the built environment, and how it enhances the wellbeing of people. Hence, it is important that vegetative roofs be designed so that they are visible by people in the areas around them and accessible by people in the building or the community.

In one of the surveyed buildings that uses its vegetative roof as a recreation place, some damage to turf was observed, but the turf recovered well. It is unknown whether the damage is due to the fact that the roof is being used by children.

In trying to find a connection between the use of a vegetative roof as a recreation place and the cost of its maintenance, no significant maintenance costs were found. All roofs have turf. One of them is being watered by a drip irrigation system, and the others are not being watered. On one of them, the turf is being weeded once or twice a year. It is possible that the turf is being weeded on the other roof. So, the maintenance cost will possibly include those for weeding, and the cost of irrigation system and irrigation water for one building. It is worth mentioning that drip irrigation is water-efficient, and therefore it will not result in much additional cost.

	Bldg. (1)	Bldg. (2)	Bldg. (3)	Bldg. (4)	Bldg. (5)	Bldg. (6)	Bldg. (7)	Bldg. (8)
Average of Initial cost (USD per square foot)	3.5	3	8	>100	7	5	8	8
Average Total maintenance cost per year	0	100	NA	1000	>6000	1000	1000	0
Type of plant	sedum	bushes	sedum	turf	Prairie grass, wildflowers	turf	bushes	sedum
Watering	no	yes	no	yes	yes	no	yes	no

Table 3: Initial and maintenance costs of vegetative roofs in comparison with their vegetation types and water needs

The initial costs of vegetative roofs in the United States vary according to the kind of system, extensive or intensive, and the type of plants used. In general, the range of cost is estimated to be between 8 and 25 USD per square foot. This cost includes the design and installation of the roof as well as the planting materials and any required irrigation system. The cost of the roof may be recouped through savings in energy consumption. Further, it is believed that vegetative roofs increase the value of the property to which they belong.

Table 3 shows the costs of an average number of the surveyed vegetative roofs. As mentioned in table 1, buildings can be categorized in 8 groups regarding the proportion of vegetative area to the total area and here, all the vegetative roofs which have the same type of plants covered the roof are investigated. The average initial costs of the roofs of buildings (group 1) and (group 2) are 3.5 and 3 USD per square foot respectively, which are much less than expected. The response received from average of the Buildings (in group1) indicated that most of the cost does not include volunteer labor and donated roof components, which justify the low cost of the roof. This condition probably applies to average of Buildings (in group 2) as well. The average cost of the vegetative roof of Building (group4) is 100 USD per square foot, which is very high and which we could not justify.

The table also shows the maintenance costs of a number of the surveyed roofs. The response from Building (group 1and 8) shows 0 USD maintenance cost. The roof has sedum that is not being watered, and generally sedum requires very little maintenance. However, one would expect some maintenance work every now and then on the roof; it is possible that some volunteer labors do the maintenance. The maintenance cost of the roof of Building (7) is relatively high. However, the large area of planted roof, and the fact that it has bushes that require maintenance as well as irrigation may explain this rather high cost.

The maintenance cost of the vegetative roof of Building (group 5) is extremely high, more than 6000 USD per year. According to the data we received regarding these buildings, average of 3 buildings, the maintenance cost includes the gardener's fees, new plant materials, and irrigation water. A closer look at the conditions of these roofs reveals that one of the buildings has leakage problems through the roof; this may explain the high maintenance costs for maintaining the roof. In fact, this is the only building under the study in the survey that has leakage problems. It is worth mentioning that the building dates back to the late-nineteenth century, and has been more recently renovated and a vegetative roof was installed. It is often recommended in such buildings that a kind of potted plants be used instead of the more conventional vegetative roof systems.

CONCLUSION

The limited number of respondents of the survey has showed that advantage was often not taken of potential benefits of vegetative roofs. Green roofs are being mostly used for controlling storm water runoff, and they often support wildlife. Although previous studies have shown savings of 1-15%, due to the many parameters involved in determining the rate of energy consumption in a building, we could not definitively draw a conclusion regarding whether or not the surveyed vegetative roofs reduce the energy consumption of their buildings. A more productive method to estimate changes to consumption would have been a before/after experiment. A solid conclusion could have been reached if we had received responses from buildings having vegetative roofs that were installed after the buildings were in operation. In such a case, a comparison between the rates of energy consumption before and after the roofs would have been added would have produced rather accurate results.

This study also has shown that vegetative roofs are often not being used as recreation places. There seem to be no technical problems in the systems of vegetative roof. However, some problems may arise when the vegetative roofs are introduced to old buildings. The use of potted plants for such roofs seems to be better to avoid leakage problems through the roof.

It should be noted that the life span of vegetative roof is 40 years and just the first 2 years need high cost maintenance. However, the conventional roof life span is 20 years. The study has shown that generally the up-front costs of the vegetative roofs and their maintenance costs are reasonable. The initial cost of conventional roof as an average is 11$ per sq ft, for extensive vegetative roofs would be 24$ per sq ft which it would be 33$ for intensive green roofs. However, the higher initial costs would be justified by the energy conservation during the life span. The energy maintenance cost annually for conventional roof is 0.15 $ per sq ft per year, but extensive vegetative roofs just need 2 years maintenance for 2 $ per sq ft per year and for intensive vegetative roofs would be 2.4 $ per sq ft per year.

In fact, previous research suggests that a good design and installation of such roofs may result in savings in energy costs in a building. However, it seems that not much real monitoring of vegetative roofs is being carried out.

This research aimed at proving the many benefits vegetative roofs-mentioned in literature review- have, since this will encourage architects, owners, and developers who are reluctant to adopt this rather new technique of roofing to use it. Although the findings of the research support only two of the benefits of vegetative roofs (control of storm water runoff and support of wildlife), they are still encouraging as no serious problems or disadvantages have been identified.

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