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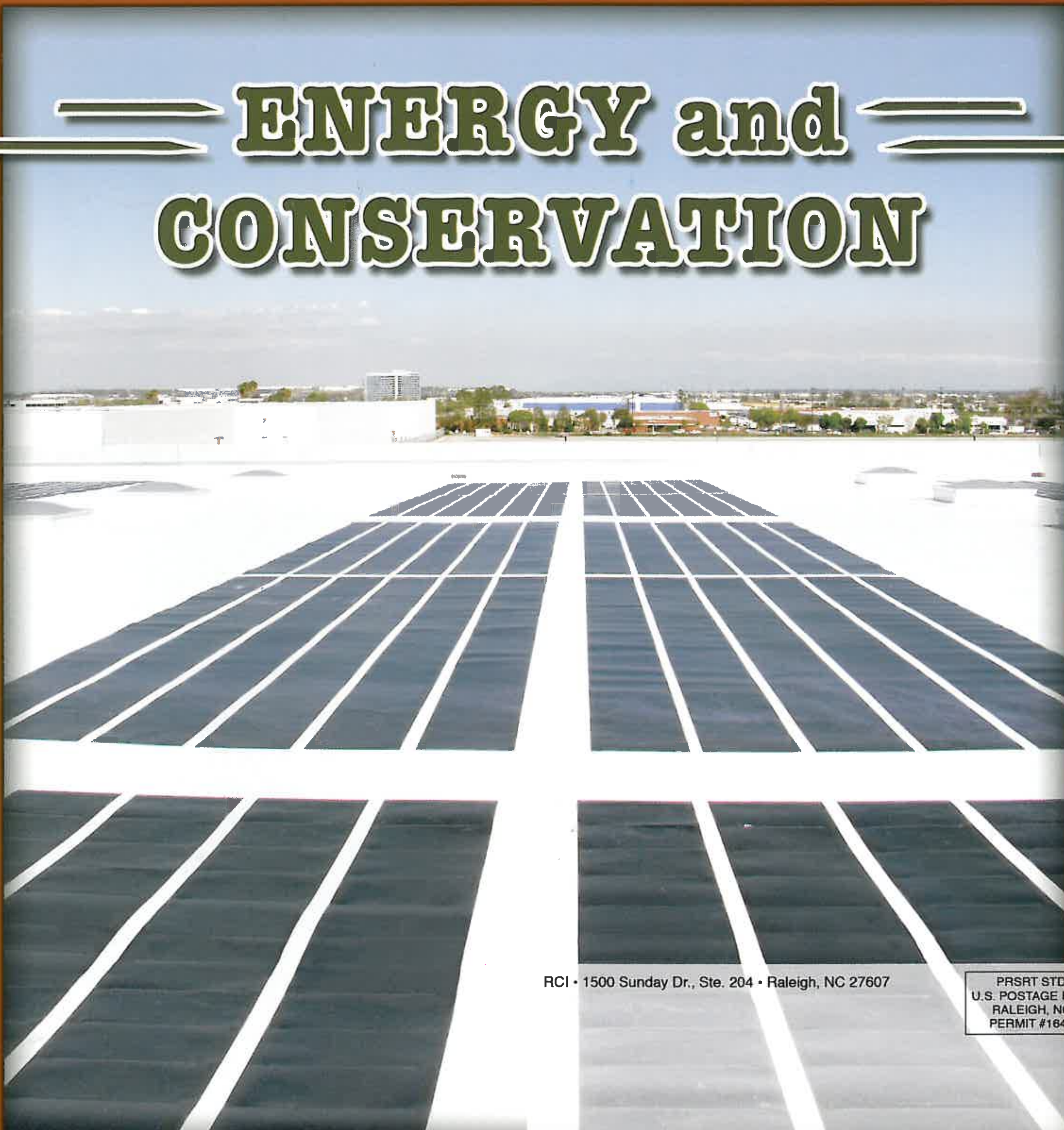

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PHOTOVOLTAICS

THE ENVIRONMENTAL BENEFITS OF A TEXAS GARDEN ROOF

By Karl A. Schaack, PE, RRC

As a community-sensitive health science institution, The University of Texas Health Science Center at Houston strives to ensure a better quality of life for humankind. Guiding principles established by UTHSC-H personnel help provide a framework for developing sustainable projects. Two of these principles – 1) "Create places of health and well-being," and 2) "Pursue integrated design solutions" – were driving concepts for roof renovation projects recently implemented by the Facilities, Planning, & Engineering Department. With these principles as building blocks and the recent experiences of devastating flooding in Houston (Tropical Storm Allison in 2001), the ever-present urban heat island condition, and problematic air quality, UTHSC personnel were interested in pursuing roof replacement options that would provide benefits not only to the building users, but also to the general public. The primary option considered was "cool roof" technology involving systems that utilize either a white reflective surfacing or garden roof.

Overview of roof area prior to replacement.

Design Development & Demonstration

One of the buildings planned for roof replacement was the School of Public Health. The subject building is a 12-story structure composed of structural concrete framing. The existing roof system consisted of a spray-applied polyurethane foam (2 to 4 inches thick) applied over a gravel-surfaced, built-up roof membrane. A thermosetting asphaltic fill (3 to 6 inches thick) was installed over the structural concrete deck. The subject roof was comprised of a main level and two mechanical penthouses encompassing a plan area of approximately 21,000 square feet. The main level was oriented in an east/west direction and consisted of two similar geometrically shaped sections (symmetrically opposed). A variety of equipment was situated on the western portion of the roof. The eastern portion of the roof was relatively free of rooftop appurtenances. The perimeter of the roof was constructed of either a low-profile metal edge or a tall parapet wall feature extending from the corners of the roof approximately 10 feet. A steel handrail was located approximately 6 feet in from the low-profile roof edge, extending to the ends of the parapet wall features, creating a "protected" roof perimeter.

Based on the previously mentioned conditions, it was determined that this roof would be a good potential candidate for the installation of an extensive garden system. UTHSC personnel had developed an initial interest in garden roofs during the planning phase of the construction of a new facility adjacent to the subject building. To provide further exposure to this technology, the author's firm, Price Consulting Inc. (PCI), organized the construction of "test plots" or mock-up samples of various extensive garden roof assemblies.

In August 2002, four different roofing/waterproofing assemblies were installed on another UTHSC building in order to display representative material types and assemblies currently promoted for this particular application and to provide an area to develop rudimentary experimentation for various plants. The systems/materials selected for the "test roofs" were identified as being different product types/technologies manufactured by several different companies that had displayed specific experiences in this type of application.

The area selected for the test roofs was on top of a parking structure of another UTHSC building. The area had a concrete curb (retaining wall) around the perimeter where a cooling tower structure once stood. The subject area was divided into four quadrants (approximately 300 square feet each) to provide independent areas to receive the new materials. A low-rise wall (curb) was constructed to form the boundary between quadrants. This curb was constructed utilizing recycled plastic lumber formed with two 2 x 10s and two 2 x 6s.

The quadrants were designated as Numbers 1, 2, 3, and 4. The waterproofing/roofing systems selected for these quadrants were as follows:

- **Quadrant No. 1** — "Monolithic Membrane 6125" by American Hydrotech, Inc., 303 E. Ohio St., Chicago, IL 60611-3387.
- **Quadrant No. 2** — "G 476" by Sarnafil, Inc., 100 Dan Rd., Canton, MA 02021.
- **Quadrant No. 3** — "Procor Deck System 3R" by W.R. Grace & Co., 62

Test Plot - Quad 1.

Whittemore Ave., Cambridge, MA 02140.

- **Quadrant No. 4** — "Teranap" by Siplast/Icopal, Inc. 1000 E. Rochelle Blvd., Irving, TX 75062.

The systems/materials installed in the respective quadrants are as follows:

Test Plot - Quad 2.

Quadrant No. 1
American Hydrotech

The system provided by American Hydrotech, called "Monolithic Membrane 6125-FR," consisted of a hot-applied rubberized asphalt reinforced with a polyester fabric. The rubberized asphalt was melted in a kettle and applied in a heated liquid form directly on top of the deck in an initial application of approximately 90-mil thickness. Polyester reinforcing fabric was embedded in the asphalt. A second layer of hot rubberized asphalt was then applied on top of the fabric at approximately 125 mils, with a resulting total membrane thickness of 215 mils. A prefabricated sheet of modified bitumen was embedded into the top layer of hot asphalt to serve as a protection mat. A 40-mil, high-density polyethylene sheet was then installed over the protection mat to serve as a root barrier. Polypropylene fiber moisture retention mat was installed on top of the root barrier. Prefabricated drain board was installed on top of the moisture retention mat. A geotextile, nonwoven polypropylene filter fabric was then installed over the drain board. "Engineered soil," consisting of expanded lightweight aggregate, sand, and compost, was placed over the filter fabric.

Quadrant No. 2
Sarnafil

The system provided by Sarnafil is called "G 476" and consisted of a prefabricated, fiberglass reinforced PVC thermoplastic single-ply membrane that is 80 mils thick. The membrane was loose-laid over the concrete deck and secured along the perimeters with a metal termination bar anchored into the concrete deck. Adjacent sheets were overlapped, and the overlapped portions were thermally fused via hot-air welding. The chemical composition of the membrane inhibits root growth, thus eliminating the need for additional root barrier mediums. Pre-fabricated drain board, consisting of a dimpled polymeric core with a filter fabric laminated to the core, was placed over the membrane. General landscaping soil was installed over the drainage board.

Quadrant No. 3
Grace Construction Products

The system provided by Grace is called "Procor Deck System 3R," which consists of a cold-vulcanized, fluid-applied synthetic rubber membrane with a polyester reinforcing fabric. The fluid-applied waterproofing membrane consists of two parts that were site-mixed and cold-applied, using conventional spray equipment, directly on top of the concrete deck in an initial application of approximately 60-mil thickness. Reinforcing fabric was embedded in the initial application of the material, and then a second layer of liquid-applied material was spray-applied at approximately 60 mils, with a resulting membrane thickness of 120 mils. Prefabricated drainage board, consisting of a dimpled polymeric core with a filter fabric laminated to the core, was then placed on top of the completed membrane. General landscaping soil was installed over the drain board.

Quadrant No. 4
Siplast/Icopal

The system provided by Siplast is called "Teranap System," which is a two-ply SBS modified bitumen membrane. The mem-

Test Plot - Quad 3.

Test Plot - Quad 4.

brane is composed of a smooth-surfaced, modified bitumen, fiberglass-reinforced base ply, 110 mils thick, which was fully-adhered to the concrete deck by torch-application methods; and a smooth-surfaced, modified bitumen, polyester-reinforced top ply, 160 mils thick, which was fully-adhered to the base ply via torch-application methods, with a resulting membrane thickness of 270 mils. The top surface of the top ply consists of a polymeric film that inhibits root growth. Prefabricated drain board was then placed on top of the membrane sheet. The drain board is manufactured with dimpled polymeric core with cross flow holes and nonwoven fabrics laminated to both sides of the core and the perforations in the core allow drainage. The fabric laminated to the top surface of the core has a "root barrier" embodied into the fabric that stops the initial root growth. "Engineered soil," consisting of an expanded lightweight aggregate (shale), coarse sand, pine bark humus, and compost was then placed on top of the drain board.

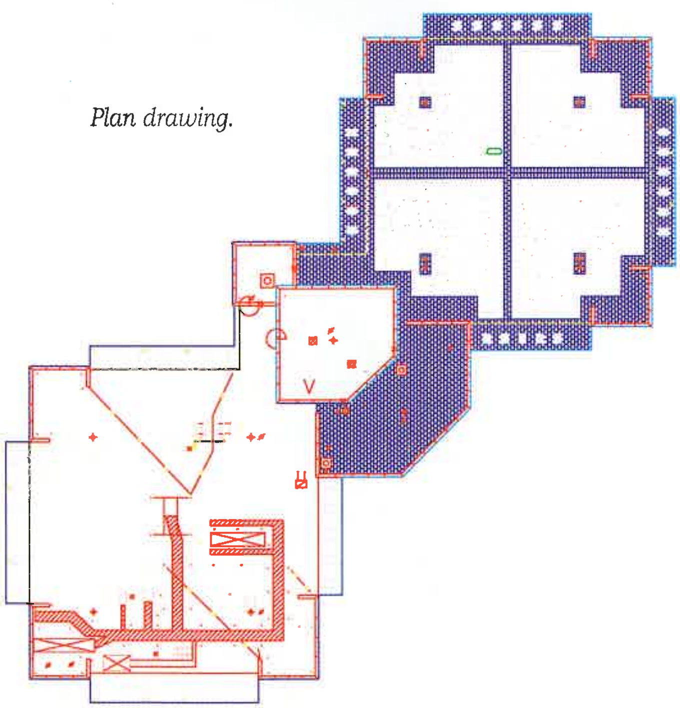
After placement of the growing medium, UTHSC personnel planted a variety of vegetation species and seeds in the quadrants. After the planting, UTHSC personnel performed random watering to help establish the various plants and monitored the progress.

Design Implementation

Upon completion of this process, PCI was directed to develop specifications and drawings for roof replacement of the School of Public Health. The scope of work included removal of the existing roof materials (including the thermosetting fill) down to the structural concrete deck. The replacement systems included a traditional low-sloped roof assembly on the western portion and the mechanical penthouses and a garden roof on the eastern portion of the roof. The traditional assembly consisted of two-ply modified bitumen membrane installed over tapered insulation set in cold-process, bituminous-based adhesive over the concrete deck. The base ply of the membrane was installed on top of the insulation board with cold-process adhesive, and the lap seams were fused via hand-held torches. The cap sheet was fully adhered to the base ply by torch-application. This same type of system had been successfully installed on several lower roof areas of the subject building over the previous couple of years.

Elevation of building.

The system for the garden roof consisted of the two-ply modified bitumen roof membrane, "Teranap," as manufactured by Siplast, one of the systems installed in the test plots. The modified bitumen system was selected for the following reasons: 1) The type of roof system that was utilized on the remaining areas of the building consisted of a modified bitumen membrane; 2) The redundancy of the multiple plies of known thickness; 3) The system would be fully-adhered to the deck; 4) Kettles or heating of molten bitumen would not be required for the installation, thus eliminating odor disruptions to occupants of the subject and surrounding buildings, and 5) Siplast's proven track record with similar applications. This renovation project was included in a Project Manual with several other roof and waterproofing renovation projects. Competition Roofing, Inc. from Houston, Texas, was the successful contractor selected in a competitive, sealed proposal process.



Plan drawing.

Construction Process

The construction process was started in the latter part of April 2003. The work was initiated on the western portion of the main level, involving installation of the conventional roof system and then proceeded to the remaining areas. The existing materials on the eastern portion of the main level were removed, and the new membrane and flashings were installed across the entire roof prior to the installation of any of the garden accessory components. The installation process was completed in the latter part of July 2003. A flood test was performed on the membrane after completion of the installation. The water for the flood-test was maintained over the membrane for 48 hours with no evidence of infiltration into the building interior. After successful completion of the flood test, the prefabricated drain panel was installed over the entire area. Adjacent panels were interlocked by nesting the perforations, and the filter fabric was overlapped by four inches.

The eastern portion of the subject roof was basically divided into four quadrants. Intersecting "paths" (two feet in width) were constructed of concrete pavers and bisected the middle of the overall roof area, creating four individual sections to receive the vegetated cover.

The paver system consisted of interlocking concrete pavers, "Ballast Paver" by Westile. A sheet metal tab was placed between adjacent pavers to interlock the adjoining abutting sides (longitudinal side) of the pavers. The pavers were installed along the perimeter of the roof, extending inward from the edge to a distance of approximately six feet. This boundary provided several functions, including the following: provided a walking surface around the planned planting areas; provided protection along the perimeters against wind erosion/scour of the soil and fire; and pro-

Installation of membrane.

vided general wind resistance of the assembly.

The sheet metal fabrications located at the low-profile roof edge and the counter-flashing assemblies along the parapet walls were extended over the top surface of the adjacent pavers to provide additional wind-uplift resistance. Concrete pavers were installed over a filter fabric that was installed over two inches of extruded polystyrene insulation board placed over the prefabricated drain panel. The board had ribs or channels on the top surface and drainage channels along the edges on the bottom surface of the board, "Ribbed," Roofmate by Dow Chemical.

An 8-inch x 16-inch x 2-inch terra-cotta colored paver was placed on end between the interlocking concrete pavers and the planned growing areas to serve as both a border and a small "retaining wall" to contain the soil within the quadrants. A primary roof drain and overflow drain were positioned in each quadrant. The drain panel was extended to the drain assemblies and white marble stone ballast was placed over the drainage panel around the drains for a distance of approximately one foot with one course of concrete pavers and the border paver positioned between the stone and soil.

The concrete pavers, polystyrene insulation, and drainage board were installed over the membrane on the area between the large roof sections to serve as access from the doorway of the mechanical penthouse.

Typical perimeter paver condition.

Common Name	Botanical Name	Qty.	Size
Mexican Heather	*Cuphea Hyssopifolia*	30	1 gallon plants
Hot Pink Moss Verbena	*Verbena Bipinnatifida*	67	1 gallon plants
White Katie Ruellia	*Ruellia Brittonlana 'Alba'*	160	4 inch plants
Gulf Coast Muhly	*Muhlenbergia Capilaris*	103	1 gallon plants
Pink Button Polygonums	*Polygonum sp. 'Pinkbuttons'*	28	1 gallon plants
Yellow Bulbine	*Bulbine Flavescens*	280	1 quart plants
Tangerine Bulbine	*Bulbine Flavescens 'Tangerine'*	280	1 quart plants
Mexican Sedum	*Sedum Mexicana*	200	4 inch plants
Ruby Star Coneflower	*Echinacea Purpurea 'Ruby Star'*	12	1 quart plants
White Swan Coneflower	*Echinacea Purpurea 'White Swan'*	24	1 quart plants
Butterfly Gaura	*Gaura Lindheimeni 'The Bride'*	5	1 gallon plants
Prostrate Rosemary	*Rosmarinus Prostrate*	3	1 gallon plants
Red Cascade Rose	*Rose 'Red Cascade'*	121	1 quart plants
Oakleaf Fig Ivy	*Ficus Quercifolia*	12	1 gallon plants
Prairie Sky Grass	*Panicum Virgatum 'Prairie Sky'*	9	1 gallon plants
Goldstrum Rudbeckia	*Rudbeckia Fulgida 'Goldstrum'*	106	1 quart plants
Baths Pink Dianthus	*Dianthus Gratianopolitanus B.P.*	24	1 quart plants
Libra Rain Lily	*Habranthus 'Libra'*	12	1 quart plants
Yellow Rain Lily	*Zephyranthes Citrina*	12	1 quart plants
Zexmania	*Wedelia Hispida*	10	1 gallon plants
Trailing Purple Lantana	*Lantana Montevidensis*	8	1 gallon plants
Grape Cool-aid Verbena	*Verbena 'Grape Cool-Aid'*	70	1 gallon plants
Mexican Feather Grass	*Stipa Tenussima*	24	1 quart plants

Table 1: Plants

The installation of the drainage panel, insulation, filter fabric, and pavers was completed in mid to late August 2003.

Growing Medium

The guidelines for the specifications of the growing medium or "engineered soil" were provided by Siplast, the roof membrane system manufacturer, based on its past experiences in garden roof technology. The proportions of the constituents consisted of the following: lightweight "engineered soil" containing 55% expanded slate, 30% coarse sand, 5% pine bark humus, and 10% compost.

The roofing contractor found and utilized a local resource for the engineered soil. The "engineered" growing medium (soil) was premixed and bagged by the LETCO Group L.P. of Houston, Texas. The soil was packaged in 4,000 40-pound bags delivered on 68 pallets to the site and raised to the roof via a hoist by the contractor. The constituents of the soil provided by LETCO were as follows: 1) an expanded shale, "Tru-Gro" supplied by TXI in Streetman, Texas; 2) coarse sand complying with specifications of the United States Golf Association; 3) compost based on horse manure blended with aged pine bark complying with U.S. Composting Council Seal of Testing Assurance Program criteria approved for use on Texas Department of Transportation projects.

A soil scientist was consulted in regard to the plant types proposed and the desired results for this project. John Ferguson, with Nature's Way Resources in Conroe, Texas, recommended mixing a bacterial root stimulator into the soil. Four 40 pound bags of "Microlife Ultimate 8-4-6" organic fertilizer supplied by San Jacinto Environmental Supplies of Houston, Texas, was blended with the engineered soil. The Microlife is an all-natural blend of minerals and nutrients that are homogenized and granulated. The primary nutrients contained in the organic fertilizer include: alfalfa, fish meal, kelp meal, bat guano, soy meal, rock phosphate, molasses, potassium sulfate, and humates. In addition, a one-inch layer of "native hardwood mulch" was installed over the base layer of growing medium. This mulch was made from native deciduous trees and brush with a small amount of bark. The mulch was composted, aged, and screened to create a product that would provide beneficial nutrients for the plants and help prevent plant and soil diseases.

Placement of soil.

Typical wall flashing.

After placement of the mulch and prior to the planting, an organic jute erosion control mat was placed and embedded in the surface of the growing medium over the entire area in each quadrant. The jute netting was designed to decompose into the soil after the vegetation becomes established. When each plant was placed, a handful of "organic leaf mold compost" was put in the hole with it to stimulate growth in the plants. This leaf mold was produced from recycled leaves, grass, and horse manure that were slowly composted.

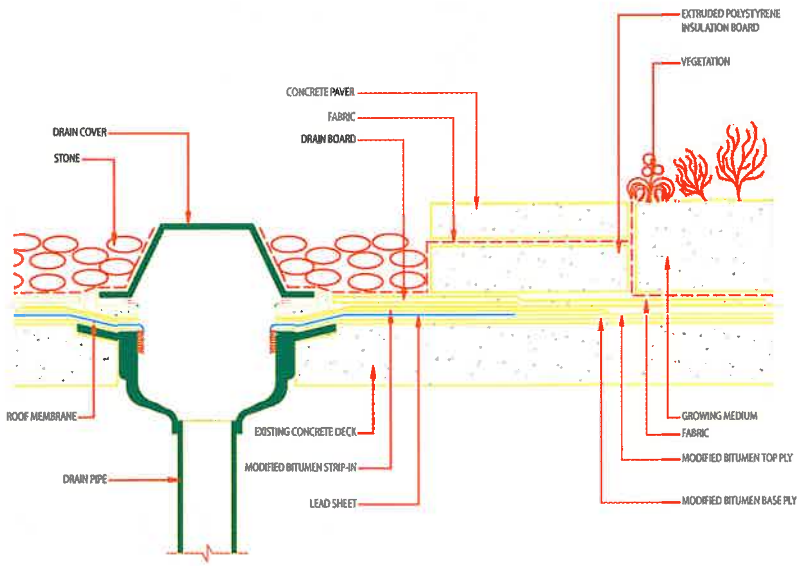
Plant Selection and Planting

Plant selection was accomplished utilizing several resources. A "Plant Selection Recommendation" was prepared by METANOVAstudios, Inc. in conjunction with Siplast and provided to the project team during the design process. UTHSC staff botanists selected and planted a variety of species in the test green roofs and monitored the growth and survival results of these plants from 2002 to 2003. During the project planning phase, Competition Roofing was referred to Heidi Sheesley at Treesearch Farms, Inc. in Houston, Texas. Sheesley was considered to be very knowledgeable regarding regional plants. She was informed of the project, provided with the lists of plants compiled by others, and requested to provide recommendations for the plant selection. Utilizing the expertise of each of these resources, a finalized list of plants was developed by Sheesley for the project. With a copy of the roof plan, she then developed a layout of the various species.

Plants would have to survive common weather characteristics of the Houston area, including high humidity, high heat, pollution, potential drought, and torrential downpours. In addition, no supplemental rooftop irrigation was planned for the project and minimal, if any, maintenance. The vegetation would also be subjected to full sun with the only shading being that created by the mechanical penthouses and parapet walls. The locations of plants within the quadrants were determined by Ms. Sheesley. The plants, provided by Treesearch Farms, were all grown with organic growing media. A total of 1,492 plants from 23 species were planted in the four quadrants (see *Table 1*). The plants were placed in rows and oriented in groupings to provide ease of identifying and monitoring of the vegetation in the future and not positioned for purposes of achieving a "sculptured landscaped design."

The plants were delivered to the site, transported to the roof via hoist, and roofing contractor personnel planted them from September 18 - 20, 2003 and then watered the entire area. The contractor was contractually responsible for the initial watering, originally specified for twice a week the first month. Watering was performed every third to fourth day for the first two weeks after the initial planting. Rain occurred at the project for two days after this two-week time frame. A site visit was performed after the rain events, the soil was found to be very moist, and the decision was made to halt the manual watering process and to visually monitor the weather, plant, and soil conditions. Several rain events occurred over the following weeks, site visits confirmed moist soil conditions, and watering was discontinued. Several of the plants (a total of four bulbines) died after the initial planting. This event was believed to be due to the shock experienced during transporting the plants to the roof and the actual planting process. No further watering was performed by the contractor or anybody else.

After completion of the planting process and other miscellaneous related work (i.e., lightning protection system reinstallation, waterproofing repairs, etc.), a white elastomeric coating was applied to the granule surfacing of the conventional roof system and the surface of the concrete pavers to provide a reflective surface to those areas not covered with vegetation.



Drain detail drawing.

Costs

Since the subject roof was symmetrical, a direct comparison of the costs of the garden roof system and the traditional modified bitumen roof system could be achieved. Reportedly, industry professionals estimate that extensive green roofs could cost on the order of $7 to $12 more per square foot than traditional systems. Based on information provided by the contractor, the cost impact (increase) of the garden roof compared to the traditional roof system was on the order of $4.20 to $4.30 per square foot. The relatively close costs experienced on this project are believed to be due to the following factors:

1) The complexity of the overall project, including the traditional roof system (i.e., 10-story building, restricted/limited site access, rooftop equipment, sensitivity of facility, etc.);
2) Utilization by the contractor of local supplier for growing medium;
3) The use of what might be considered generic materials (insulation and pavers) and not requiring a manufacturer's warranty; and
4) The overall team effort of the project personnel, including the contractor and owner, in minimizing cost and providing cost effective means to accomplish the work.

Although the anticipated roof maintenance work and related costs for garden roofs remain unknown, it is believed that on this specific roof , they should be minimal, as the roof membrane and flashings are concealed and not exposed to weathering elements. Anticipated maintenance would be related to the monitoring of the vegetation (i.e., weed control, plant replenishment, and watering, if necessary).

First Year of Existence

Many site visits were performed during the first year after all work was completed and accepted by the owner. General observations revealed that each of the plant species experienced some level of growth. The Mexican Heather, Katie Ruellia, and the Gulf Coast Muhly appeared to experience the most growth with the formation of multiple new plants. The Muhly was found to be the most pervasive, with new plant growth occurring in adjacent plant species groupings and into adjacent quadrants. The bulbines, fig-leaf ivy, and the prostrate sage experienced moderate growth (increase in height, width, and density) of the individual

TEMPERATURE READINGS July 3, 2004			
Time	Temperature at Surface of Soil	Temperature at Surface of Membrane	Air Temperature
00:01	80	87	77
06:32	77*	83	77*
08:37	90	82*	82
09:33	100	82	84
10:15	110	83	86
11:20	121	84	88
13:08	132	86	91
14:23	135**	88	92
18:24	106	92**	90**
23:59	80	88	79
DeltaT	58	10	15

*Low Temp **High Temp

Table 2

plants. The sedums appeared to exhibit the least amount of growth or change. This is believed to be due to the relatively rainy year that was experienced in Houston in 2004. The rainfall for the entire year in 2004 was the sixth greatest recorded amount with 65 inches, compared to a typical annual rainfall of 46 inches. The months of June and November in 2004 were the second wettest (comparatively for their respective months) in recorded history in Houston. Various weed growth was noted in each of the quadrants. During the first three to six months, two weed removal sessions were performed by the roofing contractor. During site visits performed two weeks after the planting was complete, numerous honeybees and several butterflies were observed within the various flowering vegetation.

A weather station was installed by UTHSC personnel on a section of the handrail located on the southern portion of the subject roof. The data collected by this instrumentation is as follows: humidity, rainfall, wind speed, photosynthetically active radiation (PAR), and ambient air temperature. In addition, temperature probes were installed at the surface of the soil and at the top of the roof membrane located below the soil. The weather station was connected to an automated data logger with cables extended to the interior of the mechanical penthouse to allow for downloading of the collected data by UTHSC personnel. Collection of the data was begun on October 3, 2003. Upon collection, compilation, and review of this data, interesting information was gathered in relation to rooftop temperatures.

The garden roof overburden (growing medium and vegetation) appears to provide significant thermal properties. In general, the temperatures recorded over the first year at the surface of the growing medium ranged from a low of 31°F to a high of 167°F

Installation of drain board.

TEMPERATURE READINGS July 25, 2004			
Time	Temperature at Surface of Soil	Temperature at Surface of Membrane	Air Temperature
00:01	85	93	85
12:51	162**	94	97
14:13	139	96**	97**
14:31	106	96	95
14:32[1]	101	96	94
14:39	86	96	91
15:06	82	95	87
16:36[2]	78	94	77
23:59	76	87*	76*
DeltaT	86	9	21

[1]First Recorded Rain; [2]Last Recorded Rain; *Low Temp; **High Temp

Table 3

with daily temperature changes/fluctuations ranging from 27°F to 86°F. The temperatures recorded at the surface of the buried membrane ranged from a low of 41°F to a high of 99°F with daily fluctuations ranging from 5°F to 15°F.

The information in the accompanying tables presents comparisons of the recorded temperatures that occurred during the summer and winter when rain occurred. On July 3, 2004 (see *Table 2*), the temperatures recorded at the surface of the soil started at the beginning of the day at 80°F, decreased to 77°F at 6:30 a.m., and increased approximately 10 degrees an hour to a high temperature of 135°F at 2:20 p.m. The temper-

TEMPERATURE READINGS August 4, 2004			
Time	Temperature at Surface of Soil	Temperature at Surface of Membrane	Air Temperature
00:01	84	93	84
08:27	91	88*	83*
09:07	100	88	85
09:49	110	88	87
10:36	120	89	89
11:05	130	89	90
12:06	140	91	93
12:35	150	92	94
13:28	160**	93	96**
18:06	100	99**	93
23:59	83*	93	83
DeltaT	77	11	13

* Low Temp ** High Temp

Table 4

TEMPERATURE READINGS August 5, 2004			
Time	Temperature at Surface of Soil	Temperature at Surface of Membrane	Air Temperature
00:01	83	93	83
14:18	160	96	98
23:59	85	95	84
DeltaT	77	10	14

Table 5

TEMPERATURE READINGS February 22, 2004					
Time	Temp. at Surf. of Soil	Temp. at Membrane	Air Temp.	Rain (Inches)	PAR
00:01	55	65	57		1.3
04:24	54*	63	57*		1.3
09:18	71	61*	60		874
11:49	92	62	69		1811
11:51	95	62	69		1401
12:13	84	62	70		973
12:50	95**	63	70**		1798
13:46	84	64	70		796
14:27	74	65	67		331
15:45	64	66	64		91
17:13[1]	60	66**	61	0.01	11.3
18:30	59	66	57	0.34	1.3
19:32	59	65	57	0.36	1.3
21:31[2]	60	64	59	0.07	1.3
23:59	61	63	59		1.3
DeltaT	41	5	13		

[1]First Recorded Rain; [2]Last Recorded Rain; *Low Temp; **High Temp

Table 6

atures then decreased throughout the rest of the day, with a final recorded temperature of 80°F resulting in a daily change of 55°F. On this same date, the temperatures recorded at the membrane started at 87°F, decreased to 82°F at 9:30 a.m., gradually increased to a high of 92°F at 6:30 p.m, and then decreased to a final temperature of 88°F, resulting in a daily change of 10°F. The air temperatures recorded on this date ranged from a low of 77°F in the morning, to a high of 92°F in the afternoon, and then back down to 79°F at the end of the day.

On July 25, 2004 (a date with one of the higher recorded temperatures - see *Table 3*), a rain event occurred during the daytime hours with significant impact on the temperatures. The temperature recorded at the surface of the soil started at the beginning of the day at 85°F, with increases of approximately 10 degrees an hour to a high temperature of 162°F at 12:51 p.m. The first recorded rain occurred at 2:30 p.m. and the recorded temperature at that time was 100°F. The temperature recorded at approximately 2:00 p.m. was 139°F (the weather was believed to be overcast at this time). The last recorded rain on this date occurred at 4:30 p.m. with a recorded temperature of 78°F. Within a 3-1/2-hour timeframe, the temperature at the surface of the soil dropped from 162°F to 78°F, or a delta T of 84°F. During this same timeframe, the tem-

Table 7

Time	Temp. at Surf. of Soil	Temp. at Membrane	Air Temp.	Rain (Inches)
00:01	61*	63*	59*	
10:09	67	63	61	
12:40	80	64	66	
14:15	72	65	69	
14:47	88**	65	71**	
18:47	67	67**	66	
23:59	63	66	61	
DeltaT	27	4	12	

TEMPERATURE READINGS
February 23, 2004

*Low Temp; **High Temp

peratures recorded at the membrane remained relatively constant throughout the day, starting at 93˚F, increasing to 96˚F, and then dropping back down to 87˚F at the end of the day, resulting in a delta T of 9˚F. The air temperature during this date ranged from an initial temperature of 85˚F, increasing to a high of 97˚F, and then decreasing to a temperature of 76˚F at the end of the day.

The temperature readings depicted in *Tables 4* and *5* represent two consecutive relatively warm days in August 2004 with similar results recorded, most notably the overall temperature fluctuation that occurred at the surface of the soil compared to the temperature change at the membrane.

Completed roof in 2003.

Similar results were also experienced during the cooler days. On January 28, 2004, the temperatures recorded at the surface of the soil ranged from a low of 31˚F to a high of 75˚F, while the recorded temperatures at the membrane ranged from 47˚F to 52˚F. (Air temperatures ranged from 38˚F to 55˚F. See *Table 8*.) The data depicted in *Tables 6* and *7* represent two consecutive days in February, when a relatively significant rain event (0.78 inches) occurred on the first day, and no significant impact was noted in the overall affect on the temperatures at the roof membrane on the following

TEMPERATURE READINGS January 28, 2004				
Time	Temp. at Surf. of Soil	Temp. at Membrane	Air Temp.	Rain
00:01	37	52	43	
02:30	37	51	40	
03:26	35	50	40	
04:20	33	50	39	
04:34	32	49	38*	
05:37	31*	49	39	
08:12	40	47	41	
09:10	47	47*	45	
11:44	70	47	53	
13:04	75**	48	55**	
16:16	60	52	55	
17:14	52	52**	50	
18:11	49	52	50	
23:59	49	51	49	
DeltaT	44	5	17	

*Low Temp; **High Temp

Table 8

day. However, cooler surface temperatures and a lower overall temperature fluctuation (delta T) were realized on the following day and most likely were the result of evaporation from within the growing medium.

Based on information gathered from recorded temperatures, the roofing/waterproofing membrane remained at a relatively constant temperature throughout the day (regardless of outside ambient air temperature and weather) with minimal fluctuations. The temperature at the membrane also remained constant with little, if any, impact from sudden weather changes such as cloud cover or precipitation as was experienced (and expected) at the surface of the soil. The temperature at the membrane also did not appear to be impacted during the warmer times by the moisture level of the soil (day after rain event).

Summary

With the installation of these technologies, project personnel are hopeful and anticipate that benefits will be multiple for many years to come and that these same practices can be implemented on other buildings for this and other building owners. The primary benefits expected and already experienced by the owner include heat load reduction, roof membrane protection, and water run-off control. Other benefits provided by this garden roof include assisting in improving the air quality, creating green space, offering an instrument for education, and increasing public awareness.

Overview of roof in 2005.

Karl A. Schaack, RRC, PE

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