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CREATING SELF-SUSTAINABLE LANDSCAPES TO MEET SITES STANDARDS

F. Jourdan[1], P.Kio[1] and Y. Luo[2]*

[1] Sustainability in The Built Environment, College of Design, Construction and Planning, University of Florida, Gainesville, FL, United States

[2] Landscape Architecture, College of Design, Construction and Planning, University of Florida, Gainesville, FL, United States

ABSTRACT: The links between urban green infrastructure, UGI, and public health benefits have been established. Also, the healthcare sector is responsible for a sizable portion of global carbon dioxide emissions, accounting for approximately 5% of the total. As energy demand in the sector continues to rise, sustainable solutions are urgently needed. Subsequently, this study presents a novel method for integrating UGIs to reduce environmental impacts and reduce the energy use intensity, EUI, of healthcare facilities during their operational phase in humid subtropical climates through a case study approach. EUI is a key metric for benchmarking buildings, therefore, the two-year average EUI of an existing student health center at a large university in the United States was the baseline for exploring UGI interventions and their influence on the resulting simulated EUI. The study utilized data from the university's facilities services and positioned UGI interventions with the aid of analysis in Autodesk Forma. The possible impacts were investigated using Autodesk Revit's Building Information Modeling tools for the energy performance obtained by the energy optimization and carbon insights capabilities. The results show that the proposed UGI could reduce the EUI of the baseline building by up to 7%, reduce runoff by 37%, and increase rainfall events without runoff by 75%. The findings provide a novel method of initiating and investigating UGI interventions and their possible impacts on the EUI of existing healthcare facilities.

1. INTRODUCTION

The construction industry is responsible for 39% of energy-related global greenhouse gas GHG emissions, with buildings contributing 27% and materials like steel, cement, iron, and aluminum responsible for the remainder (GlobalABC, 2018). Material selection, applications, and the quality of construction jointly play a role in determining a building's energy efficiency. After a building is constructed, it is imperative to reduce the operational energy required for its heating and cooling (Blok and Nieuwlaar, 2016). The operational energy use of buildings leads to about 33% of the total final energy demand globally and 30% of the global GHG emissions related to energy use (Urge-Vorsatz *et al.*, 2012). Therefore, GHG from the built environment should be reduced to achieve the target of limiting the increase in global average surface temperature to well below 2 °C as compared to pre-industrial levels.

Healthcare buildings are unique as they have strict thermal comfort requirements and their energy consumption and costs are higher than other public buildings (Ma *et al.*, 2024). The healthcare sector is responsible for a sizable portion of global carbon dioxide emissions, accounting for approximately 5% of the total (Zeynep 2024). Existing literature shows that medical equipment has a considerable impact on energy consumption and indoor temperatures. In addition, there is a lack of research addressing the unique characteristics of healthcare buildings towards energy optimization (Ma *et al.*, 2024). Therefore, as energy

demand in the sector continues to rise, sustainable solutions are urgently needed. The consumption of non-renewable resources to generate energy supplies a fairly large number of consequences, one being directly related to climate change. Excessive release of GHG emissions depletes the ozone layer, pollutes the atmosphere, and warms the planet. With 40% of carbon emissions coming from buildings, changes to building energy consumption would significantly impact the amount of GHG emissions.

Because buildings contribute a considerable number of negative effects on the environment, a more sustainable landscape can help offset and reduce these impacts. Healthcare facilities in the United States (US) account for 4.8% of the total area in the commercial sector (Bawaneh *et al.*, 2019). Healthcare facilities consume large amounts of energy, generate significant amounts of waste and biohazardous waste, and use fresh air handling units as opposed to recirculating air handling units using more energy and generate more air pollution. Subsequently, optimizing a landscape's sustainability can help offset some of the issues of healthcare facilities.

As urbanization continues, vast expanses of pervious surfaces have been replaced with impervious surfaces, significantly increasing the risk of flooding (Al-Kayiem et al., 2020; Mendez et al., 2024). In recent years, the Environmental Protection Agency (EPA) has promoted the use of green infrastructure and low-impact development (LID) to manage stormwater and mitigate the environmental impacts of development. LID involves planning and design practices that manage stormwater runoff as close to its source as possible (Coffman, 2002). Examples of LID practices include rain gardens, bioswales, permeable pavements, green roofs, and rain barrels or water cisterns.

Green infrastructure (GI) refers to a network of natural and semi-natural spaces that manage water and provide environmental and community benefits (Benedict & McMahon, 2012). Compared to LID, green infrastructure encompasses a broader range of practices and often addresses larger scales, while LID focuses more on site-specific applications. However, due to their shared goal of managing runoff, the terms are sometimes used interchangeably (Dickson, 2013). Both GI and LID offer numerous benefits beyond flood protection and water quality improvement, such as benefits include reducing water usage, increasing groundwater recharge, reducing energy use, improving air quality, sequestering carbon dioxide, mitigating the urban heat island effect, and enhancing aesthetics (CNT, 2010).

This study utilizes bioswales and green roofs to help reduce runoff, decrease energy use, and mitigate the urban heat island effect. A bioswale is a shallow, vegetated channel that collects and filters stormwater runoff, reducing flooding, improving water quality, and providing wildlife habitats. A green roof, a widely used LID technique, treats stormwater, reduces building energy consumption, mitigates the urban heat island effect, improves water quality, and increases sound insulation (Berardi & Hoseini, 2014). The Sustainable Sites Initiative is a program based on the understanding that land is a crucial component of the built environment and can be planned, designed, developed, and maintained to avoid, mitigate, and even reverse these detrimental impacts (American Society of Landscape Architects, Lady Bird Johnson Wildflower Center and United States Botanic Garden, 2015). In the past, the built environment, specifically landscapes, has been designed and implemented without consideration of the environmental impact it may have. SITES is a green landscape certification that can be utilized on existing or new landscapes with a minimum size of 2,000 square feet. The program allows 200 maximum qualifying points administered over 48 categories. The categories are split into sections of site context, predesign assessment and planning, site design (subsections of water, soil, and vegetation, material selection, human health and well-being), construction, operation and maintenance, education and performance monitoring, and innovation or exemplary performance. These sections analyze the entire impact of a landscape starting from the very beginning of the design process – the site location. The program then follows the entire process of design and construction after the project is completed and in use.

The energy use intensity (EUI) is a widely accepted indicator of the energy consumption of buildings (Melo et al., 2023). The EUI has been applied in many studies, and it is calculated by dividing a building's annual energy consumption by the building's area. A study utilized Autodesk Revit to investigate the optimal construction orientation for an existing campus masterplan and utilized EUI as a metric for the best option

(Veerendra *et al.*, 2025). Another retrofit aimed at improving energy efficiency by developing a framework that integrates BIM for retrofit categories and chose the Revit program for its speed in energy simulation while highlighting the need for improvement (Danial, Mahmoud, and Tawfik, 2023). Another framework combined Autodesk Revit, Autodesk Green Building Studio, and Minitab software as parametric analysis tools to estimate the energy performance of several alternatives based on EUI and annual peak demand (APD) (Ribeiro *et al.*, 2025).

This study examined the EUI of a student health care center, located in a large university in the US and proposed a novel workflow for retrofitting healthcare facilities through UGI and evaluated the impact of the proposed interventions.

2. MATERIALS AND METHODS

2.1 Building

The baseline facility was designed during the peak of the COVID-19 pandemic to provide services to students on campus. The facility comprises three levels at a total height of 46' 8". The actual building area per story is less than 20,000 square feet and the occupant load is 468 occupants. The design maximized daylight throughout the building with abundant windows. Rooftop gardens were proposed to promote outdoor engagement with nature on the rooftop and an outdoor area on the second floor. The three-story building is a high outpatient center that is essential for keeping students healthy. Its operational hours are Monday through Friday, from 8:00 am to 4:30 pm. The peak hours are from 8:00 am to 12:00 pm and nonpeak hours are 12:00 pm to 4:30 pm. The size of the building is 47,456 square feet. Since the function of the building is medical, there are several types of equipment using electricity that a typical building would not use. For example, equipment for vitals, extra refrigeration for specimen samples, and x-ray equipment.

2.2 Energy Use Intensity

EUI expresses a building's energy use as a function of its size. The EUI is expressed as energy per square foot per year for property types in Portfolio Manager and it is calculated by dividing the total energy consumed by the building in one year, measured in kBtu or GJ, by the total gross floor area of the building, measured in square feet or square meters. Generally, a low EUI signifies good energy performance. However, certain property types will always use more energy than others such as healthcare facilities due to their strict thermal comfort requirements and equipment. ENERGY STAR generalizes an EUI for outpatient rehabilitation healthcare facilities to be 138.3 $kbtu/ft^2$ for a source EUI and 62 $kbtu/ft^2$ for a site EUI. The EUI of the healthcare building for this study was obtained from information provided by the university facilities management; the two-year average EUI for the facility from 2022 and 2023 was 129.72 $kbtu/ft^2$.

2.3 Software

Three building information modeling software were utilized in this study – Rhinoceros, Autodesk Forma and Revit. Exterior features were analyzed using Autodesk Forma while EUI and carbon insights were analyzed in Revit. The impact of the bioswale was evaluated with the EPA Stormwater Calculator (SWC).

2.3.1 Autodesk Forma

Autodesk Forma formerly known as Spacemaker, is a cloud-based software that uses artificial intelligence (AI) to help architects and designers with pre-design and schematic design ('Autodesk Forma: Making the right decisions in the planning phase has never been easier', 2025). Its features include geolocated projects for setting up projects with real-world data; 3D modeling of model complex 3D designs; environmental impact analysis; automated massing takeoffs; collaboration with stakeholders and teams; and integration with other tools such as Revit, Rhinoceros, and Dynamo. Autodesk Forma was chosen to perform this study because of its modeling capabilities of existing conditions. Due to the very recent date of construction of

the facility, it was not automatically generated in the Autodesk Forma workspace. Therefore, the building was developed in Rhinoceros and transferred into Autodesk Forma for analysis.

2.3.2   Autodesk Revit

Autodesk Revit is a BIM software that helps architects, engineers, and construction professionals design buildings and infrastructure. The geometric model of a building is the basis for its energy simulation and analysis, which can be developed by various design software, such as Autodesk Revit (Li et al., 2021, 1017). Its features include 3D modeling for creating precise models of shapes, structures, and systems; 2D drafting for annotating and drafting elements; project management capabilities for automatic revisions of plans, schedules, and more; collaboration in a virtual environment with other professionals in the built environment; and tracking different stages of a building's life cycle from concept to construction, to maintenance and retrofitting ('Autodesk Revit: BIM software to design and make anything', 2025). Autodesk Revit was selected for this study because of its building model fluency, along with similar preexisting studies. In Autodesk Revit, the building's EUI was modeled to serve as a baseline scenario before modifications.

2.3.3 EPA National Stormwater Calculator

The EPA SWC is a web-based tool designed to estimate the amount of runoff from sites smaller than 12 acres, building upon the Storm Water Management Model. In addition to conducting hydrology analysis, the SWC incorporates GI and LID controls and provides cost estimations for future scenarios (EPA, n.d. - b).

In this project, the total site area is 1.44 acres and incorporated three main strategies to enhance stormwater management and environmental benefits. The first strategy involved converting 0.354 acres of the roof to a green roof. Additionally, a 0.08-acre bioswale was created. Lastly, existing areas were transformed into planting beds, which aided the retention of more water offering additional environmental benefits. The EPA Stormwater Calculator's primary improvements were due to the implementation of the green roof and the conversion of the lawn area. A short-term climate change scenario spanning 35 years was used for analysis. Given that the site has already been cleared for improvement, it was rated as excellent (easy to innovate) for cost estimation purposes.

2.4   Urban Green Infrastructure

The existing landscape is about 19,000 square feet and qualifies for SITES minimum program requirements. Utilizing Sustainable SITES guidelines to create a more sustainable landscape framework, results in a decarbonized footprint while promoting the health of the built environment as patients move through the facility. The landscape consists of a shared parking lot with landscaped islands, terraced planters, a public balcony, and plant species such as Lily of The Nile, Live Oak, and Coontie. The design includes the addition of a green roof and locally sourced plants. A green roof was selected for this study due to its multiple benefits. While providing habitat for insects and pollinators, treating stormwater, and sequestering carbon, a green roof could also decrease the heat that the roof will absorb and aid in the cooling of the building, thus contributing to lowering the HVAC use and EUI. The study proposed the conversion of a sod landscape island to a planted island in the parking lot and incorporating rocks and native or Florida Friendly plants into the terraced planters to create bioswales for rainwater retention. Rather than removing the existing sod surrounding the building, redesigning the planters will save on the costs of excavation and generate less waste from plant removals. Native and Florida-friendly plants preserve biodiversity, are adapted to the Florida environment, cost less to maintain, and are sourced more frequently. Native plant selections were then narrowed to include drought-tolerant plants to conserve water, and plants that can withstand wet soil for the bioswales, Table 1.

Table 1: Characteristics of native plants

Common Name	Hardiness Zone	Scientific Name	Drought Tolerance	Sun Requirements	Size	Quantity	Cost

Muhly grass	6-10	*Muhlenbergia capillaris*	Wet or dry soils	Full sun	3 gal	89	$445
Black-eyed Susan	3-9	*Rudbeckia hirta*	Moist soils	Full sun	1 gal	52	$132.6
Blue Daze	8-11	*Evolvulus glomeratus*	Dry soils	Full/partial sun	1 gal	12	$30.6
Blue-eyed Grass	4-9	*Sisyrinchium angustifolium*	Moist soils	Full/partial sun	1 gal	171	$513
Blanket Flower	2-11	*Gaillardia Burchell*	Dry to medium soils	Full sun	1 gal	50	$127.5
Seaside Goldenrod	2-11	*Solidago sempervirens*	Medium to wet soils	Full/partial sun	1 gal	70	$2100
Star Jasmine	8-11	*Trachelospermum jasminoides*	Medium to wet soils	Full/partial sun	1 gal	28	$70
Crape Myrtle	6-9	*Lagerstroemia indica*	Dry Soils	Full sun	15 gal	13	$780

There are potential conflicts associated with the installation and maintenance of green roofs: their location, building type, and roof access. In locations that experience extreme weather conditions, a green roof is not typically suitable. When the plants are first installed, they will require more maintenance until they are stable. Avoiding irrigation, manual watering and plant maintenance is the preferred option and requires roof accessibility. Also, if repairs to the roof are needed, completing the repairs and salvaging the plants may not be possible. Another potential conflict may be that the initial installation cost of a green roof is higher than the cost of a nongreen roof, which could potentially hinder broader adoption, especially in public-sector projects. These renovations are classified as a retrofit and do not account for costs and potential conflicts associated with new construction. On the other hand, for buildings located on sites with little room for landscape or have more hardscape, a green roof consumes the same square footage as the building and connects the building back to the landscape.

Ensuring the long-term performance of UGI interventions can be completed through a proper maintenance regimen. Drought-tolerant plants were specifically chosen for placement on the green roof to account for the absence of irrigation. Eliminating an irrigation system will increase the sustainability of the building and increase efficiency gains. The trade-off is that the green roof plants require manual watering. There would be no use of pesticides on the roof or ground, resulting in maintenance staff occasionally checking for pests and plant health. During the rainy season, maintenance staff would need to monitor the roof and drainage system to ensure that no leakage seeps from the roof to the interior of the building.

2.5   Methodology

The study employed primary data collection of EUIs from the university's energy audit reports. Thereafter the design, model development, and generation of iterated scenarios led to energy simulations and results. Daylight analysis was carried out in Autodesk Forma on a model that was produced and imported from Rhinoceros to Autodesk Forma. The EUI was evaluated on a building model in Revit and validated through two processes energy optimization and carbon insights. Subsequently, the energy performance comparing the baseline scenario to the proposed green roofs was investigated by varying the roof surface material from concrete to a green surface. Lastly, the impacts of bioswale interventions on the landscape were evaluated with the EPA Stormwater Calculator.

3. RESULTS

3.1   Autodesk Forma Analysis

The daylight analysis revealed areas of the building's roofscape that received full or partial sun and guided the choices of plants for the green roof. The model in Figure 1a shows that the outdoor patio and rooftop

have varying degrees of sun exposure. The top of the building had 100% daylight while the open area on the second floor had 80% daylight. Roof gardens were introduced on the third and second floor roofs and these gardens would receive 80% to 100% sunlight, Figure 1b.
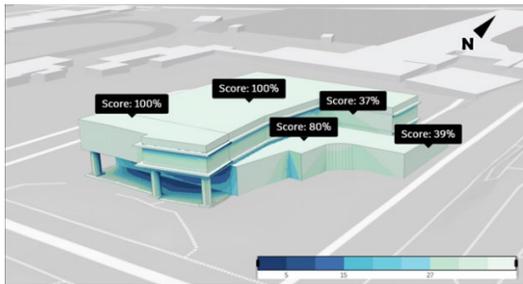

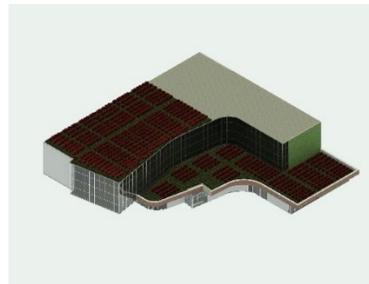Figure 1a: Daylight analysis of rooftops in Autodesk Forma

Figure 1b: Proposed green roofs

3.2   Revit Energy Optimization and Carbon Insights

The target facility was modeled in Autodesk Revit and the EUI was investigated through two processes of energy optimization and carbon insights. The analytical model of the facility is shown in Figure 2a.
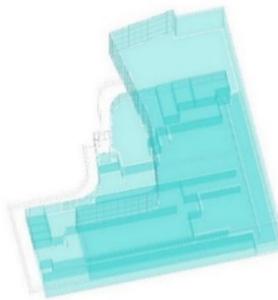

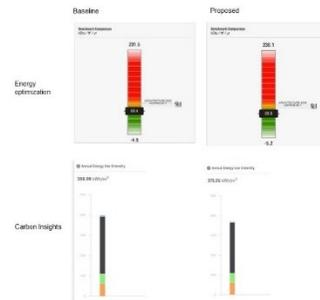Figure 2a: Analytical model of facility produced in Autodesk Revit

Figure 2b: Results of comparison of scenarios

These two ways can be utilized to obtain EUI in Revit, the energy optimization mode will be phased out in April 2025. The study obtained two EUIs as shown in Table 2. The EUI of the modeled baseline building was 60.4 kBtu/ft² and 126.5 kBtu/ft² from energy optimization and carbon insights processes respectively. While the EUI of the proposed scenarios was 59.8 kBtu/ft² and 117.6 kBtu/ft² for both processes, Figure 2b. The 2-year average EUI obtained from the primary data was 129.72 kbtu/ft^2 resulting in a 53.4% error for the baseline EUI from the energy optimization process and a 2.5% error for the carbon insights process in Revit.

The study assumed that all the EUIs were site EUIs which measured the energy consumed directly by the building at the site. The process of generating the EUI through carbon insights in Revit was 4 minutes faster than utilizing the energy optimization route. In additional it was evaluated that the proposed UGI intervention could lead to a reduction in operational carbon by 5.92% with 0.76% decrease in embodied carbon over a period of 20 years.

Table 2: Results from energy optimization and carbon insights of scenarios

Item	EUI from Energy Optimization (kBtu/ft²)	EUI from Carbon Insights (kBtu/ft²)	Total Carbon(kgCO2e)	Embodied Carbon(kgCO2e)	Operational Carbon(kgCO2e)
Baseline	60.4	126.5	6,875,022.85	392,486.79	6,482,536
Proposed	59.8	117.6	6,488,306	389,520	6,098,786

Percentage difference	0.99	7.04	5.62	0.76	5.92

The percentage difference of the EUI from this study was compared to those in similar studies, Figure 3. The percentage of EUI reduction in other studies ranged from 10% to 67%. The retrofit measures applied in other studies included building envelope materials for 1a and 1b; improving chiller plant efficiency in study 2; rooftop PV systems and energy efficiency measures in study 3; urban heat island induced temperature modeling in 4; lighting upgradation combined with plug and process load reduction for 5a and 5b; and the EUI difference between pre and post-pandemic airflow for 6a and 6b, Table 3.
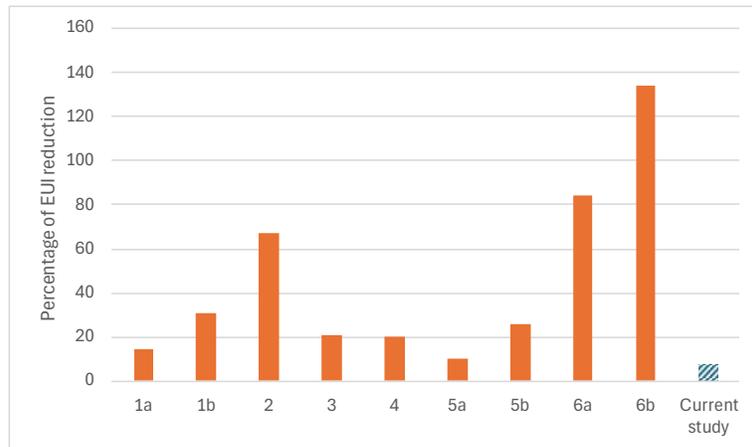

Figure 3: A comparison of the percentage differences between EUI differentials compared to the current study. Key: 1a and 1b (Deb & Lee, 2018), 2 (William et al., 2020), 3(Asis et al., 2023), 4 (Hashemi et al., 2025), 5a and 5b (Hossain et al., 2024); and 6a and 6b (Chang et al., 2024).

Table 3: Comparison of similar EUI studies

Location	Percentage EUI difference	EUI sources and modeling tools	Retrofit measures	
Singapore	14.3 to 30.6	*Energy audit reports*	Improving chiller plant efficiency	(Deb & Lee, 2018)
Egypt	67	*Design builder*	Building envelope materials at windows and walls	(William et al., 2020)
Eastern Province of Saudi Arabia	21.2	*International Performance Measurement and Verification Protocol (IPMVP)*	Rooftop PV system and five energy efficiency measures at chillers, lighting, and installing variable frequency drives	(Asif et al., 2023)
Des Moines Iowa, USA	20	*Rhinoceros and Urban Building Energy Modeling (UBEM)*	Urban heat island-induced temperature modeling	(Hashemi et al., 2025)
Pittsburg, Pennsylvania	10 to 26	*Sketchup, Energy Plus and UBEM*	Lighting upgradation to LEDs, and plug and process load reduction	(Hossain et al., 2024)
China	84 - 134	*Energy Plus and CONTAM*	Pre and post-pandemic airflow	(Chang et al., 2024)
Gainesville, Florida, USA	7.04	*Energy audit reports and Revit*	Green roofs and bioswales	Current study

3.3 Stormwater Management through Green Roof and Landscape Design

Figures 4a and 4b present some of the analysis results from the EPA Stormwater Calculator (SWC). The baseline scenario represents the existing site conditions, while the current scenario depicts the proposed site conditions after implementing the bioswale strategies.
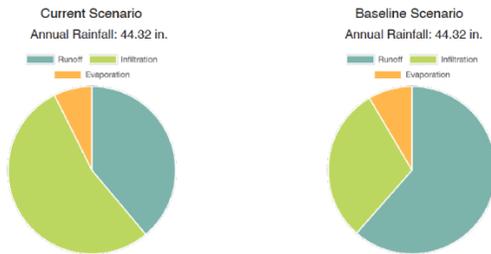

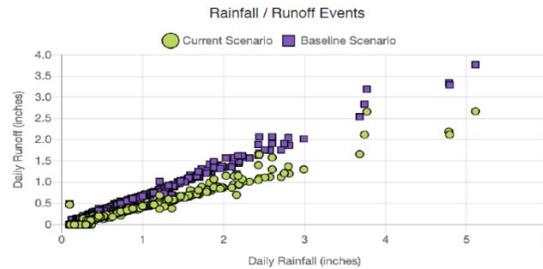Figure 4a: Annual rainfall comparison

Figure 4b: Comparison of rainfall/runoff events

Figure 4b illustrates the comparison of runoff between the baseline scenario (existing and current proposed) scenario. This figure demonstrates that the site, now featuring a green roof and increased vegetation, has a greater capacity to retain stormwater runoff, thereby reducing flood risks. It is important to note that this modeling did not account for the stormwater retention capacity of trees, making these results a relatively conservative estimation.

While evaporation rates remain relatively unchanged, the amount of runoff has significantly decreased from 27.36 inches to 17.28 inches, representing a substantial reduction of 37%. Additionally, the most significant rainfall event without runoff has increased from 0.21 inches to 0.37 inches, a 76% increase, Table 4. Furthermore, the maximum rainfall retained has increased from 1.50 inches to 2.67 inches, reflecting a 78% increase.

Table 4: Detailed Statistics of Stormwater management between the two scenarios

Statistic	Current Scenario	Baseline Scenario
Average annual rainfall (inches)	44.32	44.32
Average annual runoff (inches)	17.28	27.36
Days per year with rainfall	68.51	68.51
Days per year with runoff	40.43	52.16
Percent of wet days retained	40.98	23.87
Smallest rainfall w/ runoff (inches)	0.10	0.10
Largest rainfall w/ runoff (inches)	0.37	0.21
Max rainfall retained (inches)	2.67	150

4. DISCUSSION

4.1 Energy Use Intensity

In the presented study, UGI intervention of green roofs and bioswales led to a 7.06% reduction of EUI for a healthcare facility. Due to the introduction of bioswales, there was a significant decrease in the amount of runoff, from 27.36 inches to 17.28 inches, representing a substantial reduction of 37%. Additionally, the most significant rainfall event without runoff has increased from 0.21 inches to 0.37 inches, a 76% increase. The baseline EUI from the simulated carbon insight process was 2% lower than the actual EUI obtained from primary data.

The study demonstrates how building modeling tools were combined to contribute to the retrofit of a healthcare center. The tools comprised Rhinoceros, Autodesk Forma, Sustainable Sites, and Autodesk Revit. The results of this study show that there are positive benefits from retrofits. Finally, the study utilized a novel workflow for retrofitting a healthcare case study facility, Figure 5. The workflow shows that a building could be selected, secondly, its EUI would be obtained from facilities management/energy audits, thereafter the sustainable sites certification data would be used to obtain and choose possible UGI to be utilized. The Autodesk forma tool showed the daylight analysis at the rooftop location of the UGI Autodesk Revit provides detailed energy optimization analysis and carbon insights for evidence-based decision-making towards retrofits.
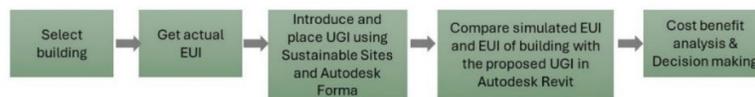

Figure 5: Proposed framework for retrofitting with urban green infrastructure

5. CONCLUSIONS

Urban green infrastructure can reduce the operational energy consumed by buildings. This study evaluated possible reduction of the energy use intensity in the health sector through a case study approach. The results of urban green infrastructure intervention of roof gardens and bioswales at the case study students' healthcare center reduced the EUI by up to 7%. There was a significant decrease in the amount of runoff, a reduction of 37%. Additionally, the most significant rainfall event without runoff increased by 76%. The study combined building modeling tools such as Rhinoceros, Autodesk Forma, Autodesk, and the United States Environmental Protection Agency's Stormwater Calculator providing a novel methodology that combines the modeling tools in the context of environmental certifications and retrofitting. Future studies will focus on studying the energy consumption of healthcare facilities towards developing models for reducing their energy use intensity.

ACKNOWLEDGMENTS

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