FIU FLORIDA INTERNATIONAL UNIVERSITY

Demonstration Project
Team Registration Number: D01

Smart Eco-Water Use:
Towards a Climate-Resilient Campus

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ABSTRACT

Florida International University (FIU), located in Miami-Dade County, has two campuses and an Engineering Center (EC) that rely on evaporative cooling towers and central chillers to maintain temperature and humidity inside buildings. From July 2017 to June 2020, the FIU EC used over 14 million gallons of utility-supplied potable water per year to make up for evaporative cooling losses in the campus central chiller plant with a cost of over $130,000 annually. Water is sometimes a limited resource, and the Water and Sewer Department (MD-WASD) promotes water conservation as a core ethic. MD-WASD has implemented water restrictions many times in past decades, with some permanent restrictions enforced year-round, as all area water is supplied by wells in the Biscayne Aquifer, which is being adversely affected by saltwater intrusion from population-driven pumping drawdown and sea-level rise. Our project proposes using remotely operated and self-cleaning rainwater harvesting systems to capture rainwater from solar panel canopies and green infrastructures such as green roofs and green facades to reduce demand for potable water and electricity at the EC while also improving the campus aesthetics. The project has multiple benefits, including flooding reduction during heavy rainfall and promoting carbon sequestration by using green infrastructures. This project and other EC components will showcase alternative energy and climate-resilience elements for tours by K-12 and college students on-campus and use augmented reality demonstrations and interactive activities at off-campus and virtual community events. Findings are transferable to commercial, institutional and industrial buildings relying on chilled water plants for cooling.

INTRODUCTION

As demands for resources increase worldwide, large educational institutions like colleges and universities need to adopt forward-thinking solutions to reduce the use of electricity and potable water, to minimize costs and promote sustainability practices. Rainwater collected from roofs can be a good alternative water source that can reduce the demand for precious potable water. Building roofs can provide the catchment surface for rainwater collection and implementation of rainwater harvesting systems (RHS). After working with the FIU Facilities Department, our team learned that the evaporative cooling towers located at the FIU consume more potable water than any other type of use at the university. Evaporative cooling towers and central chillers play a vital role in removing heat from large commercial, institutional and industrial buildings as they are far more efficient than air-cooled chillers. However, water losses from evaporative cooling in the towers increase the concentration of minerals in the water system loop, and scaling occurs, decreasing the heat exchange's effectiveness and damaging equipment unless the mineral concentration is controlled. Freshwater must be added to the cooling tower water system loop to make up for evaporative losses and part of the water in the cooling tower needs to be drained to decrease the concentration of minerals.

This demonstration project's top three objectives are to (1) use rainwater for cooling tower water makeup, reducing stormwater runoff on campus; (2) implement smart green roofs and green facades to mitigate the heat island effect and promote carbon sequestration and (3) decrease the temperature inside the building to save the campus electricity usage. Also, the smart green infrastructures will aid in public outreach and education, providing community learning opportunities. This project's implementation is expected to significantly reduce campus demand for potable water and electricity without compromising the cooling tower's performance and the comfortable temperature inside the buildings.

SITE CHALLENGES AND OPPORTUNITIES

Figure 1 shows the implementation area of the proposed Rainworks demonstration project. The proposed area includes four solar panel canopies with a total surface area of 1.95 acres (84,942 ft^2) and the FIU EC Operations/Utility (OU) building with a total occupied area of 0.57 acres. The total surface area of the proposed green infrastructures including the FIU EC OU building and the four solar panel canopies is about 4 acres, which is below the 15 acres maximum required for the Rainworks demonstration category.

The FIU EC is located in Miami-Dade County, Florida. According to the U.S Geological Survey [1], the Miami-Dade County location of the FIU EC can be characterized by distinct wet seasons, high rainfall, temperature, and evaporation rates. The average temperature between 1981 and 2010 was 76.9 °F and ranged from a low of 59.8 °F in January to a high of 90.7 °F in August. Average relative humidity in Miami ranges from a low of 67% in April to average highs of about 78% in September and October. Air conditioning is required 24/7 year-round for thermal comfort and for the control of indoor humidity, which must be maintained below 60% to avoid the growth of mold and mildew. According to the FIU Facilities Department, water supplied to the cooling tower was 14.62 million gallons between July 2017 and June 2018, 14.05 million gallons between July 2018 and June 2019, and 14.35 million gallons between July 2019 and June 2020. The corresponding water usage costs were $129,468, $131,529, and $138,156, respectively. Figure 2 shows that the rainy season coincides with the peak cooling season creating the opportunity to use rainwater to reduce potable water consumption by the cooling system.

Figure 1. Schematic of the implementation area on the FIU EC for the proposed Rainworks demonstration project

RAINWATER QUANTITY ANALYSIS

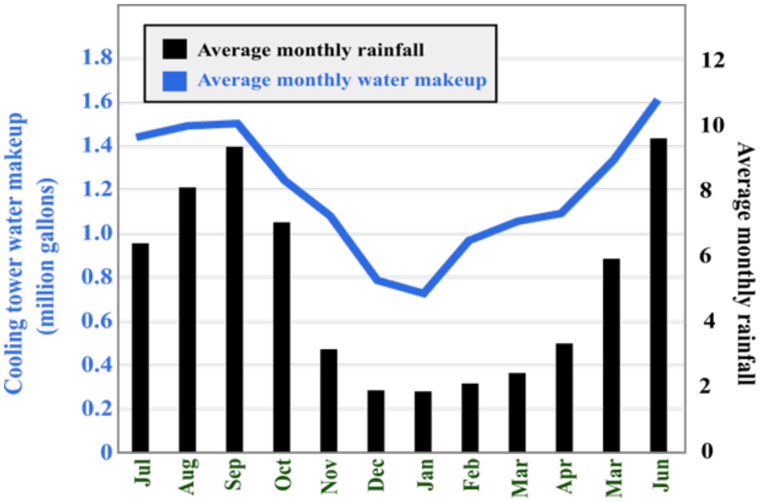


Figure 2. Cooling tower water makeup vs. average monthly rainfall.

The daily rainfall records between 1948 and 2017 for the Miami International Airport weather station were used in the rainfall analysis. This station was used because it is the closest to the FIU EC (3.36 mi).

According to the Food and Agriculture Organization (FAO) [2], the classification criteria to determine the hydrological year depends on the exceedance probability in a year. The hydrological year is classified as dry, normal, and wet when the exceedance probability in a year is 80%, 50%, and 20%, respectively. The frequency analysis steps are not shown herein due to space limitations.

A rainfall-runoff model is developed based on SWMM 5.1 to estimate the rainwater volumes harvested from the solar panel canopies. The rainfall hyetographs were developed for the three hydrological year conditions. These hyetographs are used as input data in the SWMM model. Moreover, the Rational Method (RM) is used for comparison purposes.

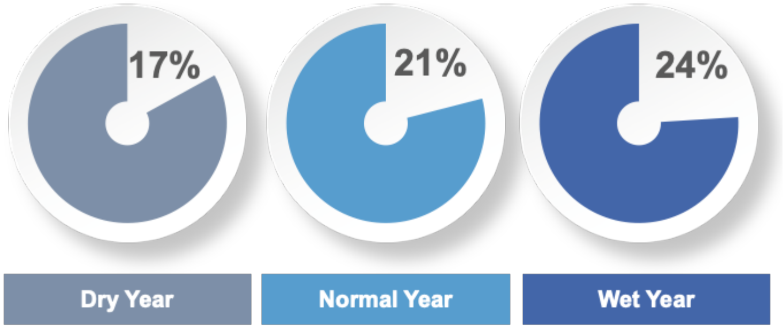


Figure 3. Proportion of rainwater to total cooling tower water makeup

Table 1 presents the rainwater volumes that would be harvested from the solar panel canopies for the three hydrological year conditions. Since the results obtained with the Rational method and SWMM are within 5%, the results calculated from SWMM were used for the analysis. The results in Table 1 show that 17% to 24% (Figure 3) of the total cooling tower water makeup can be satisfied by the collected rainwater. Such a significant amount of rainwater is worth harvesting to replace part of the potable water used for the cooling tower water makeup. By collecting rainwater, the annual reduction in runoff volume is expected to be between 2.57 and 3.58 million gallons (see Table 1).

Table 1: Rainwater volumes harvested from the solar panel canopies for the three hydrological year conditions

Year Type	RM (MG/yr.)	SWMM (MG/yr.)	Difference between RM and SWMM %
Dry Year	2.62	2.57	2
Normal Year	3.24	3.13	3
Wet Year	3.74	3.58	4

1. (MG/yr.) indicates million gallons per year.
2. RM indicates the Rational Method
3. Difference between models is calculated by (RM-SWMM)/SWMM

RAINWATER QUALITY ANALYSIS

Rainwater samples were collected directly from the surface runoff of the solar panel canopies. Since the first flush that runs off the solar panel canopies has different water quality from clean rainwater, our team decided to test these two different water types. According to the geometric parameters of the solar panel canopies, the time for the first flush is calculated as shown below by assuming sheet flow condition on the rooftop of the solar panel canopies [3],

$$T_c = T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}s^{0.4}} \qquad \text{Eq. 1}$$

where T_t is travel time (hr), n is Manning's roughness coefficient equal to 0.011 (smooth surface), L is flow length (ft) equal to 55 feet, P_2 is 2-year,24-hour rainfall (in) equal to 4.7 inches, s is the surface slope (ft/ft) equal to 0.10. The concentration time is 20 seconds. The area of a solar panel canopy is 21,725 square feet. Based on the rational method, the first flush volume is around 15 gallons. A runoff depth between 0.0079 to 0.079 inches is recommended for the estimation of the first flush volume [4]. Since the surface of the solar panel canopies is clean, the runoff depth of

0.0079 inches is selected. The calculated first flush volume is equal to 106 gallons, which is 7 times the result calculated by the rational method. Therefore, 140 seconds are recommended to separate the first flush and clean rainwater, and it is also used for the pre-set system timer for the remotely operated and self-cleaning rainwater tank system.

Table 2 shows our laboratory results for the water quality parameters for tap water and rainwater collected from the existing solar panel canopies and cooling towers. Column 7 of Table 2 shows the recommended ranges for target water quality parameters for cooling towers [5], [6]. The results in Table 2 show that the collected rainwater has significantly lower concentrations of TDS, calcium, and alkalinity than tap water and the water in the existing cooling tower.

Table 2. Laboratory results for the water quality parameters for tap water and rainwater collected from the existing solar panel canopies and cooling towers

Parameter	Unit	Tap water	Solar Panel[d1]	Solar Panel [d2]	Cooling tower[e]	Recmd for CT[f]	# of sample	Method
TSS	mg/L	-	76 [a1] (±46)	-	30-50	NA	7	Standard Methods[g]
	mg/L	-	23 [a1] (±8)	10 (±5)		NA	7	
TDS[b]	mg/L	135 (±6)	5 (±6)	8 (±8)	622-694	<1000	7	Machine[h]
pH	-	7.45 (±0.3)	6.5 (±0.3)	6.9 (±0.5)	7.94-8.84	6-9	7	Machine[i]
Calcium Hardness[c1]	mg/L	40.5 (±3.1)	<10[g]	<10[g]	250-428	30-750	7	HACH8204
Total Alkalinity[c2]	mg/L	65.6 (±6.0)	<10[g]	<10[g]	204-399	<500	7	HACH8203

a1. Total suspended solids measured using the rainwater collected from the first flash.
a2. Total suspended solids measured using the rainwater collected after the first flush.
a3. Stand method 2540D. Some of the equipment did not use without influencing the results due to the lab equipment's limitation.
b. Total dissolved solids, via Conductivity readings expressed in micro-Siemens and multiply 0.6 to convert into TDS.
c1, c2. Calcium hardness and total alkalinity are measured as $CaCO_3$.
d1. The water samples were collected from the solar panel without sand filtration.
d2. The water samples were collected from the solar panel with sand filtration.
e. The water sample was collected from the cooling tower.
f. The recommended value for cooling tower operation [5], [6].
g. Stand method 2540D. Some of the equipment did not use without influencing the results due to the lab equipment's limitation
h. Brand: HoneyForest, Model: YL-TDS2-A, range: 0-9990 mgL^{-1}, resolution: +/- 1 mgL^{-1}.
i. Brand: Thermo Scientific Dual Star pH/ISE/mV Meter Only, Model: Mfr#2115000, resolution:0.001.

According to the rainwater quantity results, rainwater supply cannot replace potable water as the sole makeup water source. Therefore, different blend ratios of sand-filtrated rainwater and tap water were analyzed to ensure the values of the water quality parameters are within the recommended range for cooling towers. Three blend ratios (sand-filtrated rainwater/ tap water), 15%, 20%, and 25%, were explored to assess whether the water quality parameters of the blended water are within the recommended ranges for cooling towers. Figure 4 shows that the values of the water quality parameters for the three different blends are within the recommended range for the cooling tower as shown in Table 2. Therefore, these three blends meet the cooling tower's water quality requirements.

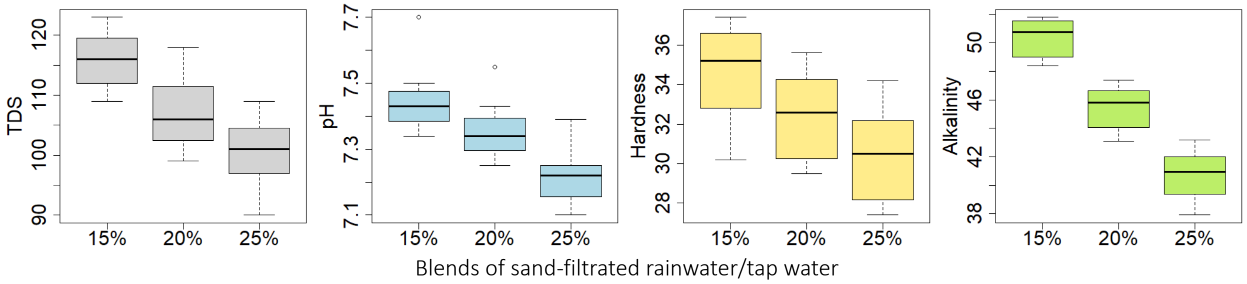


Figure 4. Water quality for different blends of tap and rainwater

RAINWATER HARVESTING SYSTEM DESIGN

Remotely Controlled and Self-Cleaning Rainwater Tank System

A traditional RHS often requires manual operation and maintenance[7], [8]. To overcome these limitations, we propose to integrate a remote control technology developed at FIU [9] into a traditional RHS architecture. This system is remotely operated and has an automated system for cleaning the sand filter.

The architecture of the remotely operated and self-cleaning rainwater tank system (ROSCRTS) is shown in Figure 5. The ROSCRTS can be broadly divided into four layers [11], namely, the decision-making system layer, Internet communication layer, automation control layer, and the rainwater tank system (RTS) itself with trigger components.

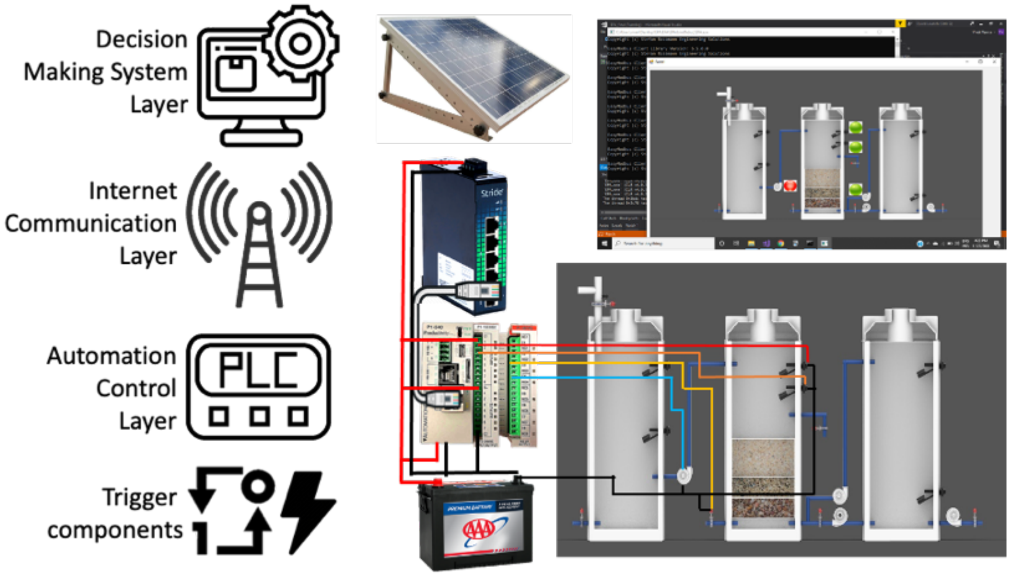


Figure 5. The architecture of the ROSCRTS (only parts of the wired connection is shown in the figure)

Our decision-making system layer is a graphic user interface (GUI) software developed in C#. This user interface displays the working status of each trigger component, and allows a manual or automated operation. In the manual mode, the user can control the individual components of the system. In automated control, the operation can be programmed to fulfill a desired set of conditions. The Internet communication layer has a virtual private network (VPN) router which uses a cellular network to interface between the decision-making layer and the automation control layer. The automation control layer uses the Programmable Logic Controller (PLC), which directly connects to the field hardware. The PLC performs a diagnostic of the system by collecting information on the status of the sensors and electrical devices. The last layer is the RTS and the trigger components. The trigger components consist of water level switches (LS), bilge pumps (BP), and actuated butterfly valves (ABV), which are shown in Figures 5 and 6.

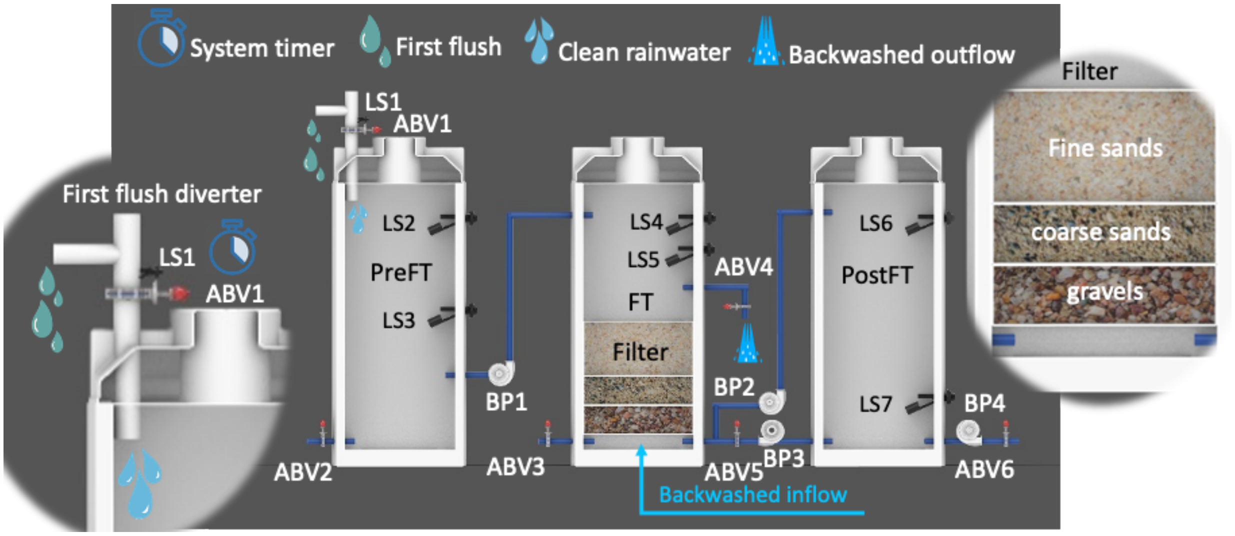


Figure 6. Sketch of the remotely operated and self-cleaning rain tank system

As shown in Figure 6, the RTS consists of three tanks. The first tank is the pre-filtration tank (PreFT), which is intended for capturing sand and other fine sediments that settle in the tank. The second tank is the filtration tank (FT) that is intended to remove suspended solids. The third tank is the post-filtration tank (PostFT) that is intended to store the filtrated rainwater. The water in the PostFT is used for the evaporative cooling tower makeup and also can be used for backwashing the sand-filtration in the FT.

The proposed ROSCRTS has two novel functionalities. The first novelty is the automated sand filter cleaning functionality. The automated cleaning is achieved by pumping water in the PostFT backward through the filtration material. The biomass and fine sediments attached to the filtration materials will be suspended in the water and flow out throughout the backwash outlet. The second novelty is the automated first flush diverter. To be specific, ABV1 is closed before a rainfall event. When rainwater flowing into the first flush diverter submerges LS1, the pre-set system timer (140 sec) starts counting down. During this period, the first flush flows out of the diverter. When the pre-set system timer finishes, ABV1 will open and the clean rainwater will flow into the tank.

Filtration Material Design and Pretreatment

Previous research introduced slow sand filtration to conduct rainwater treatment due to its simplicity, efficiency, and economy [11]. According to the slow sand filtration design criteria [12], the top layer of the filtration material (see Figure 6) should have a depth of 3-feet filled with 0.35-mm diameter fine sands. The medium layer should have a depth of 1-feet filled with 0.60-mm diameter coarse sands. The base layer should have a depth of 1-feet filled with 4.76-mm diameter gravel. According to the slow sand filtration design criteria, the water depth above the filter (the supernatant water depth) should be kept between 3 and 5 feet. The filter will be cleaned before first use.

Filtration Rate Analysis and Rainwater Tank Size Design

The size of the FT is calculated by matching the rainwater volume collected from the solar panel canopies with the daily filtrated rainwater volume. This can be written as,

$$c i_d A_c = q A_t \qquad \text{Eq. 2}$$

where c is the runoff coefficient equal to 0.98 [13], i_d is designed rainfall intensity (4.7 inches, which corresponds to the 2-year, 24-hour rainfall), A_c is the rainwater catchment area equal to 1.95 acres (84942 ft^2), q is the filtration rate, and A_t is the cross-sectional area of the filtration tank. A filtration rate simulation was conducted using the GeoStudio software [14]. The conductivity of sand filtration material was set to 3.28×10^{-4} feet per second, which corresponds to poor graded fine sands [15].

According to the GeoStudio simulation results, when the supernatant water depth is 3 feet, the filtration rate (q) reaches the minimum value which is 5.23×10^{-4} cubic feet per second per square feet (45.17 feet/day). The cross-sectional area of the FT using Equation 2 gives 722.41 square feet. Therefore, the minimum diameter of the FT should be 30.3 feet. After reviewing industrial tank sizes, the Model 3303 [16] is selected as FT. This tank has a diameter of 32 feet 10 inches, a height of 11 feet and a usable volume of 63,306 gallons. The volume of the sand filtration materials inside the FT is 31,680 gallons, which is calculated using the cross-sectional area of the FT and a sand filtration thickness of 5 feet. According to the rational method, the collected rainwater volume is 244,000 gallons per day and thus, the filtration capacity should exceed 244,000 gallons per day. Figure 7 shows the GeoStudio simulations for three different supernatant water depths (3, 4, 5 feet). The simulation results show that the FT can treat between 286,286 and 357,994 gallons per day. The filtration time is between 0.68 and 0.85 days (16 to 20 hours).

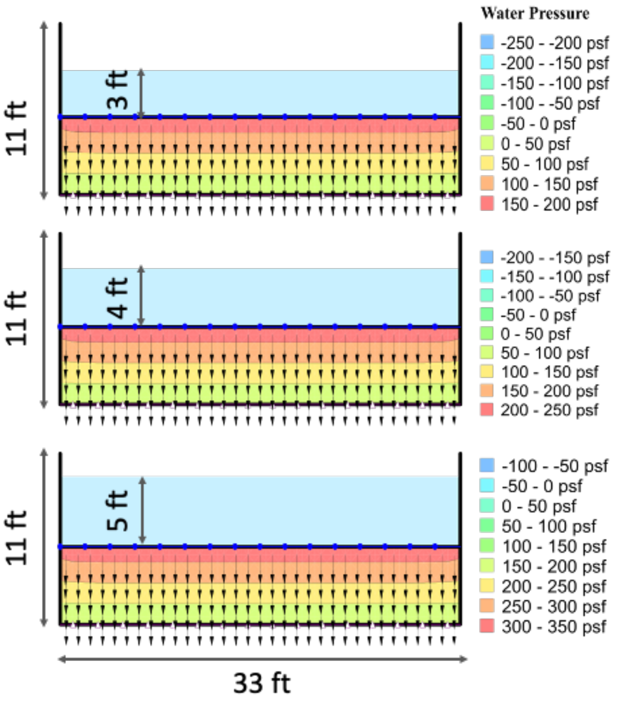


Figure 7. Filtration rate simulations for three supernatant water depths

The solar panel canopies are about 15 feet tall. Therefore, the height of PreFTs should not exceed this height. Based on the commercially available tanks, we propose to use four PreFT tanks with a height of 11 feet for each solar panel canopy. Therefore, the recommended size for PreFT should be slightly bigger than a quarter of the rainwater volume in FT, which is 7,920 gallons. The recommended PreFT is Model 1203 [16], which has a usable volume of 8,371 gallons with a diameter of 11 feet 11 inches and a height of 11 feet. Due to the layout of the rain gutter design (see details in Rain Gutter and Downspout Pipe Design), three affiliated PreFTs with storage size equal to a quarter of PreFT are set along the length of each solar panel canopy every 100 feet. The recommended industrial size for the affiliated PreFT is Model 603 [16] with a diameter of 5 feet 11 inches and a height of 11 feet. The usable volume is 2,093 gallons. The recommended PostFT is Model 2104 [16], which has a usable volume of 35,037 gallons with a diameter of 20 feet 11 inches and a height of 14 feet 8 inches. Figure 8 shows the bird view of the entire RHS.

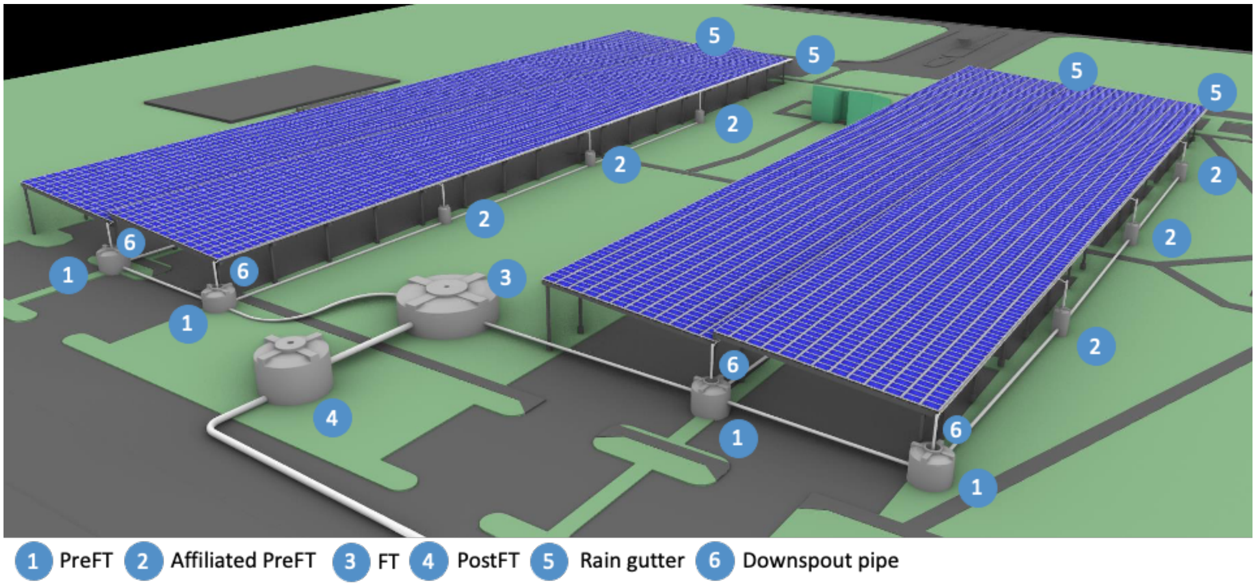


Figure 8 RHS around the four solar panel canopies at the FIU EC (The tanks are as per the scale.)

Rain Gutter and Downspout Pipe Design

According to [17], the design of rain gutters in Miami Dade County should use the 10-year, 24-hour rainfall (7.9 inches). The Soil Conservation Service (SCS) type III rainfall distribution method is recommended for South Florida [3]. Figure 9 shows the storm rainfall hyetograph developed using the SCS type III rainfall distribution method. As shown in this figure, the peak rainfall intensity is 2.0 inches per hour.

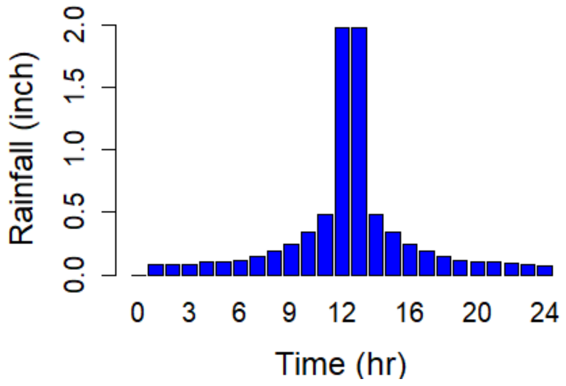


Figure 9. 10-year, 24-hour rainfall hyetograph for EC

The length of the existing solar panel canopy parallel to the gutter is close to 400 feet. The gutter slope is set to 1/4 inch per 10 feet to keep the gutter close to the edge of the solar panel canopies [18]. The downspout pipe is installed every 100 feet along the length of the solar panel canopies. That results in three downspout pipes with their corresponding affiliated PreFTs. According to our hydraulic calculations, we recommend a downspout pipe having a diameter of 8 inches and a K-type rain gutter's [19] with a minimum width of 9 inches and a depth of 5 inches.

GREEN INFRASTRUCTURE DESIGN AND ANALYSIS

Green roofs and green facades are used in our demonstration project as they are known to mitigate the urban heat-island effect, promote carbon sequestration, and improve site aesthetics [20]. The green infrastructure design also serves as the buildings' insulator to decrease temperature and reduce the electric energy used by the air conditioner [21]. A major limitation of green infrastructures, especially in tropical and subtropical cities like Miami, is that they require a significant amount of irrigation water [22]. This demonstration project proposes a smart irrigation system with water demands fully satisfied by the collected rainwater.

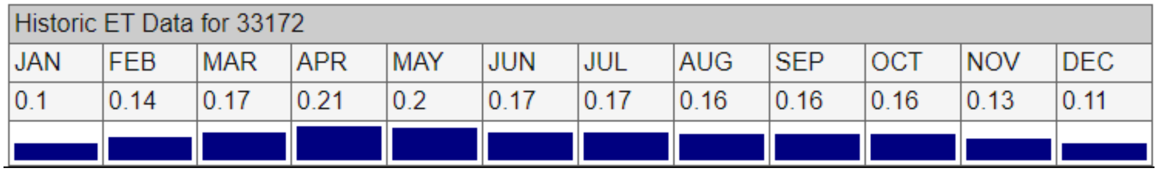
Irrigation for Green Roof and Green Facades

The irrigation water demands are determined for a hydrologically dry-year condition, which is the worst-case scenario. Equation 3 can provide the ratio of green roof area to the total catchment area, satisfying zero-irrigation water demands [23],

$$\frac{A_g}{A_c} = \frac{c \times i_D}{(ET_0 \times PF + c \times i_D)} \qquad \text{Eq. 3}$$

where c is the runoff coefficient equal to 0.98 for rooftops [13], i_D is the design rainfall intensity equal to 50 inches per year (0.14 in/day) for a hydrologically dry-year condition as shown in Table 1, A_g is the area of green roofs, A_c is the total catchment area including, ET_0 is a historic evapotranspiration coefficient (in/day) derived for the FIU EC campus, which is given in Table 3 [24], and PF is the plant factor equal to 0.8 to 0.9 [23].

Table 3. Historic evapotranspiration for FIU EC [24]



Historic ET Data for 33172											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.1	0.14	0.17	0.21	0.2	0.17	0.17	0.16	0.16	0.16	0.13	0.11

The calculated A_g/A_c ratio is around 0.50 to 0.53. Thus, 50% of the rooftop of the FIU EC OU building is designed to be occupied with green roofs. Therefore, 0.285 out of 0.57 acres of the FIU EC OU building’s rooftop are used to collect rainwater.

The irrigation water for green facades is calculated as below [23],

$$I = ET_0 \times PF \times A_g \times 0.623 \text{ (gal.)} \qquad \text{Eq. 4}$$

The area of the green facades is 0.15 acres (650 feet long and 10 feet tall). The irrigation demand for green facades is 0.182 million gallons per year.

The 2-year, 24-hour rainfall is used to design the irrigation tank. Using the rational method, an irrigation tank (Model 2703 [16]) having a diameter of 26 feet 10 inches and a height of 11 feet is proposed to fulfill the irrigation needs of the green infrastructures. The irrigation tank has a storage volume of 42379 gallons. We propose a drip irrigation system for watering the green infrastructures. The drip irrigation system supplies water directly onto the plant roots and thus, eliminates water losses due to evaporation and runoff compared to sprinkler irrigation.

Green Roofs and Green Facades Design

Generally, green roofs can be classified into two types, namely intensive and extensive green roofs. Intensive green roofs usually require additional structural reinforcement and drainage systems, increasing the technical complexity and associated costs [21]. Extensive green roofs are characterized by a shallow depth of the substrate layer and lower weight than intensive ones. The main advantages of extensive green roofs are low capital cost and maintenance, low water requirements, and lower weight [21]. To minimize structural support of the FIU EC OU building, the extensive type of green roofs was selected for our demonstration project. The design tasks can be divided into the roofing system and the green roof vegetation.

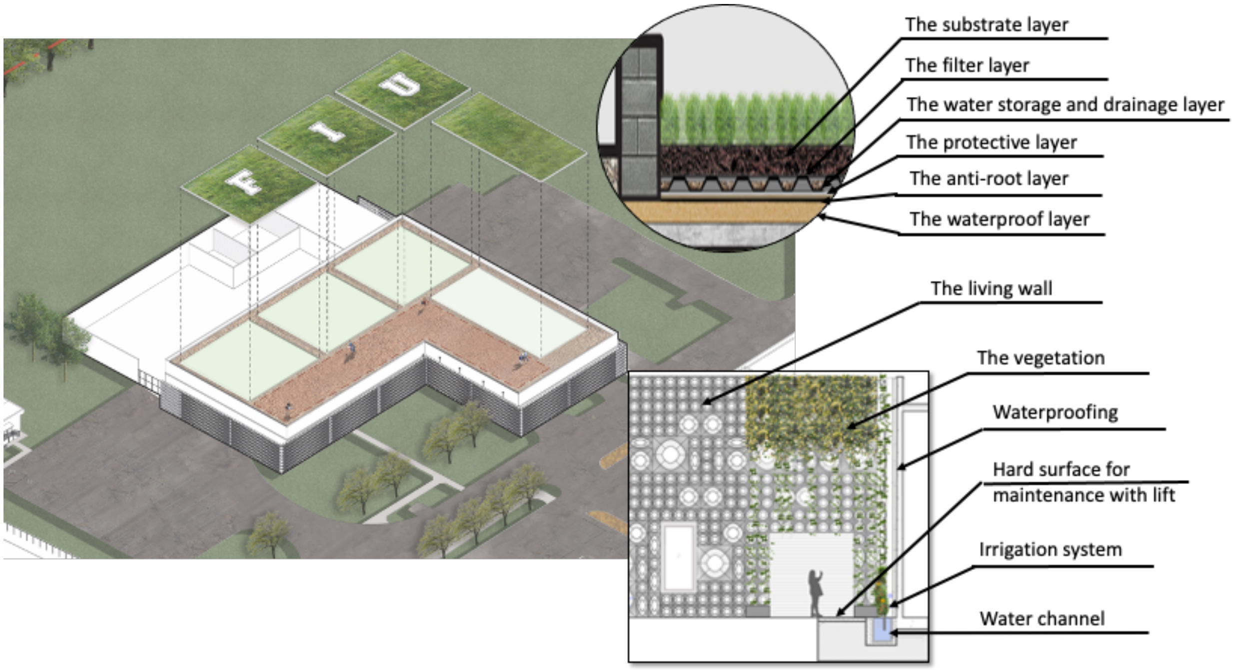


Figure 10. Green roof and green facade design for the FIU EC OU building

Figure 10 shows the details of the design of the roofing system. As shown in Figure 10, the roofing system consists of the following components, from bottom to top: a 1/8-inch-thick waterproofing membrane made of Elasto-Plastomeric, a 3/16-inch-thick anti-root barrier made of plywood sheet, a 1/8-inch-thick protection layer made of polystyrene, a 1/4-inch-thick water storage and drainage layer made of the granular materials, a filter layer using non-woven geotextiles, a 3-inch-thick substrate layer using loamy soil, and selected vegetation. The weight of the substrate layer varies from 2.45 – 2.87 lbs./ft^2 [25].

Green facades are an exterior wall with planted vegetation, mainly used for aesthetic and ecological purposes. To create the vertical green facades, the vegetation must be of certain characters and the living wall system must be equipped with both soil and water systems [26]. The designed living wall system in our project consists of a module-type wall planted with mixed species (evergreen climbing plants and small shrubs).

Vegetation Selection and Introduction

Owing to the thin substrate layer of the green roofs and the unique module-type living wall of the green facades, only limited types of vegetation can be utilized for the proposed green infrastructures. The species selected for the green infrastructures are Wild Sweet Basil, Giant Sword Fern, Wild Everglades Tomatos, Yellow Jasmine, and native grass. Since these species are native to tropical environments, they are expected to adapt and thrive under the harsh conditions of the South Florida climate. Additionally, these species are adapted to direct sunlight conditions, so there will be no need for shading devices to protect them.

The Impact of Green Infrastructures on Temperature Inside a Building

The ANSYS three-dimensional numerical model is used to investigate the impact of green roofs and green facades on the temperature inside the FIU EC OU building. Following [27], the absorptance rate is assumed to be 0.5 on the canopy, 0.6 on the soil, and 0.7 on structural materials (e.g., concrete, cement). The ambient temperature used in the heat convection is set to be the Miami average temperature of a sunny day in September [28]. Figure 11 shows the simulated solar heat flux on the FIU EC OU building at 9:00, 12:00, 15:00, and 18:00 hours for September 13th, 2020. The simulation results for the above conditions show that solar heat flux achieves a maximum value of 877.05 W/m^2 at 13:16 (1:16 PM).

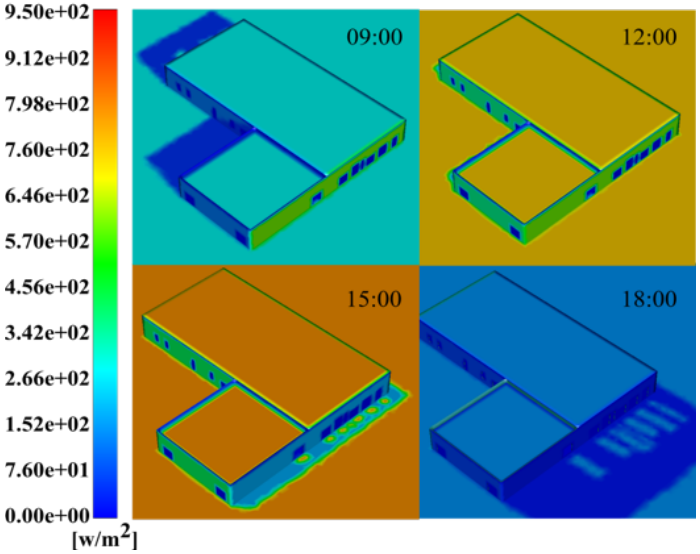


Figure 11. Simulated solar heat flux on FIU EC OU building at 9:00, 12:00, 15:00, and 18:00 hours

Figure 12 shows the FIU EC OU building's interior temperature with and without green infrastructures for 24 hours in September. The simulation results show that the green infrastructures reduce the room temperature by an average of 1.08 °F during a period of 24 hours. The maximum temperature difference between a bare concrete building and the building with green infrastructure is 3.6 °F that occurs at 13:20 h. The energy savings are computed by using the temperature reduction after adapting green infrastructures. The electricity saving at the FIU OU building is 43,911 kWh per year after adapting the green roofs and green facades. Based on the Miami electricity rate (8.72 ¢/kWh) [29], the electricity cost savings are calculated to be $3,829 per year by green roofs and green facades.

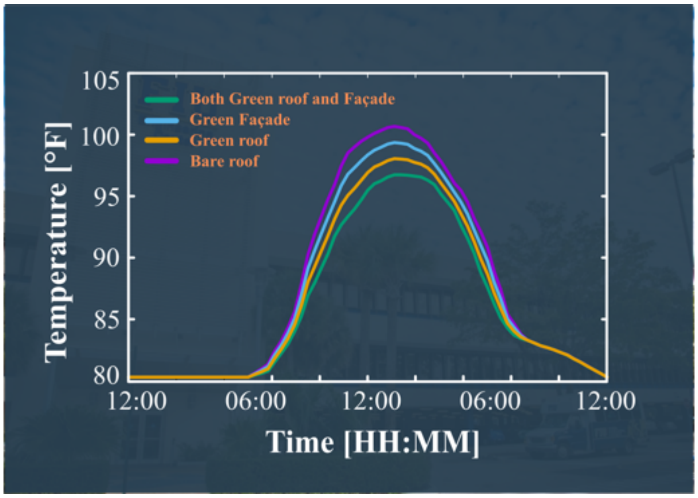


Figure 12. FIU EC OU building's interior temperature vs. time

Heat Island Reduction and Carbon Sequestration from Green Infrastructures

The installation of green infrastructure has multiple benefits for the urban environment, including heat island reduction and carbon sequestration. Taking heat island reduction as an example, according to our heat flux simulations, before applying the green infrastructure, the average sensible heat flux on the bare concrete building with asphalt roofing surface is around 600 W/m^2, while after applying green infrastructures, its value significantly decreases to about 80 W/m^2. From the perspective of carbon sequestration, based on [30] and [31], the average vegetation consists of 72.5% dry matter and 27.5% moisture, and the average carbon content is generally 50% of the tree's dry total weight. The weight of CO_2 is determined by the ratio of CO_2 to C equal to 44/12 = 3.67. Therefore, to determine the weight of carbon sequestered in the tree, we multiply the weight of carbon in the tree by 3.671 [31]. We estimate that 511 lbs. of carbon are sequestered each year in our green infrastructure system.

PUBLIC OUTREACH AND EDUCATION

To increase the impact, reach and the likelihood of replication of our demonstration project, various education outreach components will be developed and implemented. There are various on-campus outreach programs in existence with proven reach and attendance that can be leveraged to include this demonstration project. The EC campus hosts an engineering expo annually, with over 1,600 K-12 students from the surrounding community visiting to experience a multitude of interactive activities related to STEM careers and research. Additionally, the Wall of Wind hurricane simulator brings classes and community stakeholders to the campus regularly for field trips and tours. Not only will the project and its component be added as stops on these visits, but the incorporation of augmented reality technology will provide a novel way for K-12, college students and community leaders to experience and understand the benefits of green infrastructure and sustainable building design, especially as it relates to rainwater collection and use. Figure 13 shows a portion of the green facades displaying an app for public outreach and education. By scanning bar codes placed strategically at interest points of the project with smartphones or dedicated tour tablets, fascinating educational animations will interact with the real-world green infrastructure environment. These AR overlays allow additional information to be presented, such as watching carbon sequestration and plant biological function happening in real-time or animations of the inner workings of the rain capture systems accompanied with data displaying up-to-date water and energy savings. The addition of AR gameplay mechanics will increase engagement further, increasing the education effectiveness for K-12 and college students.

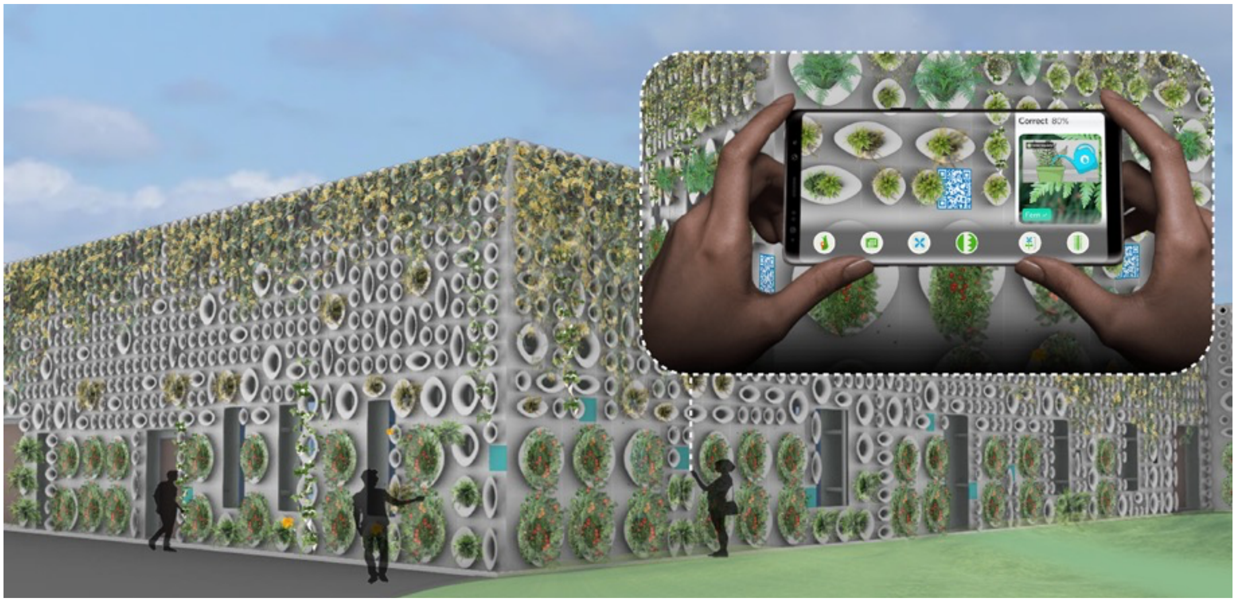


Figure 13. Green facades displaying an app for public outreach and education

To engage the community off-campus, the team will develop an interactive activity based on rainwater collection and filtration techniques paired with 360° videos of the project displayed on VR goggles to be used in existing university education outreach programs. This includes community green fairs and hands-on STEM learning days, Family STEM festivals hosted at schools and libraries as well as publishing FIU@Home articles, a free resource available online.

This multi-pronged approach aims to increase public awareness of the importance of water resource conservation, inspire the next generation of problem solvers by presenting a concrete example of solutions created through STEM learning and to encourage the use of green infrastructure in the community and beyond.

PROJECT PHASING PLAN

This project will be divided into 5 construction phases, namely Preparation, Rainwater Harvesting System, Green Roofs, Green Facades, and Commissioning. The construction period was estimated to be 183 working days from May 3rd, 2021 to Jan 12th, 2022. Please refer to Table 4 for the detailed project phasing plan.

FINANCING AND CONSTRUCTION AND MAINTENANCE COST

Construction Cost

The total construction cost of our proposed project is $468,116. The calculations relied mostly on the unit price of materials displayed on the *HOME DEPOT* website and the quotations provided by suppliers. Also, we used information on similar local engineering practices and current labor unit prices. Please refer to Table 5 for the detailed construction costs.

Maintenance Activities and Cost

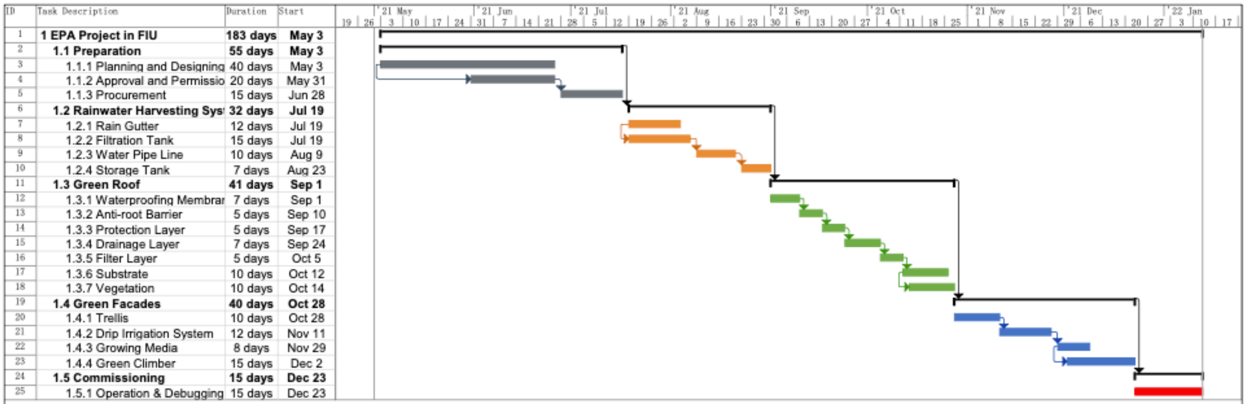
The maintenance cost comprises three parts, namely Rainwater Harvesting System, Green Roofs, and Green Facades. Typical maintenance activities include removal of debris, inspection and repair of components, replacement of filtration materials, pruning, fertilization, and pest and disease management. Please refer to Table 6 for detailed maintenance activities and costs.

Cost-benefit Analysis and Funding sources

Table 7 presents a summary of the proposed strategies, the estimated costs for construction and maintenance, the anticipated economic benefits and environmental benefits, as well as the possibilities for funding. As shown in Table 7**,** the initial investment for the RHS and the green infrastructures is $468,116 and the annual maintenance cost is about $15,825. The direct economic benefit is estimated to be $31,450 per year with a return on investment (ROI) of 3.34 %. From the perspective of sustainable development, this project brings benefits that are not readily quantifiable such as reducing the probability of ponding, decreasing greenhouse gas emissions, increasing carbon sequestration, and reducing the urban heat island effect. The most important benefit may be improving campus aesthetics which has been shown by many studies to promote recruitment and enhance academic success.

Due to the multiple benefits provided by the proposed strategies, many opportunities for loans and grant funding are available. For example, Governor DeSantis and the Florida Legislature approved $40 million in statewide funding for developing water supply and water resource development projects. The application is open each year through the South Florida Water Management District (SFWMD) Coop Funding. Our team is contacting the SFWMD to establish a partnership for our demonstration project. Also, the Clean Water State Revolving Fund Loan Program (CWSRF) provides low-interest loans to design and build water pollution control facilities. Florida's Section 319 Grant Program is another funding option that aims at reducing nonpoint sources of pollution. Eligible activities include demonstration and evaluation of urban and agricultural stormwater best management practices, stormwater retrofits, and public education.

Table 4. Project phasing plan



ID	Task Description	Duration	Start
1	**1 EPA Project in FIU**	**183 days**	**May 3**
2	**1.1 Preparation**	**55 days**	**May 3**
3	1.1.1 Planning and Designing	40 days	May 3
4	1.1.2 Approval and Permissio	20 days	May 31
5	1.1.3 Procurement	15 days	Jun 28
6	**1.2 Rainwater Harvesting Sys**	**32 days**	**Jul 19**
7	1.2.1 Rain Gutter	12 days	Jul 19
8	1.2.2 Filtration Tank	15 days	Jul 19
9	1.2.3 Water Pipe Line	10 days	Aug 9
10	1.2.4 Storage Tank	7 days	Aug 23
11	**1.3 Green Roof**	**41 days**	**Sep 1**
12	1.3.1 Waterproofing Membrar	7 days	Sep 1
13	1.3.2 Anti-root Barrier	5 days	Sep 10
14	1.3.3 Protection Layer	5 days	Sep 17
15	1.3.4 Drainage Layer	7 days	Sep 24
16	1.3.5 Filter Layer	5 days	Oct 5
17	1.3.6 Substrate	10 days	Oct 12
18	1.3.7 Vegetation	10 days	Oct 14
19	**1.4 Green Facades**	**40 days**	**Oct 28**
20	1.4.1 Trellis	10 days	Oct 28
21	1.4.2 Drip Irrigation System	12 days	Nov 11
22	1.4.3 Growing Media	8 days	Nov 29
23	1.4.4 Green Climber	15 days	Dec 2
24	**1.5 Commissioning**	**15 days**	**Dec 23**
25	1.5.1 Operation & Debugging	15 days	Dec 23

Table 5. Construction Cost Summary

No.	Alternative	Unit Price			Quantity		Total Cost	
100	**Rainwater Harvesting System**						**$**	**265,533**
101	Gutters	$	11.47	/ ft	1,600	ft	$	18,352
102	Gutter Mesh (Optional)	$	7.00 - 10.00	/ ft	1,600	ft	$	15,242
103	Gutter Outlets	$	9.62	/ unit	16	unit	$	153.92
104	Downspout	$	11.28	/10 ft	100	ft	$	113
105	Tank Inlet Screens	$	44,089.00	/ unit	16	unit	$	192
106	Pre FT (Model 1203) & Base	$	6,600.00	/ unit	4	unit	$	26,400
107	Affiliate PreFT (Model 603)	$	2,400.00	/ unit	12	unit	$	28,800
108	FT (Model 3303) & Base	$	31,000.00	/ unit	1	unit	$	31,000
109	Post FT (Model 2104) & Base	$	20,000.00	/ unit	1	unit	$	20,000
110	Pump	$	150.00 - 200.00	/ unit	19	unit	$	3,325
111	Filtration Media 4.76mm gravel	$	20.00 - 50.00	/ ft^3	847	ft^3	$	25,410
112	Filtration Media 0.35mm sand	$	20.00 - 50.00	/ ft^3	2541	ft^3	$	50,820
113	Filtration Media 0.60mm sand	$	20.00 - 50.00	/ ft^3	847	ft^3	$	16,940
114	Level Switch	$	18.85	/ unit	12	unit	$	226
115	Valve	$	400.00-450.00	/ unit	12	unit	$	5,100
116	Water Pipes & Fittings (2 inch)	$	2.48	/ ft	1,660	ft	$	4,117
117	Water Pipes & Fittings (4 inch)	$	4.63	/ ft	580	ft	$	1,343
118	Storage Tank	$	18,000.00	/ unit	1	unit	$	18,000
200	**Green Roof (12415 ft^2)**						**$**	**148,909**
201	Waterproofing Membrane (1/8 inch)	$	2.87	/ ft^2	12,414.60	ft^2	$	35,630
202	Anti-root Barrier (3/16 inch plywood)	$	1.80	/ ft^2	12,414.60	ft^2	$	22,346
203	Protection Layer (1/8 inch polystyrene)	$	1.80 - 3.00	/ ft^2	12,414.60	ft^2	$	24,829
204	Drainage Layer (1/4 inch)	$	0.75	/ ft^2	12,414.60	ft^2	$	9,311
205	Filter Layer (non-woven geotextiles)	$	0.08	/ ft^2	12,414.60	ft^2	$	993
206	Substrate (3 inch Loamy Soil)	$	5.00 - 10.00	/ ft^3	3,103.65	ft^3	$	23,184
207	Vegetation (Asiatic Jasmine)	$	1.07	/ plant	6,500.00	plant	$	6,955
208	Irrigation Tank (Model 2703)	$	25,600	/ unit	1	unit	$	25,600
209	Drip Irrigation Tubing	$	7.53	/ 100 ft	800	ft	$	60.24
300	**Green Facades (650*10 feet)**						**$**	**53,674**
301	Trellis System	$	6.87	/ ft^2	6,500.00	ft^2	$	44,655
302	Drip Irrigation Tubing	$	7.53	/ 100 ft	3900	ft	$	294
303	Water Pump	$	150.00-200.00	/ unit	7	unit	$	1,225
304	Substrate and planter boxes	$	20.00	/ unit	260	unit	$	5,200
305	Green climbing	$	0.50-5.00	/ plant	1000	plant	$	2,300
Total Cost							**$**	**468,116**

Table 6. Maintenance Cost Summary

Strategy	Activity	Schedule	Cost/time	Cost/year
Rainwater Harvesting System	**Total cost on maintenance per year**			**$ 12,430**
	Remove leaves and debris from gutters and downspouts	Semi-annually	$ 250	$ 500
	Inspect and clean prescreening devices	Quarterly	$ 140	$ 560
	Inspect and clean storage tank lids	Annually	$ 140	$ 140
	Inspect and repair any clogging	Annually	$ 280	$ 280
	Inspect tank and remove deposed sediment	Quarterly	$ 200	$ 800
	Inspect electronic components of RHS (e.g., BP, ABV, etc)	Every 3 years	$ 1,000	$ 333
	Replace the filter media in FT	Every 10 years	$ 93,170	$ 9,317
	Replace damaged or defective system components	As needed	$ 500	$ 500
Green Infrastructure (Green roof and Green facades)	**Total cost on maintenance per year**			**$ 3,395**
	Pruning and weeding	Semi-annually	$ 480	$ 960
	Fertilization	As needed	$ 660	$ 660
	Spring cleanup	As needed	$ 525	$ 525
	Maintenance inspection	Monthly	$ 70	$ 840
	Replacement of planter beds and plants	As needed	$ 110	$ 110
	Soil test to manage soil for maximum plant vigor while also minimizing nutrient leaching	Aannually	$ 300	$ 300

Table 7. Summary of Costs, Benefits, and Funding Sources

Strategy	Estimated Cost		Anticipated Outcomes			Funding Options
	Construction	Annual Maintenance	Direct Economic Benefit	Environmental Benefit	Social Value	
Rainwater Harvesting System	$265,533	$12,430	Save 17%-24% of potable water used for cooling tower every year, saving $27,621	Maximize water use efficiency, reduce stormwater runoff from a property, reduce a storm's peak flow volume and velocity in local creeks and rivers	Flood reduction; Save precious water resources; Irrigation supply	FIU; SFWMD Coop Funding; Clean Water State Revolving Fund (SRF) Loan Program; Florida's Section 319 Grant Program
Green Roof	$148,909	$3,395	Annual electricity savings of 43,911 kWh and electricity cost savings of $3,829	Adjust microclimates, mitigate the urban heat-island effect, reduces greenhouse gas emissions, improve air quality and provide urban amenities	Beautification; Promote the recruitment and academic success	FIU; SFWMD Coop Funding; Florida DEP Nonpoint Source Funds; Environmental Finance Center Network (EFCN)
Green Facades	$53,674					
Total	$468,116	$15,825	$31,450			

REFERENCES

[1] J. D. Hughes and J. T. White, "Hydrologic conditions in urban Miami-Dade County, Florida, and the effect of groundwater pumpage and increased sea level on canal leakage and regional groundwater flow," *U.S. Geol. Surv.*, no. Scientific Investigations Report 2014-5162, p. 175, 2014, [Online]. Available: https://pubs.usgs.gov/sir/2014/5162/.

[2] FAO, "World-wide agroclimatic database," *Environ. Nat. Resour. Work.*, p. 5, 2000.

[3] USDA, "Urban Hydrology for Small Watershed TR-55," *Soil Conserv.*, no. Technical Release 55 (TR-55), p. 164, 1986, [Online]. Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Urban+Hydrology+for+Small+watersheds#1.

[4] K. C. Doyle, "Sizing the first flush and its effect on the storage-reliability-yield behavior of rainwater harvesting in Rwanda," Citeseer, 2008.

[5] C. Towers, "White Paper – Monitoring Water Quality for Cooling Towers Sanitization."

[6] X. Feng, "Design Experience of Roof Rainwater Recycled as Makeup Water for Cooling Tower," *Urban Environ. Urban*

Ecol., vol. 21, no. 6, pp. 40–42, 2008.

[7] E. S. Costello, “Utilization of Rainwater as a Supplementary Water Source for Cooling Tower Makeup : A Sustainability Strategy for Potable Water Use Reduction,” 2012.

[8] J. Mun and M. Han, “Design and operational parameters of a rooftop rainwater harvesting system: Definition sensitivity and verification,” *J. Environ. Manage.*, vol. 93, no. 1, pp. 147–153, 2012.

[9] A. S. Leon, “The WISE research group remotely controlled siphon system,” 2020. https://web.eng.fiu.edu/arleon/ (accessed Oct. 20, 2020).

[10] V. Verma, L. Bian, A. Rojali, D. Ozecik, and A. Leon, “A Remotely Controlled Framework for Gravity-Driven Water Release in Shallow and Not Shallow Storage Ponds,” in *World Environmental and Water Resources Congress 2020*, Nov. 2020, pp. 12–22, doi: doi:10.1061/9780784482940.002.

[11] R. F. Moreira Neto, M. L. Calijuri, I. de C. Carvalho, and A. da F. Santiago, “Rainwater treatment in airports using slow sand filtration followed by chlorination: Efficiency and costs,” *Resour. Conserv. Recycl.*, vol. 65, pp. 124–129, 2012, doi: https://doi.org/10.1016/j.resconrec.2012.06.001.

[12] J. T. Visscher, “Slow sand filtration. Design, operation, and maintenance,” *J. / Am. Water Work. Assoc.*, vol. 82, no. 6, pp. 67–71, 1990, doi: 10.1002/j.1551-8833.1990.tb06979.x.

[13] P. Bedient, W. Huber, and B. Vieux, *Hydrology and Floodplain Analysis*, 6th ed. Pearson, 2018.

[14] J. Krahn, “Seepage modeling with SEEP/W: An engineering methodology,” *GEO-SLOPE Int. Ltd. Calgary*, 2004.

[15] STRUCT, “Hydraulic Conductivity Ranges of Various Soil Types.” https://structx.com/Soil_Properties_007.html.

[16] R. System, “RainFlo Corrugated Tank Size.” https://www.rainharvest.com/rainflo-corrugated-tank-sizes.asp.

[17] D. A. Chin, “An Overview of Urban Stormwater Management Practices in Miami-Dade County, Florida,” 2004. [Online]. Available: https://pubs.usgs.gov/of/2004/1346/pdf/ofr20041346.pdf.

[18] Hunker, “How To Calculate Gutter Slope.” https://www.hunker.com/13414625/how-to-calculate-slope-rain-gutter-installation (accessed Nov. 04, 2020).

[19] Guttersuplly, “The Advantages of K-style Gutters.” https://www.guttersupply.com/blog/the-advantages-of-k-style-gutters/ (accessed Dec. 02, 2020).

[20] AMEC Environment & Infrastructure, “Green Infrastructure Stormwater Management Practices for Small Commercial Development: City of Atlanta Stormwater Guidelines,” no. April, 2014, [Online]. Available: http://www.atlantawatershed.org/default/?linkServID=6B82F82F-5178-46B9-804C065FD9D912CC&showMeta=2&ext=.pdf.

[21] E. Oberndorfer *et al.*, “Green roofs as urban ecosystems: Ecological structures, functions, and services,” *Bioscience*, vol. 57, no. 10, pp. 823–833, 2007, doi: 10.1641/B571005.

[22] C. Van Mechelen, T. Dutoit, and M. Hermy, “Adapting green roof irrigation practices for a sustainable future: A review,” *Sustain. Cities Soc.*, vol. 19, pp. 74–90, 2015, doi: https://doi.org/10.1016/j.scs.2015.07.007.

[23] C. for L. & U. Horticulture, “Using ANSI/ASABE S623 & SLIDE to Estimate Landscape Water Requirements.” https://ucanr.edu/sites/UrbanHort/Water_Use_of_Turfgrass_and_Landscape_Plant_Materials/SLIDE__Simplified_Irrigation_Demand_Estimation/ (accessed Nov. 02, 2020).

[24] R. M. C. System, “Historic ET by Zip Code.” http://www.rainmaster.com/historicET.aspx (accessed Nov. 02, 2020).

[25] S. Cascone, “Green roof design: State of the art on technology and materials,” *Sustain.*, vol. 11, no. 11, 2019, doi: 10.3390/su11113020.

[26] A. R. Othman and N. Sahidin, “Vertical greening facade as passive approach in sustainable design,” *Procedia-social Behav. Sci.*, vol. 222, pp. 845–854, 2016.

[27] K.-T. Lei, J.-S. Tang, and P.-H. Chen, “Numerical simulation and experiments with green roofs for increasing indoor thermal comfort,” *J. Chinese Inst. Eng.*, vol. 42, no. 4, pp. 346–365, 2019.

[28] H. G. Jones, *Plants and microclimate: a quantitative approach to environmental plant physiology*. Cambridge university press, 2013.

[29] “Miami, FL Electricity Statistics,” *ELECTRICITY LOCAL*, 2020. https://www.electricitylocal.com/states/florida/miami/ (accessed Dec. 02, 2020).

[30] S. J. DeWald, S. J. Josiah, and R. Erdkamp, *Heating with wood: Producing, harvesting and processing firewood*. Operative Extension, Institute of Agriculture and Natural Resources, 2005.

[31] E. C. Toochi, “Carbon sequestration: how much can forestry sequester CO2,” *For. Res. Eng. Int. J.*, vol. 2, no. 3, pp. 148–150, 2018.