Green Design and Construction: An Example—Commercial "Green" Roofs

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Abstract

"Green" design and construction refers to architectural design and construction practices that take into consideration a number of issues related to the environment, including, but not limited to, energy savings in heating and cooling, environmentally friendly construction materials, wastewater, and placement on site. Despite the fact that only 3 % of new buildings in the U.S.A. have some environmentally friendly features, there is an ever-increasing interest in "green" design and construction. This manifests itself in paying special attention to energy conservation both in the production of materials used in buildings, as well as, energy conservation during functioning of the building. Thus the need to look at different building components with new and enhanced criteria. The guiding principle in such undertakings has been consideration and development of "green" solutions/alternatives for diverse building components/parts that: have fewer adverse ecological consequences, enhance the aesthetic appearance, are cost competitive, and are economically feasible when compared with traditional methods.

This paper focuses on applying this approach in the analysis of one of the most important components of a building: the roof. Commercial green roofs were the area of focus of a study (1) within the context of a "green" design course at IUPUI and this study forms the basis of this paper. Even though green roofs have found extensive applications in Europe, the concept and the technique has not made its way into the U.S.A. in a way to be noticed. Within the context of this paper a basic treatise is provided on "green roofs" in terms of what they are, the types, special properties, and construction details, both in text and visual terms. A comparison is then provided between EPDM roofs, white roofs, and green roof systems. This comparison entails comparing not only of useful lives, maintenance requirements, insulation and reflective properties, but also, comparisons based on life-cycle cost and pay-back analysis.

Introduction

In 1830, the world population was 1 billion; today, a staggering 6 billion people inhabit the globe. The "population bomb" has and will continue to affect global, national and local conditions in terms of economy, environmental resources, waste, and living standards. The United States, alone, is home to 284 million people, the majority of which reside in metropolitan areas. The homes, jobs and vehicles of 228 million urban dwellers concentrated in relatively small areas have significantly impacted national mineral, oil, and groundwater reserves. With the expectation of a billion new births in the next ten years, the ability to maintain adequate natural resources has become more critical (8).

Unfortunately, there is no elixir; however, careful planning and responsible use of both renewable and non-renewable resources can enable citizens to function and thrive in the coming decades. "Green" design includes, but is not limited to addressing the challenges of metropolitan development such as water quality, erosion control, energy conservation, waste disposal, and storm water drainage with environmentally friendly architectural and construction practices. Traditional roofing and paving methods often intensify environmental problems.

Types of Commercial Roof Construction – Advantages & Disadvantages

Fundamentally, roofs reduce the effects of natural elements including water, wind, and temperature fluctuation on interior spaces. A good roof must last for decades, should require minimal maintenance, and can be installed and maintained at reasonable cost. Among other things, the factors that shorten and limit the useful lifetime of a roof include, but are not limited to, membrane degradation due to ultraviolet (UV) radiation from the sun, freeze-thaw cycles, wind, rain, damage from foot traffic, biological growth, chemical reactions with air-pollutants, thermal expansion stresses due to temperature fluctuations, and poor installation (13).

i. EPDM Roofs:

Typically, EPDM roofs, and more recently, white roofs provide very economical waterproofing solutions for commercial structures. EPDM refers to a single-ply roof system composed mainly of an ethylene propylene diene monomer. The monomer demonstrates the characteristics of a lightweight "rubber," black in color, highly resistant to tear, and able to stretch. Overlying insulation, the combination creates a simple, flexible system able to meet waterproofing and thermal needs of the building. Appropriate insulation material and thickness prevent heat infiltration through the roof. Manufacturers may offer insulation options including cellulisic or glass fiber mats in one to four inch thickness. The construction methods differ with regard to attachment to the decking surface, depending on roof decking materials. Both the insulation and membrane may be nailed, adhered with bituminous-based bonding agents, or loose laid with ballast, to resist wind uplift forces. Fig.1 shows a typical EPDM roof section.

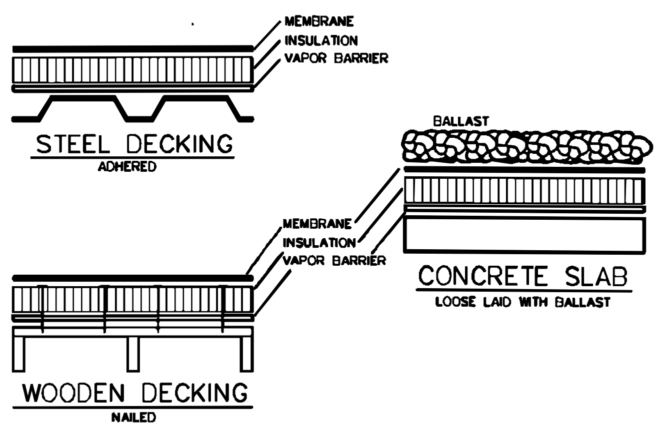

Fig. 1. Typical EPDM Attachment Sections

The advantages of choosing an EPDM roof rely on initial cost savings. A very simple system, with few main components, labor and materials, costs are very economical. Flexible characteristics and attachment options also allow for application to a various decking types and surface irregularities, and therefore, a broader range of architectural structures. Moreover, the resiliency of the membrane lends to low-maintenance operation and simple repairs.

However, the material characteristics also create disadvantages under long-term analysis. The black color of the membrane causes the majority of interacting ultra-violet (UV) light rays to be absorbed. The effects of UV exposure are detrimental to the membrane and, consequently, to the efficiency of the building's internal cooling system. Absorbing, instead of reflecting, most of the UV radiation causes the membrane to deteriorate beyond usefulness within about 15 years. As a result, the heat transferred into the insulation causes deterioration, affecting the cooling load necessary to maintain comfortable temperatures within the building. Overall, long-term costs include several entire system replacements during the life of the structure and increased operation costs for the heating, ventilation and air-conditioning (HVAC).

ii. "White" Roofs:

As an alternative, white roofs offer a product which functions like an EPDM, but without the disadvantages resulting from a high "albedo" surface, where, albedo is a function of solar reflectivity of the surface and is expressed as the ratio of solar energy absorbed by the surface as a ratio of the incipient energy. White roofs, although generally white, are also available in other colors. Chemical additives enable the membrane to resist the effects of UV rays. Applied by the manufacturer as a coating, ultraviolet light stabilizers absorb the rays but dissipate them throughout the coating to harmless intensity. Although initial costs are approximately 20% greater per square foot, building managers profit from reduced cooling load requirements and an extended product life expectancy of approximately 25 years. A typical "white" roof is shown in Fig 2.

Source: Sarnafil, Inc.

Fig. 2. A White Roof Application

iii. "Green" Roofs – Why Green Roofs ?

Both EPDM and white roofs cause problems by creating an impermeable surface even though this is supposed to be the inherent function of a roof. In order to fully realize the benefits alternative roof systems can offer, several urban environmental problems must be understood, in particular, storm-water management and urban heat islands.

Storm water management systems dealing with design capacity of water and sewer lines versus current demands and water treatment capabilities, are a serious challenge for city planners and engineers. Over 400 metropolitan areas in the U.S. rely on combined sewage overflow systems. The systems are designed to overflow raw sewage, rainwater, and wastewater into rivers and streams once conveying systems reach a maximum capacity. Many of these systems overflow several times a month, and currently many states are reviewing plans to either replace or revise systems. Urban sprawl has substantially increased runoff rates due to impermeable surfaces such as roofs, streets, roads, driveways, parking lots, etc. Metropolitan areas with sufficient storm-water capacity also suffer from poor water quality, due to the reduction in the land area able to filter runoff through natural vegetation.

In addition, urban heat islands cause uncomfortable conditions and increased cooling loads on surrounding structures in city and suburban areas. An urban heat island is a volume of space experiencing higher than normal temperatures due to radiant heat. High albedo surfaces such as dark pavement, and reflective surfaces on buildings contribute to heat islands by reflecting light rays back into the surrounding air space. Inner city temperatures at walking level can escalate to ten degrees higher than surrounding areas. Commercially developed areas and industrial park also produce temperatures 3-4 degrees higher. Aside from affecting pedestrian comfort adversely, urban heat islands increase building cooling loads (2,5). Figure 3 below depicts the urban heat island concept.

According to U.S. Environmental Protection Agency (EPA), about $ 40 billion is spent in the U.S for air-conditioning of buildings, which consumes about 1/6th of all electricity production annually. EPA statistics show that when used appropriately, a reflective roof can decrease cooling demand by 10 - 15 % and increase cooling energy savings by 50 % (13).

Green roofs, composed of vegetation and engineered soils, are able to combat urban environmental problems, while improving aesthetic appearances of existing or new structures. Enhancing the functions of traditional roof systems, they provide many environmental benefits. The two types of vegetated roofs available are “intensive” and “extensive.” Intensive green roofs, also referred to as rooftop gardens, consist of several feet of soil and cultivation of a wide range of vegetation, including trees and shrubs. Due to substantially higher material and maintenance costs, increased structural stresses and increased risk of leakage, intensive green roofs are beyond the scope of this paper. “Extensive” green roofs are similar multi-layered systems consisting of several inches of soil designed to support low-growing vegetation (3,4). Karen Liu (6) states that “green roof” is not a new concept and can be traced to the Hanging Gardens of Babylon – one of the Seven Wonders of the World.

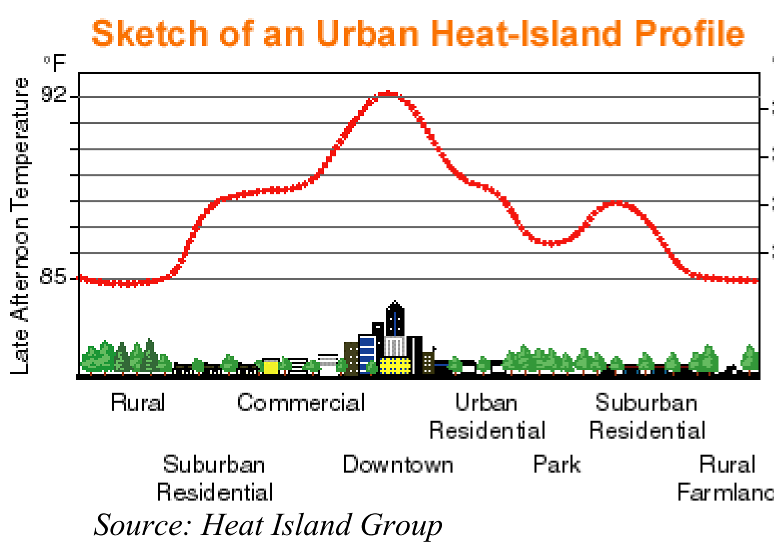

Fig. 3. Urban Heat Island concept illustration (2)

The base for a green roof is a single-ply membrane installed above the decking surface and insulation, as needed. A protective fabric is then placed over the membrane to prevent root infiltration. Above the root barrier is a specially sieved soil or small aggregate which functions as a drain medium and water storage. A range of humidity can be maintained within the drain medium, promoting plant growth and dissipating heat. A filter fabric over the drain medium retains finer engineered soil placed above. The growth substrate may be from 3"- 6" depending on the desire plant species, climate, and desired thermal characteristics. A typical section is shown in Fig. 4. below. Vegetation can then be installed either in the form of pre-vegetated blankets, machine-placed, or hand planted. Choice of plant types ranges from mosses and wildflowers to prairie grasses and may be planned to provide multi-seasonal blooms (See Figure 5).
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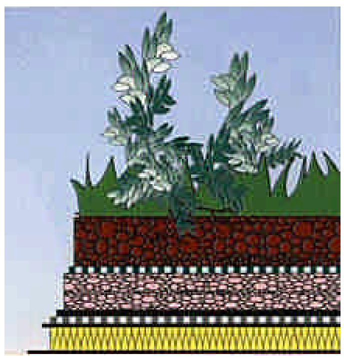

Source: Roofscapes, Inc.

Fig. 4. Cross-section of a green roof. (11)

Source: Optima

Fig. 5. An "extensive" green roof with skylight. (3,4)

The primary functioning components of the system, the soil and vegetation, provide a system that is "effective and ecologically beneficial," according to the U.S. Corps of Engineers (14). The vegetation first absorbs heat, light, and carbon dioxide, while releasing oxygen back into the atmosphere, reducing the effects of urban heat islands. Chosen to withstand high wind forces, the plants also collect dust particulates from the air. With shading abilities greater than 100% tree shade, the effects of heat and light on the roof are significantly reduced. Studies conducted in Canada (6) showed an extensive green roof maintained approximately 77degrees Fahrenheit on a 95 degree day, while the control roof, a dark membrane surface, reached 158 degrees. The life of the membrane can be extended to more than forty years if protected from ultraviolet rays and extreme temperature fluctuations. The soil in the green roof cross-section acts in several ways to promote ecological balance. Runoff can be significantly, if not completely, reduced. It is claimed that 50~70 % of the storm-water runoff captured is retained (13) in addition to delaying of the runoff into the sewer/storm-water system The high infiltration soils and drain medium provide detention for water until it can either be used by plants, transferred to gray-water storage, or released to storm sewers. Acid rain, concentrated in urban areas, can also be filtered through the soil.

The greatest financial benefit to the building operator results from the natural thermal characteristics of the soil. Soil consists contains water, air, organics, and particles. Air and water within the soil, as well as natural mineral characteristics, enable it to function as a thermal mass, or a temperature differential between outside conditions and the temperature within the drain medium. In winter, warmth is prevented from escaping through the roof as the soil layer acts as additional insulation, even if no vegetation is present. In summer, humidity within the soil and shading, keep soil and roofing materials cool. Over the life of the green roof system, significantly reduced heating and cooling loads result in measurable savings (6,7,8, 9).

Two primary challenges accompany green roof systems. Misconceptions about the basic structure and leaking issues, and high initial cost prevent green roofs from achieving the same popularity seen in Europe. Leaks are generally the result of poor workmanship during installation. Extensive plants have spreading or short root systems to prevent root penetration, but can grow through areas sensitive to root infiltration, such as flashings and seams. Special care should also be taken to protect the membrane from puncture during installation. Many manufacturers offer leak prevention by providing initial and/or annual electric field vector mapping, or EFVM, to locate holes. Leaks can then by repaired by removing a section of substrate, sealing the membrane and replacing section materials (10, 11).

Comparing Commercial Roofs

Initial cost of traditional roofing systems in terms of EPDM and white roofs range between 2~4 $/sq.ft. Green roofs, on the other hand, generally run between 15~20 $/sq.ft (13). Consequently, it is difficult to justify green roofs on an "initial cost" basis. Due to the significant differences in total useful life and savings in energy costs throughout the life of the roof, cost comparisons between roof systems must be done on a life-cycle cost basis. A study (1) was done at the Indiana University-Purdue University Indianapolis (IUPUI) Campus in Indianapolis comparing long-term costs, and payback for a campus building, comparing EPDM, white and extensive green roofs. This study, carried out for the building shown in Fig. 6 below and details included in the Appendix, has concluded that even before considering state and federal incentives and tax rebates provided for green roofs due to their extensive advantages-some monetarily quantifiable and some not- green roof comes out ahead in terms of life-cycle cost per square feet and economic feasibility.

This finding and similar findings are increasingly widely known and accepted and new building projects meeting certain Leadership in Energy and Environmental Design (LEED) requirements are given tax credits. LEED is the green building rating system of the Washington D.C based U.S. Green Building Council (USGBC). LEED evaluates environmental performance from a "whole building" perspective over a building's life-cycle (7, 12). According to Yudelson (15), several hundred buildings have been registered for LEED certification and so far 20 projects have received certification representing about 6 % of the total commercial and institutional buildings in 2001. It is expected that a comprehensive energy strategy could save $ 100 billion annually in energy bills for buildings by doubling energy efficiency and cut the carbon emissions in half in the process (7). Awareness of local and federal programs will assist building operators and owners to maximize their savings. Federal and state governments also promote green design. The EnergyStar program, funded by the Department of Energy (DOE), provides initiatives for buildings displaying efficient technologies like green roofs. In addition, many cities, including Seattle, Chicago and New York offer incentives and tax breaks for implementing environmental practices.

Fig. 6. Engineering and Technology Building, Indiana University- Purdue University, Indianapolis

"The benefits for building and business owners can be seen financially through greater energy efficiency," says Christopher Ostrowski in the Midwest Construction Magazine (7). Many roof systems today are very economical, but wear out or leak in a short period of time. Costs associated with green roofs are primarily the initial investment as a result of extensive planning, more materials, and more labor. However, in the future, materials and labor costs will recede as demand increases. Although common in Europe, green roofs represent a new technology for the U.S. With fewer local designers and manufacturers, and low demand, costs can be prohibitive if long-term energy saving goals are not considered. Other means of improving financial feasibility are available depending on local legislation and policy. For new structures, municipal charges for waste/storm water, based on square footage of sealed areas, may be reduced. Throughout the life of the structure, reduced cooling loads will result in reduces overall energy costs. Furthermore, extensive green roofs require little maintenance and last forty or more years before major replacement is necessary.

Conclusions

The main conclusions of the study referred to above and that of this resulting paper are that not only do green roofs provide advantages that none of the traditional ones do but they are very cost competitive with traditional methods in terms of a life-cycle costs analysis. Advantages of green roofs can be summarized as follows;

a. Protecting of roof membranes from UV degradation and hail damage.
b. Reducing the energy demand of HVAC systems through direct shading, evapo-transpiration, improved insulation values, and decreased temperature fluctuations as a result of substantial thermal mass.
c. Reducing and/or elimination of the urban heat island effects.
d. Functioning as part of the storm-water management strategy through water retainage and delaying of runoff into the sewer/storm-water system.
e. Filtering out of airborne pollutants washed off by rain and thus improving quality of runoff.
f. Improving air quality, providing additional green space of high esthetic value in urban areas and thus increasing property values.

g. Decreasing of hazardous greenhouse gases.
h. Increasing of employee productivity and provision of a healthier work environment.
i. Reducing the premium on green products as a result of more extensive use of green products.
j. Enhancing cost effectiveness in terms of building and maintaining in the long run.

It is common knowledge that construction education curricula that deal with roofs and roof construction rarely cover green roofs in detail, if at all. It is hoped that papers of this nature will provide a motivation for publishers to be aware of green issues and encourage authors to include such developments in their text for a more broad and meaningful coverage of the green alternatives in design and construction.

Another conclusion is that we may be short-changing our construction-management-careers-bound students in terms of not providing enough of a perspective on what the future holds so that they are more cognizant of the "green" alternatives in their undertakings and that they help to promote the green cause. "With improved education regarding the nature of sustainable projects, and their true costs and operational requirements, people will see it is not difficult to create sustainable buildings" conclude John Hennessey, CEO of Syska Hennessy Group, as quoted in Consulting Specifying Engineer (12). With this in mind, consideration should be given as to the role of colleges and educators in associated areas.

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Biography

1 **Erdogan M. Sener.,** Professor and Chairman at the Department. of Construction Technology of Purdue School of Engineering & Technology at IUPUI. B.S. Civil Eng., Middle East Technical University; M.S. Civil Eng. Michigan State University. He has over 13 years of international industrial experience in design and construction and has been in engineering and technology education for more than 19 years. Member of ASCE, ASEE, ACI and is a registered Professional Engineer in Indiana. Prof. Sener was awarded numerous teaching awards including the Indiana University President's Award for Distinguished Teaching in 1993 and the IUPUI Chancellor's Award for Excellence in Teaching in 1994.

2 **Paula Baty**., Senior standing student, Department of Construction Technology, Construction Management Bachelor of Science Program, Purdue School of Engineering and Technology at IUPUI. Member of Construction Specifications Institute (CSI), and Society of Student Constructors (SSC). Currently employed as an Engineer Student Trainee with the USDA, Natural Resource Conservation Service.

APPENDIX

EVALUATION OF ENVELOPE RESEARCH STUDY
SECTION: HEATING AND COOLING LOAD ANALYSIS AND COMPARISON

Roof Area: **30,451 sq.ft.**

	Black	White	Green
Inside Surface	0.61	0.61	0.61
Metal Lath/Sand Agg. Plaster	0.13	0.13	0.13
Structural Beam	0.00	0.00	0.00
Non-reflective Air Space	0.93	0.93	0.93
Metal Deck	0.00	0.00	0.00
4" Structural Slab*	0.32	0.32	0.32
Sarnatherm Roof Insulation, 2"	14.30	14.30	14.30
Roof Membrane/Substrate	0.00	0.00	5.00
Outside Surface	0.17	0.17	0.17
Total R-Value	16.46	16.46	21.46
U-Value	0.061	0.061	0.047

*Heavyweight Concrete U=0.08 per inch

Assumptions:

Applicable to 40 degree North Latitude only
85 degree outdoor mean temperature
78 degree Indoor Temperature
Daily range of 21 degrees
Attic with positive ventilation
Suspended Ceiling

k=color adjustment factor   k (white) = 0.5
f=attic adjustment factor   k (black) = 1.0
M=Month Correction Factor
CLTD = Cooling Load Temperature Difference
T= Indoor temperature correction

Month	Correction Factors*	Days per Month
January	19	31
February	-14	28
March	-8	31
April	-3	30
May	1	31
June	2	30
July	1	31
August	-3	31
September	-8	30
October	-14	31
November	19	30
December	21	31

*Ashrae Table 3.11

Due to insufficient research data, a color adjustment factor has not been specifically designated for the green roof. Although the roof surface, shaded by vegetation will experience significantly less effects from light raysthan a white roof, being nearly or completely shaded during summer months, a k factor of 0.5 was assigned for the purposes of this preliminary analysis.

$CLTD_{corr}$ = [(CLTD + M) x k + (78 - T) + (85)] x f = [Btu/hour]

		Hour	CLTD	$CLTD_{corr}$
January		1	30	156.75
M	19	2	29	156.00
k	1	3	27	154.50
T	3	4	26	153.75
f	0.75	5	24	152.25
		6	22	150.75
		7	21	150.00
		8	20	149.25
		9	20	149.25
		10	21	150.00
		11	22	150.75
		12	24	152.25
		13	27	154.50
		14	29	156.00
		15	32	158.25
		16	34	159.75
		17	36	161.25
		18	38	162.75
		19	38	162.75
		20	38	162.75
		21	37	162.00
		22	36	161.25
		23	34	159.75
		24	33	159.00
			Daily	3746
			Monthly	116111

		Hour	CLTD	$CLTD_{corr}$
February		1	30	132.00
M	-14	2	29	131.25
k	1	3	27	129.75
T	3	4	26	129.00
f	0.75	5	24	127.50
		6	22	126.00
		7	21	125.25
		8	20	124.50
		9	20	124.50
		10	21	125.25
		11	22	126.00
		12	24	127.50
		13	27	129.75
		14	29	131.25
		15	32	133.50
		16	34	135.00
		17	36	136.50
		18	38	138.00
		19	38	138.00
		20	38	138.00
		21	37	137.25
		22	36	136.50
		23	34	135.00
		24	33	134.25
			Daily	3152
			Monthly	88242

		Hour	CLTD	$CLTD_{corr}$
March		1	30	136.50
M	-8	2	29	135.75
k	1	3	27	134.25
T	3	4	26	133.50
f	0.75	5	24	132.00
		6	22	130.50
		7	21	129.75
		8	20	129.00
		9	20	129.00
		10	21	129.75
		11	22	130.50
		12	24	132.00
		13	27	134.25
		14	29	135.75
		15	32	138.00
		16	34	139.50
		17	36	141.00
		18	38	142.50
		19	38	142.50
		20	38	142.50
		21	37	141.75
		22	36	141.00
		23	34	139.50
		24	33	138.75
			Daily	3260
			Monthly	101045

		Hour	CLTD	$CLTD_{corr}$
July		1	30	143.25
M	1	2	29	142.50
k	1	3	27	141.00
T	3	4	26	140.25
f	0.75	5	24	138.75
		6	22	137.25
		7	21	136.50
		8	20	135.75
		9	20	135.75
		10	21	136.50
		11	22	137.25
		12	24	138.75
		13	27	141.00
		14	29	142.50
		15	32	144.75
		16	34	146.25
		17	36	147.75
		18	38	149.25
		19	38	149.25
		20	38	149.25
		21	37	148.50
		22	36	147.75
		23	34	146.25
		24	33	145.50
			Daily	3422
			Monthly	106067

		Hour	CLTD	$CLTD_{corr}$
August		1	30	140.25
M	-3	2	29	139.50
k	1	3	27	138.00
T	3	4	26	137.25
f	0.75	5	24	135.75
		6	22	134.25
		7	21	133.50
		8	20	132.75
		9	20	132.75
		10	21	133.50
		11	22	134.25
		12	24	135.75
		13	27	138.00
		14	29	139.50
		15	32	141.75
		16	34	143.25
		17	36	144.75
		18	38	146.25
		19	38	146.25
		20	38	146.25
		21	37	145.50
		22	36	144.75
		23	34	143.25
		24	33	142.50
			Daily	3350
			Monthly	103835

		Hour	CLTD	$CLTD_{corr}$
September		1	30	136.50
M	-8	2	29	135.75
k	1	3	27	134.25
T	3	4	26	133.50
f	0.75	5	24	132.00
		6	22	130.50
		7	21	129.75
		8	20	129.00
		9	20	129.00
		10	21	129.75
		11	22	130.50
		12	24	132.00
		13	27	134.25
		14	29	135.75
		15	32	138.00
		16	34	139.50
		17	36	141.00
		18	38	142.50
		19	38	142.50
		20	38	142.50
		21	37	141.75
		22	36	141.00
		23	34	139.50
		24	33	138.75
			Daily	3260
			Monthly	97785

$CLTD_{corr}$ = [(CLTD + M) x k + (78 - T) + (85)] x f = [Btu/hour]

April		Hour	CLTD	$CLTD_{corr}$
		1	30	140.25
M	-3	2	29	139.50
k	1	3	27	138.00
T	3	4	26	137.25
f	0.75	5	24	135.75
		6	22	134.25
		7	21	133.50
		8	20	132.75
		9	20	132.75
		10	21	133.50
		11	22	134.25
		12	24	135.75
		13	27	138.00
		14	29	139.50
		15	32	141.75
		16	34	143.25
		17	36	144.75
		18	38	146.25
		19	38	146.25
		20	38	146.25
		21	37	145.50
		22	36	144.75
		23	34	143.25
		24	33	142.50
			Daily	3350
			Monthly	100485

May		Hour	CLTD	$CLTD_{corr}$
		1	30	143.25
M	1	2	29	142.50
k	1	3	27	141.00
T	3	4	26	140.25
f	0.75	5	24	138.75
		6	22	137.25
		7	21	136.50
		8	20	135.75
		9	20	135.75
		10	21	136.50
		11	22	137.25
		12	24	138.75
		13	27	141.00
		14	29	142.50
		15	32	144.75
		16	34	146.25
		17	36	147.75
		18	38	149.25
		19	38	149.25
		20	38	149.25
		21	37	148.50
		22	36	147.75
		23	34	146.25
		24	33	145.50
			Daily	3422
			Monthly	106067

June		Hour	CLTD	$CLTD_{corr}$
		1	30	144.00
M	2	2	29	143.25
k	1	3	27	141.75
T	3	4	26	141.00
f	0.75	5	24	139.50
		6	22	138.00
		7	21	137.25
		8	20	136.50
		9	20	136.50
		10	21	137.25
		11	22	138.00
		12	24	139.50
		13	27	141.75
		14	29	143.25
		15	32	145.50
		16	34	147.00
		17	36	148.50
		18	38	150.00
		19	38	150.00
		20	38	150.00
		21	37	149.25
		22	36	148.50
		23	34	147.00
		24	33	146.25
			Daily	3440
			Monthly	103185

October		Hour	CLTD	$CLTD_{corr}$
		1	30	132.00
M	-14	2	29	131.25
k	1	3	27	129.75
T	3	4	26	129.00
f	0.75	5	24	127.50
		6	22	126.00
		7	21	125.25
		8	20	124.50
		9	20	124.50
		10	21	125.25
		11	22	126.00
		12	24	127.50
		13	27	129.75
		14	29	131.25
		15	32	133.50
		16	34	135.00
		17	36	136.50
		18	38	138.00
		19	38	138.00
		20	38	138.00
		21	37	137.25
		22	36	136.50
		23	34	135.00
		24	33	134.25
			Daily	3152
			Monthly	97697

November		Hour	CLTD	$CLTD_{corr}$
		1	30	156.75
M	19	2	29	156.00
k	1	3	27	154.50
T	3	4	26	153.75
f	0.75	5	24	152.25
		6	22	150.75
		7	21	150.00
		8	20	149.25
		9	20	149.25
		10	21	150.00
		11	22	150.75
		12	24	152.25
		13	27	154.50
		14	29	156.00
		15	32	158.25
		16	34	159.75
		17	36	161.25
		18	38	162.75
		19	38	162.75
		20	38	162.75
		21	37	162.00
		22	36	161.25
		23	34	159.75
		24	33	159.00
			Daily	3746
			Monthly	112365

December		Hour	CLTD	$CLTD_{corr}$
		1	30	158.25
M	21	2	29	157.50
k	1	3	27	156.00
T	3	4	26	155.25
f	0.75	5	24	153.75
		6	22	152.25
		7	21	151.50
		8	20	150.75
		9	20	150.75
		10	21	151.50
		11	22	152.25
		12	24	153.75
		13	27	156.00
		14	29	157.50
		15	32	159.75
		16	34	161.25
		17	36	162.75
		18	38	164.25
		19	38	164.25
		20	38	164.25
		21	37	163.50
		22	36	162.75
		23	34	161.25
		24	33	160.50
			Daily	3782
			Monthly	117227

$CLTD_{corr}$ = [(CLTD + M) x k + (78 - T) + (85)] x f = [Btu/hour]

		Hour	CLTD	$CLTD_{corr}$
	January	1	30	138.38
M	19	2	29	138.00
k	0.5	3	27	137.25
T	3	4	26	136.88
f	0.75	5	24	136.13
		6	22	135.38
		7	21	135.00
		8	20	134.63
		9	20	134.63
		10	21	135.00
		11	22	135.38
		12	24	136.13
		13	27	137.25
		14	29	138.00
		15	32	139.13
		16	34	139.88
		17	36	140.63
		18	38	141.38
		19	38	141.38
		20	38	141.38
		21	37	141.00
		22	36	140.63
		23	34	139.88
		24	33	139.50
			Daily	3313
			Monthly	102695

		Hour	CLTD	$CLTD_{corr}$
	February	1	30	126.00
M	-14	2	29	125.63
k	0.5	3	27	124.88
T	3	4	26	124.50
f	0.75	5	24	123.75
		6	22	123.00
		7	21	122.63
		8	20	122.25
		9	20	122.25
		10	21	122.63
		11	22	123.00
		12	24	123.75
		13	27	124.88
		14	29	125.63
		15	32	126.75
		16	34	127.50
		17	36	128.25
		18	38	129.00
		19	38	129.00
		20	38	129.00
		21	37	128.63
		22	36	128.25
		23	34	127.50
		24	33	127.13
			Daily	3016
			Monthly	84441

		Hour	CLTD	$CLTD_{corr}$
	March	1	30	128.25
M	-8	2	29	127.88
k	0.5	3	27	127.13
T	3	4	26	126.75
f	0.75	5	24	126.00
		6	22	125.25
		7	21	124.88
		8	20	124.50
		9	20	124.50
		10	21	124.88
		11	22	125.25
		12	24	126.00
		13	27	127.13
		14	29	127.88
		15	32	129.00
		16	34	129.75
		17	36	130.50
		18	38	131.25
		19	38	131.25
		20	38	131.25
		21	37	130.88
		22	36	130.50
		23	34	129.75
		24	33	129.38
			Daily	3070
			Monthly	95162

		Hour	CLTD	$CLTD_{corr}$
	July	1	30	131.63
M	1	2	29	131.25
k	0.5	3	27	130.50
T	3	4	26	130.13
f	0.75	5	24	129.38
		6	22	128.63
		7	21	128.25
		8	20	127.88
		9	20	127.88
		10	21	128.25
		11	22	128.63
		12	24	129.38
		13	27	130.50
		14	29	131.25
		15	32	132.38
		16	34	133.13
		17	36	133.88
		18	38	134.63
		19	38	134.63
		20	38	134.63
		21	37	134.25
		22	36	133.88
		23	34	133.13
		24	33	132.75
			Daily	3151
			Monthly	97673

		Hour	CLTD	$CLTD_{corr}$
	August	1	30	130.13
M	-3	2	29	129.75
k	0.5	3	27	129.00
T	3	4	26	128.63
f	0.75	5	24	127.88
		6	22	127.13
		7	21	126.75
		8	20	126.38
		9	20	126.38
		10	21	126.75
		11	22	127.13
		12	24	127.88
		13	27	129.00
		14	29	129.75
		15	32	130.88
		16	34	131.63
		17	36	132.38
		18	38	133.13
		19	38	133.13
		20	38	133.13
		21	37	132.75
		22	36	132.38
		23	34	131.63
		24	33	131.25
			Daily	3115
			Monthly	96557

		Hour	CLTD	$CLTD_{corr}$
	September	1	30	128.25
M	-8	2	29	127.88
k	0.5	3	27	127.13
T	3	4	26	126.75
f	0.75	5	24	126.00
		6	22	125.25
		7	21	124.88
		8	20	124.50
		9	20	124.50
		10	21	124.88
		11	22	125.25
		12	24	126.00
		13	27	127.13
		14	29	127.88
		15	32	129.00
		16	34	129.75
		17	36	130.50
		18	38	131.25
		19	38	131.25
		20	38	131.25
		21	37	130.88
		22	36	130.50
		23	34	129.75
		24	33	129.38
			Daily	3070
			Monthly	92093

$CLTD_{corr}$ = [(CLTD + M) x k + (78 - T) + (85)] x f = [Btu/hour]

	April	Hour	CLTD	$CLTD_{corr}$
		1	30	130.13
M	-3	2	29	129.75
k	0.5	3	27	129.00
T	3	4	26	128.63
f	0.75	5	24	127.88
		6	22	127.13
		7	21	126.75
		8	20	126.38
		9	20	126.38
		10	21	126.75
		11	22	127.13
		12	24	127.88
		13	27	129.00
		14	29	129.75
		15	32	130.88
		16	34	131.63
		17	36	132.38
		18	38	133.13
		19	38	133.13
		20	38	133.13
		21	37	132.75
		22	36	132.38
		23	34	131.63
		24	33	131.25
			Daily	3115
			Monthly	93443

	May	Hour	CLTD	$CLTD_{corr}$
		1	30	131.63
M	1	2	29	131.25
k	0.5	3	27	130.50
T	3	4	26	130.13
f	0.75	5	24	129.38
		6	22	128.63
		7	21	128.25
		8	20	127.88
		9	20	127.88
		10	21	128.25
		11	22	128.63
		12	24	129.38
		13	27	130.50
		14	29	131.25
		15	32	132.38
		16	34	133.13
		17	36	133.88
		18	38	134.63
		19	38	134.63
		20	38	134.63
		21	37	134.25
		22	36	133.88
		23	34	133.13
		24	33	132.75
			Daily	3151
			Monthly	97673

	June	Hour	CLTD	$CLTD_{corr}$
		1	30	132.00
M	2	2	29	131.63
k	0.5	3	27	130.88
T	3	4	26	130.50
f	0.75	5	24	129.75
		6	22	129.00
		7	21	128.63
		8	20	128.25
		9	20	128.25
		10	21	128.63
		11	22	129.00
		12	24	129.75
		13	27	130.88
		14	29	131.63
		15	32	132.75
		16	34	133.50
		17	36	134.25
		18	38	135.00
		19	38	135.00
		20	38	135.00
		21	37	134.63
		22	36	134.25
		23	34	133.50
		24	33	133.13
			Daily	3160
			Monthly	94793

	October	Hour	CLTD	$CLTD_{corr}$
		1	30	126.00
M	-14	2	29	125.63
k	0.5	3	27	124.88
T	3	4	26	124.50
f	0.75	5	24	123.75
		6	22	123.00
		7	21	122.63
		8	20	122.25
		9	20	122.25
		10	21	122.63
		11	22	123.00
		12	24	123.75
		13	27	124.88
		14	29	125.63
		15	32	126.75
		16	34	127.50
		17	36	128.25
		18	38	129.00
		19	38	129.00
		20	38	129.00
		21	37	128.63
		22	36	128.25
		23	34	127.50
		24	33	127.13
			Daily	3016
			Monthly	93488

	November	Hour	CLTD	$CLTD_{corr}$
		1	30	138.38
M	19	2	29	138.00
k	0.5	3	27	137.25
T	3	4	26	136.88
f	0.75	5	24	136.13
		6	22	135.38
		7	21	135.00
		8	20	134.63
		9	20	134.63
		10	21	135.00
		11	22	135.38
		12	24	136.13
		13	27	137.25
		14	29	138.00
		15	32	139.13
		16	34	139.88
		17	36	140.63
		18	38	141.38
		19	38	141.38
		20	38	141.38
		21	37	141.00
		22	36	140.63
		23	34	139.88
		24	33	139.50
			Daily	3313
			Monthly	99383

	December	Hour	CLTD	$CLTD_{corr}$
		1	30	139.13
M	21	2	29	138.75
k	0.5	3	27	138.00
T	3	4	26	137.63
f	0.75	5	24	136.88
		6	22	136.13
		7	21	135.75
		8	20	135.38
		9	20	135.38
		10	21	135.75
		11	22	136.13
		12	24	136.88
		13	27	138.00
		14	29	138.75
		15	32	139.88
		16	34	140.63
		17	36	141.38
		18	38	142.13
		19	38	142.13
		20	38	142.13
		21	37	141.75
		22	36	141.38
		23	34	140.63
		24	33	140.25
			Daily	3331
			Monthly	103253

EPDM					
Month Totals	**Btu/sq. ft.**				
January	116111				
February	88242				
March	101045				
April	100485				
May	106067				
June	103185				
July	106067				
August	103835				
September	97785				
October	97697				
November	112365				
December	117227	**Btu**	**Tons**	**Chilled Water**	**Total**
Annual Expenses	614634	1137072900	94,756.08	$16,108.53	$12,188.89
Annual Savings	635474	1175625975	11756.25975	$3,919.64	
			Therms	**Steam**	

White Roof					
Month Totals	**Btu/sq. ft.**				
January	102695				
February	84441				
March	95162				
April	93443				
May	97673				
June	94793				
July	106067				
August	103835				
September	97785				
October	97697				
November	112365				
December	103253	**Btu**	**Tons**	**Chilled Water**	**Total**
Annual Expenses	597848	1106019263	92168.27	$15,668.61	$12,017.64
Annual Savings	591359	1094014613	10940.15	$3,650.97	
			Therms	**Steam**	

Green Roof*					
Month Totals	**Btu/sq. ft.**				
January	102695				
February	84441				
March	95162				
April	93443				
May	97673				
June	94793				
July	106067				
August	103835				
September	97785				
October	97697				
November	112365				
December	103253	**Btu**	**Tons**	**Chilled Water**	**Total**
Annual Expenses	597848	848326051	70693.84	$12,017.95	$9,190.30
Annual Savings	591359	839118384	8391.18	$2,827.65	
			Therms	**Steam**	

Roof Area:	30,451 sq.ft.			**Combination**		
				21,000sq.ft. green / 9451 sq.ft. white		
	Black	**White**	**Green**	**Green**	**White**	**Total**
Initial Cost	$67,296.71	$80,390.64	$365,412.00	$252,000.00	$24,950.64	$276,950.64
Maintenance	$3,045.10	$761.28	$761.28	$525.00	$236.28	$761.28
Operating Cost*	$12,188.89	$12,017.64	$9,190.30	$4,943.40	$3,735.98	$8,679.38
Disposal	$29,841.98	$25,578.84	$25,578.84	$17,564.40	$8,014.44	$25,578.84
*Total Annual Expense difference from Heat Load Calculations spreadsheet						
** Green Maintenance Costs are for annual inspections only, same as white roof						
Year	Accumulated Cost					**Cost**
1	$112,372.68	$118,748.40	$400,942.42			$311,970.14
2	$127,606.67	$131,527.31	$410,893.99			$321,410.80
3	$142,840.65	$144,306.23	$420,845.57			$330,851.46
4	$158,074.64	$157,085.14	$430,797.15			$340,292.12
5	$173,308.63	$169,864.06	$440,748.73			$349,732.78
6	$188,542.62	$182,642.98	$450,700.30			$359,173.44
7	$203,776.61	$195,421.89	$460,651.88			$368,614.10
8	$219,010.59	$208,200.81	$470,603.46			$378,054.76
9	$234,244.58	$220,979.73	$480,555.03			$387,495.42
10	$249,478.57	$233,758.64	$490,506.61			$396,936.08
11	$264,712.56	$246,537.56	$500,458.19			$406,376.74
12	$279,946.55	$259,316.47	$510,409.77			$415,817.40
13	$295,180.54	$272,095.39	$520,361.34			$425,258.06
14	$310,414.52	$284,874.31	$530,312.92			$434,698.72
15	$422,787.20	$297,653.22	$540,264.50			$444,139.38
16	$438,021.19	$310,432.14	$550,216.08			$453,580.04
17	$453,255.18	$323,211.06	$560,167.65			$463,020.71
18	$468,489.17	$335,989.97	$570,119.23			$472,461.37
19	$483,723.15	$348,768.89	$580,070.81			$481,902.03
20	$498,957.14	$361,547.80	$590,022.38			$491,342.69
21	$514,191.13	$374,326.72	$599,973.96			$500,783.35
22	$529,425.12	$387,105.64	$609,925.54			$510,224.01
23	$544,659.11	$399,884.55	$619,877.12			$519,664.67
24	$559,893.09	$412,663.47	$629,828.69			$529,105.33
25	$575,127.08	$531,411.86	$639,780.27			$571,511.07
26	$590,361.07	$544,190.78	$649,731.85			$580,951.73
27	$605,595.06	$556,969.70	$659,683.42			$590,392.39
28	$620,829.05	$569,748.61	$669,635.00			$599,833.05
29	$636,063.04	$582,527.53	$679,586.58			$609,273.71
30	$748,435.71	$595,306.45	$689,538.16			$618,714.37
31	$763,669.70	$608,085.36	$699,489.73			$628,155.03
32	$778,903.69	$620,864.28	$709,441.31			$637,595.69
33	$794,137.68	$633,643.19	$719,392.89			$647,036.35
34	$809,371.67	$646,422.11	$729,344.46			$656,477.01
35	$824,605.65	$659,201.03	$739,296.04			$665,917.67
36	$839,839.64	$671,979.94	$749,247.62			$675,358.33
37	$855,073.63	$684,758.86	$759,199.20			$684,798.99
38	$870,307.62	$697,537.78	$769,150.77			$694,239.65
39	$885,541.61	$710,316.69	$779,102.35			$703,680.31
40	$900,775.59	$723,095.61	$789,053.93			$713,120.97