SHOULD YOU PUT YOUR ENERGY INTO GREEN ROOFS TO REDUCE ENERGY CONSUMPTION IN YOUR BUILDING

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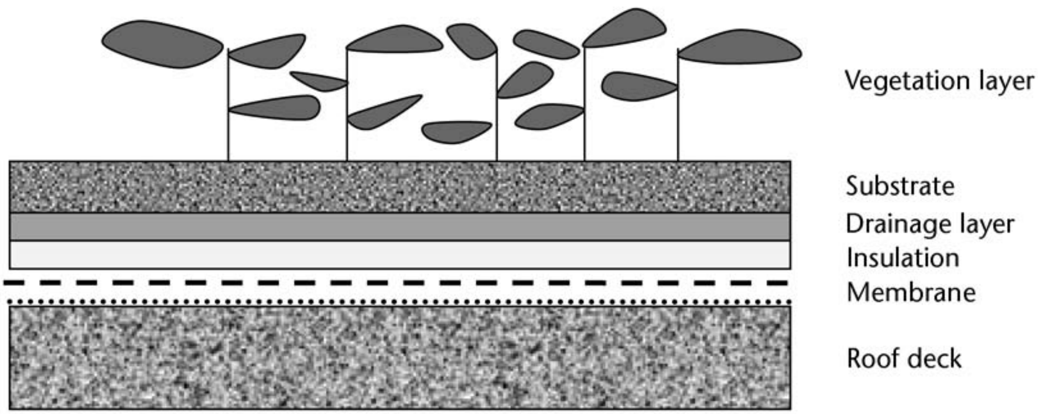
INTRODUCTION

Green roofs are touted as an environmental technology for urban areas due to their many benefits (Lundholm et al. 2008). Although the design and the benefits have been reported in many reports and articles, they are reviewed here for those who are unfamiliar with this technology. Green roofs, or more formally, green roof infrastructure, is a technology that allows for the growth of vegetation on a roof while protecting the building envelope from leakage and root penetration. A green roof is more than a layer of soil piled on the roof, planted in the way that you might plant a garden. The technology consists of multiple layers that include the plants and growing medium or substrate, but also a drainage layer for storing water that was not used by the plants and a waterproof, root-repellent membrane (Figure 1).

FIGURE 1. Typical arrangement of layers in a green roof. *Figure is provided courtesy of Susana Saiz-Alcazar [10].*



Although the schematic in Figure 1 is fairly common to all green roofs, there are several variations on this design. Most green roofs use a very lightweight growing medium or substrate to stay within the weight load of the roof, but there are examples of green roofs that use the local soil from the area to reduce the ecological footprint of building the roof and because the roof can bear the additional weight. The drainage layer is often a plastic shell that might resemble an egg carton in some respects, but other designs use a second, coarser natural media to store excess water. The water usually drains off the roof when the drainage layer is full. As this occurs after the peak of a rain event, green roofs have been recognized for their potential role in reducing combined sewer overflow events. With some green roofs, the water in the drainage layer is stored in the building for other uses that do not require potable water.

Some roofs include a waterproof, root-repellent membrane, while others will use a root cap to prevent unwanted roots from damaging the membrane or even the roof deck. A few designers will leave out

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the root protection altogether, relying solely on plant selection and the removal of unwanted plants whose seeds have managed to find the roof habitat. Some roofs use a plastic mesh underneath the growing medium that will entangle any roots that do manage to penetrate below this layer. Green roofs are typically planted with seeds or plugs, but a few are left bare, allowing seeds to be carried to the roof through wind and birds.

The two major categories of green roofs are extensive and intensive. Extensive green roofs are more common as they are relatively light in weight allowing their installation on a larger number of roofs. These roofs will typically have a growing medium between 3–6 inches (7.5–15 centimetres), but there are green roof products with even thinner growing mediums. For the most part, extensive green roofs are not designed or intended to accommodate people on the roof. Although they can incorporate innovative landscaping ideas, which are important if the roofs will be viewed from offices or residences that are situated in towers adjacent to the roof, less attention is usually paid to landscape aesthetics with these roofs. Extensive roofs are typically planted with shallow-rooted perennial plants that remain low to the ground. These plants should be tolerant of a wide number of stresses—heat, drought and wind being the most common but on other roofs cold, disease, insects, and salt will also stress the plants—that will be experienced due to a thin growing medium and elevations above ground level [1].

Typical plants for extensive green roofs include herbaceous perennials as they add a lot of colour to the roof (Figure 2). However, the most popular plants for an extensive green roof are succulents, such as sedum because they are shallow-rooted and low-growing and they are drought and wind tolerant (Figure 3). These plants can keep their stomata, the openings on the leaves, closed during the day to reduce water loss through transpiration. The stomata will open at night to store carbon dioxide. This metabolic process is known as Cruassulacian acid metabolism (CAM). Many succulents are facultative CAM, meaning that this metabolic process is operative only when they undergo moisture stress [2]. This metabolic process will be discussed in more detail in the discussion of plant selection.

Intensive green roofs utilize thicker growing mediums and can therefore accommodate a wider variety of plants, in some cases including trees (Figure 4). Intensive green roofs are often designed to accommodate people and can incorporate formal garden design, water bodies, and other landscaping features not usually associated with roofs. Although they tend to cost more and require more maintenance than the extensive variety, they allow for more design features and more plant variety. There are roofs that are classified as semi-intensive as they go beyond what is usually considered an extensive design, but do not incorporate all of the features of an intensive green roof. All of these different types of green roofs are capable of reducing summer electricity consumption, but in a colder climate, a semi-intensive or intensive roof is a better choice to reduce heating requirements.

The benefits of green roofs have been discussed in a recent review article in the journal *Bioscience* and

FIGURE 2. Extensive green roof on top of the J.A. Robertson Building, 215 Spadina, Toronto, Ontario. This is one of two buildings owned and operated by Urban Space with green roofs. The green roof features a mix of flowers and grasses. The photograph was taken from the fifth floor observation deck, facing east. *Figure is provided courtesy of Beth Anne Currie, Centre for Social Innovation, Toronto, ON.*

FIGURE 3. An extensive green roof planted with sedums is located on Yorktown Squares Condominiums in Falls Church, VA. This EnviroTech Greenroof System from Building Logics, was the award winner in the Extensive Residential category at the 4th Annual Greening Rooftops for Sustainable Cities Conference and Trade Show in Boston, MA. *Courtesy of Green Roofs for Healthy Cities. www.greenroofs.org.*

have been formally assessed for the City of Toronto. These benefits include energy conservation, but that is only one of many. Other benefits of green roofs include the reduction of stormwater runoff, improvements in air and water quality, extension of the lifespan of the roof, increasing biodiversity, reducing the urban heat island, the increase in urban temperatures due to the replacement of vegetation with hard surfaces, and the provision of additional green amenity space in urban areas. The assessment for the City of Toronto has shown how these direct benefits might be extended, such as reducing the number of beach closure days due to poor water quality [3]. Most of these benefits accrue to the public, and may provide little direct benefit to an individual building owner. Energy conservation is unique in that it is one of the few, and in some cases the only, direct advantage to the building owner, although it may also benefit the public by preventing blackouts or brownouts.

The idea of incorporating vegetation into the building envelope is not new. Green roofs and walls can be traced back to Scandinavia, when Vikings roamed the North Sea, and the Roman Empire [4, 5]. Interestingly enough, the reasons for adding vegetation to roofs and walls was not all that dissimilar to our reasons for building green roofs. In Pompeii, a green roof provided additional green space in a densely populated urban area. For the people in Scandinavia, the vegetation was used to help regulate the indoor temperatures of their dwellings.

FIGURE 4. Intensive green roof on the Schwab Rehabilitation Hospital designed for both horticultural therapy and recreational use, all within the safety of the hospital grounds. The 10,000-square-foot green roof occupies 50% of the total roof space and has growing medium depths of 8 to 18 inches. The green roof, supplied by American Hydrotech, was the award winner in the Intensive Institutional category at the 4th Annual Greening Rooftops for Sustainable Cities Conference and Trade Show in Boston, MA. *Courtesy of Green Roofs for Healthy Cities, www.greenroofs.org.*

Green roofs have been shown to reduce the amount of electricity used for cooling a building in some circumstances, and yet in other buildings, the energy conservation appears to be quite minimal. There are several reasons for this variation in results, many having nothing to do with the roof but having much to do with the environmental factors created by the location of the building. Once these environmental factors are understood, a decision can be made as to whether a green roof will have the potential to reduce energy consumption.

If this benefit is to be realized, there are several design features that might become more important and should be considered in order to maximize the energy conservation potential of a green roof. This article tries to guide you through how a green roof can conserve energy, what features of the roof can be altered to maximize the conservation of energy, and what environmental factors may enhance or reduce the potential energy conservation.

Some evidence from previous work will be presented to demonstrate that green roofs can conserve energy. The physical processes at work in the roof have been well understood for sometime in the fields of agricultural and urban meteorology and systems ecology. These processes will be described in order to understand how green roof technology works and to understand the important features for maximizing this benefit. The green roof will then be put in the context of its location and those extra-roof environmental factors that will determine whether energy conservation is a benefit that will be maximized for your location.

CAN GREEN ROOFS INCREASE ENERGY CONSERVATION?

Green roofs can certainly reduce energy. The first bit of evidence for this is the observation of heat flux through a roof and the temperature variation underneath a roof. Between November 2000 and September 2001, temperature and heat flux data were collected on the first green roof field site in North America, a site located at the National Research Council (NRC) Campus in Ottawa, Ontario. This site, maintained by the National Research Council's Institute for Research in Construction, and funded by a consortium of roofing companies and Environment Canada, is a small one-story building with a test roof of 80 m.[2] The roof was divided in half with three data collection sites on each half. One half of the roof was built as a reference roof, similar to many roofs found in a typical North American urban environment. The other half of the roof was set up as an extensive green roof, with a mix of grasses and wildflowers.

The data collected over this time indicated that, between June and August, the average daily flow of heat from the atmosphere through the reference roof into the building was equivalent to 4 kWh. Over the green roof, the average daily heat flow, over the same time period, was virtually reduced to zero. Other data from this observation period indicate that a green roof can reduce the variation of temperature on the roof membrane. During this same time period, the difference between the minimum and maximum temperature on the reference roof membrane varied between 20°C and 60°C. The differences between the maximum and minimum temperatures on the green roof membrane varied between zero and a few degrees [6].

Other data suggest how green roofs reduce heat flux and in turn green roofs reduce summer energy consumption. At a green roof field site maintained by Penn State University's Department of Horticulture, data were collected on the surface temperatures of conventional and green roofs planted with sedums, a very typical green roof plant. Data collected between July 1 and July 21, 2003 showed that the surface temperature on the conventional roof could exceed 70°C, and did so on nine days. Except for four days, the surface temperature of the conventional roof exceeded 50°C. The green roof temperature only exceeded 40°C, by a very small amount twice in this period, and was close to or below 30°C for 7 days during this period [7]. Surface temperatures of the green roof in Ottawa rarely exceeded 30°C during the initial observation period between 2000 and 2001.

These types of data do translate into energy savings. The estimated cumulative energy savings at the NRC test site, between November 22, 2000 and September 31, 2001 was 967 kWh, a savings of almost 50% between the two roofs. Two other studies on inhabited buildings also support the energy savings attributable to green roofs. The estimated energy savings in July were on the order of 6% for an eight-story building in Madrid, while the peak demand savings for the same building were on the order of 10%. For the floor immediately beneath the roof, the savings in July varied from 22–25% [8].

Based on a computer simulation model during the time of peak demand, the surface temperature of the building with a conventional roof equalled or exceeded 70°C for four hours. Using the same computer model, the surface temperature of the green roof during the same four hours would vary between 29°C and 39°C. However, the green roof temperature increase lagged the conventional roof such that when the surface temperature of the reference roof exceeded 70°C, the surface temperature of the green roof was just above 30°C. Inside the building, the peak temperature underneath the green roof, which never exceeded 35°C, lagged the peak temperature underneath the reference roof, approximately 37°C, by two hours (Figure 5). This lag in temperature would delay the impact of the peak demand time for that day by two hours. Over the whole summer, the results are similar. When this computer simulation model was applied to the NRC test facility for a typical Ottawa summer, the peak temperature inside the facility underneath the reference roof was 37°C, while the peak temperature underneath an extensive green roof did not exceed 31°C (Figure 6). From June to August, this would reduce the cumulative energy consumption in this facility from 800 to 500 kilowatts.

These energy savings can yield an energy cost saving and play an important role in evaluating a green roof. A study conducted by The Solution Organization in the UK for a one-story building estimated that the energy savings of a green roof would equal £5,200 per year for a green roof of 1,000 m^2 [9]. In life cycle assessments, comparing green roofs to conventional roofs, the energy savings were an important contribution in ranking the green roof above the conventional roof [8, 9].

HOW DO GREEN ROOFS SAVE ENERGY?

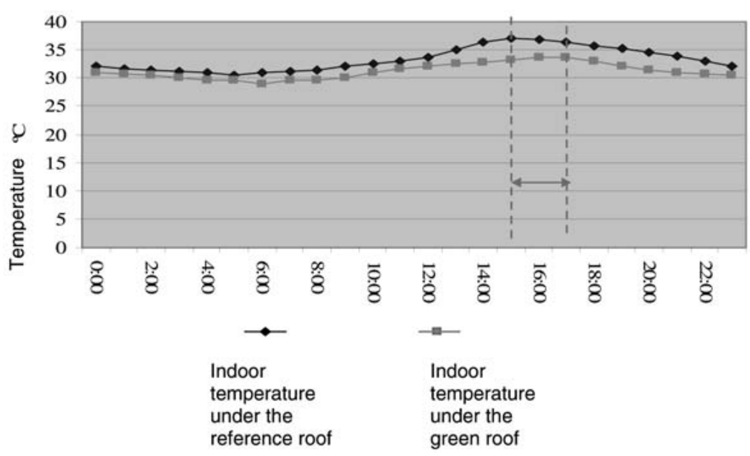
Having established that green roofs do reduce the surface temperature of a roof, the temperature variation on the membrane, the heat flux through a roof, and that these reductions reduce energy consumption during the summer, we can explore how green roofs achieve these results. Most of this discussion will apply to extensive green roofs as most of the research has been conducted on extensive green roofs and summer energy consumption, and these types of roofs still account for the largest part of the green roof market. However, some comments will be made about intensive green roofs and the potential winter energy savings. There are three mechanisms of heat transfer, and to some extent all of them play a role in reducing the heat flux through a green roof. These three mechanisms are conductive, convective, and radiative heat transfer. Conductive and radiant transfers are most important in the growing medium and within the canopy respectively.

Conductive Heat Transfer

Conduction is the transfer of kinetic energy from more energetic to less energetic molecules by collision when two bodies are brought into contact. Conductive heat transfer is the transfer of heat between two bodies in contact from a higher to a lower temperature. It can occur through the vegetation canopy and through the growing media or soil on the green roof.[1] Both the vegetation layer and the growing media will increase the thermal resistance of the roof.

The conductive heat transfer through vegetation has been shown to be small and ranges from 0.06 to 0.2 W/m^2. The variation may be due to different plants, seasonal changes, and weather. It has proven difficult to incorporate this into energy analyses and simulation models, and it appears that it can be ignored without a loss of accuracy in these types of studies [10]. The conductivity of the growing me-

FIGURE 5. Comparing indoor peak temperatures during the day underneath the reference and the green roofs. Note the lower temperature and the two-hour time lag behind the peak underneath the green roof.



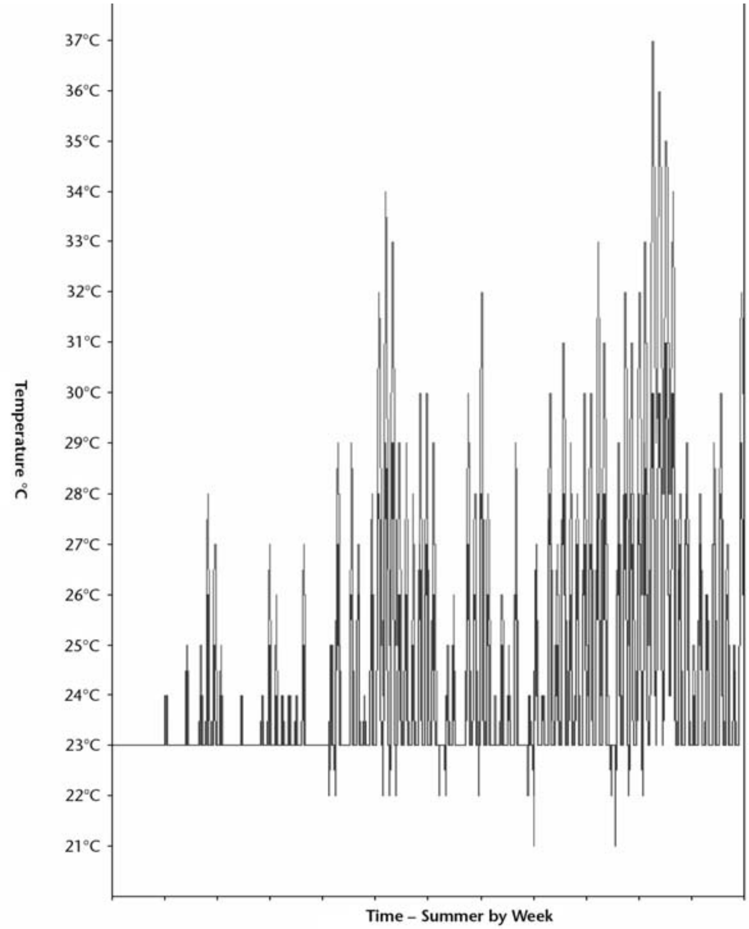


FIGURE 6. Simulated comparison of indoor temperatures in the Field Roofing Facility at the National Research Council for a typical summer in Ottawa, ON. The simulation was carried out with the Environmental Performance Services-research (ESP-r) simulation model with green roof parameters courtesy of Susana Saiz-Alcazar [10].

dium, and of any soil, will increase with increasing moisture, or the resistance to heat flow will decrease. The conductivity of the growing medium can be as low as 0.2 W/m^2 with 20% moisture, and will increase in a non-linear manner to 0.8 W/m^2 with an 80% moisture content.

Although we are jumping ahead, the increase in conductivity, which means an increase in heat flux through the roof, with increasing moisture presents a conundrum. Moisture is needed for evapotranspiration, the movement of water back to the atmosphere, which in turn will be shown to be an important process in reducing green roof surface temperature. Preliminary results from an ongoing laboratory study suggest that increasing the moisture content does indeed reduce the heat flux through the green roof, even with the higher conductivity associated with the higher moisture content. Initial speculation is that under conditions that favour evapotranspiration,[2] the additional moisture is responsible for a higher rate of evapotranspiration and a further reduction in the surface temperature of the green roof.[3] Other research suggests that in an extensive roof, the conductivity of the growing medium may not play a large role in determining the surface temperature of the roof [11].

The situation may be different for an intensive green roof, as the growing media tend to thicken, anywhere from 1/3 to 3 metres (1–3 feet). The thermal resistance of a growing medium of this depth would be expected to be much more important, especially under meteorological conditions that might suppress evapotranspiration. Although we are jumping ahead again, the deeper growing mediums available on intensive green roofs allow for a wider variety of plants with larger leaf area indices, or a larger leaf surface and hence more shade. Shade can play an important role and will be discussed in the context of radiative heat transfer. The wider variety of plants can also include coniferous or evergreen plants, which in turn would be important in reducing heat losses during the winter in colder regions.

Convective Heat Transfer

Convective heat transfer occurs through the movement of one fluid mass over a solid material that is at a different temperature. For green roofs, convective heat transfer would increase with increasing wind speeds. In energy analyses of green roofs, convective heat transfer has been shown to be a good proxy for evapotranspiration, which is related to radiative heat transfer [11]. As radiative heat transfer is considered to be the most important mechanism in explaining how a green roof reduces heat flux, convective heat transfer is usually not accorded a great deal of explanatory power. Although conduction and convection may not be as important as radiative heat transfer mechanisms in understanding summer extensive green roof performance, the importance of these two mechanisms should not be ignored in looking at the whole building as heat can flow into the building through other surfaces.

Radiative Heat Transfer

Radiation provides energy as electromagnetic waves, and the lengths of those waves determine the type of energy. Short wavelengths are received as light, and the longer wavelengths or infrared wavelengths are received as heat. Heat, which is thermal radiation emitted by a heated surface, is also affected by the temperature of the surface, the type of surface, and the direction of emission as well as the wavelength. If emission in all directions is considered, and the surface is a black body, the heat transferred by the radiation is a function of the surface temperature. For non-black surfaces, the heat transferred by radiation is also a function of temperature modified by a constant. White surfaces reflect a large amount of incoming energy, and this energy cannot be absorbed.

If the surface is not white or reflective, a large fraction of the incoming light is absorbed and emitted as longwave energy, i.e., heat. On a non-black body a small portion will be transmitted through the body or reflected from the body. On a green roof, the amount of radiation absorbed, transmitted, and reflected depends on leaf characteristics such as colour, roughness, porosity, and the geometry of the canopy or layout of leaves. For example, lighter coloured leaves will reflect a larger amount of incident radiation [10]. Transmittance of energy through a leaf is estimated to be 20%, but can be reduced significantly through a vegetation layer due to the superposition of leaves.[4] Therefore, the reflectance and the absorption of radiation by the leaves define the overall balance. Values of absorption range from 50 to 80%, while values of reflection range from 20 to 50% [12].

As the geometry of the canopy can severely restrict transmission of radiation through the canopy, i.e., shade, the size of the leaves and their arrangement can reduce the amount of radiation absorbed by the surface of the roof. The leaf area is often expressed by a term called leaf area index or LAI. LAI is defined for broad leaf canopies as the area of the leaf per unit ground area and for needle leaf canopies, as the needle leaf area per unit ground area for needle canopies [13]. Shading and any possible reflection are important considerations particularly with a dense, broad leaf canopy. Shading and reflection reduces the amount of short-wave and long-wave radiation that can be absorbed by the roof surface.[5] Concrete or gravel roofs have absorption coefficients that are close to 90%. The reduction in the absorbed solar energy underneath the green roof canopy is noticeable in reducing roof surface temperatures, reducing the energy radiated to the atmosphere, and reducing the conductive heat transfer through the roof [10].

Many extensive green roofs are primarily needle leaf plants and grasses and/or contain gaps in their canopy. Yet they can still be effective at reducing summer energy consumption, i.e., the cooling load. The reason has to do with the latent heat flux. For extensive green roofs, latent heat flux is either the most important or second most important contribution to reducing the heat flux through the roof surface. For the purposes of this discussion, latent heat flux can be considered synonymous with evaporative cooling because it is a result of evapotranspiration.

Evapotranspiration is the movement of water or evaporation from the surface of the soil, or in this case the green roof growing medium, and movement of water or transpiration from the leaf surface. Water is moved through the atmosphere in gaseous form, or as water vapour. Converting water to water vapour requires an input of energy, and this energy is provided by the sun. However, energy that is used for evaporation cannot be absorbed by the surface of the canopy or the roof and reradiated in the long-wave form or as heat. The "heat" is now bound up in the water vapour and is released when the water vapour condenses into liquid form, returning to the earth as rain. Condensation releases heat but at higher levels in the atmosphere, far enough above the surface as to not affect surface temperatures.

Thus, wet surfaces tend to be cooler than dry surfaces, hence the term evaporative cooling. The degree of cooling to expect on a green roof has already been discussed. A 25° to 30°C reduction in surface temperature is not unusual and is in line with results on other, ground level canopies [14]. The amount of solar energy utilized for evapotranspiration has been estimated to be as low as 20%, which dissipates approximately 3 kWh/m^2 [15, 16] and as high as 48% [17].

Thus the surface of a green roof is expected to be cooler than the surface of other roofs found in the urban environment,[6] and this is important in reducing the heat flow through the roof. The discussion of radiation and evapotranspiration is summarized in Figures 7 and 8. Figure 7 indicates the energy balance on a reference roof, and Figure 8 indicates the energy balance on a green roof. The figures indicate slightly more reflection on the green roof, but more important, the effect of evapotranspiration on the energy balance of the roof.

One question that usually emerges at this point is whether the same results could be obtained through misting an impermeable surface or eliminating the plants and just using a moistened growing medium.

FIGURE 7. The energy balance of a conventional roof. *Courtesy of Green Roofs for Healthy Cities, www.greenroofs.org, by permission of Marco Schmidt.*

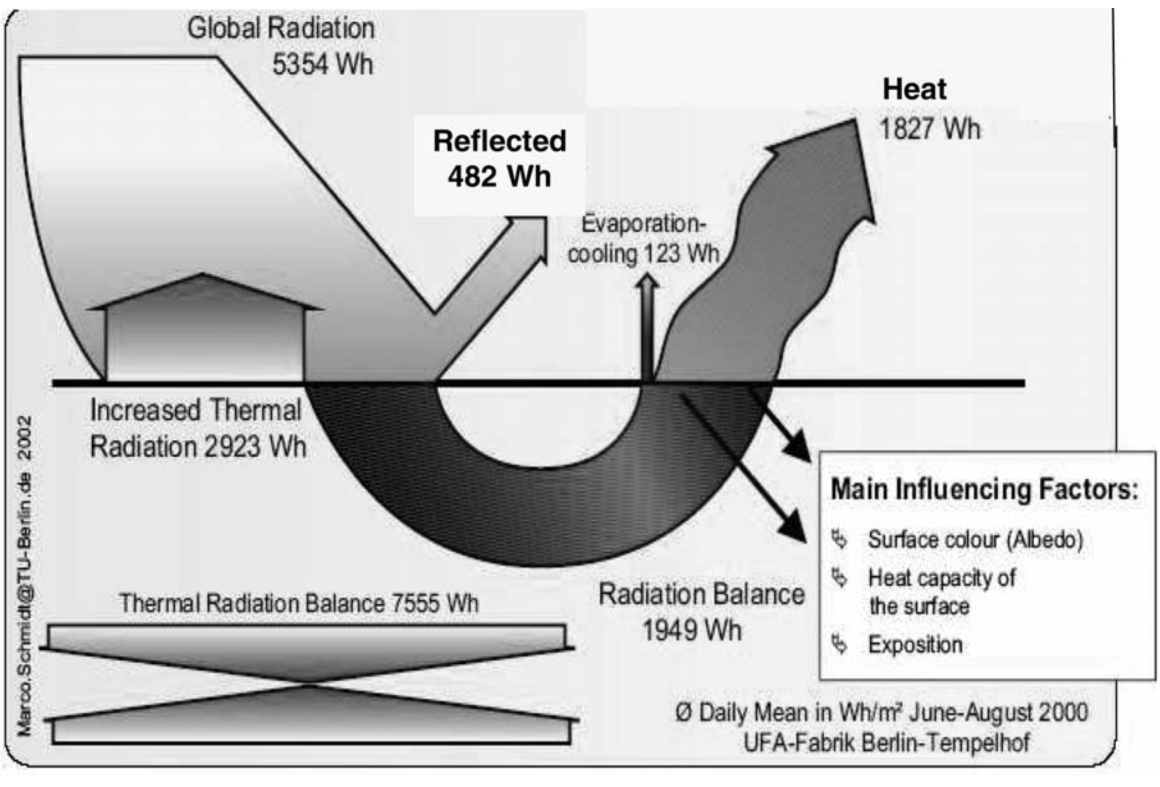
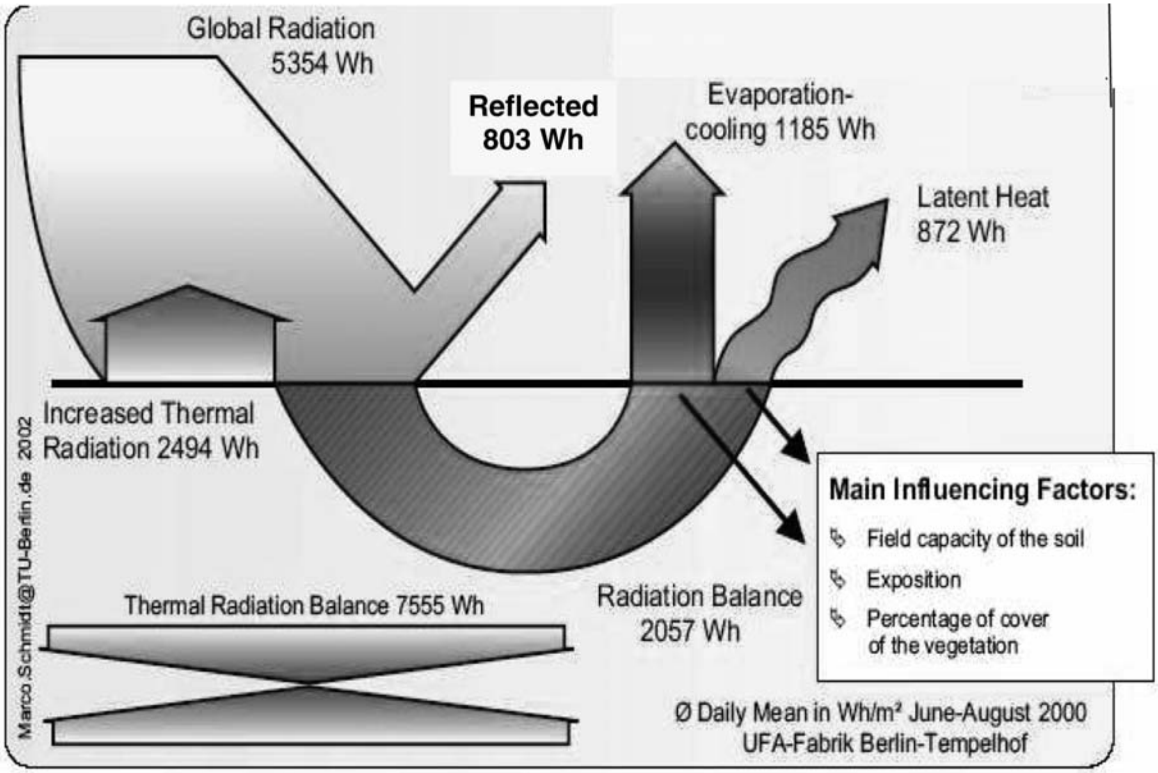


FIGURE 8. The energy balance of a green roof. Note the difference in energy radiated as heat versus evaporative cooling in comparison with Figure 7. *Courtesy of Green Roofs for Healthy Cities, www.greenroofs.org, by permission of Marco Schmidt.*



Foregoing the previous discussion on transmittance, which may be of equal importance in reducing heat flow through a green roof in some cases, the exposed area of a vegetation canopy is 20 to 40 times greater than the flat area that it covers. The evaporation increases proportionally to the exposed area under still air conditions [10]. The cooler surface temperatures of a vegetation canopy have also been shown to be an indicator of biological activity, which is taken to imply increased biodiversity, meaning that surface temperatures will decrease further with increasing biodiversity [17, 18].

The property of a surface that characterizes the amount of energy that is reflected is called albedo. As the albedo of a surface increases, the reflectivity of the surface will also increase. White roofs typically have an albedo of 0.65. In the previous research conducted on an 8-story building with a white roof, the white roof was cooler than the reference roof, but not as cool as the green roof [10]. For a white roof to be thermally equivalent to a green roof, it would require an albedo of 0.85 [11].

Intensive Green Roofs and Winter Energy Savings

The processes of heat transfer that were applied to extensive green roofs would also apply to intensive green roofs. As mentioned previously, in cases with large gaps in the canopy and/or conditions that do not favour evapotranspiration, the thicker growing mediums will impute increasing importance to the reduction in conductive heat transfer. However, intensive green roofs can also support many larger plants with a larger LAI, thereby increasing the amount of shading. As many intensive green roofs may be designed to resemble formal gardens with large amounts of space for pedestrian traffic, the thicker growing mediums and the extra shading are important in maintaining a heat flux into the roof that is virtually zero.

Winter savings from green roofs have not been given the same attention as summer savings. In cold-climate regions, where winters are typified by below zero temperatures (Celsius), extensive green roofs with a grass, wild flower, or sedum vegetation canopy will lose their canopy and any moisture in the growing medium will freeze. The period of observation at the National Research Council site showed extremely marginal reductions in heat loss, but these were insufficient to affect internal temperatures. Studies on green walls [19, 20] have suggested that there are two effects of using technologies that grow vegetation on a surface: additional insulation and reducing the wind chill by reducing the wind speed, the latter being far more important. When these factors have been incorporated in a building energy simulation of green roofs for winter, the results for a typical two-story house indicated energy savings of 5%. The savings were higher for another building where the roof was the major source of heat loss, but these other contextual factors will be discussed at the end of the paper [21]. These results, however, are considered extremely preliminary.

DESIGN FEATURES TO MAXIMIZE ENERGY CONSERVATION

Summer Energy Savings

Based on the foregoing discussion, there are several design features that might be a good focus for maximizing the potential savings from a green roof, particularly an extensive green roof. Given the importance of evapotranspiration and transmittance through the canopy, i.e., shading, it is important to maximize the plant canopy. Generally this is done by planting sufficient plants to fill in all gaps as quickly as possible. Many extensive green roofs are not completely planted at first and take a few years for the canopy to cover most of the surface. Because most extensive roofs are planted in sedums, which are small succulents, the LAI is relatively small. If sedums are the choice for your green roof, then in the first year, they can be supplemented with moss. Moss can be established relatively quickly and will provide a good habitat for the further expansion of sedums.

Sedums are a very popular choice because they are tolerant to many of the stresses encountered by plants on extensive green roofs, and they are shallow rooted, making them ideal for thin growing mediums. Many sedums are CAM, but some are facultative CAM. To fully understand the CAM and facultative CAM plants, we need to digress and compare the C3 and C4 photosynthetic mechanisms that work in these plants. Most plants use the C3 pathway and use less energy for photosynthesis than C4 and CAM plants but are at a disadvantage under heat and moisture stress. C3 plants are not efficient users of water and lose about 600 molecules of water per fixed molecule of CO_2. C4 plants require more energy for photosynthesis but are far more efficient and lose 100 molecules of water per fixed molecule of CO_2 [22].

CAM is a unique photosynthetic pathway allowing CAM plants to conserve water while assimilating CO_2 at night [23]. Facultative CAM plants switch from C3 to CAM metabolism under conditions of stress [24]. Facultative CAM plants use the C3 pathway to maximize growth when water is abundant but undergo a C3 to CAM transition when moisture is reduced, often coincident with seasonal moisture availability. The C3 to CAM transition reduces water loss yet maintains photosynthetic integrity. CAM plants are so efficient at retaining water that they lose only 10 molecules of water per fixed molecule of CO_2 [22]. Many of the plants that are facultative CAM are succulents and include a number of sedums.

Facultative sedum plants are ideal for green roofs as they can thrive in high and low moisture regimes. From an energy conservation perspective, they are highly desirable because they will allow C3 rates of transpiration when moisture levels are high, thus keeping the roof surface cool enough for maximum energy savings. *Mesembryanthemum crystallinumn* and *Sedum telephium,* succulents found in the northern temperate zone, are two such facultative CAM plants although *Mesembryanthemum* can only be used on green roofs in temperate regions [22].

Evapotranspiration and shading can be increased by choosing plants with a larger LAI. Plants such as Rhododendrons might prove suitable for an extensive green roof, especially if the roof can support a growing medium of 15 cm or 6 inches, as their roots will spread out and there are varieties that are suitable for colder climates.[7] At a depth of 15–18 cm, it might be possible to identify other coniferous plants that will provide vegetation during the winter. It is best to speak with an experienced green roof professional about plant selection for extensive green roofs with slightly deeper growing mediums.

Many green roofs are installed with an irrigation system to ensure that sufficient moisture is available to establish the vegetation canopy and as insurance in climates that are prone to long dry periods. While this is an option, it may be seen as a preferable option. Since moisture is needed to drive evapotranspiration, and if energy conservation is an overriding concern, then an irrigation system should be considered in drier climates or in locales with a recent history of drought. If an irrigation system is not deemed necessary under current conditions, it is worthwhile to check the future climate change scenarios for your area, and perhaps to create customized site-specific scenarios for your site, to assess the changing probability of extreme drought and extreme heat over the next 30 years. Climate change scenario maps and monthly data for Canada can be accessed from the Canadian Climate Change Scenarios Network at cccsn.ca, although bioclimate profiles[8] can be obtained for the whole world. Scenarios for other areas of the world will be available through the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre.

For reducing cooling loads, the most important design features concern radiation and evapotranspiration. For an extensive green roof, increasing soil depth beyond the minimum will only impute marginal benefits in terms of energy conservation. However, a deeper growing medium should be considered in climates where weather conditions might inhibit evapotranspiration.[9] With this type of situation, soil conductivity will assume a greater importance. At the other end of the spectrum is the issue of how shallow a growing medium is possible for an extensive green roof. While many companies recommend a minimum depth of 9 cm (3.5 inches), there are products on the market with thinner growing mediums. Thinner growing mediums may require irrigation to maintain sufficient moisture for evapotranspiration. Maintenance, which is important on all green roofs, becomes even more important, particularly the removal of unwanted plants that could produce roots that are too long for the growing medium.

Winter Energy Savings

The winter case is not as well researched as the summer case. However, if heating loads are an important concern, a green roof can be used to reduce the flow of heat through the roof and out of the building. Green roofs can provide additional insulation and reduce the wind speed, and hence the wind chill, above the roof. Although the plants will also shade the roof, preliminary research on green walls suggests that the reduction of wind speed more than makes up for any losses due to shading. It is important to establish a canopy of coniferous plants that will provide a rough surface to reduce the wind speed in order to obtain this benefit.

This type of green roof is most likely an intensive green roof. The plants will often require a deeper soil because they may be bigger plants with deeper roots, and thinner growing mediums will freeze over the winter. A deeper soil will also provide additional insulation for the roof. However, adding more weight to the growing medium is not possible on all roofs, due to limits on the weight load. If weight is a concern, there are coniferous plants that can be established in thinner soils, albeit deeper than the 4 inches that are typically used on an extensive roof.

The other concern in the winter is snow. Snow is the great leveller in that it is an insulator whether a roof is green, white, or black. A coniferous plant canopy may inhibit or delay the accumulation of snow in an even layer across the roof. It is not yet known whether preventing this accumulation would be beneficial or detrimental to lowering heating loads. If the plant canopy remains above the snow, then the plants will still play an important role in reducing wind speed.

BUILDING AND ENVIRONMENTAL FACTORS AFFECTING SUMMER PERFORMANCE OF THE GREEN ROOF

Building Factors that Affect Green Roof Thermal Performance

There are several aspects of the building that can inhibit or enhance the thermal performance of a green roof. The most important are the roof-to-building envelope ratio; building orientation; window size and exposure; the thermal properties of the walls; the heating, ventilation, and air conditioning (HVAC) system; other equipment in the building; and usage of the building. The roof-to-building envelope ratio is probably the most important building factor. As it increases, the overall savings attributable to the green roof increase. In a study of an eight-story residential complex in Madrid, the summer electricity savings ranged from 6–10%, but if the building had only been one story, these savings would have been as high as 25% [8, 10].

Many green roofs only cover a portion of a building. If the section under the green roof is on the northern or eastern side of the whole building, the savings may be less than expected because the solar gain is lower than it would be on other parts of the roof. The thermal properties of the building envelope are important, because if they provide a high resistance to heat flow, the impact of the roof might be very small unless the roof-building envelope ratio is quite large. Similarly, if the roof-to-building envelope is small and the resistance value of the walls is low, the green roof will have a smaller impact on energy consumption. Also, large windows with a southern or western exposure will lead to increased solar gains, increasing the internal temperature of the building.

Highly efficient HVAC systems can reduce the energy impact of the green roof as many potential savings may already be realized in the building. Other equipment, such as computers and lights, contribute to the base load of the building, and this load is not affected by the green roof. The impact of equipment on the consumption of electricity in a building is also affected by the usage of the building. For example, is the building occupied during the times of peak energy demand? Is most of the building used for the whole week? What are the daily hours of operation? Alone or in combination, these building factors may reduce or enhance the thermal performance of the green roof and should be considered if reducing energy consumption is a necessary justification for installing a green roof.

Environmental Factors that Affect Green Roof Thermal Performance

There are several factors external to the building that could affect the thermal performance of a green roof. Two factors that are very important are of course temperature and radiation. The green roof will not reduce summer cooling loads in a climate or during a summer season characterized by low temperatures and a potentially small amount of solar radiation. Assuming that this is not the case, the height of other nearby buildings may exert a strong impact on energy consumption. For example, if the roof is shaded by other buildings, this shade will help reduce the flow of heat through the roof. The impact of the green roof on energy consumption will be reduced because the building's exposure to sunlight is reduced. On the other hand, if the building is surrounded or attached to other buildings of the same height, then the exposure of the walls to sunlight and heat is reduced, effectively increasing the importance of the roof on the overall heat gain and hence the effect of the green roof. In the northern hemisphere, reducing or eliminating the western and southern exposure of a building will leave the roof as the sole or largest source of heat, amplifying the effect of the green roof.

The urban heat island (UHI) is an increase in urban temperatures primarily due to the replacement of vegetation with hard surfaces. Even an increase of two degrees Celsius is important. For example, in Ontario, an increase in summer temperatures by 2°C will increase the demand for electricity by 8%, and this demand is primarily for air conditioning [23]. If a green roof can assist in reducing the use of air conditioning by reducing the heat flux through the roof, then a large UHI should favour technologies like green roofs. However, the real excitement lies in the fact that green roofs might have a significant role to play in reducing the urban heat island. Since it is primarily due to the reduction of vegetation canopies, increasing the number of green roofs will reverse this trend and hence the UHI [6].

Climate change is another environmental factor that should be considered, and here I will refer you back to the earlier discussion on the use of scenarios to assess the need for irrigation over the next 30 years. In addition to our concerns about green roof survival under climate change, a warmer climate will also increase the viability of green roofs because of the expected increasing use of air conditioning, at least in the current building stock. Green roofs can directly reduce the cooling load of a building and thereby the demand for electricity. Green roof adoption on a larger scale would help in reducing the UHI. Although the UHI is not caused by climate change, any reduction in summer temperatures will reduce a city's vulnerability to climate change [24]. One other climate change issue affecting green roofs is whether a green roof designed for current climatic conditions will survive under a changing climate without significant management intervention. It is hoped that this issue will become an emergent area of green roof research in the future.

FUTURE DIRECTIONS

The discussion of energy savings in the summer left out one potential area of additional savings: cooling the air that enters the building through the air exchange. Currently, large buildings exchange air with the external environment in order to maintain mandated air quality standards. In the summer, this air is warm and energy must be used to reduce its temperature, further increasing the energy used for air conditioning. This air should be cooled to some degree over a green roof. If the air is not being cooled by passing over a green roof, or if it is desirable to cool the air even further, it may possible to select and situate specific plants near the air intake.

Beyond the roof, this technology is already moving onto walls, both external and internal. External green walls are built for primarily the same reasons as green roofs, and as already indicated, the energy conservation benefits in both summer and winter are quite impressive [20]. Internal green walls are often installed to remove volatile organic compounds and CO_2 from indoor environments (Figure 9). These walls can be integrated into the building's HVAC system so as to move cleaner air throughout the building. Although these walls do require some additional energy for lights, fans, and pumps, if they are used in such a manner as to reduce or eliminate the conventional air exchange, the summer energy savings would be quite impressive. These savings would result from the elimination of the air exchange, and the air inside the building, passing through a green wall would be somewhat cooler than the air outside the building.

FIGURE 9. The Genetron Systems "Breathing Wall"™ in the Galbraith Building, University of Toronto, Toronto, ON. This wall is modelled after a rainforest ecosystem and integrates aquatic and terrestrial ecosystems with rain-harvested, or the equivalent, water. *The Breathing Wall was installed courtesy of Tamir El-Diraby, Department of Civil Engineering and Wolfgang Amelung of Genetron Systems, Inc.*

CONCLUSIONS

There are many benefits to green roof technology, but in the private domain, green roofs do reduce the consumption of energy, particularly electricity for space cooling. The savings in the summer are achieved primarily by reducing the radiative heat flux, particularly the sensible heat flux or heat from a roof and increasing the latent heat flux, i.e., the energy bound in the molecules of water vapour due to evapotranspiration. There are a few design features that can be used to enhance the thermal performance of a green roof, for both summer and winter. It should be noted that any design features that increase winter energy savings will not have a negative impact on the summer energy savings and may even lead to further reductions in a building's cooling load. Other environmental factors can reduce or enhance the thermal performance of a green roof. These include the location and height of other buildings as well as the current and future climate of your city.

A decision to purchase a green roof should be made based on a number of benefits, although energy savings are often of high concern for an owner as it is cost that is directly borne by the owner. Categorizing energy expenditures and energy savings as a private benefit is not completely correct. If a green roof can reduce the peak demand for electricity, the widespread adoption of green roofs is also a benefit to the utility and the public if this reduction in demand reduces the likelihood of a brownout or even a blackout. And if the widespread adoption of green roofs can reduce the urban heat island, this will reduce electricity consumption for everyone and the lower temperatures could lower the severity and even the occurrence of smog episodes.

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NOTES

1. Typically, green roofs do not utilize soil, due to weight considerations. The growing media is usually composed primarily of a lightweight material, such as lava rock, and a small amount of organic material. However, the growing media of a green roof is still often referred to as soil or the soil layer.
2. Evapotranspiration will be highest under hot and dry weather conditions. Evapotranspiration will be depressed with increasing cloud and humidity.
3. Personal communication from Graig Spolek, Portland State University.
4. Most canopies to allow for some transmittance as leaf density is often not sufficient to shade the whole canopy and intercept all radiation. In addition, radiation that is not intercepted is also reflected off the surface of leaves within the canopy (Saiz 2004).
5. Longwave radiation might be emitted from the growing medium, other leaves in the canopy, or may be a downward flux from atmospheric sources.
6. White roofs have been considered to be thermally equivalent to green roofs, but more recent research suggests that they may in fact be less effective than a green roof in reducing surface temperatures (Gaffin, 2006; Saiz et al. 2006).
7. Personal communication from Wolfgang Amelung, Genetron Systems.
8. Bioclimate profiles provide a graphical interpretation of the climate change scenarios in terms of bioclimatic variables for applications in agriculture, forestry, and ecology.
9. Conditions that might inhibit evapotranspiration include high humidity, high cloud cover, drought, and limited supplementary irrigation and low wind speeds.

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