WATER INDEPENDENCE: A PATH TAKEN

Joe Webb[1]

INTRODUCTION

The most prevalent questions we encounter regarding green roofs are: What drove this decision? Why an intensive green roof? What are the benefits such a constructed and constrained feature can provide? What did we discover? What changed? Is there a premium? Is the green roof a true contributor to a process?

These questions give rise to the underlying issue of resilience. Resilience is the result of individuals interacting with their environments and the processes that either promote well-being or protect them against the overwhelming influence of risk factors. Resilience and water are intertwined.

First, a short bit of history. Our experience with green roofs began in 2005 and has resulted in five buildings—ranging in size from roughly 48,500 square feet (4,506 m^2) down to 5,000 square feet (465 m^2)—creating an aggregate of 1.6 acres (.648 ha) of intensive green roofs. Another acre plus of green roofs is currently in various stages of permitting, initial planning, schematic design, and construction documentation. Construction on our next roof is scheduled to be complete in June of 2013. All of our green roofs are in the Houston region.

KEYWORDS

green roofs, water conservation, long term operating costs, healthier interior environments, stormwater retention, water independence, Living Building Challenge

What initially drove this desire to incorporate green roofs into the design of our newest commercial buildings? The initial answer: long-term economics; energy costs; decreased water usage and demand; and the influence on our personal well-being. That may seem odd when the common perception is that green roofs are expensive to install and maintain. Our client's objective was to control long-term costs in the operation of his buildings. How? The roof is the most exposed and vulnerable face of the envelope surrounding any building. Sun, wind, and rain assault the roof surface on a daily basis with usually nothing to mitigate those elements. Walls at least have the benefit of building orientation, shade, sun position, prevailing winds, and intervening structures. Roofs tend to be completely and totally exposed. When a roof is shaded by other structures in an urban environment, the benefit is for only part of the day and the wind issues created by that same environment add another set of challenges. Protecting that face of the most exposed facet of the envelope is what a green roof does best. Roof life alone could extend as far as forty years into the future.

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Returning to the initial premise of economics, we have documented to our clients the savings in not only long-term operating costs, but also initial equipment investments, and therefore initial overall investment. This is the attention-getting portion of the answer to the question—what drove the decision? To best describe this part of the answer, we provide the example of our mirror pair of professional medical office buildings constructed in Webster, Texas. Each has an almost 16,000 square foot (1,487 m^2) intensive green roof. The first building's lessening of solar radiation and evapotranspiration impacts were calculated at 76 and 68 tons of HVAC capacity respectively, meaning we could eliminate that quantity of tonnage of equipment capacity. The engineering consultants were skeptical—unconvinced is a better term—of our initial calculations that established significantly decreasing projected equipment capacities necessary for this building to perform appropriately. The engineered response to the standard loading conditions resulted in a 250-ton, multi-stage chiller. That installed 250-ton capacity air-cooled chiller, as of this date, has only activated 120 tons at any given time, including during last summer's string of thirty-plus 100° F (38° C) days. Intriguingly, that installed unit turned out to be a direct beneficiary of our green roof's performance. Unbeknownst to both the client and the mechanical contractor, the ten-stage chiller at one point only had six operating chiller sections for an extended period of time. A duty cycling pattern evolved that led to discovery of defective controls on four of the units. The load removed thanks to the green roof allowed the chiller to operate and maintain the proper conditions for the building while certain segments of the equipment had failed. Repeating those calculations for the mirror twin building with that greater understanding of the roof's impact, the new engineered response was a 140-ton capacity chiller. A significant downsizing in equipment capacity—therefore a significant cost decrease—was provided for our client. Not only has that second, smaller system functioned well and efficiently, that same building incorporated a 9,000 square foot (836 m^2) controlled manufacturing environment (think level 100,000 clean room) for the medical research and development tenant without negatively impacting the in-place, smaller HVAC system. Thanks to this documented example, followed now by subsequent projects, we have a working pattern methodology for future development and reasonable expectations regarding economic performance, initial costs, and operating costs.

A second facet of the benefits of our usage of green roofs evolved from our initial understanding of the potential for water conservation and stormwater retention. From our initial research, we understood how green roofs had the potential to greatly decrease the flow of rainwater from our sites into the local storm systems. With more research, we began to understand not only the economic impacts but the ecological. What we did not anticipate was the significant impact this premise would have on our approach to designing buildings. Yes, saving energy is important for many reasons, but understanding the value of water and using—and reusing—it wisely and efficiently while significantly decreasing demand has provided us a new focus.

That third part of our initial premise—influence on our personal wellbeing—is best exemplified by the experience of one of the physician tenants in our first building. The doctor has historically suffered from allergy issues that are exacerbated by our Gulf Coast humidity and "anything grows" climate. When she is in her office on the third floor of that first building, her allergy issues completely subside. The combination of a tight building envelope, filtration, CO_2 monitoring and controls, and consistent interior temperature, work together to provide a healthier interior environment. Our green roof impacts each facet.

Prior to continuing, we need to establish certain terms and definitions that will be helpful in understanding the processes and calculations that we will be presenting as this document proceeds. Here are some key words to remember and understand:

Evaporation—accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies.

Transpiration—accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

Evapotranspiration—a key element or part of the water cycle; describes the sum of evaporation and plant transpiration from the Earth's land surface to the atmosphere.

Acre-foot—a unit of measure denoting one acre of ground (a chain (60') × a furlong (660')) × one foot depth of water equaling 325,851.4 gallons (1,233,482 l). That quantity has been historically visualized as the amount of water a *suburban* family household will use in a year.

1 kilowatt hour (kWh) = 3,413 British thermal units (Btu)

Evaporation—1 gram of H_2O = 580 calories

1 Btu = 252 calories

1 ton = 72,576,000 calories

1 gallon = 3,783 grams

1 cubic foot (cf) = 7.4805 gallons

Intensive green roof—soil depths ranging from greater than 6" (15 cm) in depth and typically average around 12" (30 cm) in depth, yet can go much greater.

Extensive green roof—soil depths ranging from roughly 2" (5 cm) in depth up to 6" (15 cm) in depth, most often in a removable tray type container system.

Green roof—vegetated roof assembly

These definitions will prove timely as we discuss calculations and design for energy, economics, and water, yet I feel the need to illustrate why we changed our primary focus of energy savings to one that equally balances the case for water independence.

My research led me to the following statistics regarding water and the planet. Seventy-five percent of the surface of our planet is water. Twenty-five percent of the surface of the planet is dry land. Of that 25%, 50% is habitable and of that 50%, 50% is arable. That calculates out as 6.75% percent of the surface of the planet is arable. That small quantity is where we work to feed our planet. We have a population of roughly seven billion people and growing. Ninety-eight percent of our water is in the oceans. Two percent of all the water around us is fresh, but 1.6% is locked in polar ice caps and glaciers and .36% is underground in aquifers and wells. That leaves us with 0.036% that is actually found in rivers and lakes.

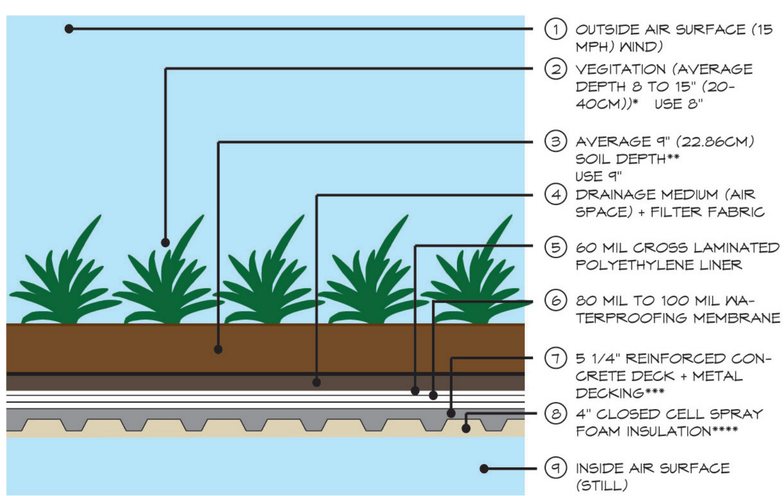
While I must admit I can visualize many concepts and constructs, that small a percentage of the vast quantities of water on earth is a stretch to truly understand. I ran across a very simple way of conceptualizing this minute quantity. We all know what a Toyota Mini-Van looks like with its myriad cup holders. Take a standard 20 oz. (592 cc) water bottle and place it in one of those cup holders. Now you have a reasonable facsimile of the volumes of the water found in rivers and lakes and the mass of the planet. While most of us have concerns regarding fossil fuels, very few of us understand the issue of potable water, access to that potable water, and the growth of the planet's population. Daunting might be too soft of a word. And yet, the good thing about water is that it is in a constant cycle—we never lose it. Water is in the air, the oceans, rivers and lakes, plants, ice caps, and our own bodies. But having it where we need it, when we need it, is the unpredictable and sometimes irresolvable part of the larger equation.

Complicating the urgency for understanding the need for water conservation, 2% of the surface of the earth is comprised of cities. Those cities account for 53% of the population of the Earth—and cities are growing. A disconcerting side note to this set of statistics: 35% of the residents of our cities live in slums with minimal or no services—i.e., no running water, sewage conveyance, or storm water controls.

Understanding why we chose the type of green roof used in our designs is a necessary next step in our progression toward water independence and our ultimate quest of net zero water, with the significant added benefit of energy use reduction.

We chose the intensive green roof approach thanks to our research of roof systems, waterproofing, plant media, and constructability. Intensive green roofs involve a systematic approach to plants, planting media, waterproofing, and structure, yet are not a "system" as is typical in the assemblies encountered in most extensive green roofs. The best visualization of an intensive green roof is imagining your back yard—or front yard—placed on the roof of a building. Intensive green roofs provide for greater choices and sizes in plantings, better insulation properties, more complicated water barrier maintenance, less wind challenges, and significant storm water management, while requiring a more robust structure for support.

Our intensive green roofs are based on one cross section of construction in which the only variables are the depth of the soil medium and the location of supplementary building insulation. Only our first green roof has insulation above the plane of the structural roof system; the following roofs have insulation located below the roof structure. The cross section of our roofs follows this pattern: 1) plantings; 2) soil medium varying from a minimum of 8" (20 cm) to a maximum of 12" (30 cm), averaging 9" (23 cm) in depth; 3) a drainage/filter media that incorporates a water retention membrane; 4) waterproofing system one consisting of a 0.06" (1.5 mm) thick reinforced, loose laid membrane; 5) waterproofing system two consisting of a 0.08" (2 mm) water-based, asphaltic spray applied membrane; 6) structural roof deck that is a 5½" (14 cm) thick composite concrete/steel deck; and 7) 4" (10 cm) of open or closed cell, water borne, spray applied insulation.



Drainage of a green roof is as critical as waterproofing. We have taken two approaches: first, all internal drainage within the perimeter of the roof boundaries; and secondly, all drainage occurs outside the building envelope. Three buildings have used the all-internal approach and two have used different variations of outside the building envelope. Our upcoming new buildings are all taking the internal drainage approach, hence our focus in this document. Key factors to remember in using internal drainage: slope and distance traveled. We use an absolute minimum of 1/4" (6 mm) slope per foot on all our roofs and try to assure we do not exceed 1/2" (13 mm) per foot in order to maintain proper water movement across the roof. Being in Houston, where rainfall rates within the city can range from 49" (124 cm) at IAH Bush Airport in north Houston, to 54" (137 cm) at Hobby Airport in south central, and 64" (163 cm) at Pearland Regional Airport immediately south of the city and closest to three of our buildings, roof drainage must be taken seriously. We typically double the quantity of internal roof drains accompanied by their emergency overflow drains normally required for roofs of our size and complexity. This is driven by two factors: very inexpensive assurance that the roof will drain consistently with minimal effort across the shortest distance and the actual depth of our drainage media. Our drainage media, which has been in use in the United States for over thirty years and over forty years in Europe, depth is about ¾" (18 mm). So once our soil media has reached saturation and then begins discharging water our channel to move water is actually rather shallow. Slopes and locations of drains become very important.

Placing roof drains more frequently within our roof landscape clearly enhances our ability to drain the roof. Another facet of green roof construction that facilitates not only drainage but maintenance is the juncture of the soil media and the drains, or any fixed object on the roof, be it a piece of equipment and its support pad or the parapet. We accomplish this by maintaining a consistent non-vegetated zone, typically 18" to 24" (46 cm to 61 cm) in width around or along those items on the roof. Currently we use lava rock due to its light weight and water absorptive characteristics. We are pursuing alternatives because lava rock is not the friendliest of walking surfaces and has the potential to become an airborne projectile in high winds, even though our experience does not support that particular theory. The reasoning for the non-vegetated perimeters is based on ease of maintenance. The most problematic and recurrent roof leak issues center on changes in direction of the roofing membrane and the flashing of that membrane to another surface. These are the areas where our non-vegetated zones occur, allowing easy access for repairs in event such is needed. In the instance of our roof drains, which are exposed, the non-vegetated zone allows an additional filtration/settlement zone for any water-borne material to be removed prior to entering the drains.

And lastly, the composition of our soils medium was driven by our dual needs to support plant stock and address the roof's fully-saturated weight limitation. Our soil design took into account our current, purposely limited, plant preferences and their specific needs regarding soils depths and types, moisture, and nourishment. But more importantly our soil mixture addresses our self-imposed, fully-saturated weight criteria. Our target is thirty pounds (14 kg) fully saturated. Our soil medium consists of expanded shale, leaf mulch compost, enriched loam, and two particular organic soil additives for nourishment.

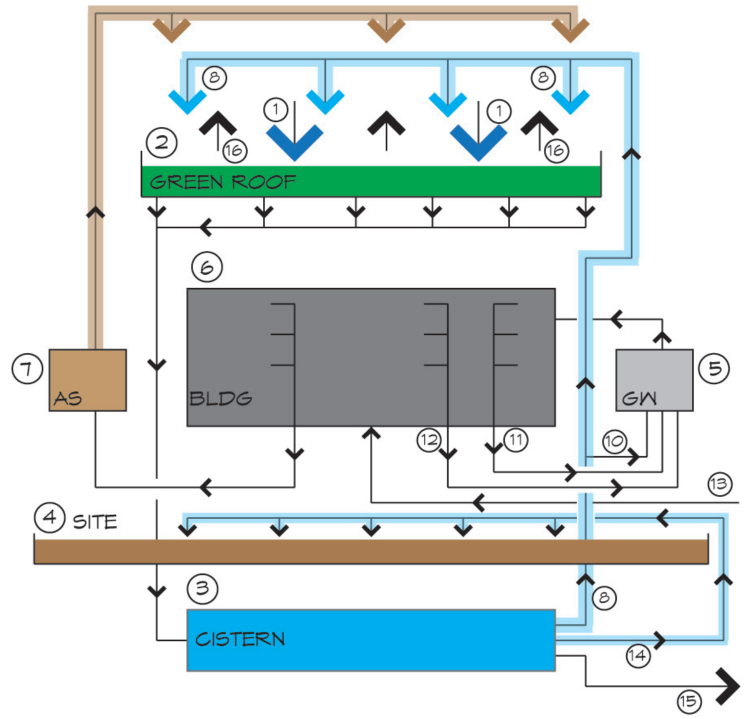
While we understood from the outset the potential for storm water impacts of the green roof we did not fully comprehend the holistic impacts. Each of our designs incorporates a cistern that will allow us to detain and retain storm water. Those designs provide both above- and below-ground solutions and provide the capability on each project to completely eliminate the need for an irrigation connection to any public water supply. All landscape irrigation—including the green roofs—is supplied by each building's cistern. Those cisterns range in size from 28,000 gallons (105,991 L) to 395,000 gallons (1,495,238 L). During Houston's drought conditions in 2011—six months without rain (25+ inches (64+ cm) behind our normal) along with a record thirty-nine days with temperatures exceeding 100°F (38°C)—our cisterns still maintained sufficient capacity thanks to our recycling design efforts. Our newest cistern design has grown in size thanks to the inability of the local storm system to absorb even our minimal outflow. That system will hold underground, cleanse, and reuse over 465,000 gallons (1,760,217 L) of stormwater. Not only do we decrease this new site's water needs but we significantly lessen the impact of our new development on an existing storm system. We are able to make the case to our clients that new development is possible even in areas that have restrictions or serious challenges.

The following diagram—a water map of our Gulf Freeway Office Building—provides a visual illustration of how the following data enlightened our comprehension of the real impact of our efforts on the local and regional environment.

- Green roof retains 73% of all rain that hits that roof—330,000 gallons (1,249,186 L)/year
- First inch (2.54 cm) of rain is totally held within the soil mixture on the roof
- Green roof sheds 27%—133,000 gallons (503,460 L), sending water to our underground cistern
- Underground cistern holds 395,000 gallons (1,495,238 L)
- Collect condensate from air handling units—in excess of 85,000 gallons (321,760 L)
- Gray water system collects 2,500 gallons (9,464 L) from lavatories and drinking fountains every two days supplemented by condensate and cistern
- Green roof serves as aerobic septic system spray field for 500 gpd (1,893 L) system
- Site is 1.6583 acres (.671 ha) and retains or detains 2.238 acre feet of water
- Site discharges less or no greater than the original undeveloped site and discharges filtered storm water when it does discharge.

We created our water map in order to communicate how our system's overall process operates. We can clearly demonstrate to our clients, regulatory authorities, and peers how captured stormwater becomes an asset. Once again, visualizing the process becomes a step to be conquered. Understanding how an almost closed system does not run out of water in the case of atypical conditions becomes an invaluable tool towards clarifying the benefits of the costs invested. Water from multiple sources is captured once and gets reused multiple times and in multiple venues.

Our initial efforts at understanding the payback on costs associated with the cisterns and necessary equipment to supply irrigation systems, based on current city of Houston water costs, was ten to fifteen years for above ground based systems. We are now factoring into that equation the diminished stormwater fee costs and seeing a small change of roughly one year less to payback based on today's cost. For our analysis relating to underground storage systems, the results become even more significant. Our latest project, in the permitting process for the first of three buildings, allowed us to prove to the client the payback for such a significant investment in an underground cistern. Each of the three buildings will hold 465,000 gallons (1,760,217 L) in their own separate underground cistern. Had we not taken this approach, the client would need to acquire an additional 1.22 acres (.4964 ha) of land in order to create a new detention pond incurring maintenance and property taxes for the life of the project.



1 RAINFALL:

2 GREENROOF:

3 CISTERN:

4 SITE:

5 GRAY WATER:

6 BUILDING:

7 ON SITE WASTE WATER SYSTEM:

8 IRRIGATION:

9 AEROBIC SYSTEM SPRAY FIELD:

10 IRRIGATION: SUPPLEMENTATION OF GRAY WATER SYSTEM:

11 GRAY WATER SOURCE:

12 GRAY WATER SOURCE:

13 DOMESTIC WATER SUPPLY:

14 IRRIGATION:

15 CISTERN DISCHARGE:

16 EVAPOTRANSPIRATION:

Add to this the indignity of having prime property not being used at its highest and best use. The acquisition cost alone for the additional land would have added almost $750,000. The approximate cost of the three cisterns is projected at under $1,300,000, based on the first unit's cost. Maintenance for the cisterns is minimal, consisting of annually insuring the viability of the filtration section and the monthly maintenance of 1.22 additional acres of land. Add property taxes on escalating land values to the equation and underground retention/detention becomes not only viable, but imminently justifiable. And in the instance of our Gulf Freeway site, taking the approach of creating a detention pond would have necessitated acquiring an additional 1 acre (.4047 ha) of land, almost doubling the tract size in a case where the additional land was not available.

What began as a response to conditions on a site that had no public sanitary sewer access (even though located adjacent to a major freeway within the City of Houston), our Gulf Freeway Office Building resulted in a building that incorporates many features addressing water inputs, outputs, and storage towards meeting the water imperatives of the Living Building Challenge. The gap analysis between our Gulf Freeway building design and the Living Building Challenge requirements include the processing of water for potable use on-site for a true closed-loop system, which was not allowed by state law until a significant change in 2011, and some potential minor additional capacity to respond to dry seasons that is discussed later in this document.

The Gulf Freeway Office Building is our fourth office building where the intended outcome is to design and deliver an asset to our client that consumes energy at a level 50% percent below that of his currently owned office facilities of similar size and complexity, along with our new focus of water independence. The Gulf Freeway Office Building was also part of our ongoing education toward simplifying the process, exploring materials and methods, and subtly refining how we achieve our goals. One key, yet unique, common thread running through each building is our usage of an intensive green roof and the associated water cycle.

The first three office buildings, while serving as our learning curves, all have achieved—even exceeded—our desired outcomes. The first and third buildings are 48,500 square foot (4,506 m^2) three story office buildings located in the medical center area of Webster, Texas. Cheyenne One (the first building) is primarily medical offices in support of the immediately adjacent regional hospital and tertiary medical facilities. Cheyenne One survived Hurricane Ike, with recorded winds of roughly 120 mph (193 km/h) (gusts to 140 mph (225 km/h)) and over 11" (28 cm) of rain with no damage or impact to site, building, or green roof. This building has been in operation and occupied since late 2006 and is now fully occupied. Cheyenne III (the third building) is a mirror twin of Cheyenne One and is home to a single tenant researcher and developer of specialty medical devices and incorporates a controlled manufacturing environment encompassing one-third of a floor. Cheyenne III has been occupied and in operation since the third quarter of 2008. Jacob White Offices (the second building) is a one story, 10,001 square foot (284 m^2) office building that serves as the headquarters for our client's operations. This building has been occupied since early 2009. Each building is LEED

certificated and has admirable Energy Star scores. The lowest score on the Energy Star scale of the four buildings is 94. The Gulf Freeway Office Building, Cheyenne III, and the Jacob White Offices have all obtained LEED Platinum certification. The remaining buildings are targeted at LEED Gold and Platinum. Our new buildings are targeted at LEED Platinum.

Our focus and most aggressive approach to water independence to date, the Gulf Freeway Office Building, is a two-story, core and shell office building of 24,084 conditioned square feet (2,238 m^2) situated on approximately 1.683 acres (.671 ha). It has parking for ninety-one cars, including dedicated carpool and low-emission vehicle parking plus bicycle racks. The site is immediately adjacent to a Metro (Metropolitan Transit Authority) park and ride facility that reaches to multiple connecting bus lines and the city's light rail system. As a professional-oriented office building being completed in May of 2010, it is now fully leased. The overall site has approximately 44% of the land area that remains permeable while providing sufficient parking at grade. A minimum of 50% of that parking area will be shaded thanks to tree canopy coverage, bringing welcome relief in Houston's long summers.

Integral to the building is a 15,781 square foot (1,446 m^2) intensive green roof of a minimum 10" (25.4 cm) depth supporting regionally native plantings. The roof retains 73% of all rainfall that strikes the surface while providing a roof with an R value of 66. Additionally, the roof will remove approximately 650 pounds (295 kg) of airborne particles every year and produce enough oxygen per day for 975 people. Thanks to our continued work with green roofs, we have developed a methodology that allows us to understand the evaporative cooling capacity of our roofs on a monthly basis along with solar radiation mitigation. The Gulf Freeway roof at its peak performance provides the equivalent of 65 tons of HVAC capacity offset thanks to evaporative cooling effects and 79 tons due to solar radiation mitigation. The decision to incorporate a green roof, especially an intensive green roof, in this and the other buildings has been borne out in our experience on the four buildings. The savings from the evaporative cooling calculations equates to a high of $798.60 per month in June, with a low of $482.67 in December, and the savings from the solar radiation shielding equates to a high of $658.34 per month in June, with a low of $227.88 in December.

Evaporative Cooling Capacity - Green Roof — 08019 - Gulf Freeway Office Building, 12941 Gulf Freeway

1 kWh = 3413 btu
Evaporation - 1 gm of H2O = 580 calories — 1 btu = 252 calories - 1 ton = 72,576,000 calories — 1 gallon = 3785 grams
6.4mm = 1/4" — 7.4805 gallons/cf

to offset solar radiation received by roof based on monthly average daily direct solar radiation, 30 year average at JSC/NASA

green roof area	15741											
Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Ave direct solar radiation in kWh/m2/day	2.79	3.39	3.57	3.79	4.1	4.55	4.43	4.39	4.15	4.34	3.44	2.75
Ave direct solar radiation in btu/sf/day	884.6189	1074.86	1131.932	1201.687	1299.978	1442.658	1404.61	1391.927	1315.831	1376.074	1090.713	871.9362
converted to calories/sf/day	222924	270864.6	285246.8	302825	327594.3	363549.8	353961.7	350765.7	331589.4	346770.6	274859.6	219727.9
converted to grams/sf/day	384.3517	467.0079	491.8048	522.1121	564.8178	626.81	610.2788	604.7684	571.7059	597.8803	473.8959	378.8412
resultant gallons per day overall roof	1598.436	1942.185	2045.31	2171.352	2348.956	2606.768	2538.018	2515.101	2377.602	2486.456	1970.831	1575.519
required evaporation in feet	0.013575	0.016494	0.01737	0.01844	0.019949	0.022138	0.021554	0.02136	0.020192	0.021116	0.016737	0.01338
mm	4.137588	5.027391	5.294333	5.620594	6.080326	6.747679	6.569718	6.510398	6.154476	6.436247	5.101542	4.078267
equivalent tons of ac avoided	48.34995	58.74779	61.86714	65.67968	71.0519	78.85028	76.77071	76.07752	71.91839	75.21103	59.61428	47.65676
equivalent power saved in kWh	4080.736	4958.313	5221.587	5543.365	5996.78	6654.963	6479.448	6420.943	6069.912	6347.811	5031.445	4022.231
cost savings at 0.12/kWh	489.69	595.00	626.59	665.20	719.61	798.60	777.53	770.51	728.39	761.74	603.77	482.67

anticipated evaporative cooling based on average monthly Eto (inches/month) based on climatic data over entire record period available from NWS

average monthly Eto (in inches)	2.36	2.83	4.32	5.01	6.11	6.57	6.52	6.08	5.57	4.28	2.9	2.35
resultant inches/day	0.076129	0.101071	0.139355	0.167	0.197097	0.219	0.210323	0.196129	0.185667	0.138065	0.096667	0.075806
converted to gallons/day over roof	747.0196	991.768	1367.426	1638.695	1934.021	2148.948	2063.8	1924.525	1821.863	1354.764	948.5461	743.8543
equivalent tons of ac avoided	22.59607	29.99929	41.36229	49.56773	58.50084	65.00199	62.42642	58.2136	55.10823	40.97931	28.6919	22.50032
equivalent power saved in kWh	1907.108	2531.94	3490.977	4183.516	4937.47	5486.168	5268.79	4913.228	4651.135	3458.654	2421.596	1899.027
cost savings at 0.12/kWh	228.85	303.83	418.92	502.02	592.50	658.34	632.25	589.59	558.14	415.04	290.59	227.88
resultant kBtu/sf (of building per day)	4.44571	6.534659	8.13791	10.07738	11.50987	13.21525	12.28222	11.45336	11.2038	8.062559	5.833216	4.426872
average resultant kBtu/sf	8.9319											
resultant cost savings/sf	0.11											

Cheyenne One incorporated a multi-stage, air-cooled chiller of 250 tons, as none of us fully appreciated or comprehended the roof impacts (hence our creating our evaluation methodologies in support of our initial calculations)—in particular our consulting engineers. To date that system has yet to activate no more than 120 tons of capacity. Cheyenne III, thanks to what we learned from our first building, incorporates a 140 ton, air cooled, rotary scroll chiller. This building also incorporates a unique area for specialty medical device manufacture into its mission—a controlled manufacturing environment with strict temperature, air quality, and humidity controls—that has yet to present any performance issues to the entire building system. At Cheyenne One—and each following building—we have had sensors in place since the activation of each building feeding data into our building management systems. Temperature sensors are located in the air above the green roof, buried mid-depth in the soil mixture, and a final sensor at the bottom of the soil mixture immediately above the drainage/filter media. Here are the trends we have come to expect, using as an example a summer air temperature in the low- to mid-90s range. The mid-depth sensor typically reads temperatures in the mid-80s range and the base sensor typically reads in the low 80s or upper 70s. Moisture content directly impacts these ranges. As a result, our HVAC systems only have to address a temperature differential of ten to fifteen degrees at the underside of the roof. Our current analysis endeavor encompasses filtering through the last two years worth of data on Cheyenne One towards identifying a pattern of how heat through the roof is mitigated. Those sensors above the green roof, mid-depth, and just above the concrete deck are tracking temperatures 365/24/7 every twenty seconds. Significantly less air tempering is required than a typical office building with a single-ply roof over a structure with normal insulation values.

More importantly, we are combing the summer/winter of 2011 statistics in order to better understand how our green roofs and cisterns weathered our record drought and heat. We will be evaluating for heat patterns and the mitigation of heat, along with the impacts related to irrigating our green roofs.

Looking beyond the energy impacts, we reduced stormwater run-off, improved water quality, reduced the heat island effect, conserved energy, reduced sound reflection, created wildlife habitat, and improved the aesthetics of the roof proper. Secondly, we have extended the life of the roofing membrane—potentially to fifty years—since we provide protection from UV rays, extreme temperature swings, and harmful pollution. Thirdly, we have brought additional value to the project. Research, we have seen of late by Ray Tomalty and Bartek Komorowski for the Canadian Mortgage and Housing Corporation (CMHC), in their document "The Monetary Value of the Soft Benefits of Green Roofs," has developed methods for estimating the benefits that green roofs provide towards increased property values, confirming our previously held beliefs that what we do adds value to our client's projects.

Supplementing not only the roof but providing all site irrigation—the Gulf Freeway building and all of our buildings have no connection to city potable water for irrigation—is an underground cistern that holds approximately 52,804 cubic feet (395,000 gallons) of water in addition to providing detention for storm events on site. That cistern is a network of 48" diameter piping situated below the parking areas. We not only hold two two-year events, but we discharge at a rate equal or less than the original undeveloped discharge of the site. The cistern system can also supplement the building's gray water system if it becomes a necessity.

The building envelope is faced with Portland cement plaster on the exterior. The use of vapor barriers and 100% water-blown, spray-on, closed-cell foam insulation within a 6" thick frame, provides an assembly with a minimum R value of 26 and the ability to achieve 0.001 air

changes per hour at natural pressures, effectively eliminating energy losses due to infiltration/exfiltration. The eastern, western, and southern faces all have sheltered balconies at each floor providing effective solar shading of glazing. The structural framing system is a composite design steel and reinforced concrete. The steel is 100% recycled material and the Portland cement uses a certain percentage of fly ash. Glazing, which comprises approximately 39% of the building's exterior skin, uses 1" (2.54 cm) tinted, insulated glazing with a low-emissivity coating and a U value of 0.33, no UV transmittance and solar heat gain coefficient of 0.15. Ninety percent of the occupied portions of the building will have access to daylight.

What does this mean for energy usage? Here are our results for the Gulf Freeway Office Building:

Energy Use Intensity (EUI) = 81kBtu/sf/yr.

Percent CO_2 Reduction = 54%

Energy Star Design Rating = 95

Annual Savings Statistics:

Energy Savings = 2,700,000 kBtu

CO_2 Savings = 143 metric tons CO_2

The building systems incorporate an electric traction, guide rail mounted power unit elevator requiring only a 6.7 HP (4.93 KW) motor, no machine room, and integral electronic logic controls. HVAC systems consist of a roof-mounted, air-cooled, non-CFC, variable load stepping rotary scroll chiller of 100-ton capacity with twin air handlers per floor using MERV 13 filtration along with UV-C light air purification. The air handlers all incorporate variable frequency drive motor controls. The outside air is one hundred (100%) percent pre-treated and pre-filtered prior to entering the envelope. CO_2 sensors are incorporated allowing the digital monitoring and control systems to maintain a level of no greater than 750 ppm while optimizing indoor conditions and air quality.

All plumbing fixtures are (tenant fixtures are and will be) low water usage fixtures. The previously alluded to gray water system also recycles condensate water (roughly 84,000 gallons (317,975 L) per year), plus water from lavatories and drinking fountains. After treatment and coloration, the reclaimed water is used in the flushing of toilets and urinals. The building is the first commercial reclaimed (gray) water system approved by the City of Houston. The location of the site is such that the City of Houston has no sanitary sewer service available in spite of being immediately adjacent to a major freeway system and having adjacencies to commercial retail, restaurant, and multi-family uses. The inability to obtain public sanitary sewer service necessitated on-site treatment through the use of a commercial grade aerobic system that uses the green roof as its spray field. Admittedly, this was a benefit of a green roof that we had not anticipated. This usage of a green roof as a spray field is the first approval of such a system by the Texas Commission on Environmental Quality (TCEQ).

Low- to no-VOC finish materials have been used throughout the core and shell. Their usage is required in tenant build-out construction, as established in the tenant construction guidelines and manual. Construction-phase recycling of steel, aluminum, wood and paper products, and plastics occurred and will be required in tenant build-out processes. The building is a no-smoking facility and as mentioned earlier has MERV 13 level filtration at the air handlers and the outside air pre-treatment unit plus UV-C light treatment towards eliminating airborne bacteria. Environmentally-friendly cleaning materials are used in this building by the janitorial services as they are in each of the previous buildings. The Gulf Freeway building has an additional feature thanks to the extensive usage of anti-microbial touch surfaces that kills MRSA and other bacteria.

The Living Building Challenge offers a path toward more independent use of resources, including water. Our Gulf Freeway Ltd office building has incorporated multiple features addressing the differing types of water inputs, outputs, and storage. The site is an office building with surface parking. The facility has leveraged the roof and storm water systems to help capture and hold water. The intensive green roof retains 73% of all rainfall and the underground rainwater cistern holds 395,000 gallons (1,495,238 L) for irrigation and supplementing other uses. The cistern holds enough capacity to accommodate two two-year twenty-four hour design storm events (each at 4.5" or 11 cm). Additionally, grey water is captured from hand sinks along with HVAC system condensate for reuse within the building. The facility's black water is processed via an aerobic septic system and the constraints of the site led the team to obtain permission to put the leach field on the green roof as noted previously.

There are two requirements regarding water in the Living Building Challenge:

> Net Zero Water—One hundred percent of occupants' water use must come from captured precipitation or closed-loop water systems that account for downstream ecosystem impacts and that are appropriately purified without the use of chemicals.
>
> Ecological Water Flow—One hundred percent of storm water and building water discharge must be managed onsite to feed the project's internal water demands, or released onto adjacent sites for management through acceptable natural time-scale surface flow, groundwater recharge, agricultural use, or adjacent building needs.

The gap analysis shows that the gaps between the current design and the Living Building requirements include the processing of water for potable use on site for true closed-loop system and some potential minor additional capacity during dry seasons.

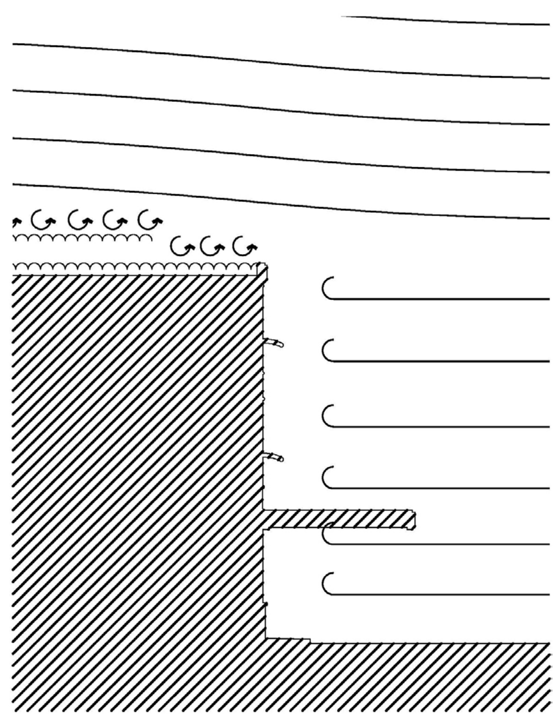
The holistic impact became readily apparent after hearing a colleague remind a seminar of architects of the impact of adding a single 55-gallon (208 L) drum size rain barrel at each residence in the Braes Bayou watershed—above the Medical Center in Houston—would have decreased the impact of Tropical Storm Allison in the medical center by twenty-five (25%) percent. That is a significant impact. Imagine the impact of green roofs similar to ours on just the commercial building stock. Now we begin to address the concept of resilience and begin creating water independence.

The wind facet of green roof performance, while significant, turned out to be simpler to address. Using an intensive form of the roof eliminated issues associated with the extensive roofs and their tray or container systems. Such systems, thanks to their shallowness—and therefore lighter weight—are more susceptible to wind uplift. The intensive roofs in section are similar to your front yard. Well-anchored and substantial, they resist wind issues similar to those of a typical front yard. Taking care to design the parapets and the building to acknowledge and accommodate that roof section results in decreasing or even negating wind impacts on our green roofs. What we did by trying to understand how wind works was move the boundary layer upwards to a point above the surface of the green roof and therefore not impacting any parts of that assembly. The following data highlight our performance to date in a significant wind event.

- Green roof survived Hurricane Ike with no damage
- Sustained 110 to 120 mph (204 to 222 km/hr.) winds—gusts to 140 mph (259 km) and 11 inches (27.94 cm) of rain
- Parapets at a height equal to or less than some plant material effectively raising the boundary layer to above the roof plane
- The photo to the right was taken 7 days after Ike passed over the building (eye of the hurricane passed roughly 5 miles (8.05 km) to the east).

The accompanying diagram illustrates how our assembly and design react to and respond to wind.

Finally, a few tidbits relating to our green roofs:



- Total R value of 66.235 for an average 9" (23 cm) soil depth
- On-going heat mitigation study—temperature probes in air 6" (15 cm) above green roof, mid depth, and at bottom
- Temperatures—in air: 95°F (35°C); mid: 85 to 88°F (29 to 31°C); bottom: 82 to 85°F (28 to 29°C). Data compilation in progress.
- Other benefits
  - Green roof produces enough oxygen for 975 people a year
  - Absorbs 643 pounds (292 kg) of airborne particulates a year
  - Estimated avoidance of 42,600 tons of CO_2 per year—the equivalent of 888 fully mature trees

Do our green roofs provide resilience? Understanding that resilience is part of a process that promotes well-being and protects against risks, and that our green roofs provide a prime asset in a cyclical system, the answer is an unequivocal yes. And what better way to exemplify promoting well-being than the creation of a healthy, secure habitat for not only us but our fellow wild creatures.

Returning back to the lead-in paragraph, I have worked through how we provide answers to our questions with our methods, designs, and constructed buildings, along with the results. Yet the question I have not specifically answered is—what is the premium? It is less than you imagine.

Our first building, Cheyenne One, once complete was roughly eight percent higher in construction cost than our client would typically spend on an equivalent size office building. Eight percent may sound substantial but when you look through the developer/owner lens that our client uses, the costs are well within the ultimate budget. His initial analysis projected payback on all systems attributable to being a "green" building at four years. That particular time scale was driven by the costs of the traction elevators. And remember this client builds to own—not sell—so as we noted earlier, he understands that his initial costs pale in comparison to the long-term operations and maintenance costs. He looks at his investments holistically and sees a strong financial reason to build sustainably. Our second and third green roof buildings allowed us to benefit from what we learned on the initial building. The second and third building costs were in the range from two to four percent above their equivalent sized buildings. He also understands the value of these unique properties and uses those assets in his marketing. Since he can control his long-term costs more effectively than most developer/owners, he can control expense stops that we all see yearly when we rent commercial space. Aware that he has this solid, financial underpinning to his projects, he can effectively prove to a tenant that lower expense facet, while at the same time charge a premium rent. Evidence to support this: each of his buildings is fully leased even in this era of uncertainness. So are green roofs a true contributor? The answer is an emphatic *yes!*

We have taken to heart the challenge of *Architecture 2030–The 2030 Challenge,* put forward by the American Institute of Architects: a reduction of 50% in energy usage and greenhouse gas emissions now and elevating the requirement every five years ending up with carbon neutrality in 2030. Each of our last four major buildings, and now a new smaller building, are all designed with features that have and will allow us to meet and/or exceed the 50% reduction on energy usage now. Each of our new buildings is targeted similarly. Our client on the Gulf Freeway Office Building understands the ultimate benefits for the community from his efforts. He continues to urge us to find other features or technologies that will keep us ahead of the curve in making his facilities operate more efficiently. And we continue in that effort. Another way of understanding his desires toward the intended outcome for Gulf Freeway—and for that matter each of his buildings—is expressed more pointedly by our client: "It's not just about doing the right thing and saving the environment; *sustainability is profitable."*

So in wrapping up, why should we build green? My client asked us to answer that question in an effort to help him prepare for a presentation on his approach to building sustainable structures. Here is what we gave him.

Most of us can list several reasons without hesitating. They are the somewhat obvious, easily imagined responses we keep at the ready. We should build green: to save energy; to sustain our and our children's lifestyles; to inflict less damage on our environment; to rid our inhabited realm of chemicals, additives and supplements that harm; to improve our living environments; to improve our mental well-being; to energize ourselves; to reduce our dependence on fossil-based fuels; and lastly, to save the planet.

All good but woven amongst these actions are results that will fundamentally change us. We have the opportunity to impact aspects of our daily lives that have more far reaching consequences than we currently suspect. Imagine working in a building that is healthier and therefore causes us to miss fewer days of work, school, and recreation. Imagine the positive economic impact on our businesses, educational systems, and even more significantly, our healthcare systems, when thanks to the environment we live in, we are ill less often. We actually want to go to work, to school, to socialize, to participate, to be a contributor. Imagine the impact on the quality of their lives when our children and our senior citizens are provided healthier environments. We encourage the next Einstein; we nurture our youth through the wisdom and experience of our active and engaged seniors. We live longer, healthier, fuller lives contributing much to our communities. All by simply considering how we build.