Cool Roof/Green Roof:
Benefits and Biophilia – A comparative study

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ABSTRACT

The Oregon Health Sciences University Center for Health and Healing (OHSU–CHH) in Portland, Oregon goes beyond LEED Platinum to provide exceptional environments for work, research, and healing. Among the building's green features is approximately 22,000 sq. ft. of high Solar Reflectance Index (SRI) roofs in the form of both eco-roof and cool roof systems. To investigate the effectiveness of both roof systems in mitigating heat-island effect and other sustainability related benefits, we have set-up a 2x2 quasi-experimental research design to study the performance of both roofs in a southern verses a northern orientation as well as in an accessible verses non-accessible roof conditions. This research setting ensured that design variables are studied across and between the two systems and their materials. Data analysis indicates that on average, the southern eco-roof reduces daytime temperature peaks 2.2^{o}C more than the OHSU southern cool roof. On the northern orientation both roofs are within a 0.6^{o}C temperature difference with an advantage for eco-roofs. While the northern OHSU eco-roof does not show great surface temperature variation over cool-roof, an advantage of the eco-roof is its accessibility to pedestrian traffic and its water retention properties. Specific data regarding their performance is presented, which can aid designers in specifying the right roof material strategies to fit their future design goals and inform the applications of these roof systems in commercial buildings.

1. Introduction:

The Oregon Health Sciences University Center for Health and Healing (OHSU–CHH) in Portland, Oregon goes beyond LEED Platinum to provide exceptional environments for work, research, and healing. The mixed-use building is a cutting edge example of high-performance building design. The CHH is located in Portland's transit oriented South waterfront redevelopment district. (Fig.1).

Fig. 1: OHSU-CHH location in Portland, OR

The OHSU-CHH building utilizes both eco-roof and cool roof materials in its roof design and LEED certification process. One of the building's key green design strategies features a 22,756 square foot eco-roof for stormwater management, rainwater harvesting, and temperature moderation (Fig. 2). Given the growth of LEED certified high performance building design, the effectiveness of utilizing roof systems materials and strategies, such as eco-roofs, is under tight scrutiny [1]. This study compares the performance of eco-roofs and cool-roofs surface materials heat reduction capacity. The study compared the performance of both systems for the north and south roof exposure areas of the building. (Fig. 2)

Fig. 2: OHSU-CHH North & South eco-roof and cool-roof

3. <u>Eco-roofs verses cool-roofs:</u>

City areas are warmer than suburbs or rural areas due to less vegetation and more infrastructure surface coverage that radiates heat back into the atmosphere. When a metropolitan area is significantly warmer than its surrounding rural areas, this areas experience an urban heat island effect [2] (see Fig.1). To mitigate the urban heat island effect, conventional roofing material may be replaced by a white or reflective cool roofing material with high solar reflectance and thermal emittance or an eco-roof, which consists of a layer of vegetation over a growing medium on top of a synthetic, waterproof membrane.

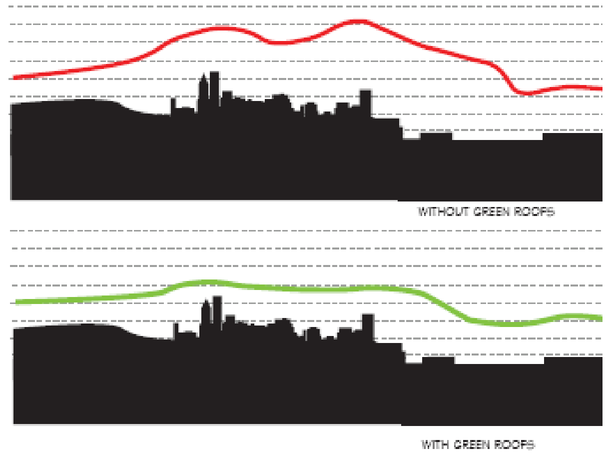

Fig. 3: Urban Heat Island Effect

Interface Engineering believes that, "In cooling a building, it's always more efficient to keep heat from ever entering than it is to flush that heat out with refrigerated air" [3, p.18]. This was one of the overarching goals intended for the OHSU-CHH building (Fig. 2). One of the strategies they used to accomplish this goal was the implementation of high Solar Reflectance Index (SRI) roofs technology in the OHSU-CHH building. Cool roof technology can be broken down into three types of systems. Those are: fluid applied coating system, single-ply roof membrane, and spray polyurethane foam. These systems have 70 percent surface reflectivity 75 percent surface emissivity and are available in a wide array of light colors [8]. These properties help reduce the cooling loads an average of 10-20 percent better than a standard 'dark roof' system [2, 8].

Another strategy for mitigating the urban heat island effect is eco-roofs. Eco-roofs are living, breathing vegetated roof systems. An eco-roof consists of a layer of vegetation over a growing medium on top of a synthetic, waterproof membrane. In addition to mitigating the urban heat island effect, an eco-roof significantly decreases stormwater runoff, saves energy, and reduces erosion. In addition to their temperature mitigation effects, eco-roofs has other sustainable advantages in absorbing carbon dioxide and acting as filters of air pollutants as well as increase habitat for birds and insects and provide much needed green space for urban dwellers [4, 5]. Installation of an eco-roof may also help a building project qualify for Leadership in Energy and Environmental Design (LEED) credits [2]. Among the barriers for market penetration of eco-roofs are their high cost compared to cool roofs, their propensity to water leaks and high maintenance schedules, as well as the need for a comparative quantification of their environmental impacts. This study aims at providing information in response to the latter market barrier and in response to a current gap in the literature regarding quantifying eco-roofs benefits.

3. Raising the Roof: A Comparative Analysis

To investigate the effectiveness of both roof systems in mitigating heat-island effect and other sustainability related benefits stated above, we have set-up a 2x2 quasi-experimental research design to study the performance of both roofs in a southern verses a northern orientation as well as in an accessible verses non-accessible roof conditions so as to vary the variables studied between the two systems. The CHH building offered an ideal setting for our research investigation due to the existence of the four different comparative scenarios stated above (Table 1 & Fig. 3).

Table1: Roof types distribution at the OHSU-CHH building

Total Roof Surface Area	22,756 sq. ft.
South Eco-roof (36%)	8,192.16 sq. ft.
South Cool Roof (32%	7,281.92 sq. ft.
North Eco-terrace (18%)	4,096.08 sq. ft.
North Terrace (14%)	3,185.84 sq. ft.

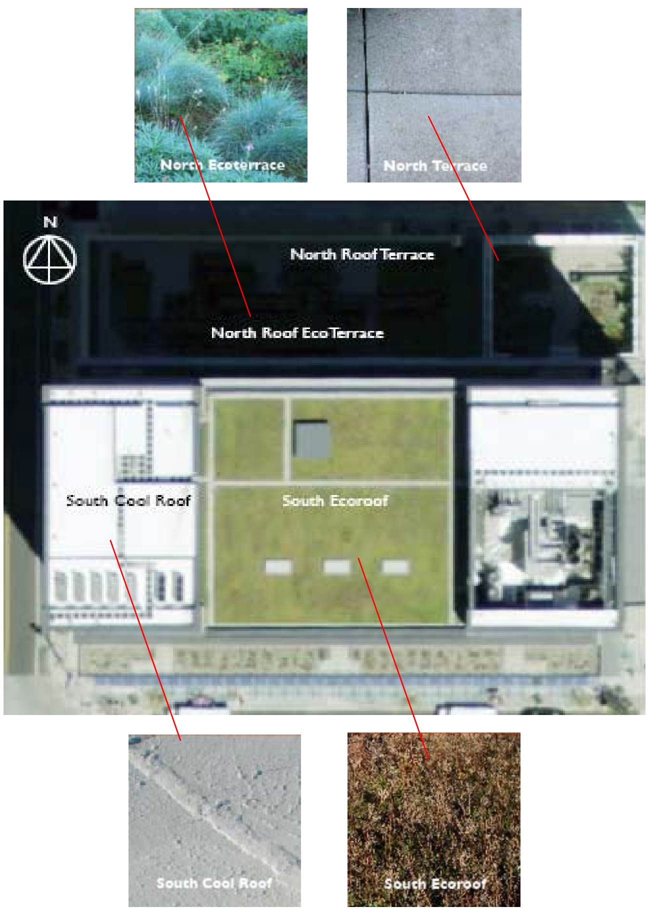

Fig. 3: Roof location for the OHSU four roof material types

The variety of roof systems employed at the CHH building offered an interesting quasi-experimental setting for our study. Due to the variation in slope compositions and layering details of both systems towards the primary drainage point, the moisture content of 20 square feet of eco-roof and cool-roof were monitored using an established grid system. The moisture content changed over a one-month period of time and these findings were mapped to determine if the roof was functioning efficiently. Furthermore, these findings may also help understand which species of plants grow best with respect to moisture content as well as pin point whether moisture content helps stimulate invasive species on green roofs (Fig. 4) [see 5].

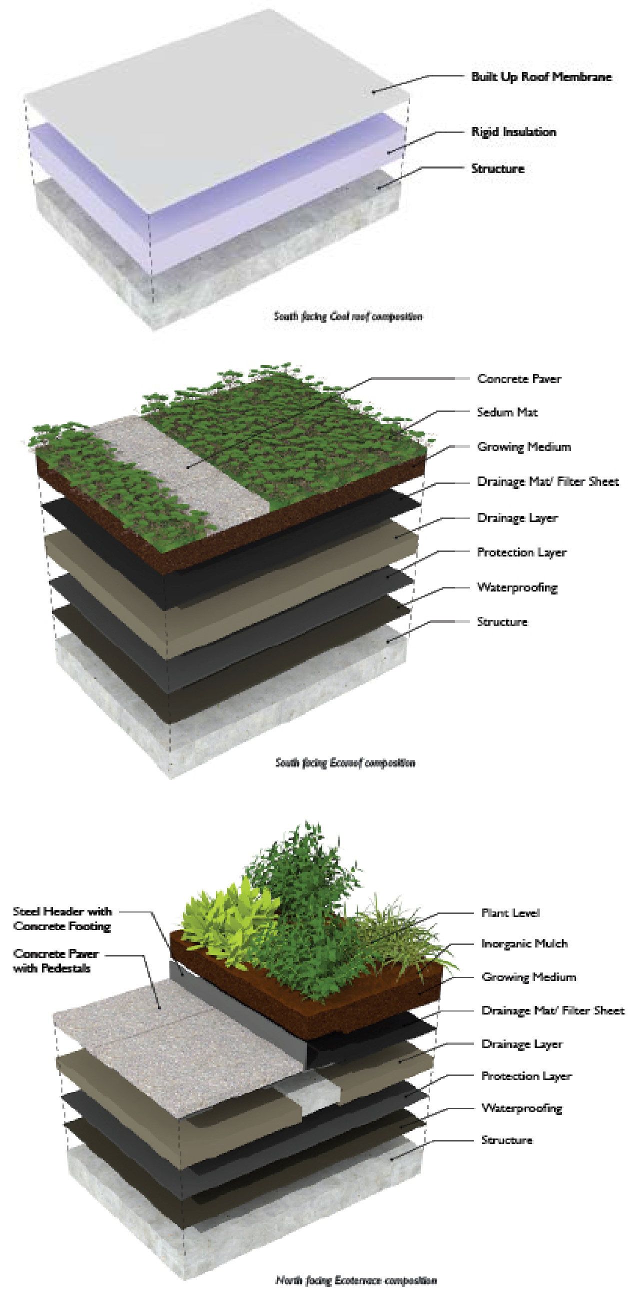

Fig. 4: Roof details and layers for the different roof systems

4. Methods and Measurements

A key aspect of a well performing green roof is the reduction of surface temperature [4, 5]. This helps deter the "heat island" effect in urban areas. Looking at the roof plan of the OSHU building, there are two distinct sections of green roofs, one upper roof with southern sun exposure and one lower roof with northern sun exposure. For our study, we measured the heat reduction capacity of the two different roof exposure areas. To begin our testing, we determined four unique roof points to collect our data: Southern eco-roof, southern cool roof , northern terrace vegetation, and northern terrace tiles (Figure 5). These points were chosen to give an accurate data reading of the surface while eliminating as many outside variables that were present on the roofing surfaces, such as shade, sun, and mechanical equipments.

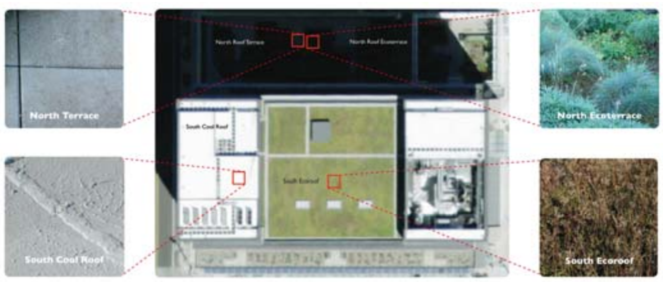

Fig. 5: Roof locations chosen for testing.

In total, our group placed seven environmental data loggers and sensors (HOBO™ U12 and U22-001). Of these instruments three were waterproof while four of them had to be protected from the weather**.** In an effort to ensure that the four non-waterproof instruments were protected, they were placed within a waterproof plastic bag. An external sensor was then attached to the data collector that extended out of the plastic bag to collect the temperature data. The external sensors were placed accordingly and fixed in place to provide accurate data throughout the testing period.

In addition to finding whether or not the green roofs aided in surface temperature moderation, we also wanted to determine the stratification that occurred within the layers of these roofs. Determining the stratification will help to establish a good understanding of the different microclimates that occur within each roofs. In order to accomplish this, a series of sensors were placed at the green roof location as well as the green terrace location (Fig. 6). On the green roof, a sensor was placed on the surface of the growing medium under the canopy of the sedum and a sensor was then placed an inch within the growing medium (Fig. 6). At the green terrace location, a sensor was placed on the surface of the growing medium underneath the vegetation canopy and a sensor was placed an inch into the growing medium. Additionally, a sensor was placed approximately eighteen inches above the surface in the vegetation canopy (Fig. 6 & 7).

The data collectors were programmed to collect temperature readings every fifteen minutes and remain at their respected locations for eleven days. They were periodically checked to ensure that they are functioning properly in-place. Upon the completion of the eleven days the data was compiled for comparisons between the effectiveness of the upper green roof and the green terrace to mitigate surface temperatures. The green roof was compared to the data from the cool roof surface and the green terrace was compared to the patio stone surface.

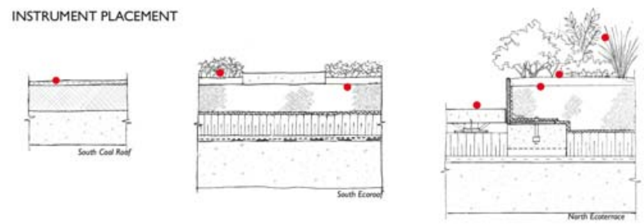

Fig. 6: Seven data locations chosen for testing

Fig. 7: Setup for the eco-roof (left) and eco-terrace (right)

5. Green Roofs Advantages Over Cool Roofs

In addition to mitigating the urban heat island effect, green roofs have excellent insulative properties, which help moderate the heating and cooling loads on a building [1]. This may lead to lower heating and cooling utility bills. Focusing on the highs over the 11 day period, our data shows that the green eco-roof surface averaged 2.2 degrees Celsius lower during the day than the cool roof surface. When comparing the performance on the low night temperature over the 11 day period, the green eco-roof surface averaged 0.6 degrees Celsius higher during the night than the cool roof surface (Fig. 8).

Temperature fluctuations on the south roofs were much more dramatic than the north roofs. Over the 11 day period, the average surface temperature fluctuation of the eco-terrace was 25% less than the south-exposed eco-roof surface. Focusing on the highs over the 11 day period, the green vegetation in the eco-terrace surface averaged 0.6 degrees Celsius lower during the day than the cool tile surface of the terrace. When comparing the low night temperatures over the 11 day period, the vegetated eco-terrace plantings averaged 1.1 degrees Celsius higher during the night than the cool tile surface (Fig. 9).

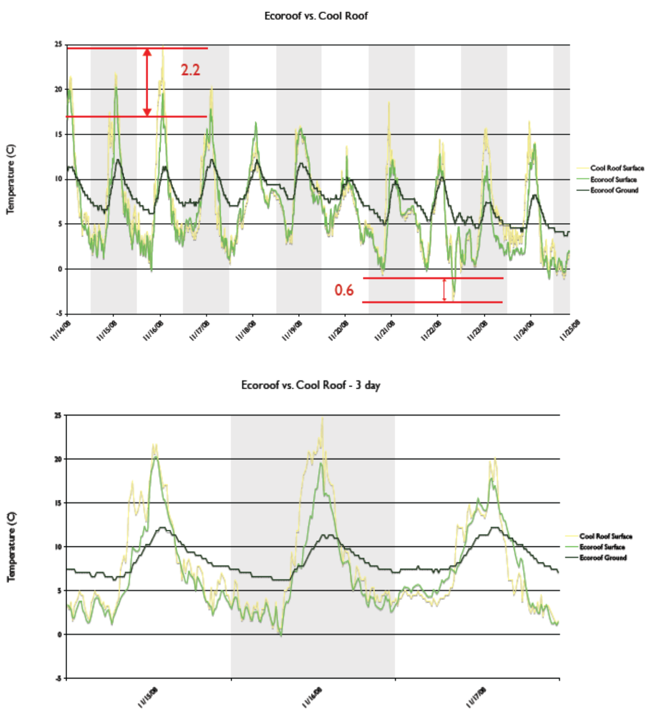

Fig. 8: Temperature data comparing the southern eco-roofs and cool roofs performance

Unlike cool roofs, the vegetative surface area of green eco-roofs also absorbs carbon dioxide and filters air pollutants. This can lead to an improvement in the ambient air quality of the surrounding areas. Depending on the composition of the vegetative roof system and its surface area, green and eco-roofs may significantly decrease stormwater runoff during normal and peak events [5]. Based on local city codes, decreasing stormwater runoff may lower fines incurred from large runoff events. In addition, green roofs increase habitat for birds and insects and provide much needed green-space for urban dwellers [4].

Green and eco-roofs can be employed for both visual and physical accessibility, which can offer an important aesthetic appeal or biophilic attraction. This aesthetic appeal can lead to an increase in property value and the marketability of the building as a whole [2]. Our preliminary post occupancy evaluation assessment of the building occupants corroborates this finding based on questionnaires and interviews of the building employees. While not widely tested, green eco-roofs may also offer acoustic insulation depending on the composition of the living substrate [6]. In some cities, they have been successfully employed for food production [4].

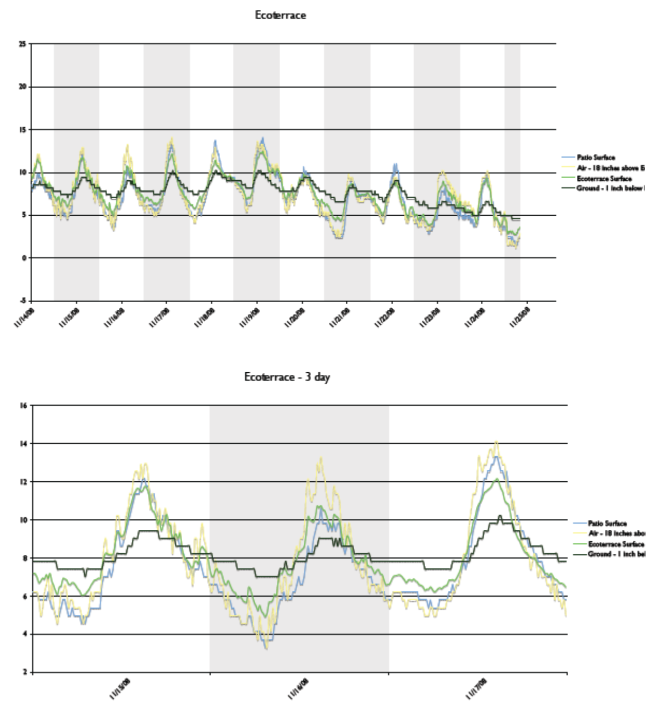

Fig. 9: Temperature data comparing the northern eco-terrace and cool tiles for the terraces

6. Cool Roofs Advantage Over Green Roofs

The biggest advantage a cool roof system has over green roofing systems is its ease of installation. Whether it is a fluid applied coating system, single-ply roof membrane, or spray polyurethane foam, the installation of cool roofs can be applied to most commercial and residential buildings with low slope roofs relatively painlessly. In the case of OHSU-CHH, the single ply roof membrane was rolled out like a carpet and mechanically attached and sealed [3]. The cost of installation of a cool roof is very dependent upon the type of system that is being used. Fluid applied coating systems, whether water based or not, are cheaper at first cost but need to be replaced more frequently. The single-ply and spray polyurethane foam roof systems are considered high performance materials because they do not need to be replaced as often and can handle more wear and tear. Furthermore, the spray-on foam systems adds R-value to the roof so long as they use 90-93 closed cell foam. The bottom line is that no matter which system is used, the average cost of a cool roof system is about $0.50-$1.50/sq. ft. while a green roof costs in average $4-$8 per square foot [2, 7, 8]. These figures do not consider the upkeep charges of green roofs such as irrigation, pruning, and maintenance.

In our quasi-experimental analysis cool roof technology variables were easier to measure and quantify over eco-roofs. We found within our study that a green roof has too many variables to consider when testing its thermal performance outside a controlled experimental chamber. With about 20 years of industry testing, cool roofs have been proven to be very effective and are already adopted by some states as a way for new commercial buildings to help mitigate the urban heat island effect in their cities. (see California's Title 24 amendments 2006 [9]).

7. Conclusions: Shades of Green

To evaluate the effectiveness of roof materials in mitigating urban heat island effects, a designer needs to establish clear performance goals prior to the design and installation. If the goal is to reduce urban heat island effect, south facing eco-roofs are most successful at mitigating daytime temperature peaks. Data analysis indicates that on average, the OHSU-CHH southern eco-roof reduces daytime temperature peaks 2.2 degrees Celsius more than the OHSU southern cool roof. While the OHSU southern eco-roof mitigates the urban heat island effect and provides rainwater retention, a major disadvantage of this type of eco-roof is its inaccessibility to building occupants and its lack of visibility from most locations in the city.

Northern protected eco-roofs are not as successful at mitigating daytime temperature peaks. Data analysis indicates that on average, the OHSU northern eco-roof reduces daytime temperature peaks by 0.6 degrees Celsius more than the OHSU northern cool roof patio. Given the cost effectiveness and ease of operation and maintenance of cool roof systems, they might offer a better solution in northern exposed roof surfaces. While the northern OHSU eco-roof does not greatly mitigate the urban heat island effect, an advantage of this roof at OHSU is its accessibility to pedestrian traffic for employees and patients as well as its water retention properties. We hope this information can aid building designers and facility managers in specifying the right roof system and strategies to fit their intended design and building use goals.

8. REFERENCES

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NOTE: All sections and detail drawings appear courtesy of GBD architects, Portland, Oregon.