NET-ZERO WATER BUILDINGS & THE AIR FORCE

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NET-ZERO WATER BUILDINGS & THE AIR FORCE

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LIST OF SYMBOLS AND ABBREVIATIONS

3-D	Three-Dimensional
AFB	Air Force Base
BIM	Building Information Modeling
DoD	Department of Defense
DOE	United States Department of Energy
EIA	United States Energy Information Administration
EPA	United States Environmental Protection Agency
FY	Fiscal Year
Gal	Gallon
GAO	Government Accountability Office
ICC	International Code Council
IgCC	International Green Construction Code
ILFI	International Living Future Institute
KGal	Kilo-Gallon
LEED	Leadership in Energy and Environmental Design
NCEI	US National Centers for Environmental Information
NDAA	National Defense Authorization Act
OASDI	Office of the Assistant Secretary of Defense for Infrastructure
PRV	Plant Replacement Value
UFC	Unified Facility Criteria
US	United States
USGBC	United States Green Building Council

SUMMARY

The Department of Defense has tasked the uniformed services to make a percentage of their installations net-zero waste, water, and energy. The purpose of this study is to determine if United States Air Force can make 10% of their large sized installations net-zero water installations and what building types are best suited for net-zero water operations. To accomplish this, existing building floor plan data for 14 different building types on Air Force installations was collected and replicated in Building Information Modeling software. These models were then analyzed in software to determine estimated water usage and the amount of rainwater harvested per building. The models were tested for four different installations in the continental United States to account for different climate areas. The results of the 56 tests were then analyzed for trends to determine which installations and building types were most relevant for net-zero water operations. It was found that installations that experience higher average rainfalls each year are more likely to have successful net-zero water buildings. Installations in the Atlantic Ocean & Gulf of Mexico coastal areas are installations to target. Additionally, with the parameters selected for the procedure – it was found that 8 of 14 building types simulated at Eglin AFB, FL, are net-zero water positive as they harvest more rainwater than they are estimated to use. With additional floorplan data for all buildings on an installation, it would be possible to completely verify if an entire installation would be net-zero for water operations – however, the tests ran are a good indicator if net-zero water is possible or not.

CHAPTER 1. INTRODUCTION

This chapter will contain the background of the US Department of Defense's order to create net-zero water installations and introduce research questions for this study.

1.1 Background

The sustainable building movement in the United States Federal Government gained major traction in the 1990's with the founding of the ENERGY STAR program in 1992, US Green Building Council (USGBC) in 1993, and Leadership in Energy and Environmental Design (LEED) certification in 1998. The passing of Energy Policy Act of 2005, signing of Executive Order 13423 in 2007, and passing of the Energy Independence and Security Act in 2007 included multiple high performance sustainable building standards for federal buildings. Examples of these standards include use of energy meters on all federal buildings, reduction of energy use, and use of renewable energy platforms (EPA, 2016).

The Department of Defense (DoD), which consists of the Army, Navy, Air Force, Marines, and Space Force, falls under the US federal government. This means that almost all military installations are owned by the federal government, and that their facilities fall under the same guidance as non-military federal buildings would. The US Army took charge in the early 2010's with the "US Army Net-Zero Initiative" by pledging to turn 17 existing military installations into net-zero installations. Net-zero means that the installation would only use as much energy and water as they produce, as well as recycle enough material to offset their waste. Large reasons cited for taking this initiative (besides federal mandates) were energy independence, water scarcity, and environmental concerns (US Army, 2017). While the US Army made small improvements to limiting their water, energy, and waste use - the US Government Accountability Office (GAO) found that the entire DoD had not established an integrated net-zero program, and that the US Army's program was one that was meant to draw awareness to the issue and not to solve the issue (USGAO, 2016). In 2021, Congress passed the FY22 National Defense Authorization Act (NDAA) which included the mandate that 10% of all large US military installations are required to be net-zero energy, net-zero waste, and net-zero water by Fiscal Year (FY) 2035. Additionally, a study would need to be completed on how to accomplish this task by the end of January 2023 (FY22 National Defense Authorization Act, 2021).

This research will explore the ability for the US Air Force installations to become net-zero water efficient. Additionally, this report will provide data for which US Air Force installations should be targeted as pilot installations as well which types of buildings should be targeted to become net-zero water efficient.

1.2 Research Questions

The issue of converting current US Air Force installations into net-zero water installations, has sparked motivation to ask several research questions. These include: 1) Do building activities influence the building's water usage on Air Force installations? 2) How can Building Information Modeling (BIM) be used in terms of modeling water efficiency of a building for design and facility operations on Air Force installations? 3) How can the Air Force leverage this technology to create efficient net-zero water installations?

Background information will also be provided on: current strategies for net-zero water buildings with corresponding lifecycle costs; current sustainability & plumbing codes that the US Air Force builds and operates with; what are current regulations for the collection and use of rainwater; and lastly which US Air Force large sites should be targeted to become net-zero water installations.

CHAPTER 2. LITERATURE REVIEW

This chapter will discover the contemporary strategies for net-zero water buildings, water usage by building type and building occupant water usage behavior, how Building Information Modeling is used for modeling water efficiency in buildings and its potential for the US Air Force, the current codes for buildings that the US Air Force designs, constructs & operates to and which ones should be updated to meet modern net-zero water facilities, and lastly the US Air Force installations that Department of Defense should target to invest in net-zero water infrastructure at.

2.1 Current Strategies for Net-Zero Water Buildings

There are multiple strategies for harvesting water in net-zero water buildings. Most buildings nowadays, gather their freshwater from municipalities. In this scenario, the building would purchase water from the local municipal government, use the water and then return it back to the wastewater treatment plant. The International Living Future Institute's preferred method of water harvesting is to collect rainwater using a rooftop rainwater collection system. After collecting the rain, it would be treated for use in the building, and then returned to the groundwater table. Other ways of harvesting water for buildings are stormwater system collection, groundwater, onsite reclaimed water, and off-site reclaimed water (Cascadia Green Building Council, 2011).

The US Department of Energy has published strategies for net-zero water systems in buildings. Their preferred strategy is to harvest rainwater by using rooftop collection system (as a potable source) and storm drain collection system (as a non-potable source). After precipitation is collected from the rooftop system, it is transported to a treatment tank through piping, then to a storage tank where it will be held until it is used in potable systems like sinks and showers. After potable water is used in sinks and showers, it becomes grey water and is then treated again before being used as a non-potable source for use in toilets and irrigation. After being used in toilets it is considered blackwater, since it has human waste in it, and is then sent to the buildings septic tank before being returned to the groundwater table (US DOE, 2022). See Figure 1 for image of US DOE's ideal net-zero water building. Not pictured, but often used in net-zero water buildings is an emergency water connection that is supplied by municipal and city water sources. This is used in case of droughts and if the fire protection system needs to operate in case of a building fire (Cascadia Green Building Council, 2011).

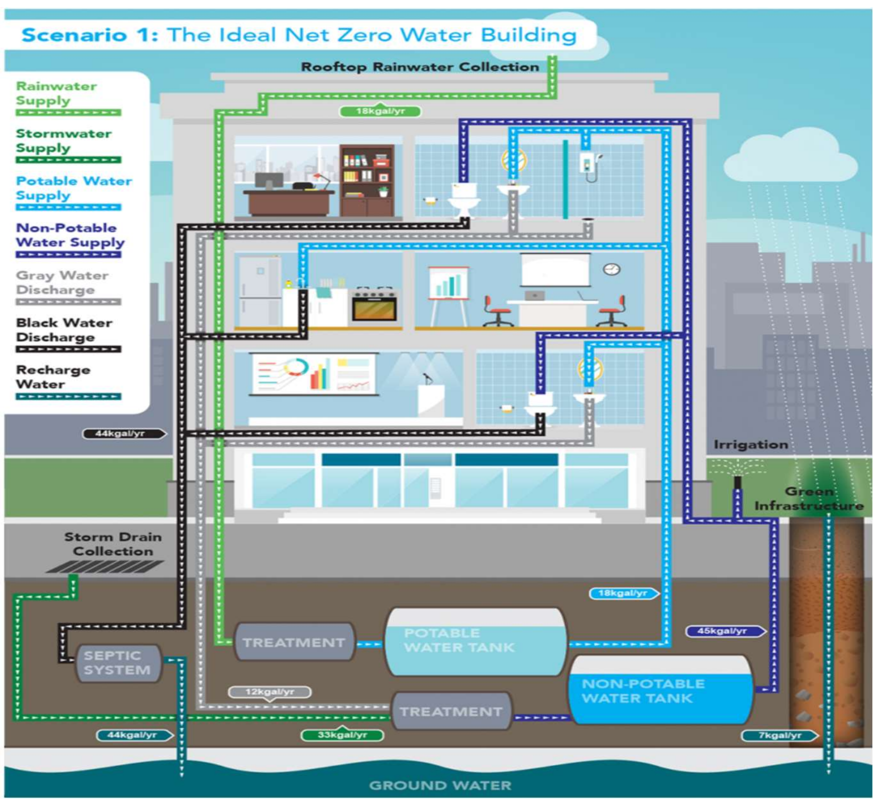


Figure 1: US Dept of Energy's Ideal Net-Zero Water Building (US DOE, 2022)

In this system, rainwater is stored in potable water storage tanks after being treated before being utilized by occupants of the building. A water balance analysis must be conducted to determine the size required for a storage tank. The volume of a potable water storage tank while in use can be determined using equation 1:

$$S_t = S_{t-1} - ff - C - O - E_p + P \quad (1)$$

Where S_t is the current storage tank volume, S_{t-1} is the initial volume of the storage tank, ff is the first flush volume which is the first pass of water that is collected from the roof and is diverted from the system, C is the volume consumed by building occupants, O is the volume of water that overflows from the storage tank, E_p is the evaporation rate from the tank, and P is the rainfall collected in the storage tank (Naserisafavi et al., 2022). This equation is useful in terms of being able to size the tank as well predict how much volume is in the tank.

Rainwater harvesting as an alternative freshwater source is becoming increasing in popularity in the United States and around the world. Rainwater harvesting systems have been used in residential homes, and by commercial buildings. In a survey conducted in the United States, the average rainwater harvesting system is used on an asphalt shingle roof with aluminum gutters (Thomas et al., 2014). Other common roof types with rainwater harvesting systems include metal and tile roofs. The most common water storage tank is made of polyethylene material after being disinfected through in-line ultraviolet treatment. Since the rainwater collection systems collect many different contaminants like traces of fecal matter created by birds, microbial organisms, and chemicals from the roofing & piping system that lead to the treatment tank. There are several techniques to address the contaminants in the system. These techniques include routine washing of the roof, use of the first flush technique mentioned above, and scheduled chemical testing of the potable water to ensure the treatment system is effective (Thomas et al., 2014).

The US Department of Energy's Office of Energy Efficiency & Renewable Energy has published their ideal above ground rainwater harvesting system and is pictured in Figure 2 on the following page:

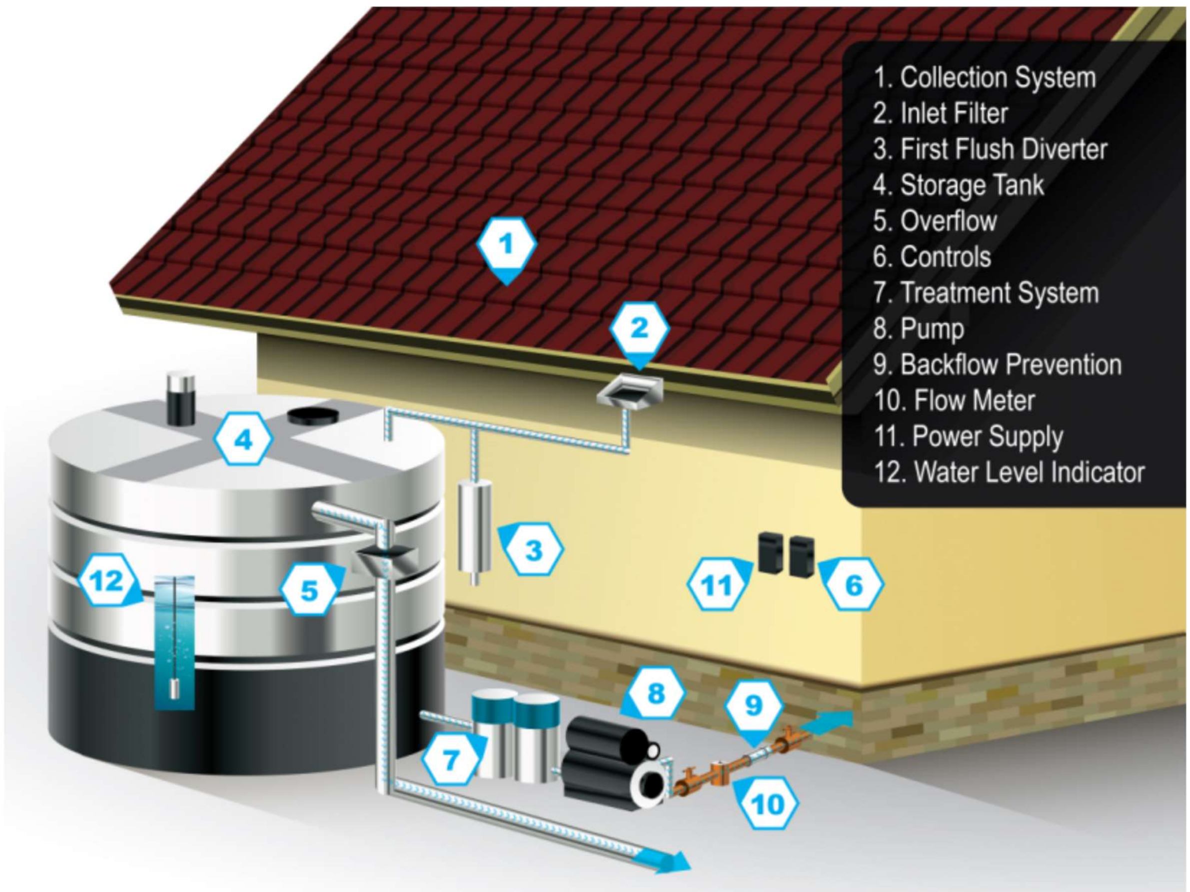


Figure 2: Ideal Rainwater Harvesting System Components (US DOE, 2022)

The components in this above ground system would be ideal for Air Force installations with ample spacing for its facilities. Since the components in Figure 2 are above ground, it allows for easier maintenance and replacement of parts as opposed to an underground storage and treatment tank. One concern with an above ground storage tank would be its evaporation rate, which would have to be accounted for in the design of the tank.

Looking at net-zero water buildings as a whole – many case studies for net-zero water buildings do not publicly include lifecycle costs for the installation of the net-zero water system, costs to treat rainwater and greywater, and the maintenance on the system. Therefore, there is a research gap in terms of reliable lifecycle cost data. In 2013, the International Living Future Organization conducted a financial review on the predicted costs of constructing a net-zero water system in Washington, D.C. They found that the construction of a net-zero water system in a new 328,095 square foot office building would cost $3.80 per square foot for a total of $1,246,761. Additionally, they found that the installation of a net-zero water system in a 235,172 square foot renovated office building project would cost $7.85 per square foot for a total of $1,846,100 (ILFI et al., 2013). From their financial review, it can be determined that it is much cheaper to install a net-zero water system in a new construction project as opposed to installing a net-zero water system in a building renovation project. Net-zero buildings can be very costly in terms for Air Force installations considering their sizes (square footage and the number of buildings).

2.2 Water Usage by Building Type and Building Occupant

For a net-zero water building to effectively operate, the concept of net-zero water systems must be applied differently to different building types. In 2012, the US Energy Information Administration (EIA) completed the Commercial Buildings Energy Consumption Survey and found that the 46,000 large commercial buildings, which are those that have building areas of larger than 200,000 square feet, in the United States used a total of 359 billion gallons of water. The consumption of water by large sized buildings accounted for 2.3% of the total municipal water supply in the country. The EIA then further extrapolated the data to 22,000 gallons used in each building per day and 50.1 gallons used by each worker in these buildings per day. Different building classifications used different amounts of water – where businesses like hospitals and hotels used large amounts of water while warehouses and strip malls used the least amount of water (EIA, 2017). Water intensity of different business types can be seen in Figure 3 on the following page:

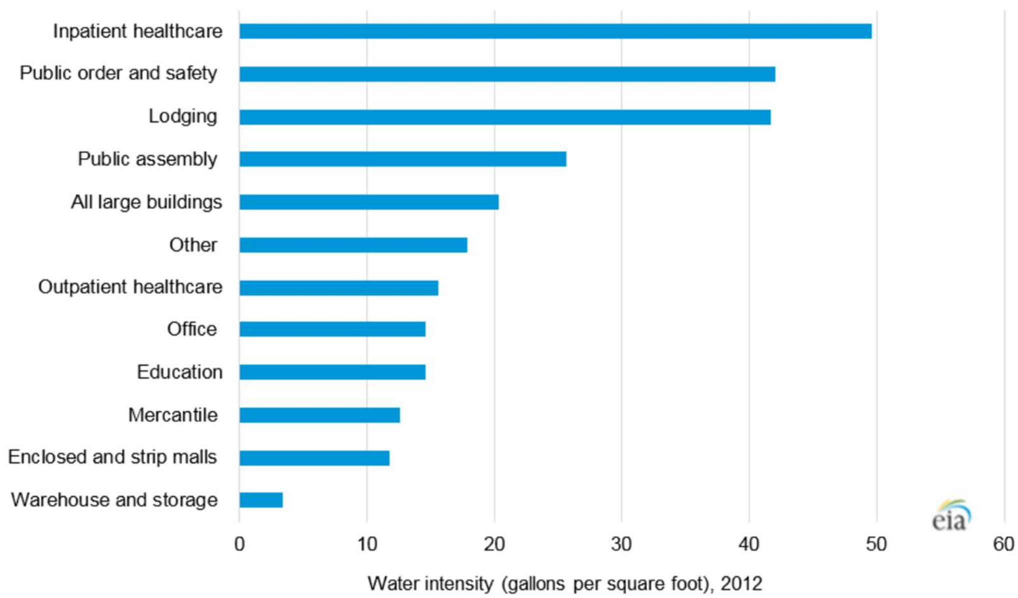


Figure 3: Comparison of Water Consumption by Different Building Types (EIA, 2017)

While most buildings in the US Air Force are under 200,000 square feet in area, the types of buildings and their water consumption rates would be roughly the same on US Air Force installations. Hangars and warehouses would have less water consumption than medical clinics and base lodging due to the nature of the activities that happen inside each building type.

Additionally, net-zero water buildings are only effective when the building occupants have adopted water conservation measures along with highly efficient water fixtures. Building occupant behavior coupled with occupant water usage is typically affected by many different physical and mental factors such as: the occupant's viewpoint on their personal comfort; the occupant's income level; the occupant's education status; building features and daily activities which correspond to water usage; if they pay for the water bill for the building they are in; personal habits of the building occupants; and many other factors (Ergöz Karahan et al., 2021). These factors shape behaviors of the building occupants which result in their water usage actions in their residential buildings and also in their place of work.

In a study completed in 2014, participants were asked two open-ended questions in a survey – "What could they possibly do to reduce water usage?" and "What could other Americans do to reduce their water usage?". The responses of 1,020 participants were summarized in Table 1 on the following page:

Table 1: Survey Results of Perceived Routes to Reduce Water Use (Attari, 2014)

Activity	Curtailment or Efficiency	Self, %	Americans, %
Shorter of fewer showers	Curtailment	42.6	28
Turn off water while not doing activities (not including brushing teeth)	Curtailment	9.9	10
Turn off water while not brushing teeth	Curtailment	6.9	6.7
Conserve water or use water efficiently	N/A	4.5	6.6
Do less laundry or full loads of laundry	Curtailment	4.3	2.2
Pay more attention to water use	N/A	4.2	6.4
Water lawn less	Curtailment	4.1	12.5
Reduce dishwasher use or hand wash dishes	Curtailment	3.6	1
Other reasons (only mentioned once in survey)	N/A	3.2	3.6
Harvest water by using rain barrels	Efficiency	2.4	1.6
Check for leaks and repair them	N/A	2.1	2.9
Bathe less and shower instead	Efficiency	1.8	1.5
Switch to water-efficient fixtures/technologies	Efficiency	1.7	2.4
Water-efficient toilet	Efficiency	1.5	2.4
Flush Less	Curtailment	1.2	1.4
Turn off shower while shampooing and soaping	Curtailment	1	1.3
Switch to low-flow showerheads	Efficiency	0.9	1.1
Eat less meat	Curtailment	0.8	1
Switch to low-flow faucets	Efficiency	0.7	1.1
Don't drink bottled water	Curtailment	0.6	1.9
Recycle	N/A	0.5	0.7
Wash car less	Curtailment	0.5	1.2
Get rid of lawns or switch to water-efficient plants	Efficiency	0.5	2.2
Switch to water-efficient clothes washing machines	Efficiency	0.4	0.4
Buy fewer products	Curtailment	0.3	0.4

The results of the survey mostly resulted in actions that either improve their plumbing/water fixtures efficiency or conserve water through conscious changes in their water usage (Attari, 2014). While some actions are focused solely on water usage in residential buildings, most actions can translate to the reduction of water use on military installations as well. Actions taken by the military installation facility operators, such as the US Air Force Civil Engineers, like changing existing regular water flow fixtures to high-efficiency fixtures would result in savings of fresh-water and also tax-payer dollars when it comes to paying base water utility bills. Curtailment actions taken by all members of a military installation, like conscious efforts to eliminate wasteful water habits, would also result in savings of fresh-water and tax-payer dollars.

The adoption of net-zero water will require individuals to make the choice to reduce water consumption, to consume precipitation that has been treated into potable water and pay for potentially added costs to operate a net-zero water facility (Englehardt et al., 2016).

2.3 Use of BIM in Water Efficiency Modeling

Building Information Modeling (BIM) has been an effective tool in design and construction of buildings. It allows for added coordination between the entire construction project team and enhanced model imagery of the buildings. Additionally, BIM is gaining traction in the facility management realm for buildings and can be very helpful in the daily operations & maintenance for a facility. BIM is starting to be used in sustainable functions to achieve a certain level of building performance objectives during design of the facility (Khoshdelnezamiha et al., 2020).

Green BIM which is a operation of utilizing Building Information Modeling like Autodesk's Revit to govern data regarding the performance of a building and its sustainable goals defined during the design of a building. Green BIM is the product of using BIM, sustainable design, and building performance analysis as shown in Figure 4 on the following page

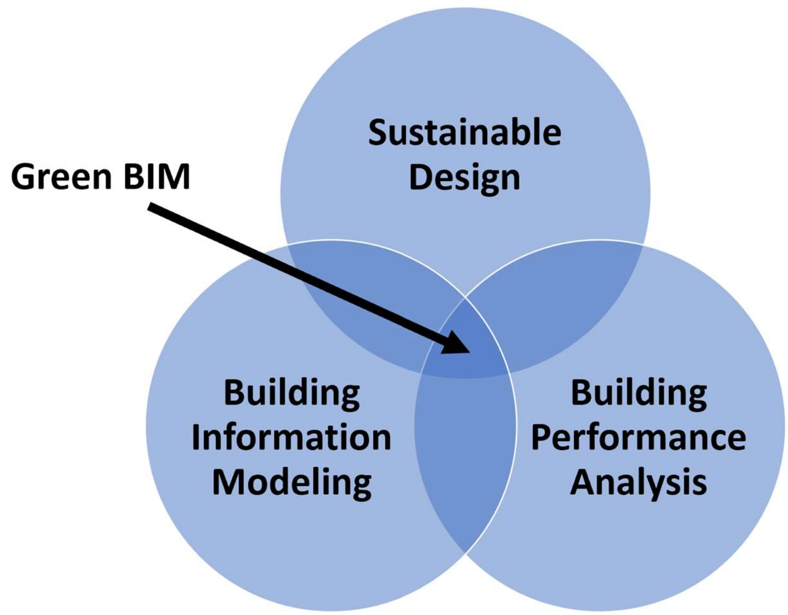


Figure 4: Green BIM Components (Hui, 2019)

Using the principles of Green BIM, the designer of a building can set water usage guidelines with input from the building's owner and design the plumbing system to meet those water usage guidelines. Additionally, rainwater collection systems and net-zero water systems can be input to operate sustainably. Sustainable design coupled with the ability to measure water efficiency performance while the building is operating, will allow the owner to verify the systems are working efficiently and sustainably. Lastly, the previous two components can be input to BIM programs in one single model which creates the Green BIM concept (Rathnasiri et al., 2020). Green BIM would be very useful for energy managers at US Air Force installations where they can verify actual sustainable utility performance beyond their current practice of verifying high performance systems using utility meters and spreadsheets.

Building Information Modeling tools such as Autodesk's Revit can model water efficiency and many other energy predictions using Autodesk's Green Building Studio cloud service program. To get started the building must be modeled in Autodesk's Revit, and then exported to Autodesk's Green Building Studio. First the building's location must be input to get accurate weather station data for the building. Then the building classification type must be properly set along with its building inhabitants, the type & type & number of fixtures in the building, the efficiency of fixtures, and the settings for net-zero water buildings such as roof type and catch basin size must be set. Then the simulation can be conducted through the BIM energy tool Green Building Studio. The program will then output the amount of water the building is expected to use throughout a 365-day period. Additionally, researchers have created tools that compare water efficiency of BIM facilities with Green Certifications such as the Living Building Challenge and LEED. Programs like Green Building Studio can determine how many LEED points your building will get in the water category (Nguyen et al., 2021).

Since the use of BIM in water efficiency modeling is relatively new, there are limitations in the use of the concept. A few research gaps that are proposed for future research are: the modeling of annualized rainwater collection to simulate and predict volume of water at different points in the year for a building; and the use of real-time monitoring of water use with intelligent sensors in buildings for BIM & digital twin purposes (Liu et al., 2019).

In further sections, this study will use Building Information Modeling tools to model the quantity of water that certain building types located on Air Force installations will use each year. Additionally, these building types will be modeled as net-zero water buildings, which will verify if net-zero water buildings receive enough water to become a viable option on US Air Force installations.

2.4 Current US Air Force Plumbing and Sustainability Construction Criteria

The US Air Force uses Unified Facility Criteria (UFC) as guidelines for the design and construction of its facilities. These criteria are published by the Department of Defense and outline which design and construction codes, along with policies that the DoD requires of its facilities in terms of operation and maintenance. Two UFCs that will be highlighted in this literature review are UFC 1-200-02, High Performance and Sustainable Building Requirements, and UFC 3-420-01, Plumbing Systems.

UFC 1-200-02, High Performance and Sustainable Building Requirements, outlines the minimum requirements that US Air Force should meet for high performance and sustainable buildings. This UFC refers to the most recent International Green Construction Code (IgCC) which is the third version of the 2018 code, more specifically Chapter 6 Water Use Efficiency, for official guidance on the specifications in terms of high performance and sustainable plumbing fixtures and building water systems. Key statements solely from UFC 1-200-02 include: ensuring the installation of water meters in facilities to track measurement of utilities; prohibiting the use of potable water for landscaping besides the planting of new vegetation; and the use of alternative water for non-potable applications when it is life cycle cost efficient and permitted by local & state laws and regulations (DoD, 2020). Water meters are required on buildings on DoD installations, but in practice they are often not present in buildings. The theoretical use of utility meters, and grey water (water that has not been through a toilet but used in a sink or other similar fashion) for landscaping are not new revolutionary practices. However, the ability to use alternative water sources, such as collected rainfall, is the first step to create net-zero water buildings on Air Force installations. Currently, this UFC would allow for water to be collected and used in non-potable functions such as being used in toilets or urinals. Additionally, there would need to be further updated guidance in the UFC to be allowed to create a building that collects non-potable water, treats it, and then allows for it to be used in drinking fountains, sinks, and other functions that require potable water.

IgCC Chapter 6, Water Use Efficiency, is referenced by UFC 1-200-02, in terms of what minimum water efficiency standards are required of plumbing fixtures in buildings on Air Force installations. These benchmarks outline the maximum amount of water, in gallons or liters, that can be used per flush or per minute in common plumbing fixtures. Chapter 6's Table 601.3.2.2 holds the maximum flush volume and flow rate standards and is referenced in Table 2 below:

Table 2: IgCC Table 601.3.2.2 for Plumbing Fixture Standards (ICC, 2021)

Plumbing Fixture	Maximum
Water closets (toilets) - flushometer single-flush valve type	Single-flush volume of 1.28 gal (4.8 L)
Water closets (toilets) - flushometer dual-flush valve type	Full-flush volume of 1.28 gal (4.8 L)
Water closets (toilets) - single-flush tank type	Single-flush volume of 1.28 gal (4.8 L)
Water closets (toilets) - dual flush tank type	Full-flush volume of 1.28 gal (4.8 L)
Urinals	Flush volume 0.5 gal (1.9 L)
Public lavatory faucets	Flow rate - 0.5 gpm (1.9 L/min)
Public meters self-closet faucet	0.25 gal (1.0 L) per metering cycle
Residential bathroom lavatory sink faucets	Flow rate - 1.5 gpm (5.7 L/min)
Residential kitchen faucets	Flow rate - 1.8 gpm (6.8 L/min)
Residential showerheads	Flow rate - 2.0 gpm (7.6 L/min)
Residential shower compartment (stall) in dwelling units and guest rooms	Flow rate from all shower outlets total of 2.0 gpm (7.6 L/min)

If not already installed in current buildings, retrofitting these plumbing fixtures along with the piping needed to accommodate them would help Air Force installations become more water efficient overall. In new buildings, these fixtures would be designed into the facility since the designers have to follow UFC 1-200-02 and UFC 3-420-01. These systems would be instrumental in allowing the net-zero water system in a building to work, as it would limit excessive use of water.

UFC 3-420-01, Plumbing Systems, outlines the requirements for plumbing systems in Air Force buildings. The plumbing in a building is to be designed to accommodate high-performance plumbing fixtures, however if an Air Force installation's mission cannot accommodate sustainable practices – water conservation targets are optional (DoD, 2021). This statement is left vague in order to accommodate missions that require large amounts of water and to also make water conservation not mandatory. The commercial designers of facilities will have to work with base personnel, such as the US Air Force Civil Engineers, to determine if net-zero water buildings would or wouldn't interfere with mission requirements. This UFC will need to be updated if net-zero water buildings are allowed to accommodate language and design guidelines for them.

Mentioned above, UFC 1-200-02 allows for use of alternative water in non-potable water scenario such as water used in toilets, urinals, and land irrigation. The collection of rainfall is not federally regulated. However, it is regulated as the state and local level. Currently, it is not illegal in any state but there are some major restrictions in states like Colorado & Nevada. For example, Colorado only allows for the maximum of 110 gallons of rainwater to be collected and can only be used for non-potable outdoor activities like gardening (US DOE, 2022). Some states require permits to use rainwater collection systems for purposes beyond normal residential use. Several states have deregulated rainwater harvesting and have zero restrictions for individuals or businesses to collect and treat water. Additionally, there are several states that further encourage the use of rainwater collection due to the increasing scarcity of freshwater in parts of the United States. This encouragement is through two different means – resources and or incentives. Resources that US states typically provide are guides and specifications for installation of rainwater harvesting systems. Incentives that US states generally provide are tax rebates on rainwater systems along with utility bill rebates. Lastly, each state has small variations on how rainwater is collected and if it can be used for potable or non-potable water functions. It is important to understand the individual state's laws regarding this topic when having facilities designed by outside agencies such as commercial design firms (US DOE, 2022). See Figure 5 below and Table 3 on the following page for the general classification of each state on their regulation of rainwater harvesting:

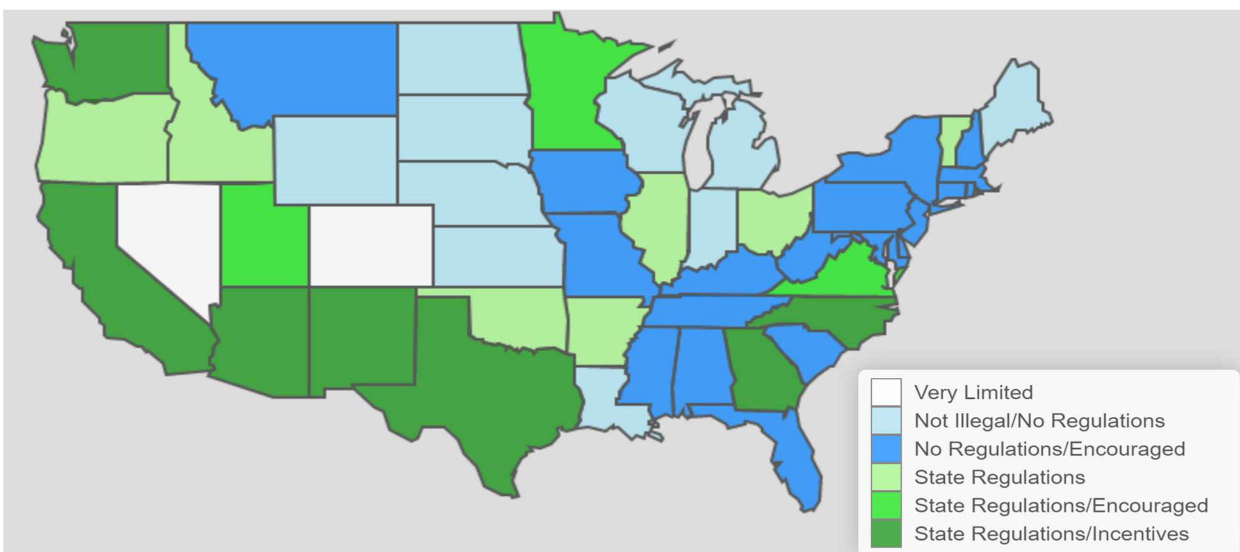


Figure 5: Rainwater Harvesting Legality Status Map (US DOE, 2022)

Table 3: Regulation Status for Rainwater Harvesting by State (US DOE, 2022)

Status	States
Very Limited	(2) Colorado, Nevada
Not Regulated	(10) Indiana, Kansas, Louisiana, Maine, Michigan, Nebraska, North Dakota, South Dakota, Wisconsin, Wyoming
Not Regulated & Encouraged	(21) Alabama, Alaska, Connecticut, Delaware, Florida, Hawaii, Iowa, Kentucky, Maryland, Massachusetts, Mississippi, Missouri, Montana, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, South Carolina, Tennessee, West Virginia
State Regulated	(7) Arkansas, Idaho, Illinois, Ohio, Oklahoma, Oregon, Vermont
State Regulated & Encouraged	(3) Minnesota, Utah, Virginia
State Regulated with Incentives	(7) Arizona, California, Georgia, New Mexico, North Carolina, Texas, Washington

When it comes to the harvesting of rainwater for net-zero water buildings on US Air Force installations, it would be best to choose installations in locations that encourage the practice of rainwater collection with little regulation involved. To choose a few, the states of Florida, Louisiana, Mississippi, and South Carolina are favorable towards rainwater harvesting and US Air Force installations in these states would be excellent candidates for net-zero water installations.

2.5 Large Military Sites with Potential for Net-Zero Water Capability

The definition of a military installation's size according to the Department of Defense is not determined by its area or number of buildings, but by the plant replacement value (PRV) which is the cost of replacing all of the facilities on that specific installation. The Base Structure Report for Fiscal Year 2018 is the most recent summary of the entire Department of Defense's unclassified installation inventory and the corresponding plant replacement value of their installations. There are four categories of military installation sizes. These distinctions are large, medium, small and other (other is defined as being under the threshold for small category). For the purposes of this research, the large category will be focused on. To be classified as a large sized military installation in any branch of the Department of Defense, the military installation's plant replacement value must be greater than or equal to $2.067 Billion.

The US Air Force has a total of 1,535 sites with a vast majority of them being small sized military owned property. There are a total of 37 large Air Force sites located in the United States in the FY18 Base Structure Report published by the Office of the Assistant Secretary of Defense for Infrastructure, which are summarized in Table 4 along with the US state they are in (OASDI, 2017). The 37 installations include active-duty Air Force Bases (AFB), Air Force Stations which are fairly similar to Air Force Bases but have little flying activity, Air Force Plants where US aircraft are made, and Joint Bases which are shared with another branch in the DoD. The installations may be seen in Table 4 on the following page:

Table 4: Large Air Force Installations from FY2018 Base Structure Report (OASDI, 2017)

Number	Air Force Installation	Location
1	Eareckson Air Station	Alaska
2	Eielson Air Force Base	Alaska
3	Joint Base Elmendorf-Richardson	Alaska
4	Davis Monthan Air Force Base	Arizona
5	Air Force Plant 42	California
6	Beale Air Force Base	California
7	Edwards Air Force Base	California
8	Vandenberg Air Force Base	California
9	US Air Force Academy	Colorado
10	Dover Air Force Base	Delaware
11	Eglin Air Force Base	Florida
12	MacDill Air Force Base	Florida
13	Robins Air Force Base	Georgia
14	Mountain Home Air Force Base	Idaho
15	Scott Air Force Base	Illinois
16	Barksdale Air Force Base	Louisiana
17	Joint Base Andrews	Maryland
18	Keesler Air Force Base	Mississippi
19	Whiteman Air Force Base	Missouri
20	Malmstrom Air Force Base	Montana
21	Offutt Air Force Base	Nebraska
22	Nellis Air Force Base	Nevada
23	Joint Base McGuire-Dix-Lakehurst	New Jersey
24	Holloman Air Force Base	New Mexico
25	Kirtland Air Force Base	New Mexico
26	Minot Air Force Base	North Dakota
27	Wright-Patterson Air Force Base	Ohio
28	Tinker Air Force Base	Oklahoma
29	Joint Base Charleston	South Carolina
30	Ellsworth Air Force Base	South Dakota
31	Arnold Air Force Base	Tennessee
32	Joint Base San Antonio-Fort Sam Houston	Texas
33	Lackland Air Force Base	Texas
34	Sheppard Air Force Base	Texas
35	Hill Air Force Base	Utah
36	Joint Base Langley-Eustis	Virginia
37	Fairchild Air Force Base	Washington

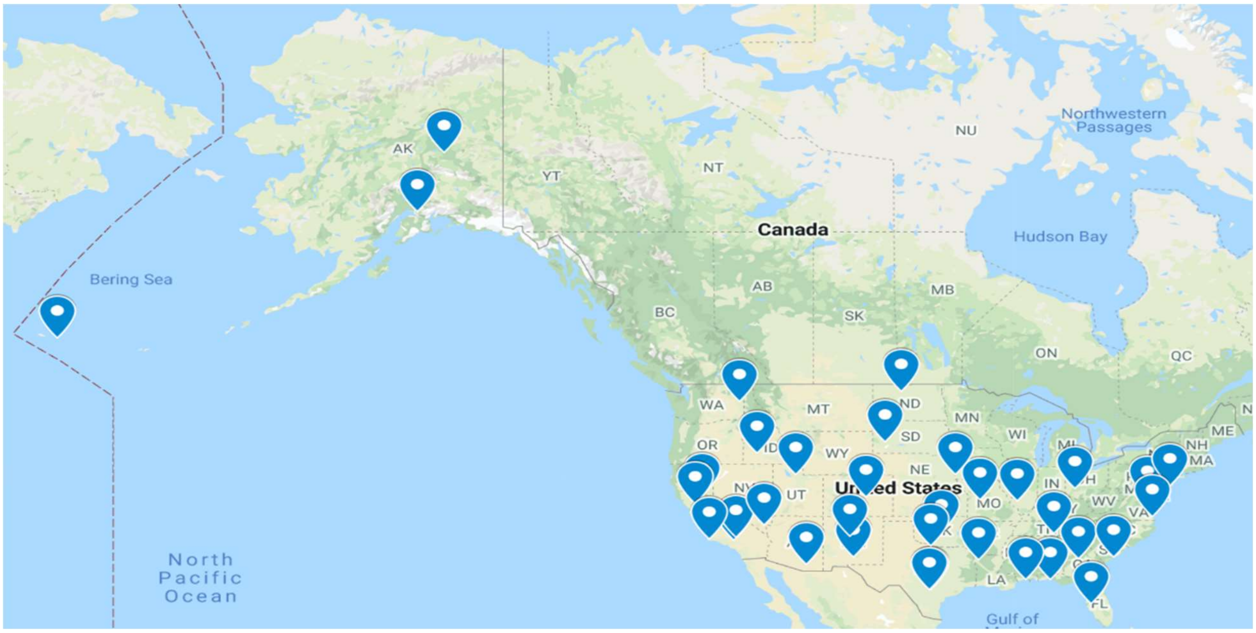


Figure 6: Overview Map of Large Air Force Site Locations

The locations of the large installations listed in Table 4 can be seen in Figure 6. These 37 installations are located across the country, and some are in areas that are prone to freshwater shortages. The ability for a military installation to collect, treat, and use its own freshwater would allow the installation to become sustainable in terms of water and to prevent the problems of water scarcity from interfering with the US Air Force's missions in the United States and abroad. The International Living Future Institute (ILFI), the organization known for their sustainable building practices with the Living Building Challenge, states in their net-water imperative that net-zero water buildings must be able to supply their own water through rainfall collection or other closed water loops (ILFI, 2022). This would be rather straight-forward for buildings on installations in areas that experience large amounts of annual precipitation but would be very difficult to do at installations that are in more arid climates. The ability to for an entire installation to become net-zero water capable would require large amounts of water as each installation is like a small city. There are hundreds of buildings that are used daily that account for large amounts of water consumption, but many other activities consume water like landscaping, aircraft maintenance, and firefighting training. For example, energy managers at two large Air Force sites (Ellsworth Air Force Base, SD, and Wright-Patterson Air Force Base, OH) provided how much water is used per fiscal year. Ellsworth Air Force Base used 189,594 KGal (equivalent to 189,594,000 gallons) in FY21, and Wright-Patterson Air Force Base, which is much larger and has a larger population than Ellsworth Air Force Base, used 1,072,860 KGal (equivalent to 1,072,860,000 gallons) in FY21. Historical data for Ellsworth Air Force Base was also provided, with the installation using 540,286 KGal (equivalent to 540,286,000 gallons) in FY91 (Fiscal Year 1991). The reduction in the usage of water from 1991 to 2021, would be due to the advent of water conservation culture in the DoD and installation of efficient water fixtures on military installations.

To determine what Air Force sites are in areas with suitable amounts of rainfall, it is prudent to look at the historical climate data of each location. Historical annual precipitation data can be accessed using the US National Centers for Environmental Information (NCEI) online database. The most recent normalized annual data found in their database is averaged over a 30-year period from 1981 to 2010. The annual precipitation can be found in Table 5 on the following page:

Table 5: Average Annual Precipitation for Large Air Force Sites (NCEI, 2022)

Number	Air Force Installation	Nearby Weather Station	Annual Precipitation (in)
1	Eareckson Air Station	Shemya Island, AK	31.87
2	Eielson Air Force Base, AK	Fairbanks, AK	10.81
3	Joint Base Elmendorf-Richardson	Anchorage, AK	15.73
4	Davis Monthan Air Force Base	Tucson, AZ	11.59
5	Air Force Plant 42	Palmdale, CA	7.4
6	Beale Air Force Base	Yuba City, CA	22.75
7	Edwards Air Force Base	Edwards, CA	7.4
8	Vandenberg Air Force Base	Lompoc, CA	15.99
9	US Air Force Academy	Colorado Springs, CO	16.54
10	Dover Air Force Base	Dover, DE	46.05
11	Eglin Air Force Base	Valparaiso, FL	62.91
12	MacDill Air Force Base	Tampa, FL	46.3
13	Robins Air Force Base	Warner Robins, GA	48.13
14	Mountain Home Air Force Base	Mountain Home, ID	10.55
15	Scott Air Force Base	Belleville, IL	41.65
16	Barksdale Air Force Base	Shreveport, LA	51.41
17	Joint Base Andrews	Morningside, MD	41.88
18	Keesler Air Force Base	Biloxi, MS	64.83
19	Whiteman Air Force Base	Knob Noster, MO	42.94
20	Malmstrom Air Force Base	Great Falls, MT	14.75
21	Offutt Air Force Base	Lincoln, NE	32.16
22	Nellis Air Force Base	Las Vegas, NV	5.37
23	Joint Base McGuire-Dix-Lakehurst	Trenton, NJ	46.44
24	Holloman Air Force Base	Alamogordo, NM	10.77
25	Kirtland Air Force Base	Albuquerque, NM	9.45
26	Minot Air Force Base	Minot, ND	17.19
27	Wright-Patterson Air Force Base	Dayton, OH	41.05
28	Tinker Air Force Base	Oklahoma City, OK	37.61
29	Joint Base Charleston	Charleston, SC	51.03
30	Ellsworth Air Force Base	Rapid City, SD	16.29
31	Arnold Air Force Base	Tullahoma, TN	58.59
32	Joint Base San Antonio-Fort Houston	San Antonio, TX	32.27
33	Lackland Air Force Base	San Antonio, TX	32.27
34	Sheppard Air Force Base	Wichita Falls, TX	28.92
35	Hill Air Force Base	Salt Lake City, UT	16.1
36	Joint Base Langley-Eustis	Hampton, VA	53.4
37	Fairchild Air Force Base	Spokane, WA	16.56

From a glance at the precipitation annual data, the locations on the Atlantic Ocean and Gulf of Mexico coasts along with inland locations that are east of the Mississippi River, are ones that receive the highest amount of rainfall. According to the 2021 National Climate Report, the continental United States received an average of 30.48 inches of rainfall which is a middling average rainfall (NCEI, 2022). Installations that are in areas that received more than the 2021 average rainfall for the United States are labeled in orange in Figure 7 on the following page:

Figure 7: United States Air Force Installations with Above Average Rainfall

16 out of 37 installations, marked in orange, should be investigated further for the opportunity to become net-zero water installations since they receive above average rainfall compared to the rest of the continental United States.

CHAPTER 3. METHODOLOGY

To answer the research questions posed in the introduction chapter, models were created using BIM software and then analyzed using cloud-based software for their estimated water usage. In this chapter, the methodology to test the net-zero water capability for existing US Air Force buildings, will be described in detail.

The first step to creating models in BIM software was to gather floorplan information on relevant buildings that are commonly found in Air Force installations. The buildings chosen for this study were ones that were unique in usage but also ones that are fairly standardized in design. The buildings selected for this study may be seen in Table 6 below:

Table 6: US Air Force Building Types Selected for Water Analysis

Number	Building Type	Building Activities
1	Air Traffic Control Tower	Monitor Airfield & Communicate with Aircraft
2	Aircraft Hangar	Aircraft Storage & Maintenance
3	Base Exchange Shopping Center	Shopping Center Similar to Walmart or Target
4	Childcare Center	Full-day Childcare & After-School Programs
5	Dining Facility	Breakfast, Lunch, Dinner, and Midnight Operations
6	Dormitory (Barracks)	Living Quarters for Junior Airmen on Installation
7	Fieldhouse	Running Track & Cross-Fit Training Areas
8	Fire Station	Living Quarters and Work Center for Firefighters
9	Fitness Center	Base Gymnasium Similar to Civilian Gyms
10	Hotel	Temporary Lodging Similar to Civilian Hotels
11	Large Warehouse (Logistics)	Base Storage for all Equipment, Vehicle Maintenance
12	Medical Clinic	Urgent Care Facility with Pharmacy, Dental, and Public Health Offices. No Emergency Capabilities
13	Office Building	Specific to Office's Occupants. The Building Modeled for this Study was the Civil Engineer Building
14	Small Warehouse (Munitions)	Warehouse for Munitions

Since buildings in the US Air Force are designed off similar standardized criteria, building floorplan data was collected from the Engineering Flight at Ellsworth Air Force Base, SD, for purposes of creating models of different building types. Since BIM is not commonly used in Civil Engineer Squadrons in the Air Force – these buildings were recreated using the provided architectural floorplan documents. The program, Autodesk Revit, was used for three-dimensional BIM Modeling.

A modified level of design (or detail) 100 was used for the models. Key features included in the creation of the buildings in Autodesk Revit are all pertinent building dimensions, walls, floors, roofs, windows, staircases, doors, ceilings, room names, and plumbing features that were denoted in the floorplans on the architectural floorplan drawings. Common plumbing features that were found in the provided documents were sinks, showers, toilets, urinals, and washing machines. These features were required to create accurate models of the existing buildings at Ellsworth Air Force Base, SD. These models would also have enough detail in order to estimate the amount of water used in these buildings in Autodesk's cloud-based software Green Building Studio.

The 14 buildings' computer models were then completed on Autodesk Revit. The 3-D model can be viewed in Figures 14-41 in Appendix A. After completion of the models – the buildings' rvt files could then be exported to gbXML files which are required for use in the Green Building Studio software. Projects for each building were created on Green Building Studio. When creating the projects, information such as building activity classification (such as gymnasium, hotel, etc.), building hours of operation, and building location. The building location is necessary as the software can pull 30-year average rainfalls from the nearest weather station. Since the project can only have one location – it would require multiple projects to be created for the same building to compare water usage at different Air Force installations in different parts of the continental United States.

To gather an adequate sample size for large sized Air Force installations, four bases were selected for their geographical locations and 30-year average rainfalls. The bases selected were Ellsworth Air Force Base, SD, Wright-Patterson Air Force Base, OH, Eglin Air Force Base, FL, and Joint Base Charleston, SC. Ellsworth Air Force Base, SD, was selected because the buildings modeled for this study are physically present there, available historical data on base-wide water usage, and the installation exists in the Great Plains region of the United States. Wright-Patterson Air Force Base, OH, was selected as the Air Force Institute of Technology is located there, available historical data on base-wide water usage, and the installation exists in the Midwest region of the United States. Eglin Air Force Base, FL, was selected because of its above average 30-year average rainfall (62.91 inches per year on average) and its location on the Gulf of Mexico. Joint Base Charleston was selected because of its above average 30-year rainfall (51.03 inches per year on average), and its location on the Atlantic Ocean. The models were based on existing buildings from Ellsworth Air Force Base, SD, but were tested with the four locations' rainfall data. This means that a model of an existing building at Ellsworth Air Force Base, SD, would be tested using Eglin Air Force Base, FL, rainfall data. Therefore, there were a total of 56 different tests run in Green Building Studio.

After projects were created in Green Building Studio, the settings were set for each section of the program. The unit water prices were set at $0.94 per KGal for water utility rates and $0 per KGal for sewer utility rates. The water utility rate was the amount that Ellsworth Air Force Base, SD, paid per KGal in FY2021, and the sewer rate is assumed to be $0 as grey water would be reused and black water would be returned to the ground as is recommended by the US Department of Energy's ideal net-zero water building. The outdoor water factors were set to 0 Gal per day and 0 ft^2 irrigation area as there will be no potable water used for outdoor purposes specifically for the building. Grey water is allowed for use in irrigation of landscaping as specified in UFC 1-200-02. The building summary is different for all 14 buildings as it is specific to the number of fixtures located in the building. The water efficiency is set to low flow for toilets, urinals, and showers. Sinks use either hands-free or low flow depending on the activities in the building. For example, if food preparation is suspected to occur in the building – it would use low flow instead of hands-free efficient sinks. Clothes washers are set to horizontal-axis fixtures if they are present in the building. Dishwashers are set to efficient if they are present in the building as well. Lastly, net zero measures settings are input for the building. Rainwater harvesting is selected for every building as this procedure is the primary route for collecting water to use in the facility. The nearest weather station's annual rainfall and the imported BIM catchment area are provided by Green Building Studio. The roof surface type was selected based off the existing building's roof type. Grey water reclamation was selected for purposes of using in buildings and landscaping where regulations allow. The last setting, site potable water sources, is selected for each building with a yield of 274 Gal per day (which equates to 100,010 Gal per year). The logic behind this setting is that each building would be outfitted with two 50,000-Gal storage tanks that are filled to max capacity before the buildings are commissioned. This tank configuration is currently used by The Kendeda Building on the Georgia Institute of Technology's campus in Atlanta, GA. In practice, the storage tank size and number of tanks would be calculated for each building based on estimated usage and amount of rainfall harvested. This setting was universally made for the 14 buildings in order to make calculations standardized between the models and tests. An example of the entire settings can be seen in Figure 8 on the following page. After all settings were input – the 56 tests were run and the results can be seen in the following chapter, Chapter 4. Results, and in Figures 42-97 in Appendix B.

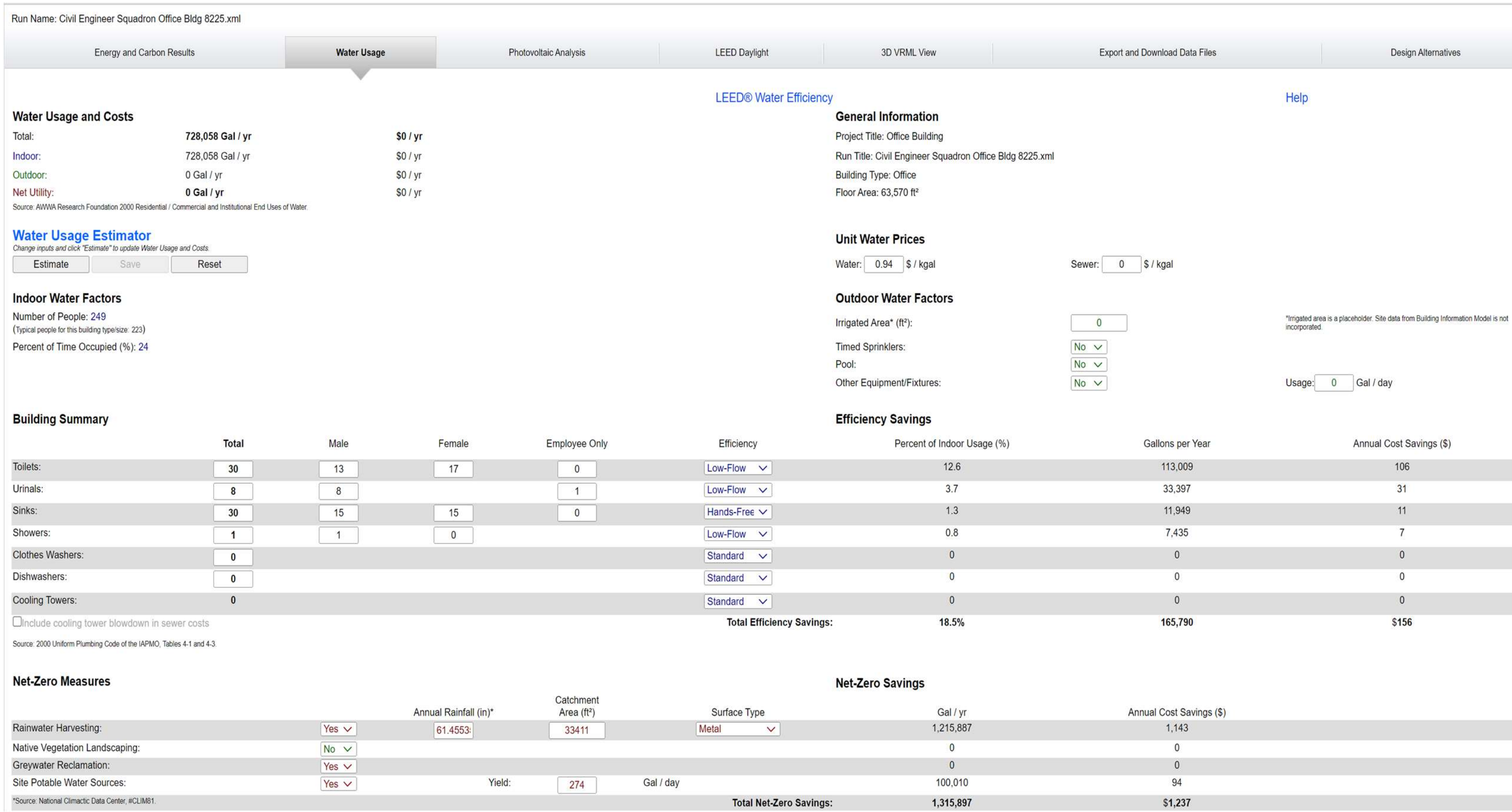


Figure 8: Example of Green Building Studio Settings

CHAPTER 4. RESULTS

This chapter presents the results of the 14 models that were analyzed on Green Building Studio. After performing the procedure in the methodology chapter – the results of each of the 56 tests are presented in Table 7 on page 34.

In table 7, the buildings were each tested for their estimated water usage based on their model characteristics and settings chosen before the official tests were run. The results of the estimated water usage can be seen in the "Estimated Annual Water Usage" column – where the total water used for a calendar year (365 days) in the building is estimated. After selecting the appropriate settings for the building, the Green Building Studio software could then estimate the net water annual amount that the building would collect through net-zero water measures and then use through its efficient plumbing fixtures. The results of these 56 tests can be seen in the "Net Annual Water Amount (Gal) after Water Efficiency & Harvesting per Location" columns in Table 7. If the amount in the column is a negative amount, this means that the building requires that amount of water through other means such as its water connection from its local municipality. For example, the Air Traffic Control Tower has a value of -60,112 Gal for Ellsworth AFB, SD. This means that the building requires 60,112 Gal on top of the water collected through net-zero water measures. If the value is positive, then the number is a surplus of water created through net-zero measures.

The results of Table 7 conclude that it is possible to use Building Information Modeling to model water efficiency for buildings on Air Force installations which answers the second research question posed in the introduction. After a service wide adoption of BIM, the Air Force Civil Engineers could use BIM to create models of their existing buildings to monitor estimated water usage through cloud-based software like Autodesk Green Building Studio. This could then be verified by the introduction of real-time data taken from water meters, if water meters are presently installed for buildings, on existing buildings that have been modeled in BIM.

In table 8 on page 34, the values for each building are added together for each installation. Since all values are negative, the value represents how many gallons of water would be required to meet the installation's estimated water usage for the 14 buildings on the installation.

Table 7: Results of Estimated & Net Annual Water Amounts per Building & Location

Building Type	Estimated Annual Water Usage (Gal)	Net Annual Water Amount (Gal) after Water Efficiency & Harvesting per Location			
		Ellsworth AFB, SD	Wright-Patterson AFB, OH	Eglin AFB, FL	JB Charleston, SC
1. Air Traffic Control Tower	167,530	-60,112	-53,024	-42,846	-46,831
2. Aircraft Hangar	1,142,877	-669,969	-313,129	199,222	-165,827
3. Base Exchange Shopping Center	843,621	-297,980	128,461	740,746	501,015
4. Childcare Center	428,532	-85,768	146,531	480,068	349,476
5. Dining Facility	4,483,313	-4,236,180	-4,095,391	-3,893,247	-3,972,394
6. Dormitory (Barracks)	2,918,111	-2,641,567	-2,472,635	-2,230,082	-2,325,050
7. Fieldhouse	2,140,553	-989,876	15,549	1,459,139	893,922
8. Fire Station	795,947	-278,813	-8,538	693,466	469,070
9. Fitness Center	3,046,025	-2,267,653	-1,618,501	-686,448	-1,051,380
10. Hotel	2,364,516	-2,122,267	-1,986,153	-1,790,721	-1,867,240
11. Large Warehouse (Logistics)	2,382,890	-571,605	1,065,979	3,417,227	2,496,631
12. Medical Clinic	4,864,729	-3,869,759	-3,013,337	-1,783,686	-2,625,137
13. Office Building	728,058	-263,017	86,295	587,839	391,467
14. Small Warehouse (Munitions)	25,051	98,444	120,918	149,377	140,552

Table 8: Total Net Water Amount (Gal) per Location

Ellsworth AFB, SD	Wright-Patterson AFB, OH	Eglin AFB, FL	JB Charleston, SC
-18,256,122	-11,996,975	-2,699,946	-6,811,726

Figures 9, 10, 11, and 12 on pages 36 and 37 show the estimated water usage in the blue column for each building. The blue columns are the same for each building in all four locations. The orange column represents the water collected through net-zero measures which is different for each test. If the orange column is larger than the blue column, this means that the building is estimated to collect enough water in its location to sustainably run net-zero water operations in its building. Ellsworth AFB, SD had 1 of 14 buildings meet the threshold of net-zero water capable. Wright-Patterson AFB, OH had 6 of 14 buildings meet the threshold of net-zero water capable. Eglin AFB, FL, had 8 of 14 buildings meet the threshold of net-zero water capable. JB Charleston, SC, had 7 of 14 buildings meet the threshold of net-zero water capable. The eight buildings that exceeded the threshold for Eglin AFB, FL, are Aircraft Hangar, Base Exchange Shopping Center, Childcare Center, Fieldhouse, Fire Station, Large Warehouse (Logistics), Office Building, and Small Warehouse (Munitions). The six buildings that did not meet the net-zero water capable threshold were Air Traffic Control Tower, Dining Facility, Dormitory (Barracks), Fitness Center, Hotel, and Medical Center.

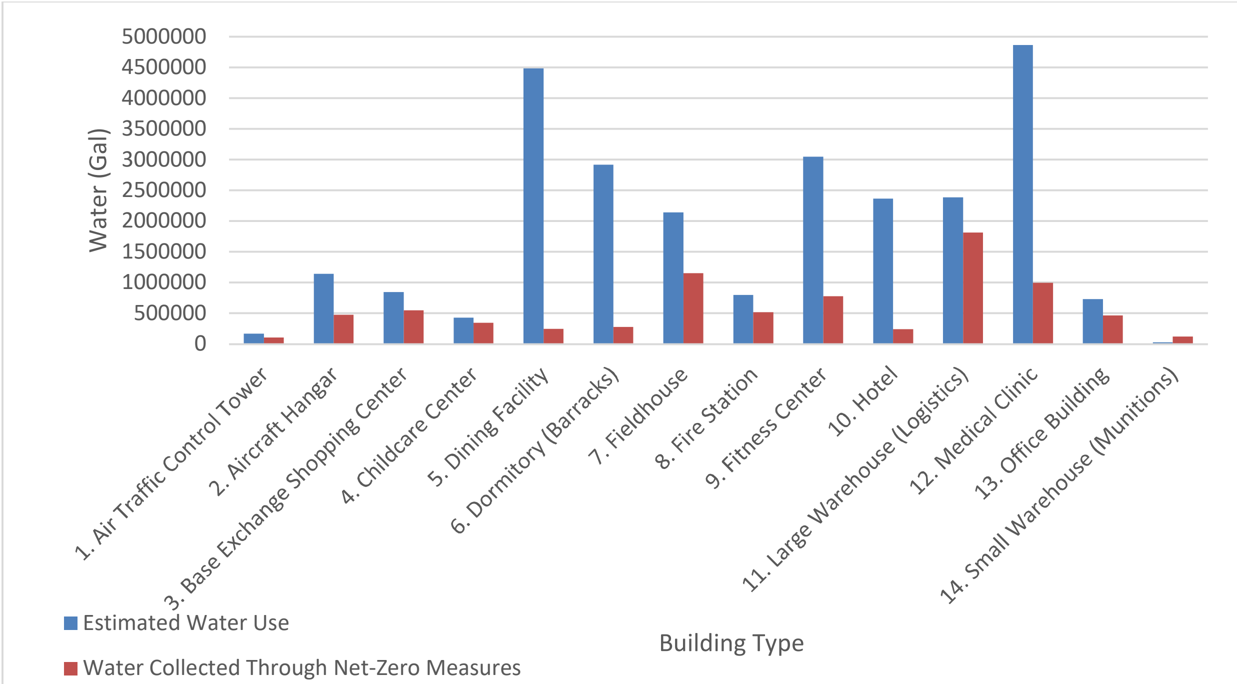


Figure 9: Estimated Water Use & Net-Zero Water Collected for Ellsworth AFB, SD

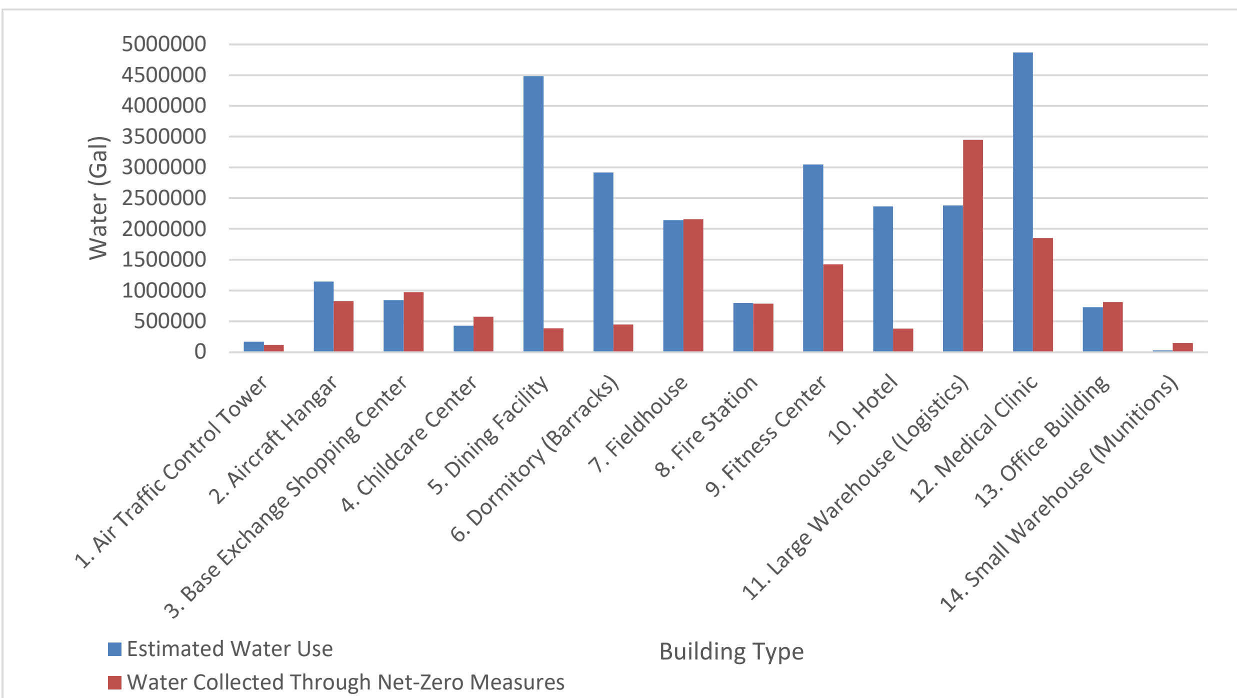


Figure 10: Estimated Water Use & Net-Zero Water Collected for Wright-Patterson AFB, OH

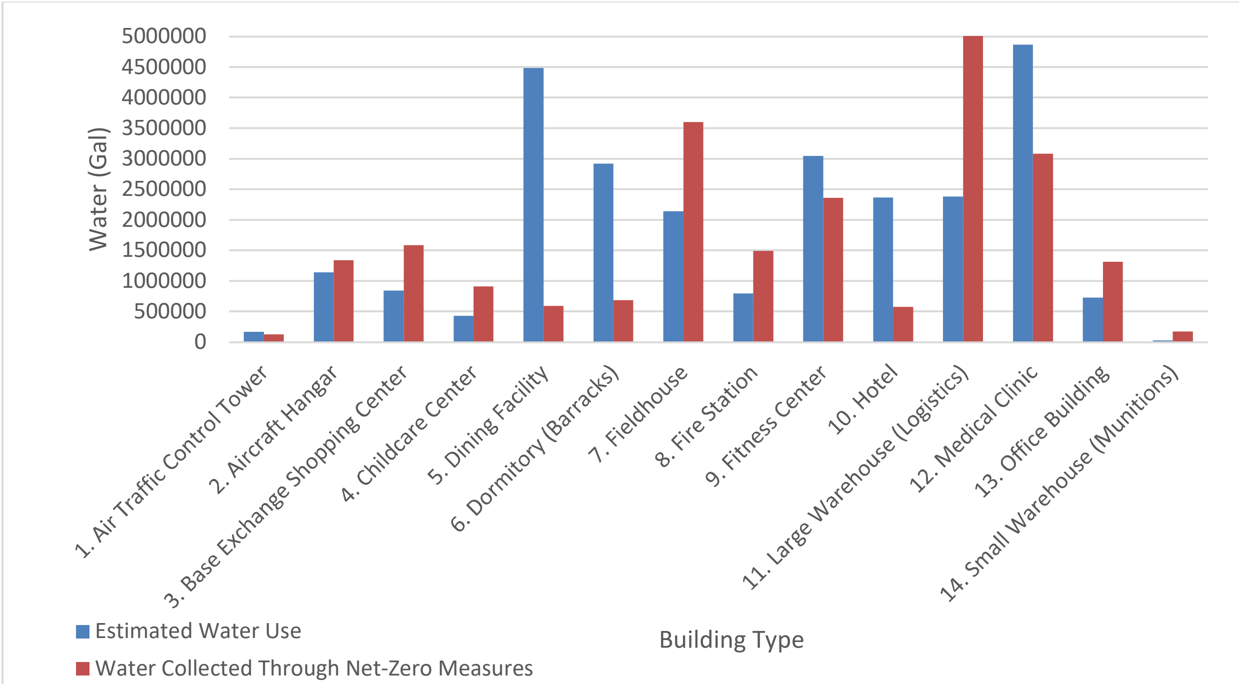


Figure 11: Estimated Water Use & Net-Zero Water Collected for Eglin AFB, FL

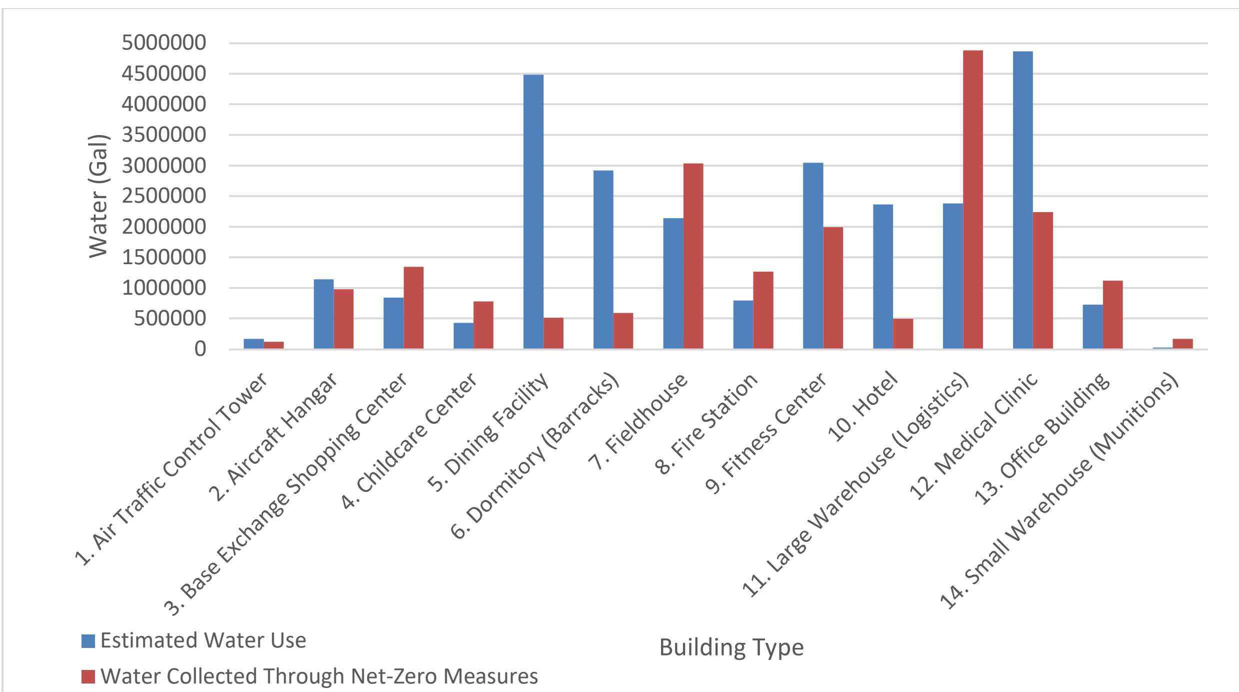


Figure 12: Estimated Water Use & Net-Zero Water Collected for JB Charleston, SC

From the results of the analyses, the installations tested for net-zero water capability varied in ability to collect rainwater for alternative water sources. Ellsworth AFB, SD, experiences very little average rainfall (16.29 inches per year) in the Great Plains Region of the United States, so it performed very poorly with only 1 of 14 buildings reaching the threshold of net-zero water possible. Wright-Patterson AFB, OH, experiences about approximately 2.5 times the amount of average rainfall (41.05 inches per year) so it performs better in terms of reaching net-zero water possible threshold with 6 of 14 buildings meeting the required water amount. Eglin AFB, FL, and JB Charleston, SC, both performed better than Wright-Patterson AFB, OH, as they receive larger amounts of average rainfall (62.91 inches per year and 51.03 inches per year). These installations reached 8 of 14 & 7 of 14 buildings meeting the net-zero water possible threshold.

In terms of installations themselves, Eglin AFB, FL, performs the best as it receives the most rainfall per year. This allows its buildings to collect the rainfall to sustain its buildings water operations and rely on its storage supply during times of drought. Even though both Eglin AFB, FL, and JB Charleston, SC, had a negative net annual amount in Table 8 – both installations could have improvements to their net-zero water systems to make them achieve net-zero water positive. The Department of Defense should focus on placing its net-zero water installations in areas of high rainfall such as the coastal areas of the Gulf of Mexico and Atlantic Ocean in the Eastern United States.

The main reason that these installations were negative were because of buildings that require large amounts of water for their daily operations. Buildings that were unable to reach the net-zero water possible threshold for Eglin AFB, FL, were Air Traffic Control Tower, Dining Facility, Dormitory, Fitness Center, Hotel, and Medical Clinic. The Air

Traffic Control Tower not meeting net-zero water threshold is due to not having a large enough catchment area for its roof and not due to its small building water usage. The Dining Facility does not meet net-zero water threshold due to its very large water demand during its constant operations in feeding the base population. The Dormitory does not meet net-zero water threshold due to its large water demand since its where our junior Airmen reside when they are not at work. Since there are Airmen that work in different shifts – the dormitory's plumbing is being used around the clock by its 100 plus residents. The Fitness Center does not meet the net-zero water threshold because of its large water demand due to its operations where people exercise and then shower afterwards. The Hotel does not meet net-zero water threshold due to its large water demand since it is a place of temporary residence for people on the installation and operates every day of the year. Lastly, the Medical Clinic does not meet net-zero water threshold due to its large water demand since it's a place where people receive medical care.

Buildings that performed very well in the study at Eglin AFB, FL, were Aircraft Hangar, Base Exchange Shopping Center, Childcare Center, Fieldhouse, Fire Station, Large Warehouse (Logistics), Office, and Small Warehouse (Munitions). These buildings perform well for net-zero water operations as they either have a large roof which allow for large rainfall catchment areas, or they have minor water demands during normal building operations. Some buildings such as the Large Warehouse have a combination of a large catchment area and a small water demand due to its building activities.

The results of different buildings performing at various levels of efficiency after net-zero water measures were taken conclude that building activities do influence building water usage on Air Force installations. This answers the first research question as different buildings are estimated to use varying amounts of water based on their occupancy and activity inside the building. A building like the dormitory that is a residential area for 100 plus junior airmen will use more water than a small warehouse used to store munitions.

In table 9 below and figure 13 on the following page, the eight buildings that were net-zero efficient for water were compared to the six buildings that did not meet net-zero thresholds for water consumption after net-zero water measures were taken. The buildings that resulted in net-zero efficient for water were combined to make a single entity while the buildings that did not meet net-zero thresholds for water were kept as individual buildings. The 8 net-zero water efficient buildings that were combined had an estimated surplus of 7,727,084 gallons while the 6 buildings that were not net-zero efficient had varying deficits if they were in closed loop systems that used only rainwater as their water consumed. The surplus created by the 8 buildings can in theory make up for the deficit for a portion of the other 6 buildings. For example, the surplus created can cover the deficits of the Dining Facility, Dormitory, Fitness Center, and Air Traffic Control Tower while still having a surplus of 874,461 gallons to be used at the Medical Center and/or Hotel.

Table 9: Comparison of Buildings that did not Meet Net-Zero Water Efficiency & Net-Zero Water Buildings at Eglin AFB, FL

Building Type	Estimated Water Usage (Gal)	Eglin AFB, FL (Gal)	Amount Needed for Net-Zero (Gal)
Air Traffic Control Tower	167,530	124,684	42,846
Dining Facility	4,483,313	590,066	3,893,247
Dormitory (Barracks)	2,918,111	688,029	2,230,082
Fitness Center	3,046,025	2,359,577	686,448
Hotel	2,364,516	573,795	1,790,721
Medical Clinic	4,864,729	3,081,043	1,783,686
All Others (8 Buildings)	8,487,529	16,214,613	-7,727,084

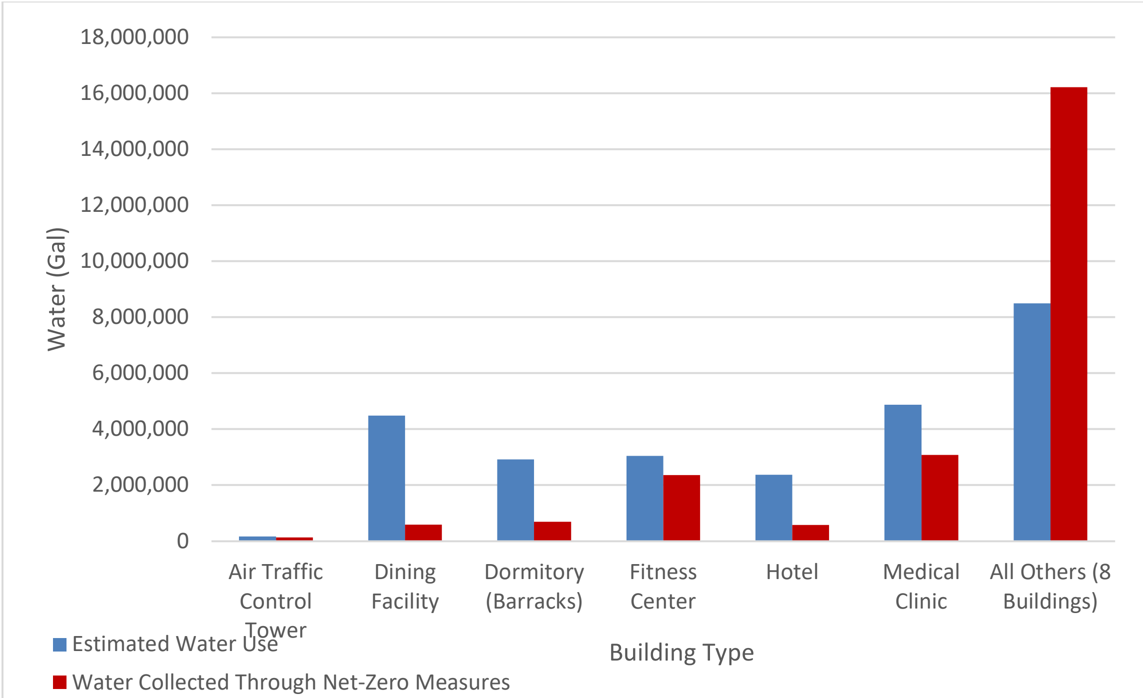


Figure 13: Comparison of Building Types at Eglin AFB, FL

This idea of combining net-zero water systems for buildings that are properly designed would allow for the creation of a net-zero water installation in an area with high rainfall like Eglin AFB, FL. The theoretical system answers the third research question by concluding that a net-zero water installation is possible through a system of individual close looped buildings that are properly designed to be net-zero water buildings or through a system of interconnected net-positive water and net-negative water buildings that overall create a net-zero or net-positive water installation.

CHAPTER 5. DISCUSSION

Net-zero water buildings are becoming more popular in the United States and around the world but have not been attempted yet on DoD federal property. With the goals from US Congress for the DoD to become 10% net-zero large installations, the US Air Force needs to adapt and plan to achieve this goal.

The first suggestion for execution of construction of net-zero water buildings on US Air Force installations would be to couple buildings that are in proximity of each other for shared net-zero water systems. This could be expanded to create systems of any number of buildings that are connected through their net-zero water system. Buildings such as a fieldhouse and fitness center that are close together can be connected to share a plumbing system that allows each building to deposit rainwater into and pull from a common storage tank for their water needs. This would allow for buildings that capture large amounts of water because of their large catchment area, but also have building activities that require small amounts of water to share with buildings that may have smaller catchment areas or have building activities that require larger amounts of water than they can obtain on their own. Continuing with the example above – the net positive water fieldhouse building can help overcome the fitness center's deficit in water requirement after net-zero water measures are implemented if they shared a common system. This idea would allow for cheaper installation of net-zero water systems between the system.

Taking the above-mentioned system, a step further, a suggestion to look further into would be to create an installation net-zero water system where all buildings supply harvested rainwater to and withdraw treated water from. This system would work like a municipal water treatment plant where water is collected by buildings, distributed to the centralized plant where water is treated and stored until it is sent back to a building on the installation for use. Some installations in the US Air Force have existing water treatment plants but it would be a large undertaking in terms of cost and schedule for those who do not. Regardless of if a plant is existing on an installation, additional piping may be required to transport the greywater or rainwater to the centralized location for treatment. This would require a large upfront cost to create a system like this as it would require interoperability between each building on the installation to the centralized water treatment & storage plant. This effort would require extensive amounts of piping to transport clean freshwater and harvested grey water since most installations are rather large. Additionally, it would require a large, and lengthy segmented construction project since all existing buildings would require the net-zero water system piping, and for the piping to the centralized plant.

The next suggestion for implementation is that net-zero water buildings have resilient back-up plans in case the power is disrupted for the facility. Areas of high rainfall are susceptible to extreme weather events such as hurricanes which interrupt electrical power for facilities. This is necessary for facilities to maintain plumbing operations when the power is out rendering parts of the net-zero water unable to operate. Suggestions to maintain integrity of the net-zero water system would be using the municipal water hook-up to the building when required to because of a failure in the net-zero water system or having dedicated back-up generators to power the net-zero water systems if they lost their main electrical power.

This study has limitations on the ability to determine if an installation can completely run its building operations on alternative water resources and for its buildings to become net-zero or net-positive water. The first limitation is that only 14 buildings from Ellsworth AFB, SD, were tested in this study. Large installations contain large amounts of buildings that can reach the hundreds. To determine if an installation's buildings can become net-zero water efficient – it would require all buildings to be tested. This can be done through BIM like in this study, or in a simpler manner such as checking building's actual water usage through its water meter, if available, and then calculate how much rainfall it could collect. However, these 14 building types give an insightful picture if the installation can become net-zero water efficient as these are the most common types of buildings on an installation. Additionally, there are usually only one or two of high-water consuming buildings like Medical Centers and Fitness Centers on installations, while there are usually numerous Office Buildings, Aircraft Hangars and Storage Warehouses on Air Force installations. The only exception for a building type that uses high amounts of water and has several present on an installation is the Dormitory (Barracks) as they are needed to house junior Airmen.

The second limitation in this study is that buildings were assumed to have two 50,000-gallon storage tanks. This assumption was used to standardize the 56 different tests, but in reality, a building would be designed to have a storage system that is suited for its water usage and the amount of rainfall it would receive. Buildings such as the Hotel and Dormitory can be net-zero water efficient if: they are properly designed to have the appropriate sized storage tanks; placed on installations that are in regions appropriate for net-zero water operations; use water efficient plumbing fixtures that reduce water usage; and have occupants that make conscious decisions to not waste water while using the facilities. Buildings in Ellsworth AFB, SD, and Wright-Patterson AFB, OH, have potential to become net-zero water possible with proper design of their net-zero water systems, implementation of efficient plumbing fixtures, and occupants who choose to use appropriate amounts of water in their activities inside or around the building.

A third limitation to this study is that Green Building Studio analyzes the amount of rainwater that a building would collect annually, and not on a monthly or shorter basis. The program currently assumes that each month would have the same amount of rainfall. In reality, installations receive different amounts of rainfall monthly. When net-zero water buildings are designed, they are designed to operate off the average rainfall of the driest month each year. If the software, Green Building Studio, was fine-tuned to use monthly rainfalls, it would be a much more accurate depiction if the building was net-zero water efficient or not.

There are several things to consider during implementation of the net-zero water installations across the country. The first thing to consider during application of net-zero water facilities is the legality of the operations in the states they are located in. Current Air Force guidance would also need to be updated to allow for alternative water sources to be used in potable water fixtures such as sinks and showers. In a similar vein of the legality, the public also will need to adopt treated rainwater as a means of cleaning their hands, taking showers, drinking water, etc. This will be an uphill battle in persuading medical professionals in the Medical Clinic, and the patrons of the installation Hotel to use treated water as it has a stigma of being "dirty" or not for consumption. Water through a properly treated tank in the net-zero water system is perfectly good for consumption and for use in potable water functions. Education programs would be beneficial in getting the general public of the installation to accept the use of net-zero water systems in the buildings they occupy.

The next thing to consider is the cost of the systems. The net-zero water system in The Kendeda Building at the Georgia Institute of Technology in Atlanta, GA, cost $460,000 extra for additional plumbing components to implement the specialized system during a new construction project. This is an especially high cost when the US Air Force receives municipal water at-cost – Ellsworth AFB, SD, pays only $0.94 per KGal. For example, the largest water consuming building, the Medical Center, only consumes an estimated 4,864,729 gallons per year. This amount of water would only cost $4,572.85 per year at the current municipal water rate that Ellsworth AFB currently pays for. Assuming there are no increases in rates or water usage, no additional costs for the net-zero water system over its lifecycle, and the cost of the project to be the same price as a net-zero water system in The Kendeda Building – it would take 100.6 years to breakeven for the costs required. This is an extraordinary amount of time for a system to breakeven on cost and it is not financially practical as the building will most likely be replaced by then assuming the installation still exists in the 2120's. The effort to place net-zero water buildings on Department of Defense installations would have to come from the federal government's desire to become more sustainable on its federal property; or from a future forced position because freshwater has become scarce. Regardless of the cause of implementation for net-zero water buildings, this increase in initial cost will be required to become net-zero water possible.

Additionally, since installations in the United States have existing permanent buildings – most net-zero water systems would have to be placed in as an existing facility construction project. This would involve major renovation of the building and force the designers & construction workers to work around existing systems in the building. This renovation process would be an extensive project that would disrupt the users of buildings on Air Force installations and most likely displace the building occupants. Some buildings on DoD property are unable to suspend their around the clock operations and which would make the process of renovating the facility for net-zero water system more difficult. Besides potential interruptions to global missions, renovating existing facilities for net-zero water operations would be more costly than implementing net-zero water systems into new construction projects where the system is a priority during the initial design phase. One way to avoid major costs would be to phase the construction of net-zero water systems in new construction buildings, and then eventually as buildings are replaced the entire installation will be net-zero water.

Lastly, the US Congress and Department of Defense should reconsider their goal of 10% of large sites being net-zero water and replace their current goal with a 10% reduction of water used across all Department of Defense sites. This can be done in a cheaper fashion by installing high-efficient water fixtures and by promoting water conscious behavior through educational programs. This idea would have the same effect without having to complete rigorous and costly projects for net-zero water installations.

Even with the extreme limitations that are discussed previously – this study is important because it sheds light on the potential for net-zero water buildings on Air Force installations, and it highlights buildings & installations that would have higher chances of success for net-zero water buildings and installations as a whole.

CHAPTER 6. CONCLUSIONS

6.1 Study Conclusions

Net-zero buildings are the future of the Department of Defense and other federal entities due to the requests of US Congress to combat freshwater scarcity and achieve energy independence. The efforts of this movement will hopefully be seen in the next few decades in the continental United States and abroad. This study found using Building Information Modeling and specialized energy software, that locations with high rainfall are excellent targets for the US Air Force to target as potential net-zero water installations. Additionally, different building types were identified as targets for net-zero water implementation and for recommendations on building types that have difficulties with net-zero water.

6.2 Recommendations

Recommendations for furthering this study would be to create models of all existing buildings on an installation in BIM and then modeling their estimated water usage using Green Building Studio or similar software. Creating a model of every building would be beneficial for estimating utility usage and for the operations & maintenance personnel in their daily duties. Additionally, it would be beneficial to use the real-time water data, if available, from building water meters to verify the accuracy of the program. Lastly, the study could be furthered by adding in activities outside of the building's envelope such as fire hydrant operations, vehicle washing, and landscaping to the study. The combination of all installation water data would truly tell if an installation is net-zero or net-positive water.

APPENDIX A.

Appendix A shows the models that were created in the BIM software Autodesk Revit. The 3-D model and the most detailed floorplan are shown in this appendix.

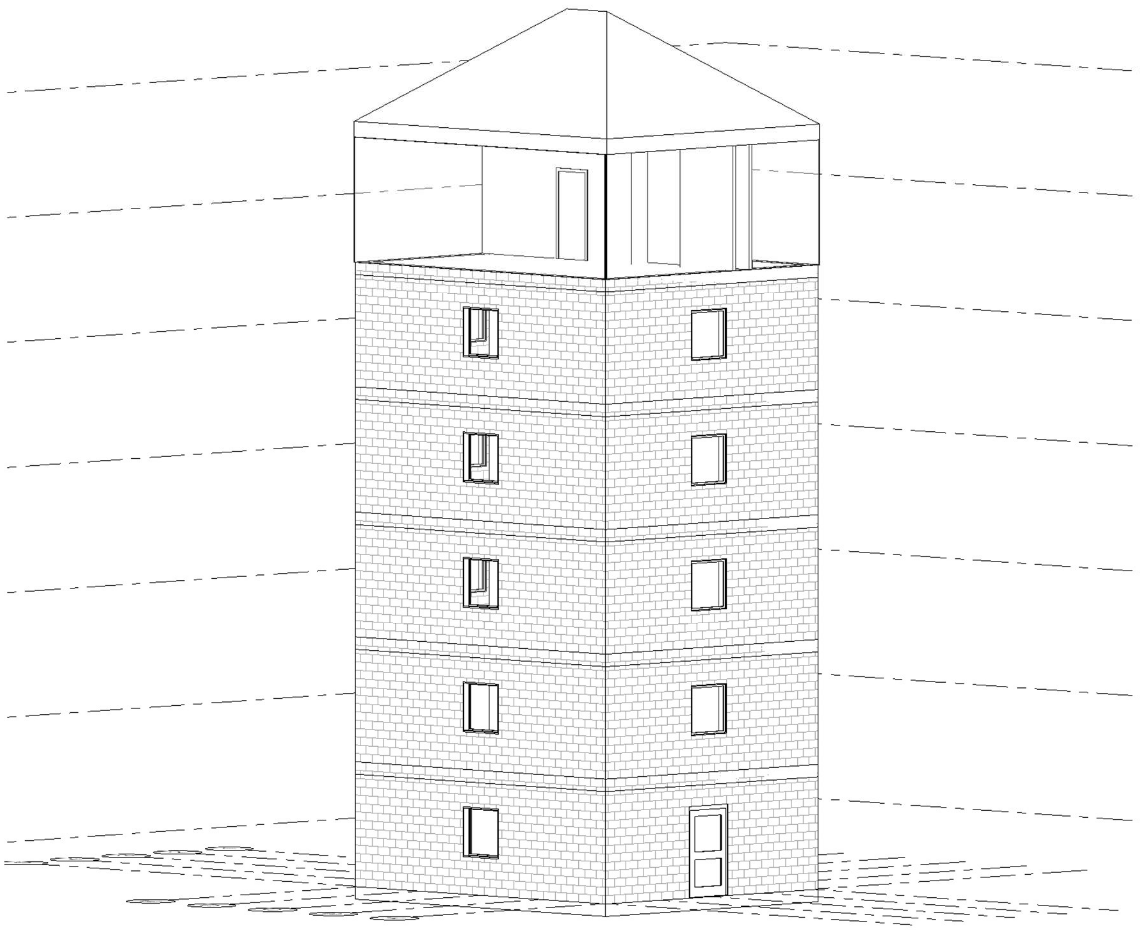


Figure 14: 3-D Rendered View of Air Traffic Control Tower in BIM

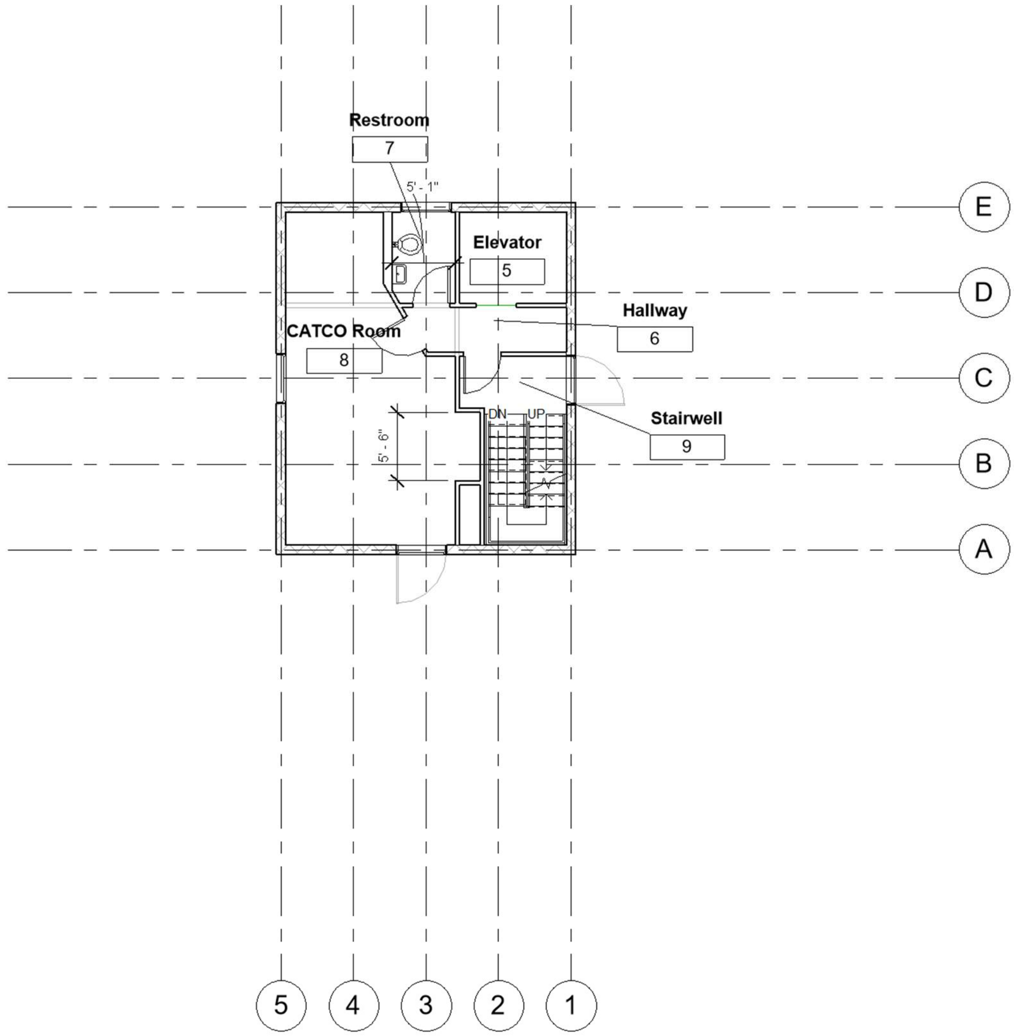


Figure 15: 2nd Floor Plan View of Air Traffic Control Tower in BIM

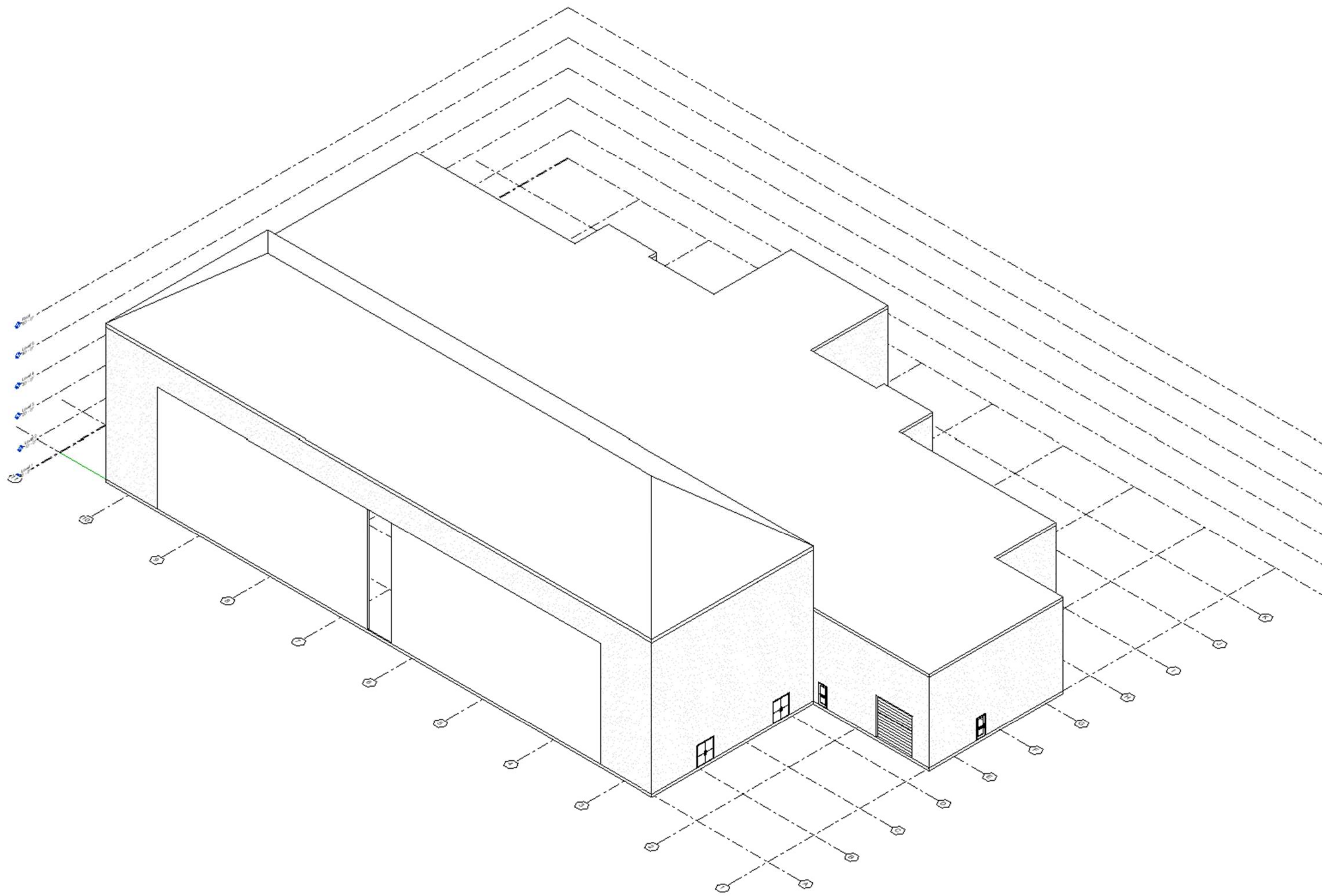


Figure 16: 3-D Rendered View of Aircraft Hangar in BIM

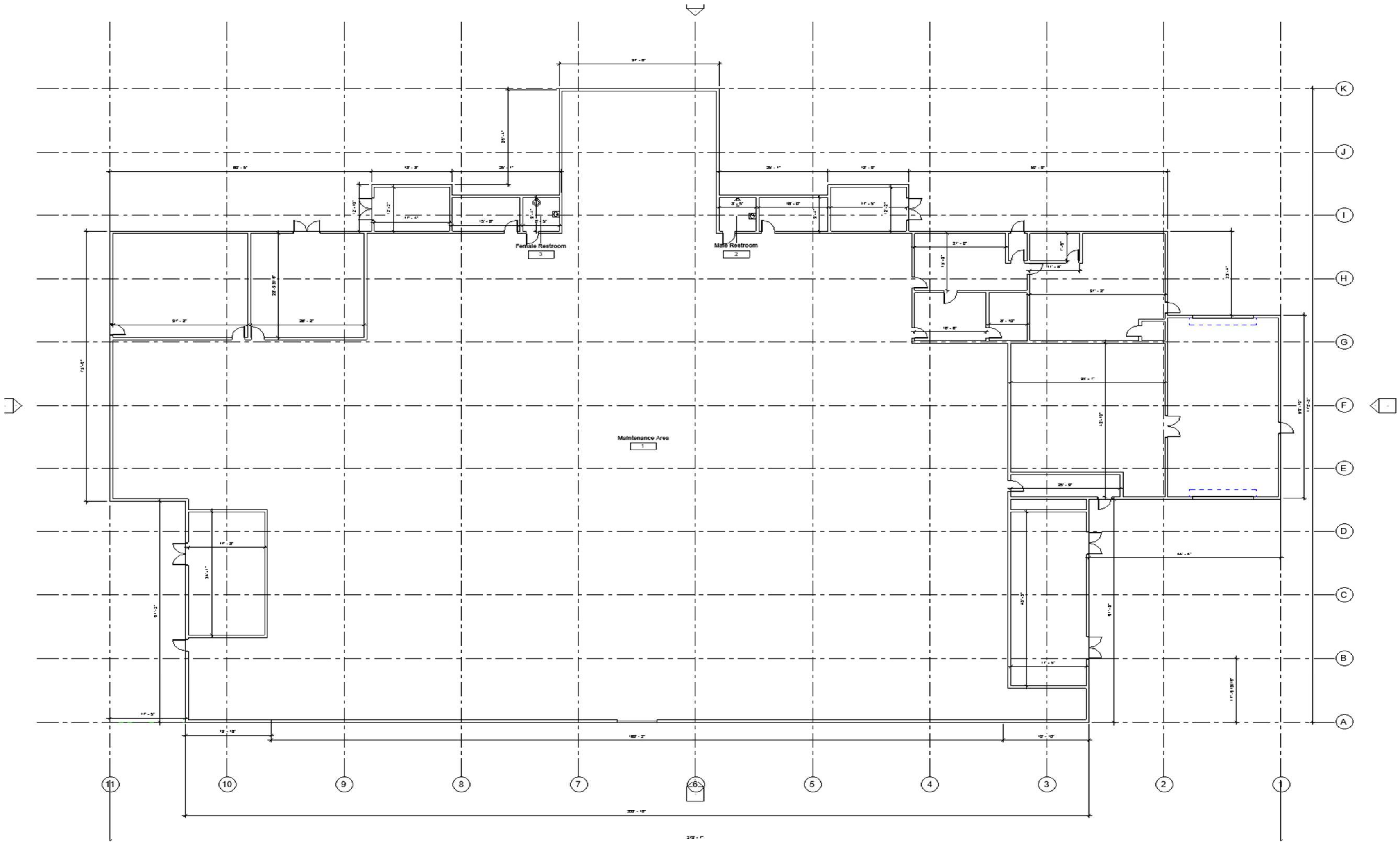


Figure 17: 1st Floor Plan View of Aircraft Hangar in BIM

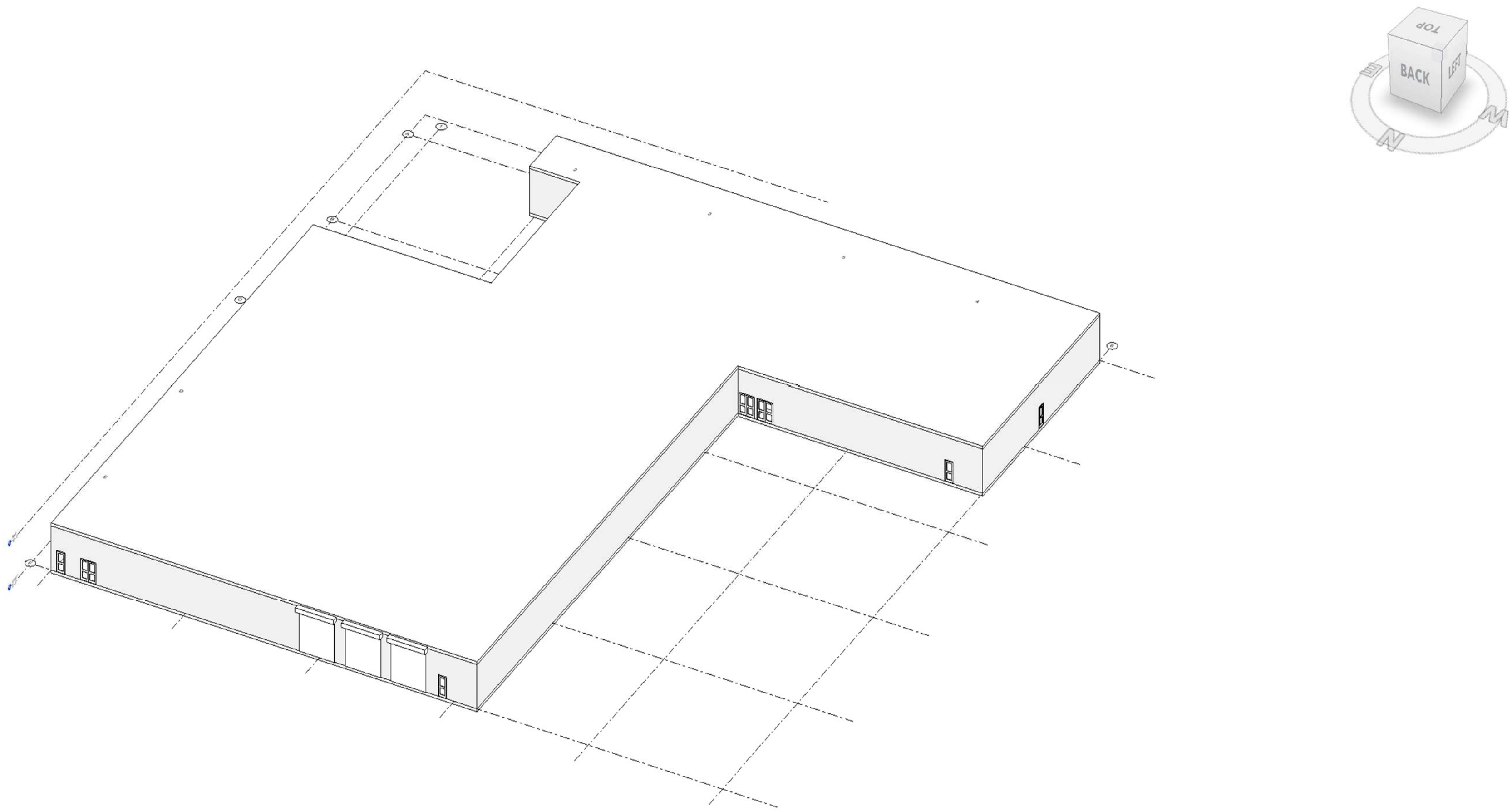


Figure 18: 3-D Rendered View of Base Exchange Shopping Center in BIM (Backside View)

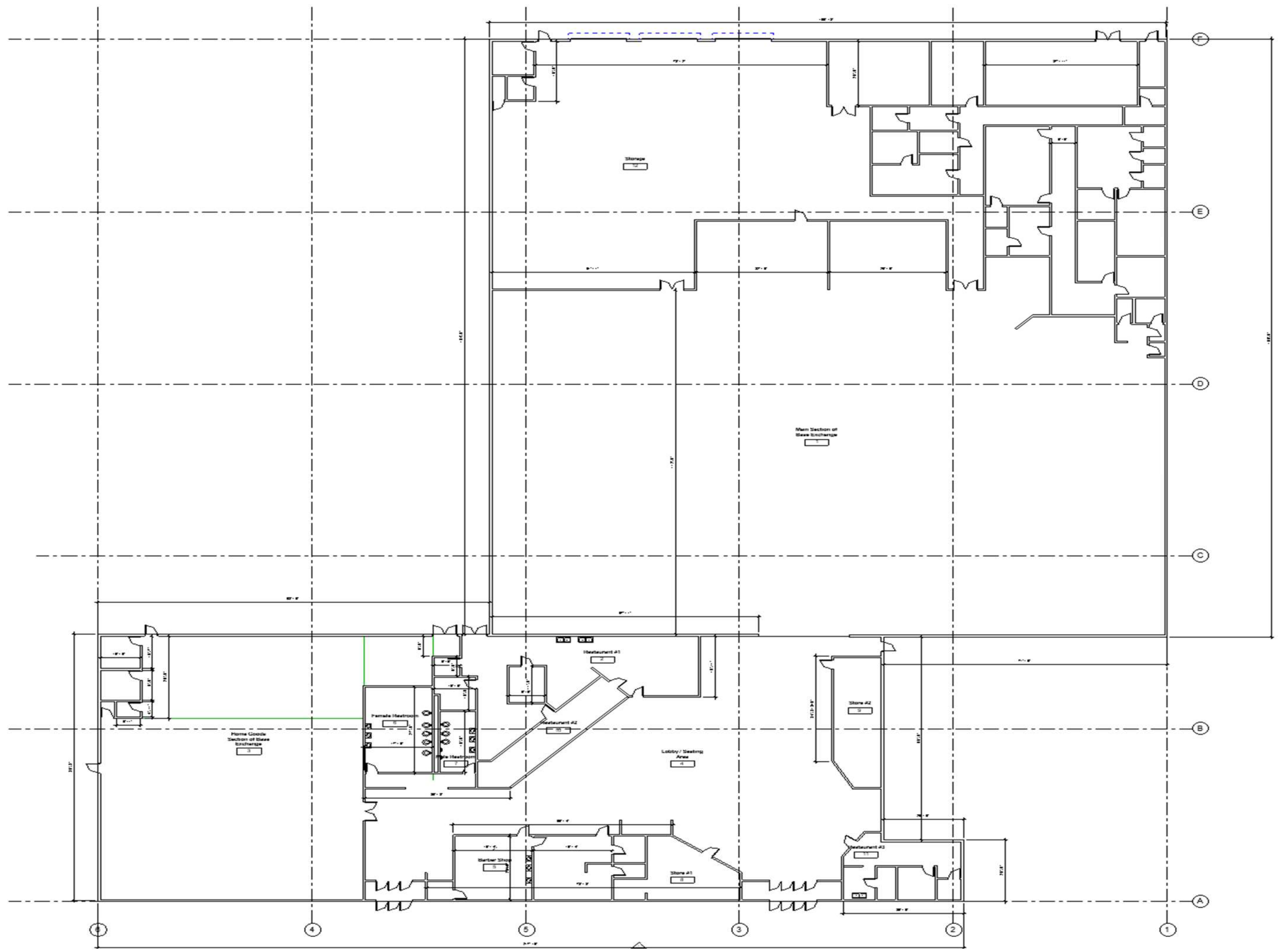


Figure 19: 1st Floor Plan View of Base Exchange Shopping Center in BIM

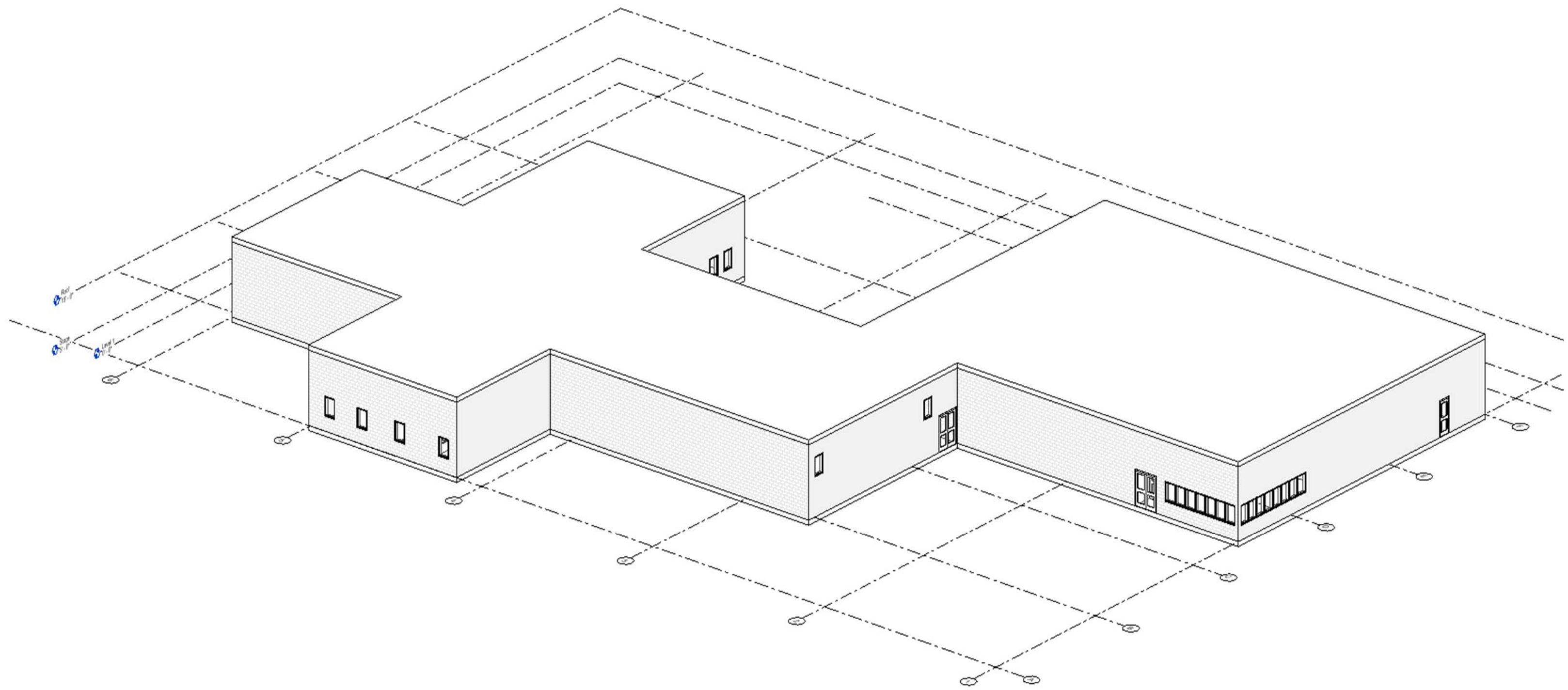


Figure 20: 3-D Rendered View of Childcare Facility in BIM

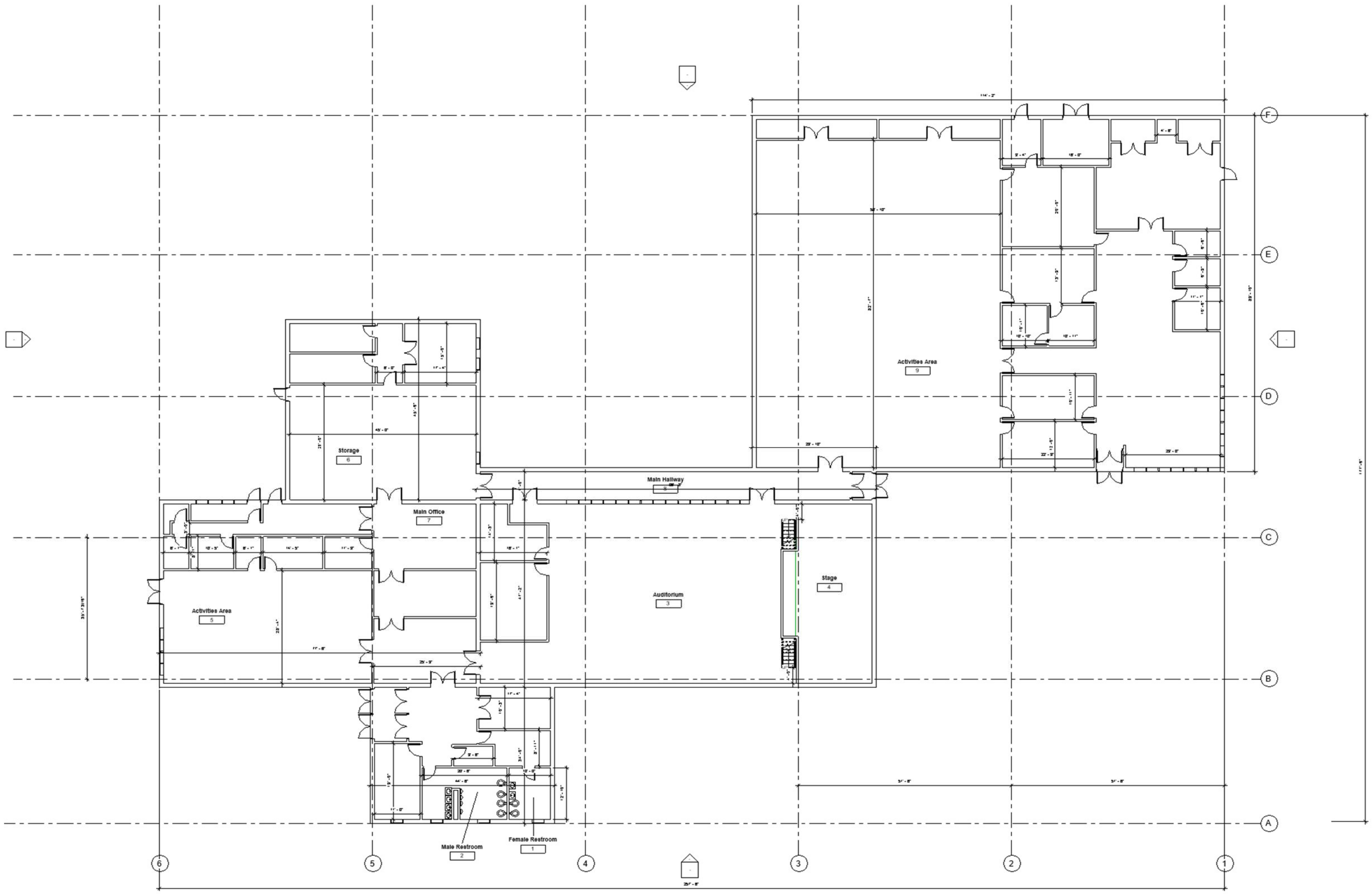


Figure 21: 1st Floor Plan View of the Childcare Facility in BIM

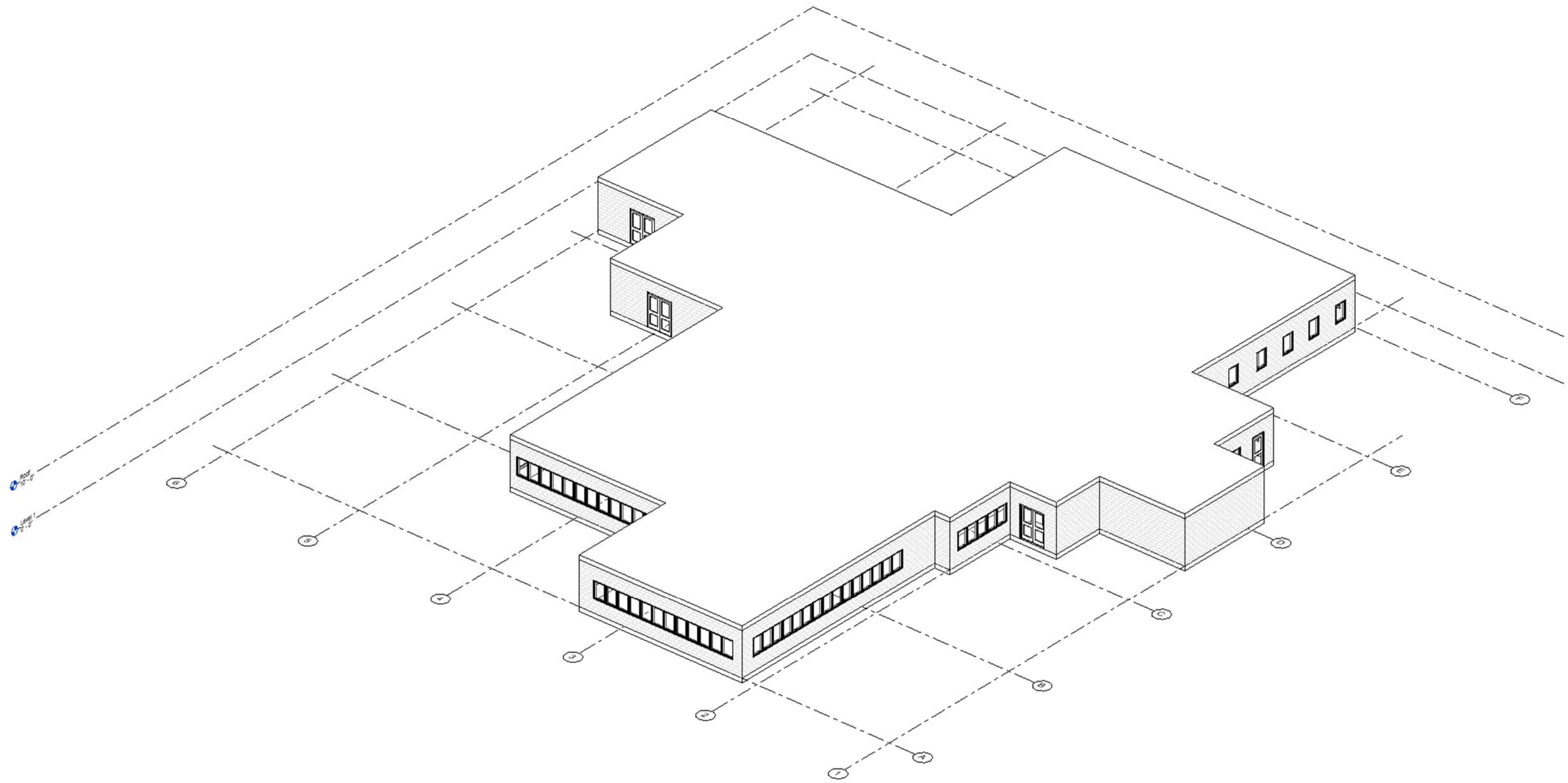


Figure 22: 3-D Rendered View of Dining Facility in BIM

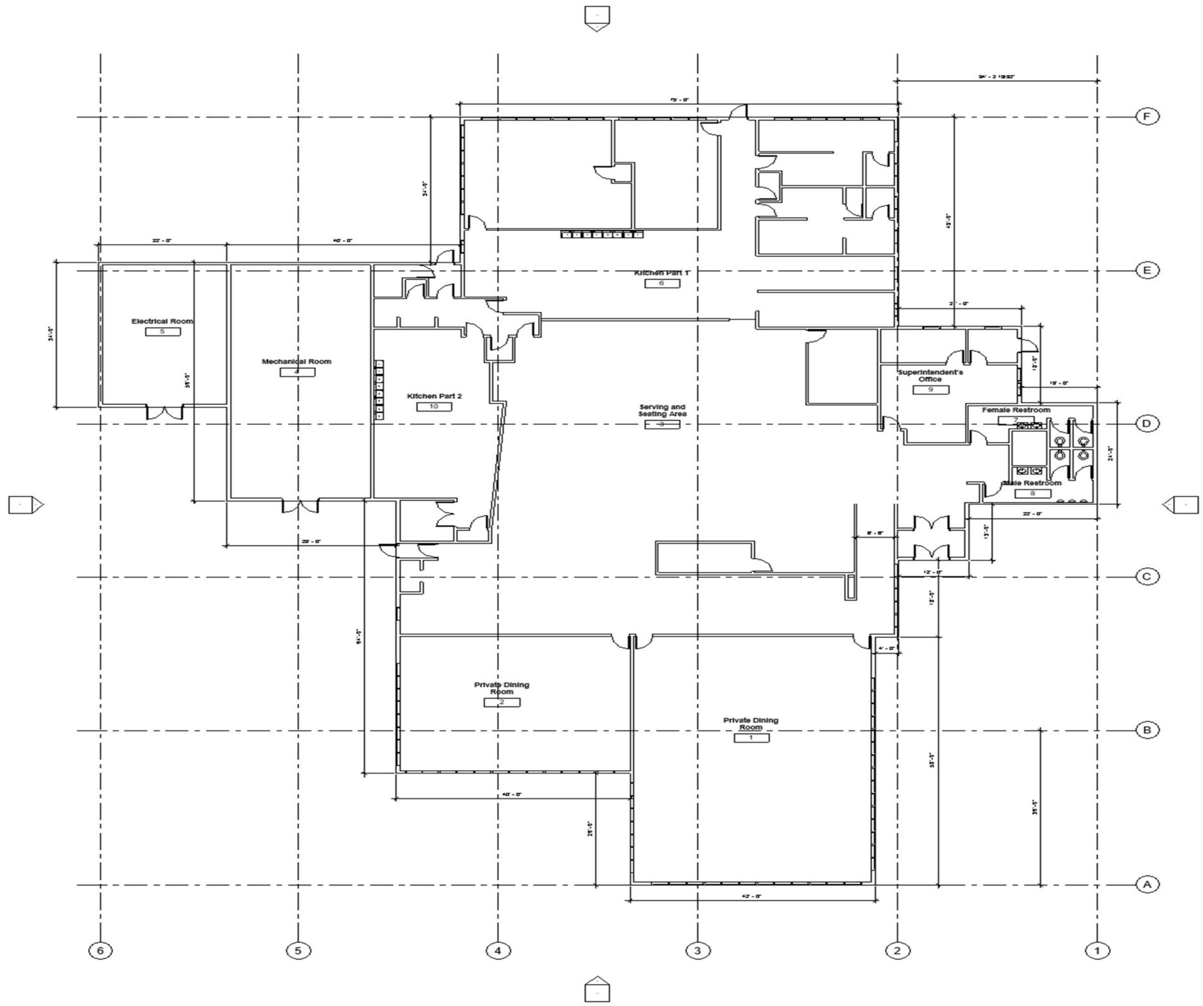


Figure 23: 1st Floor Plan View of Dining Facility in BIM

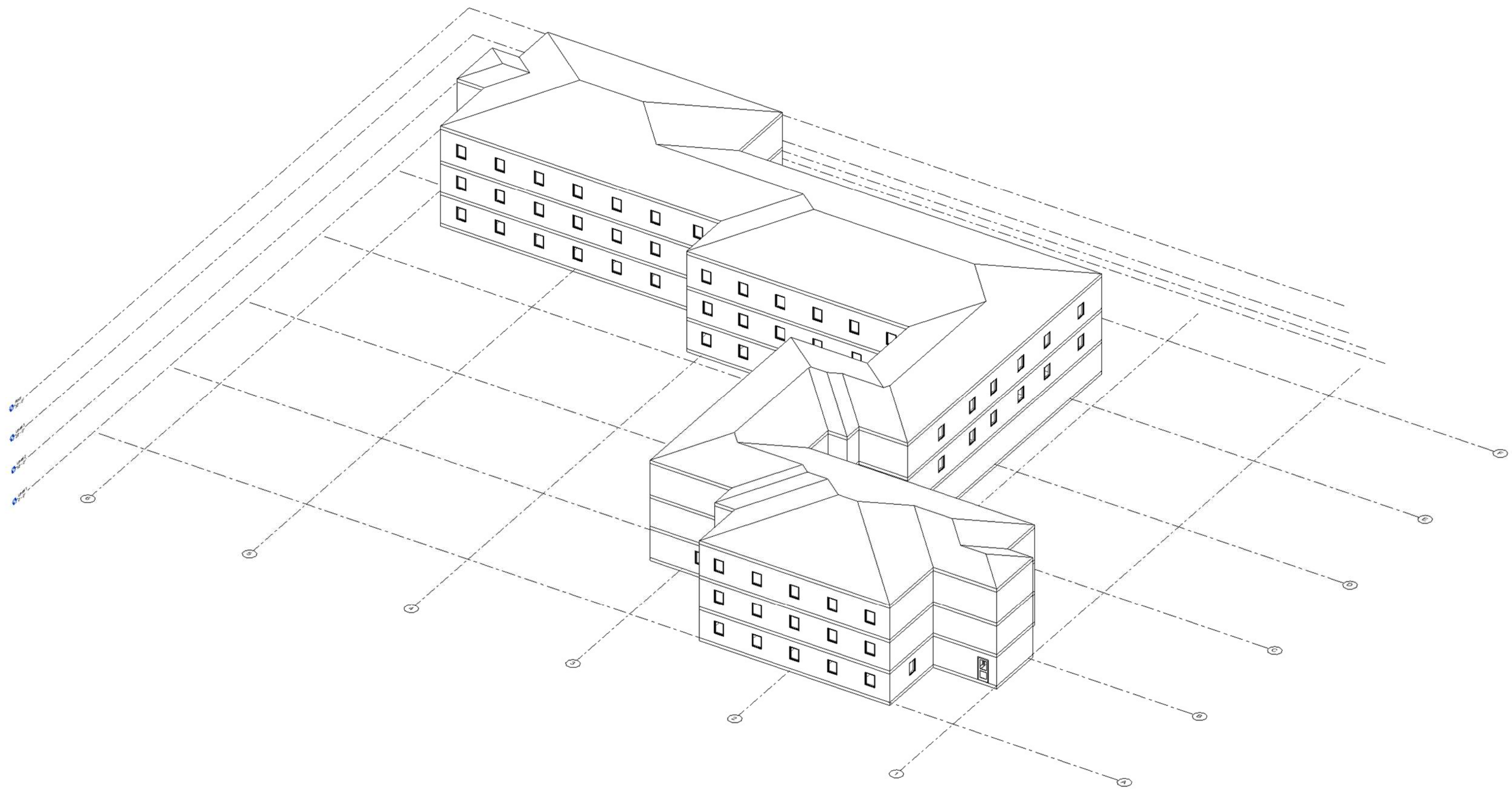


Figure 24: 3-D Rendered View of Dormitory in BIM

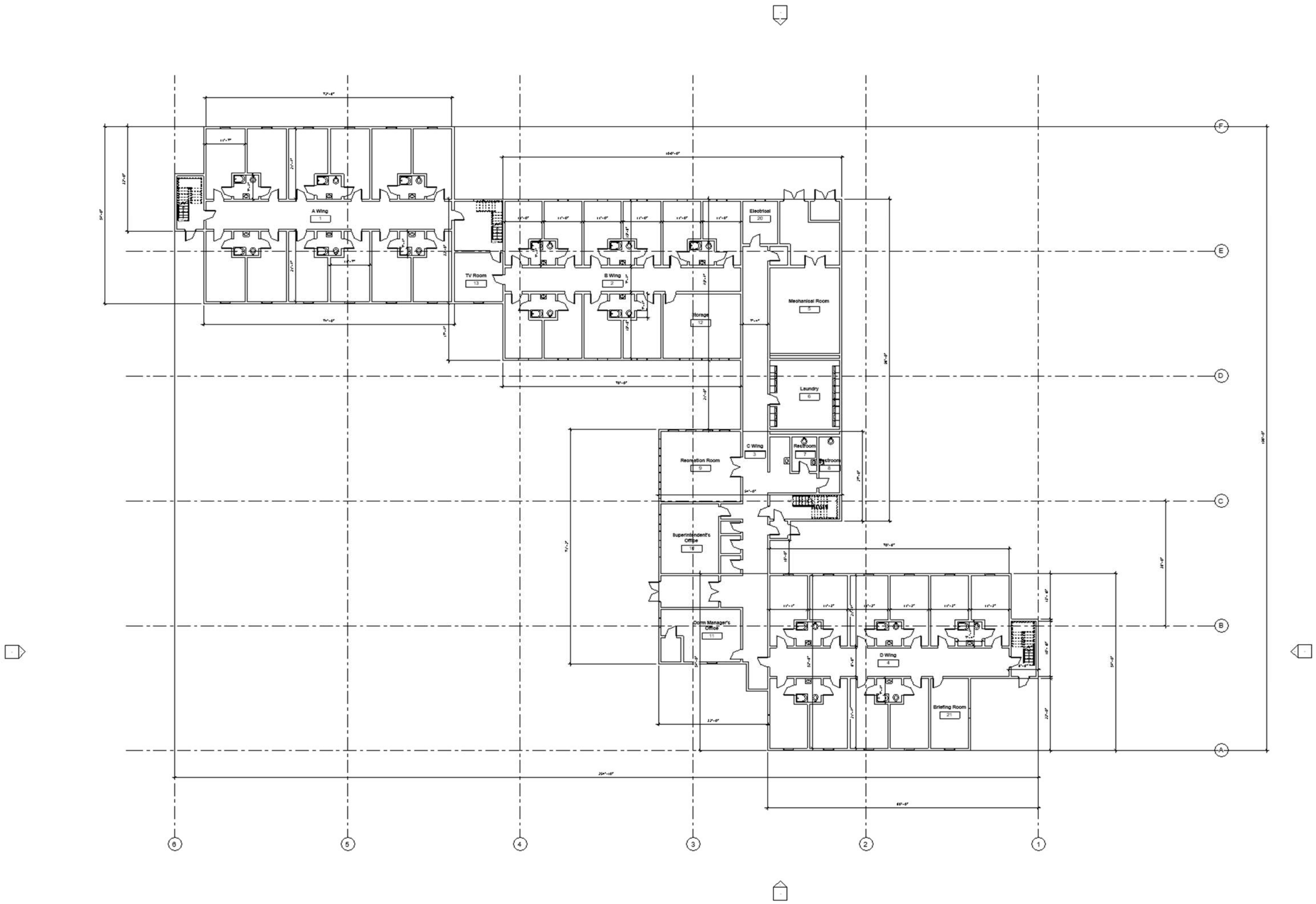


Figure 25: 1st Floor Plan View of Dormitory in BIM

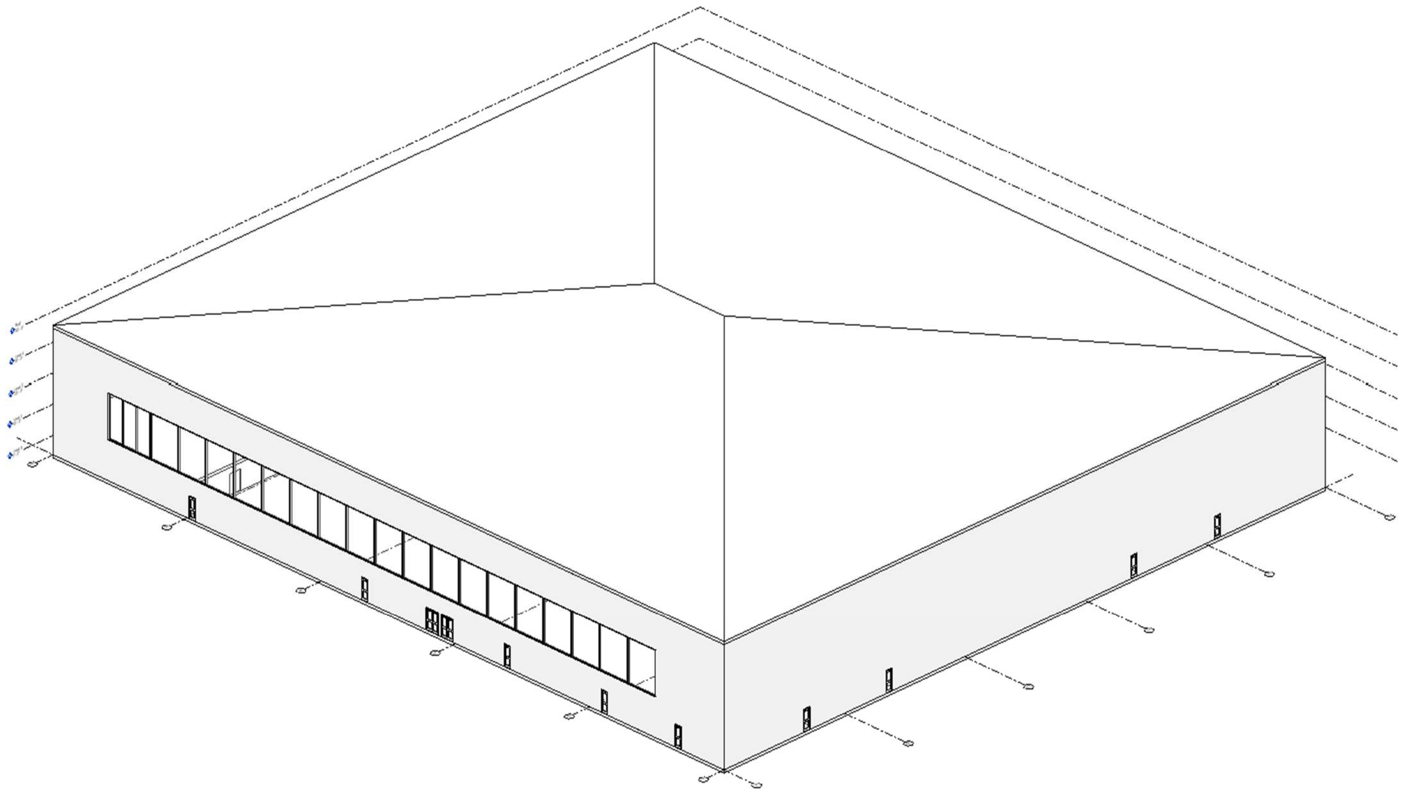


Figure 26: 3-D Rendered View of Fieldhouse in BIM

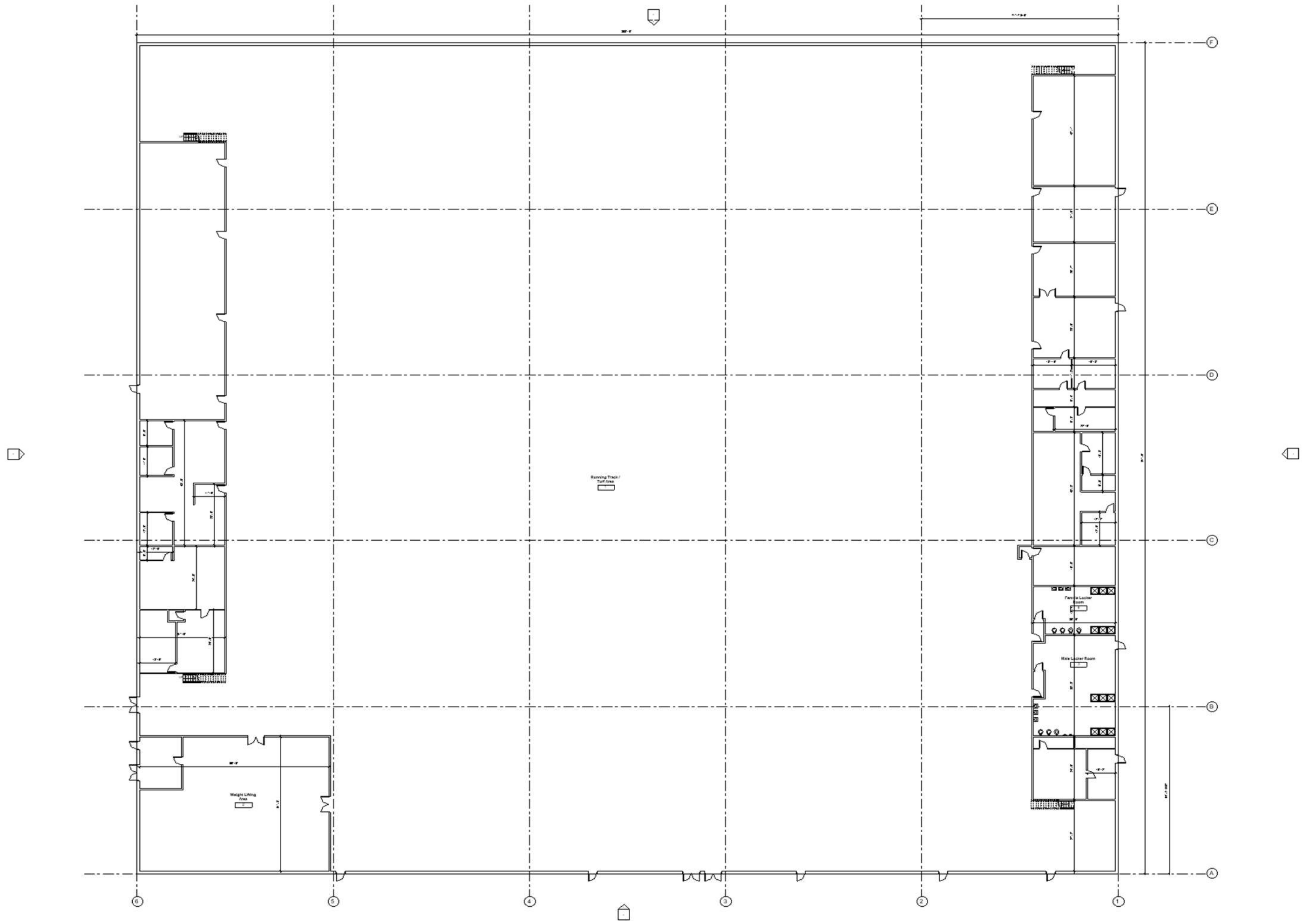


Figure 27: 1st Floor Plan View of Fieldhouse in BIM

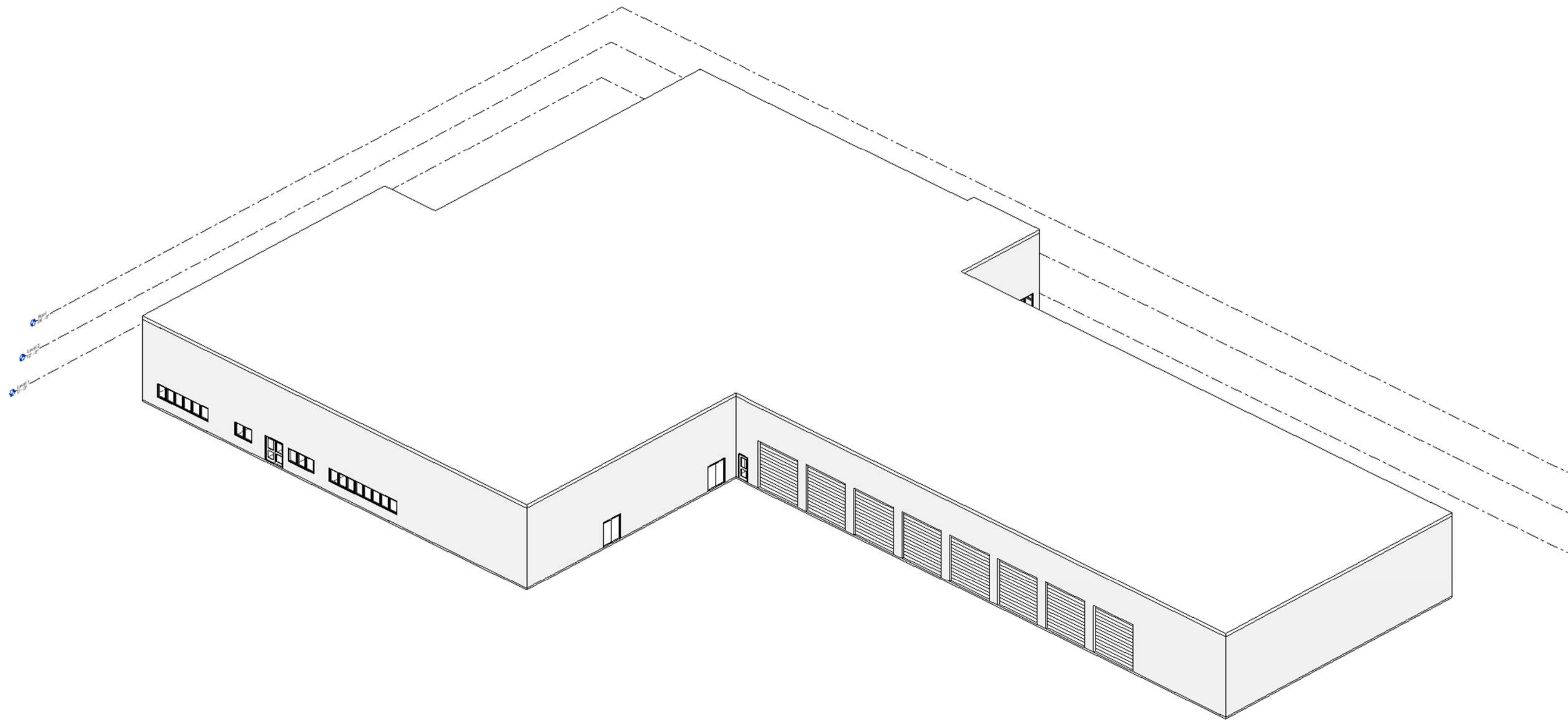


Figure 28: 3-D Rendered View of Fire Station in BIM

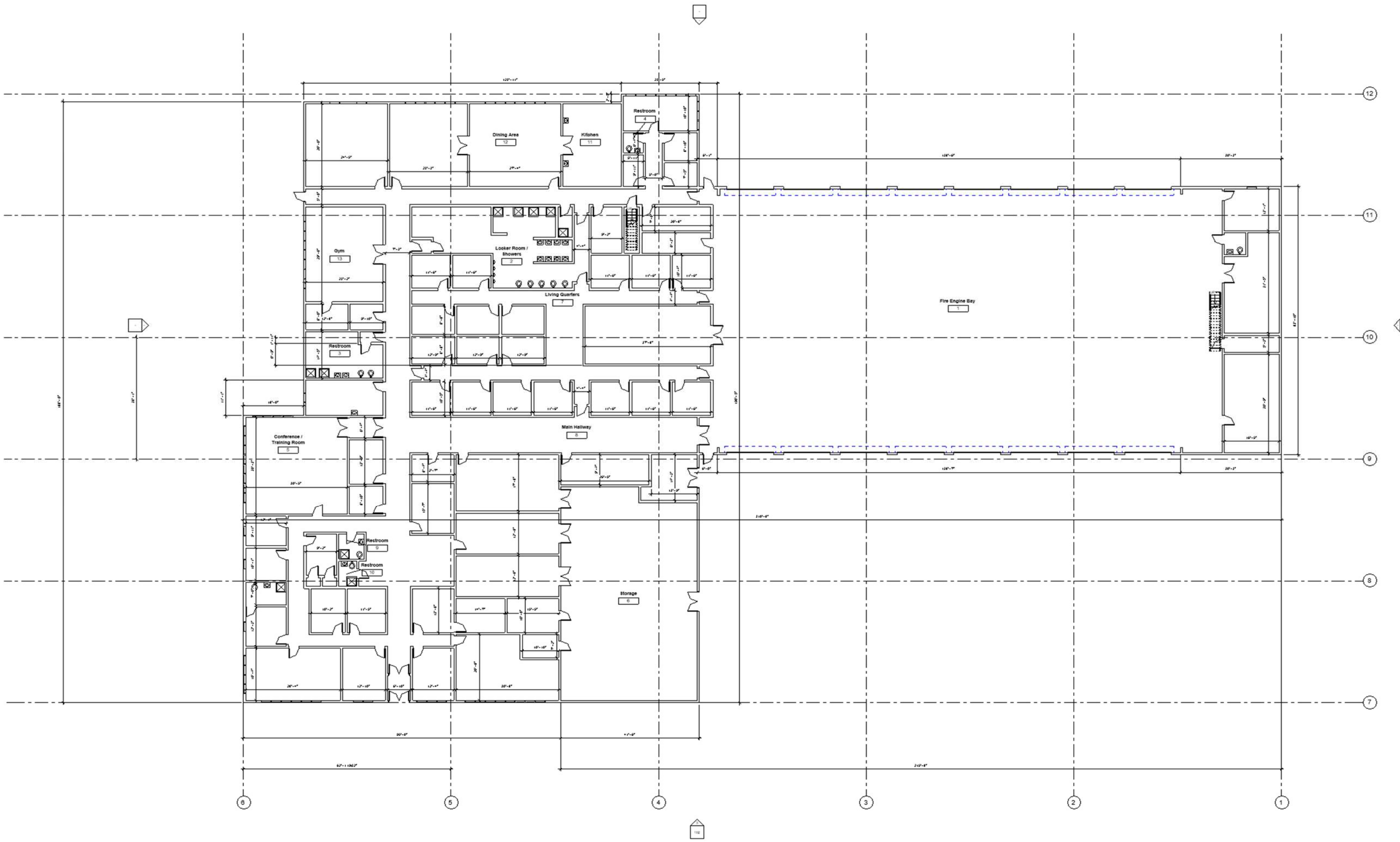


Figure 29: 1st Floor Plan View of Fire Station in BIM

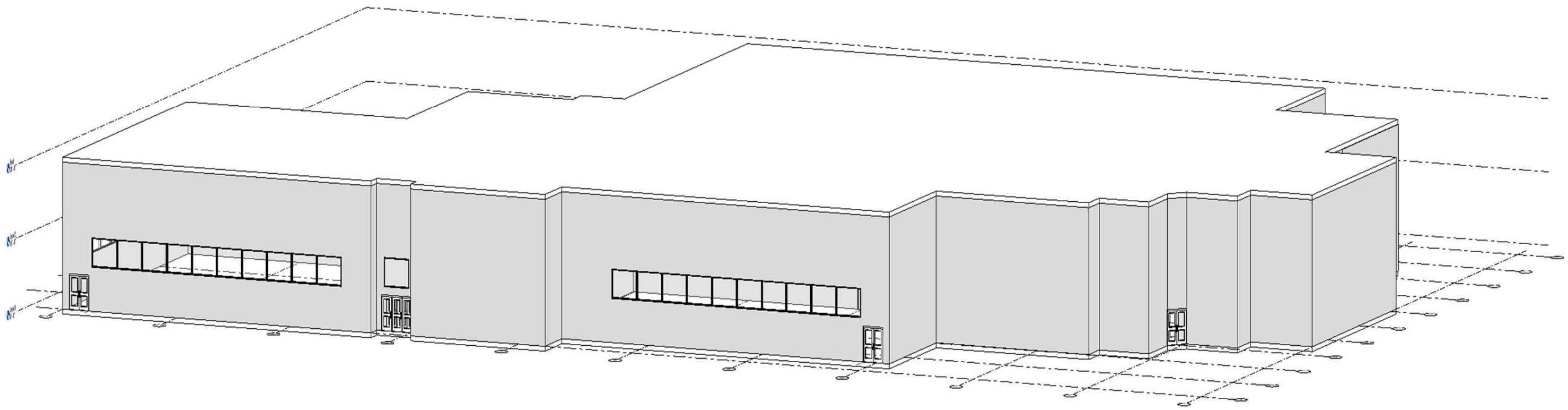


Figure 30: 3-D Rendered View of Fitness Center in BIM

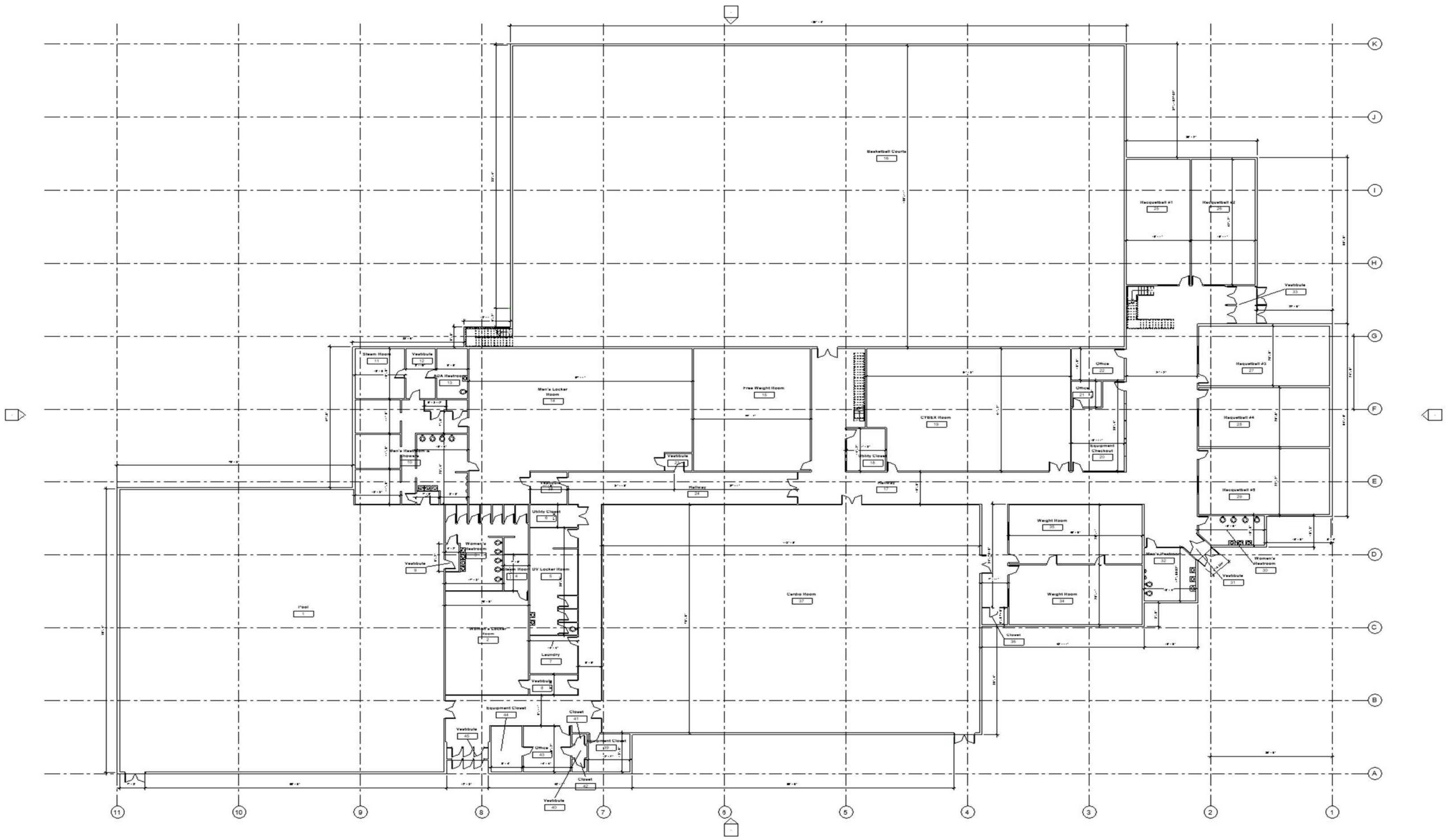


Figure 31: 1st Floor Plan View of Fitness Center in BIM

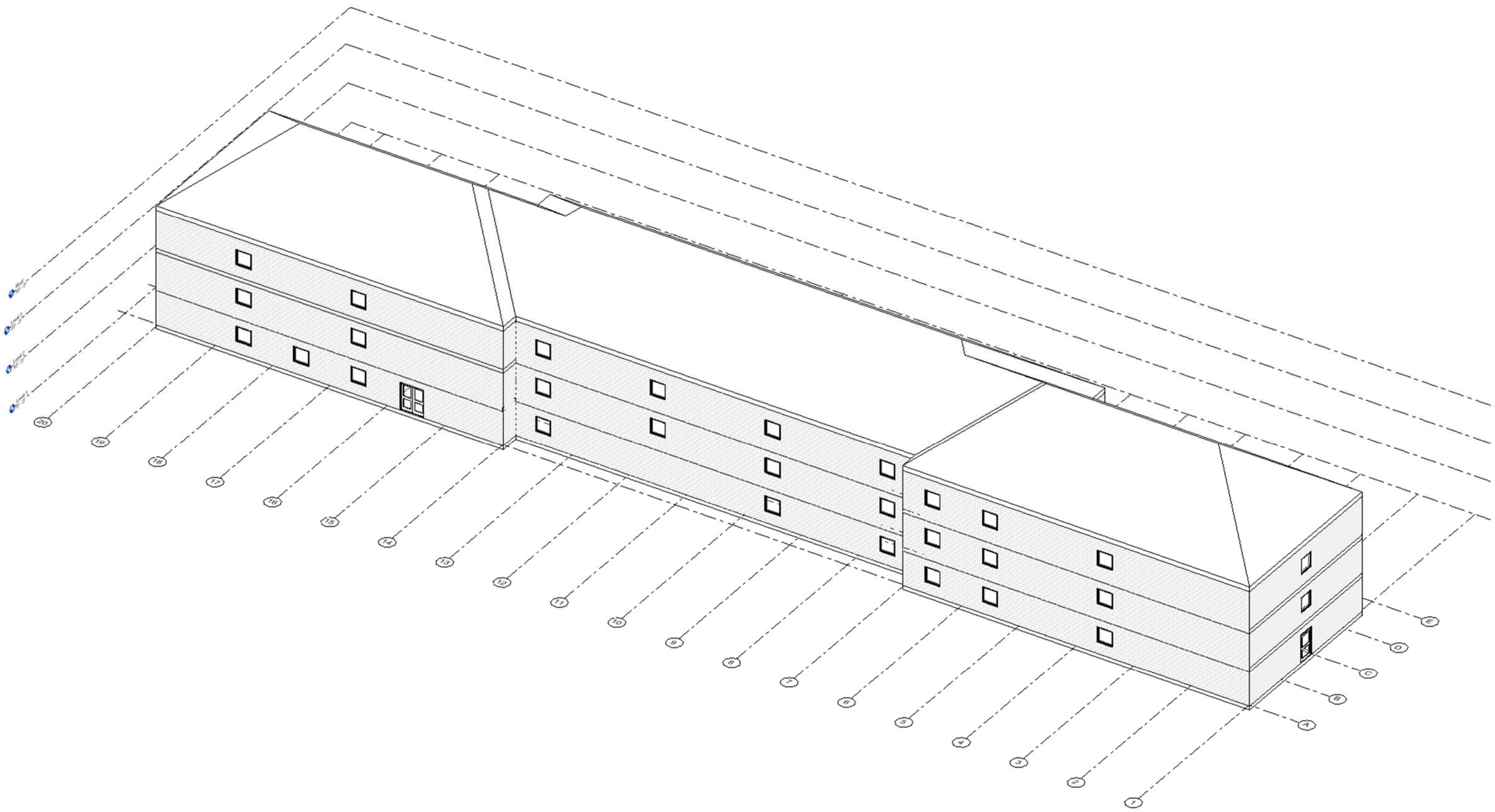


Figure 32: 3-D Rendered View of Hotel in BIM

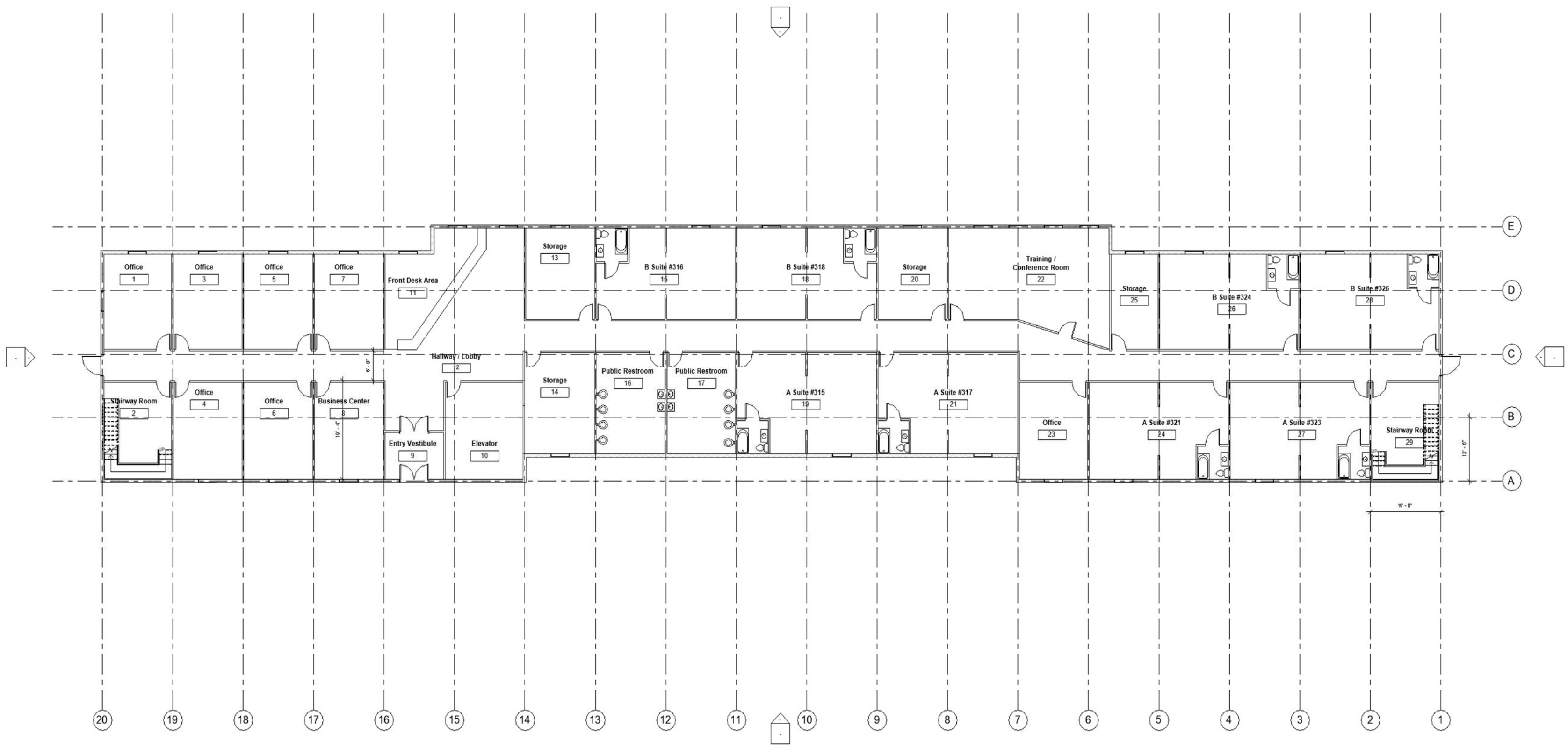


Figure 33: 1st Floor Plan View of Hotel in BIM

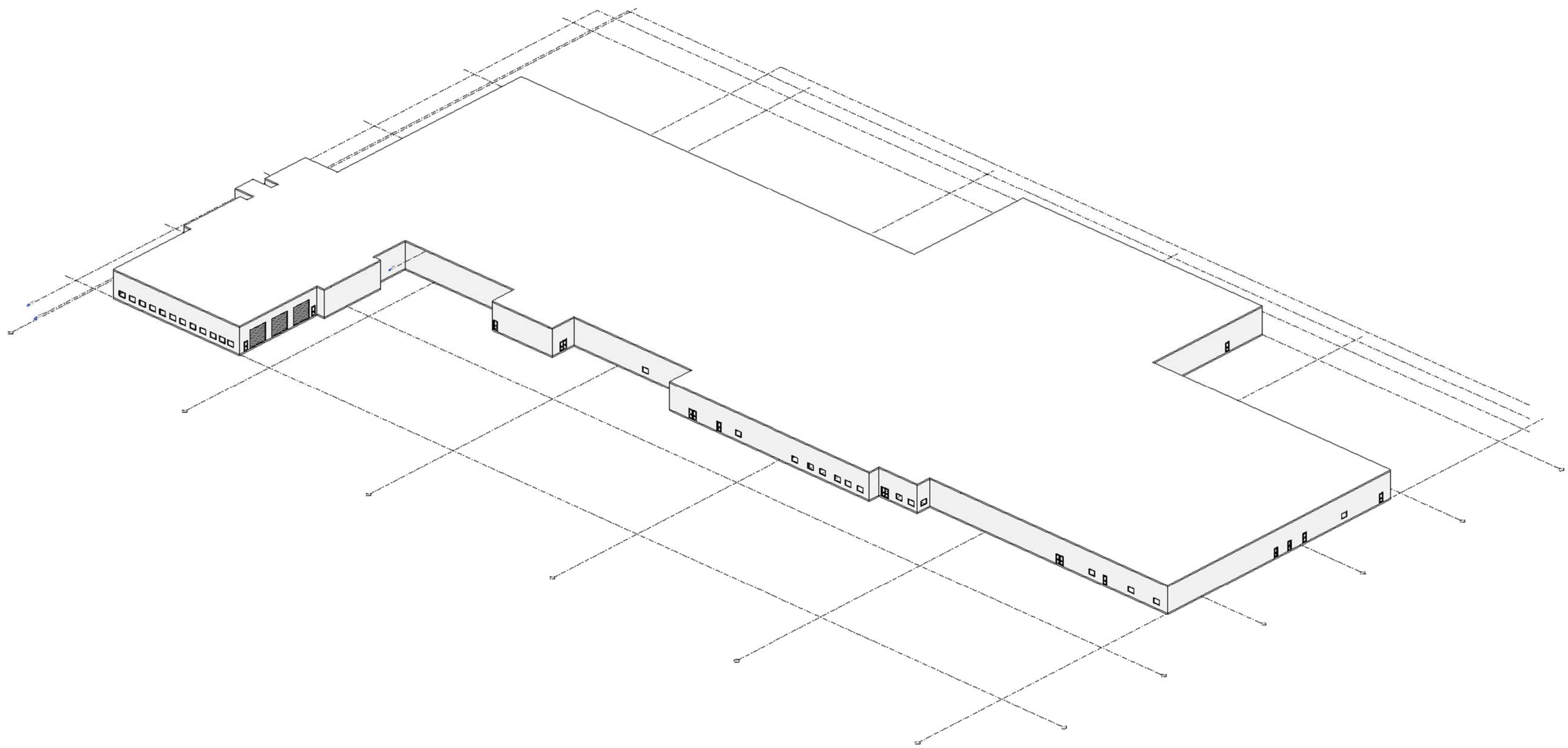


Figure 34: 3-D Rendered View of Large Warehouse (Logistics) in BIM

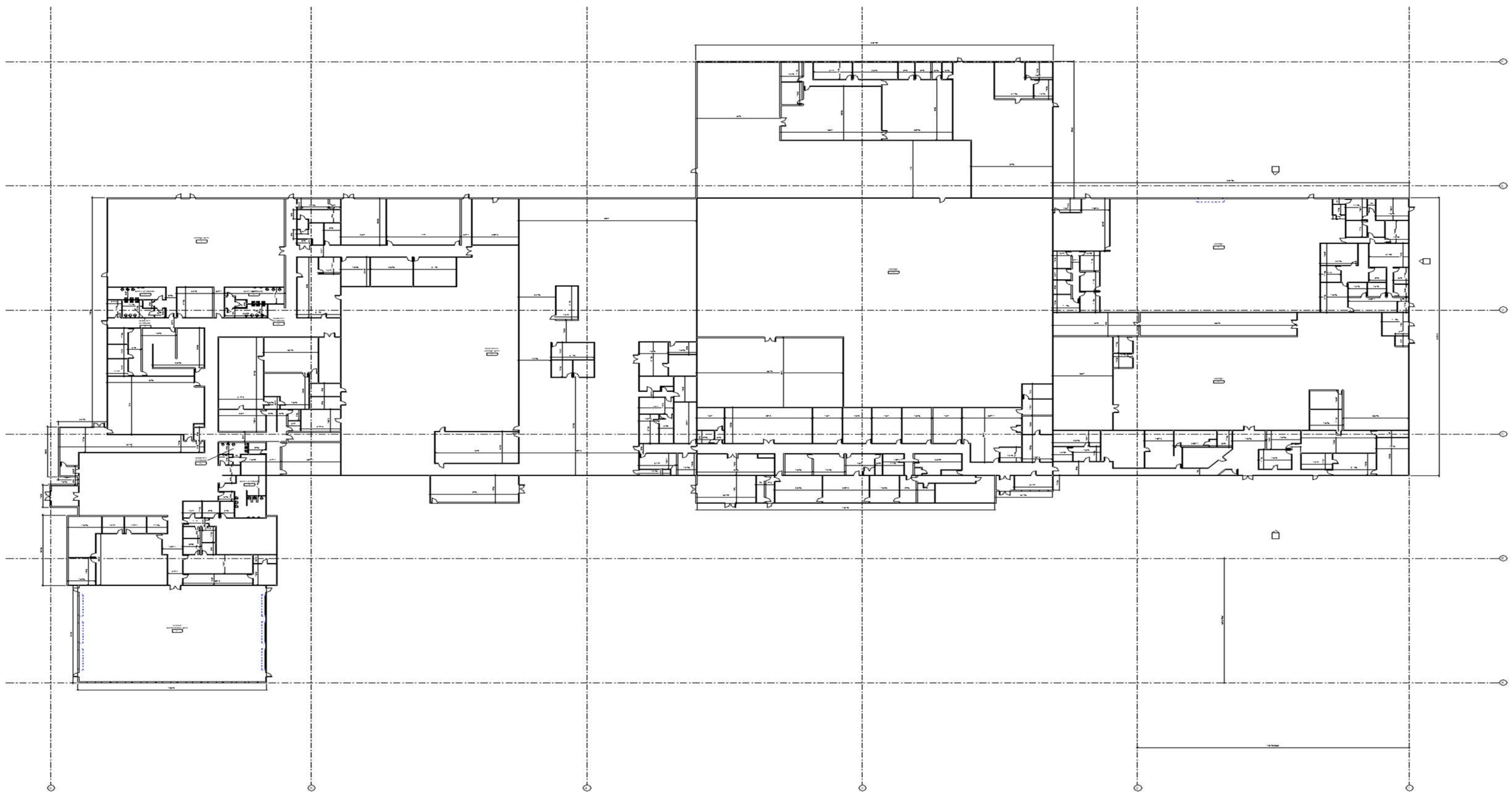


Figure 35: 1st Floor Plan View of Large Warehouse (Logistics) in BIM

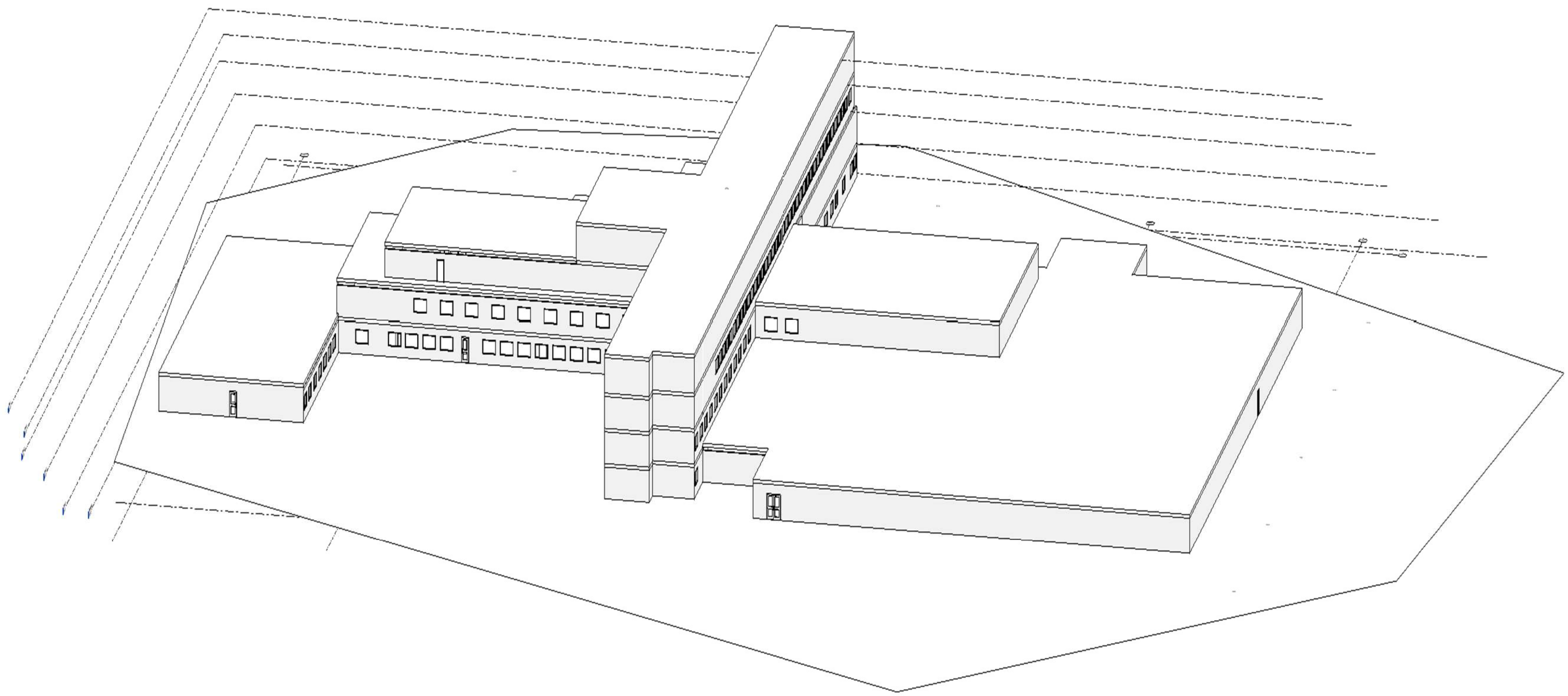


Figure 36: 3-D Rendered View of Medical Center in BIM

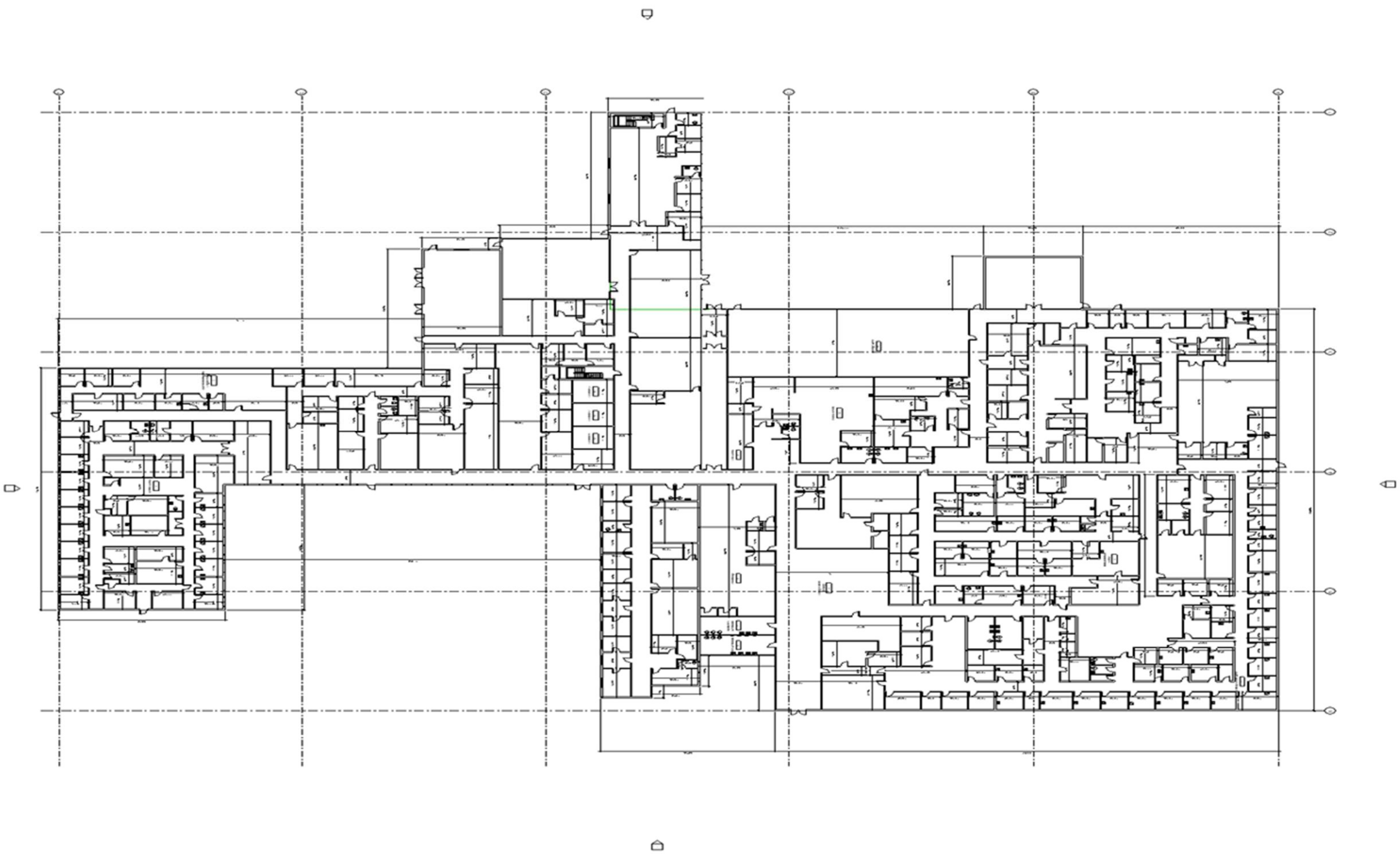


Figure 37: 1st Floor Plan View of Medical Center in BIM

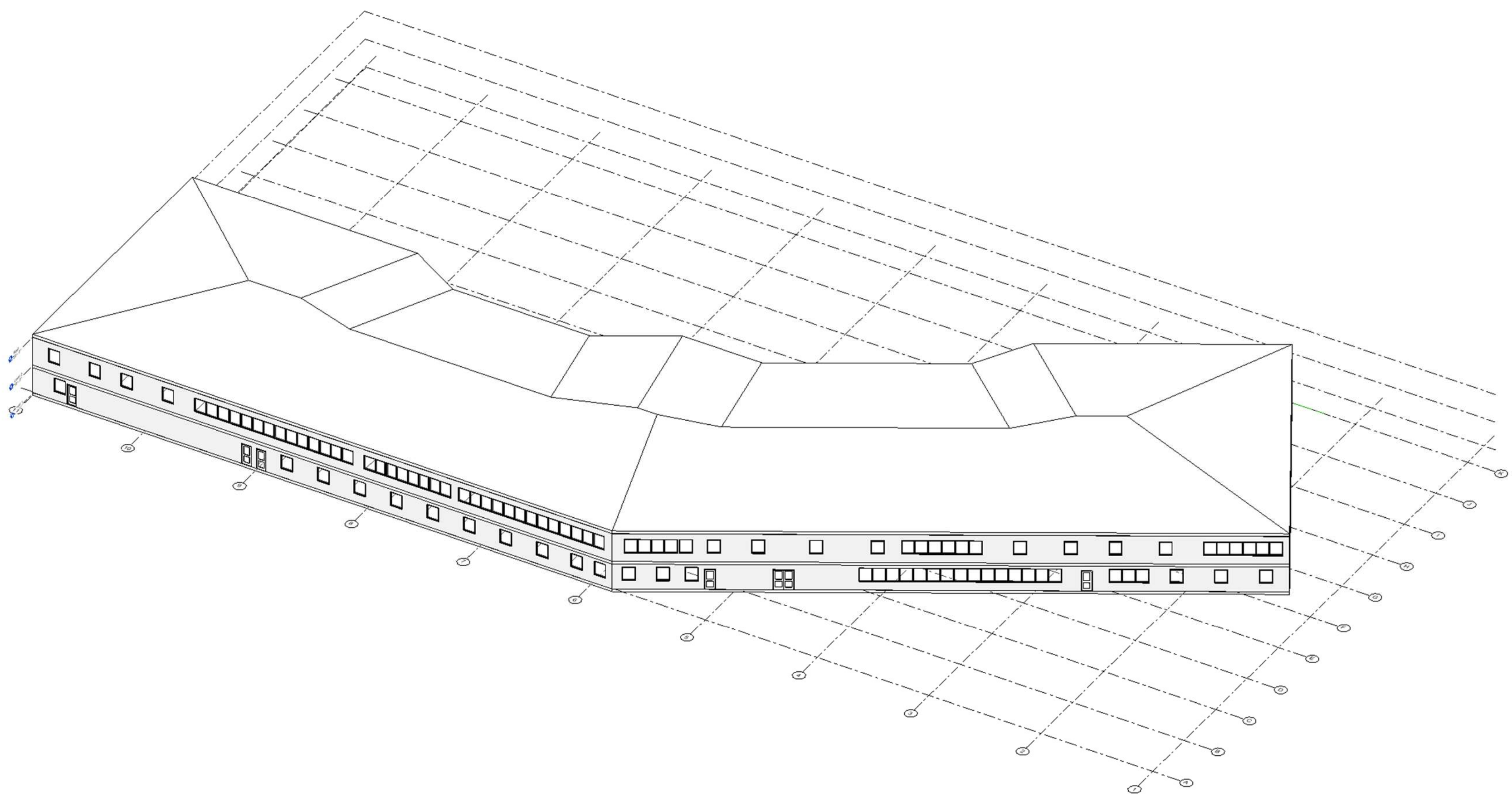


Figure 38: 3-D Rendered View of Office Building in BIM

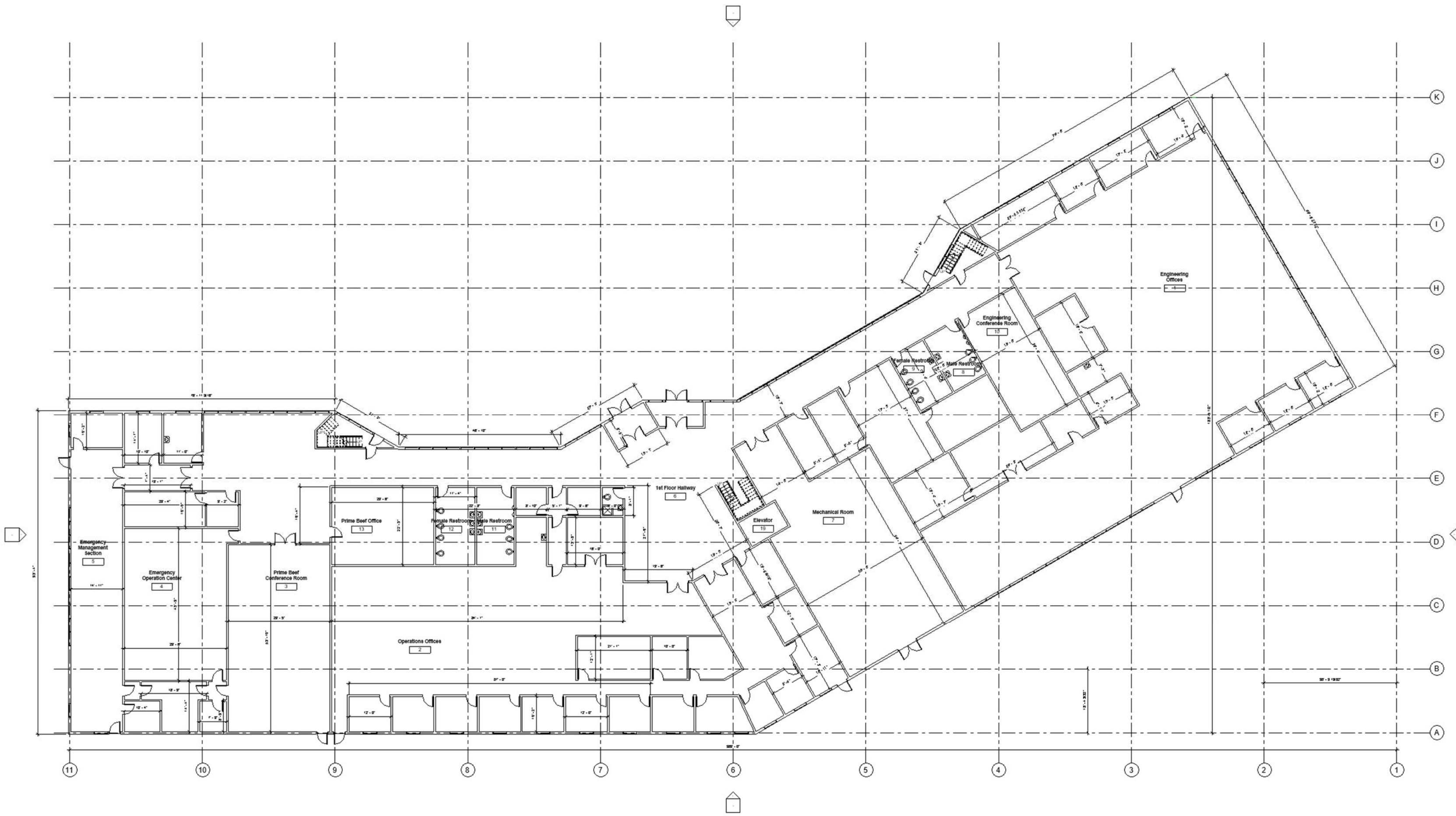


Figure 39: 1st Floor Plan View of Office Building in BIM

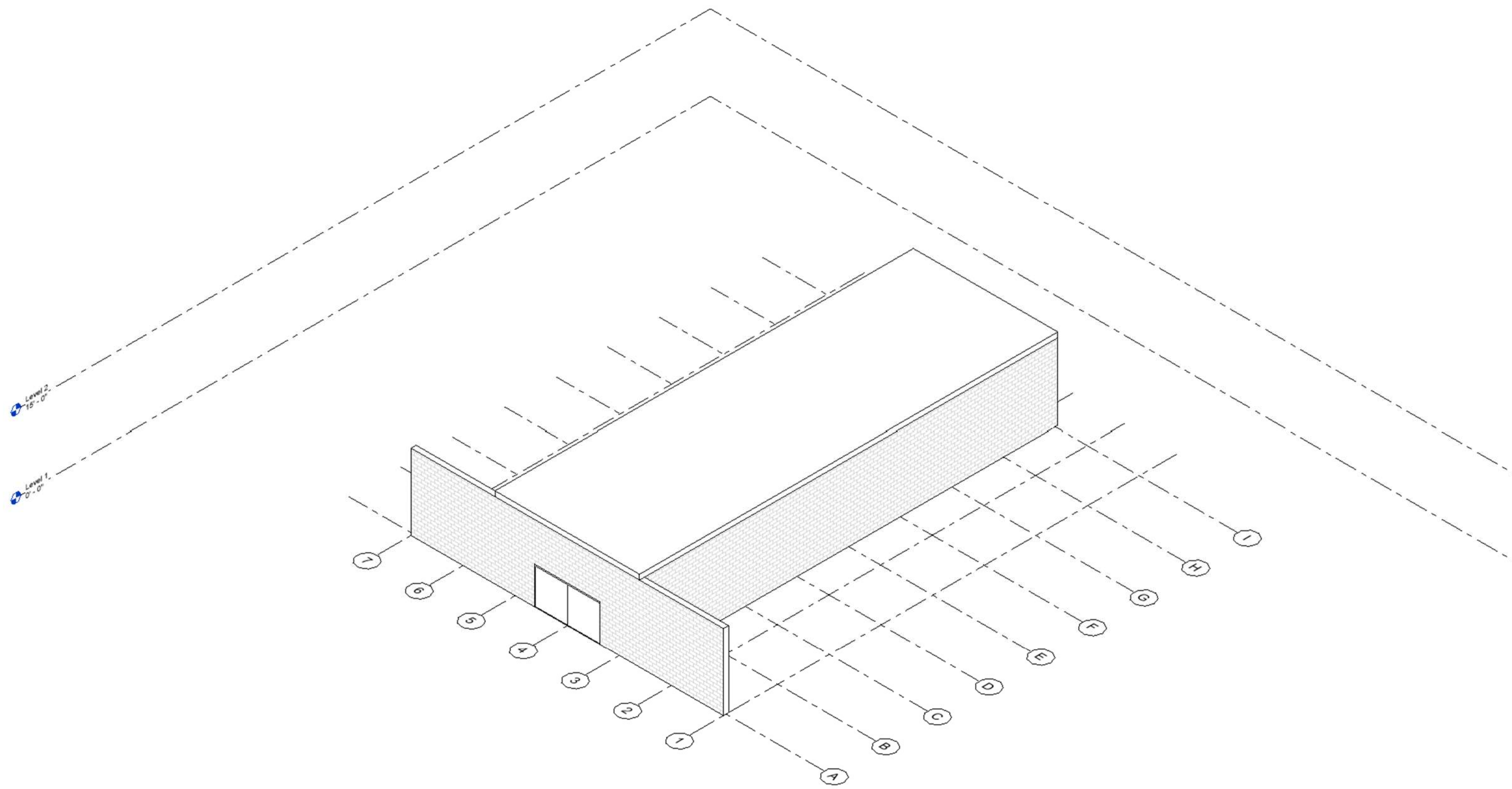


Figure 40: 3-D Rendered View of Small Warehouse (Munitions) in BIM

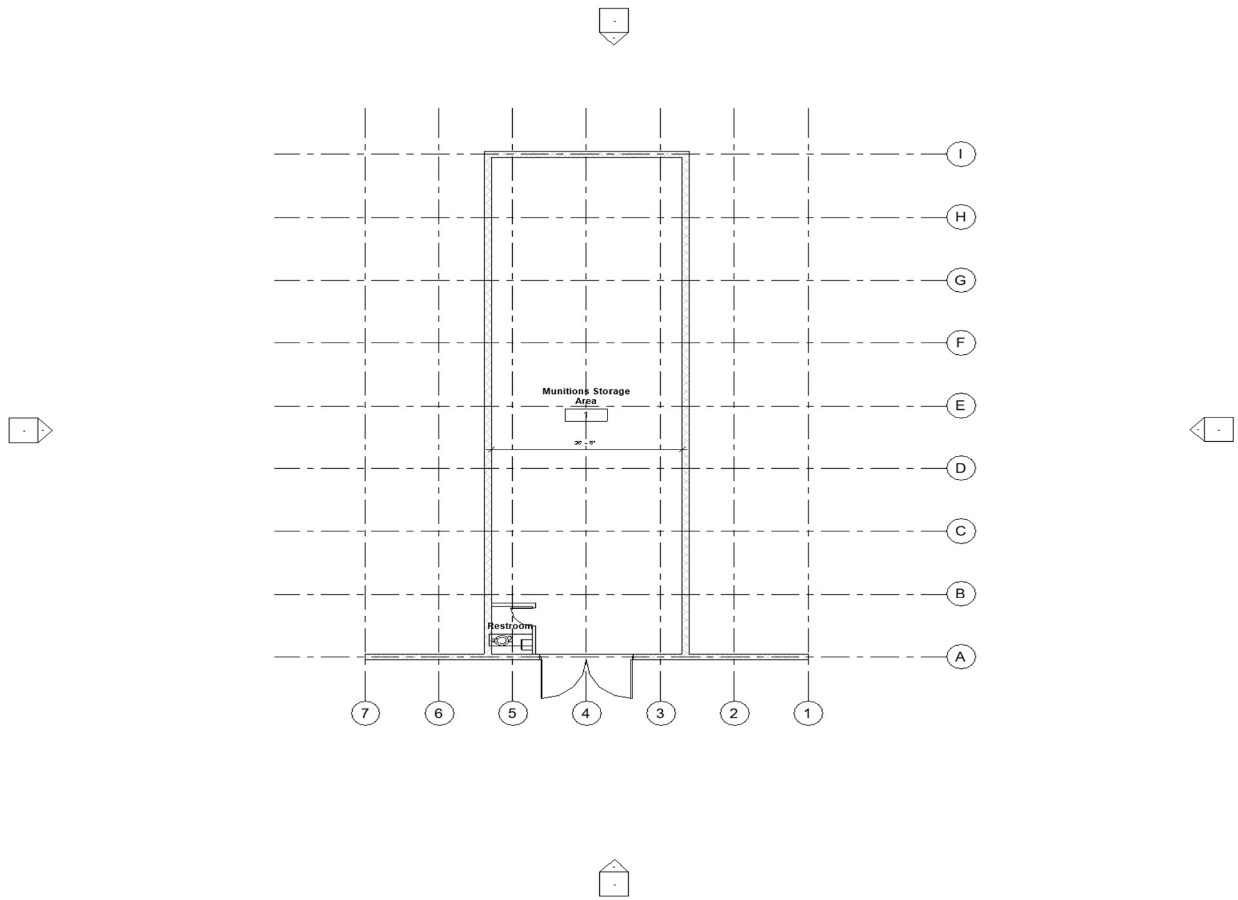


Figure 41: 1st Floor Plan View of Small Warehouse (Munitions) in BIM

APPENDIX B.

Appendix B contains the results of the 56 tests completed on Autodesk Green Building Studio cloud software. The tests are organized by building.

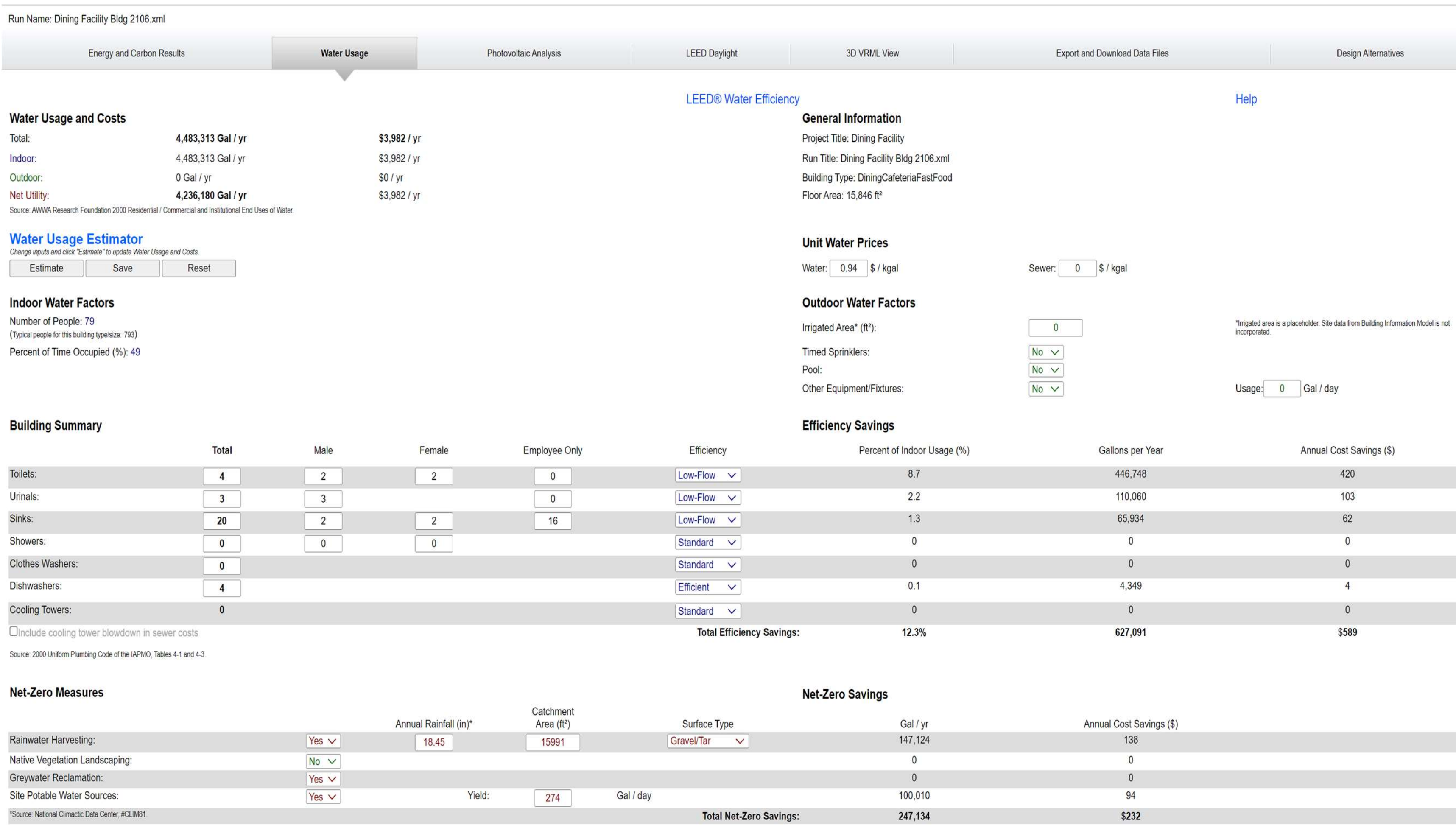


Figure 42: Green Building Studio Results for Air Traffic Control Tower at Ellsworth AFB, SD

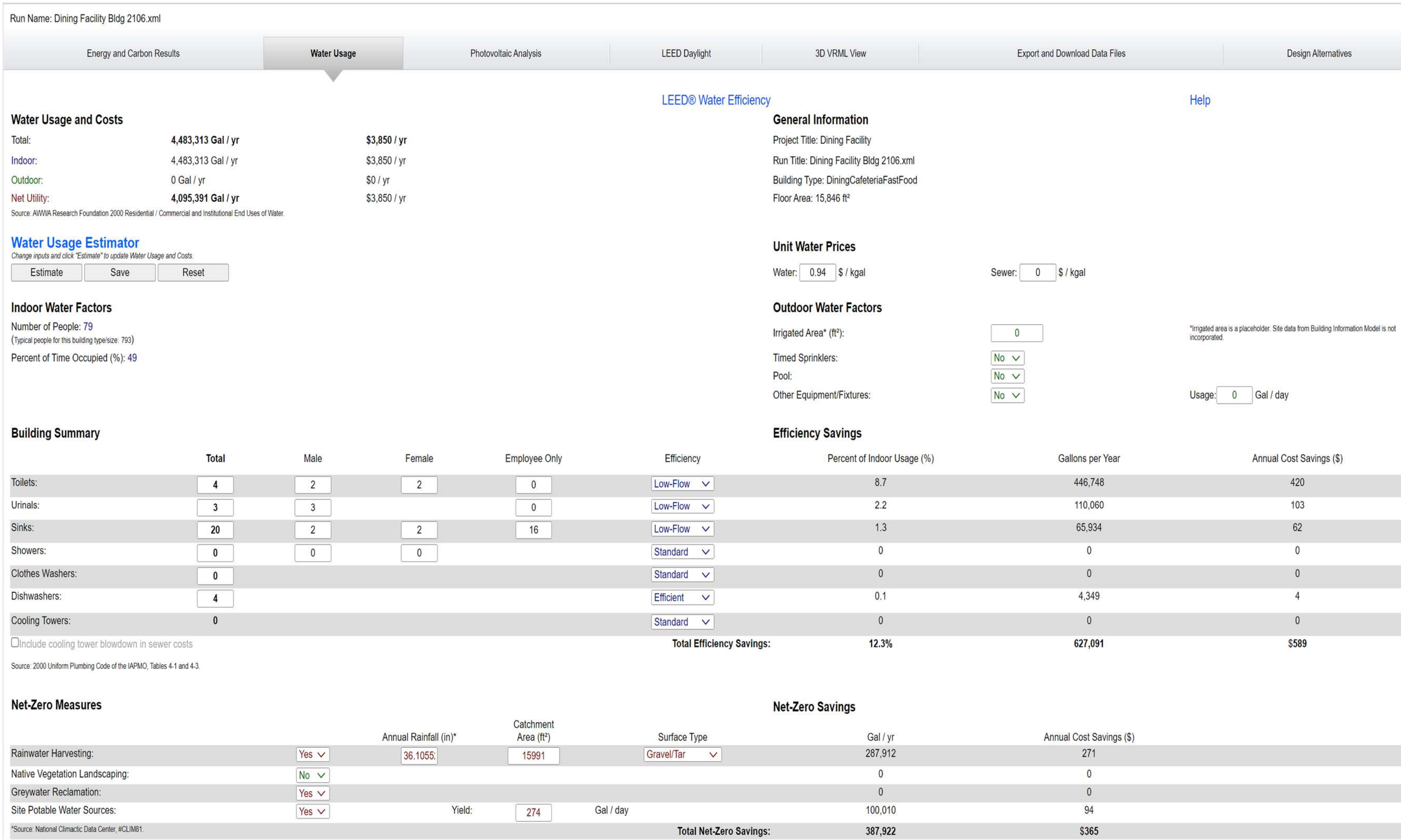


Figure 43: Green Building Studio Results for Air Traffic Control Tower at Wright-Patterson AFB, OH

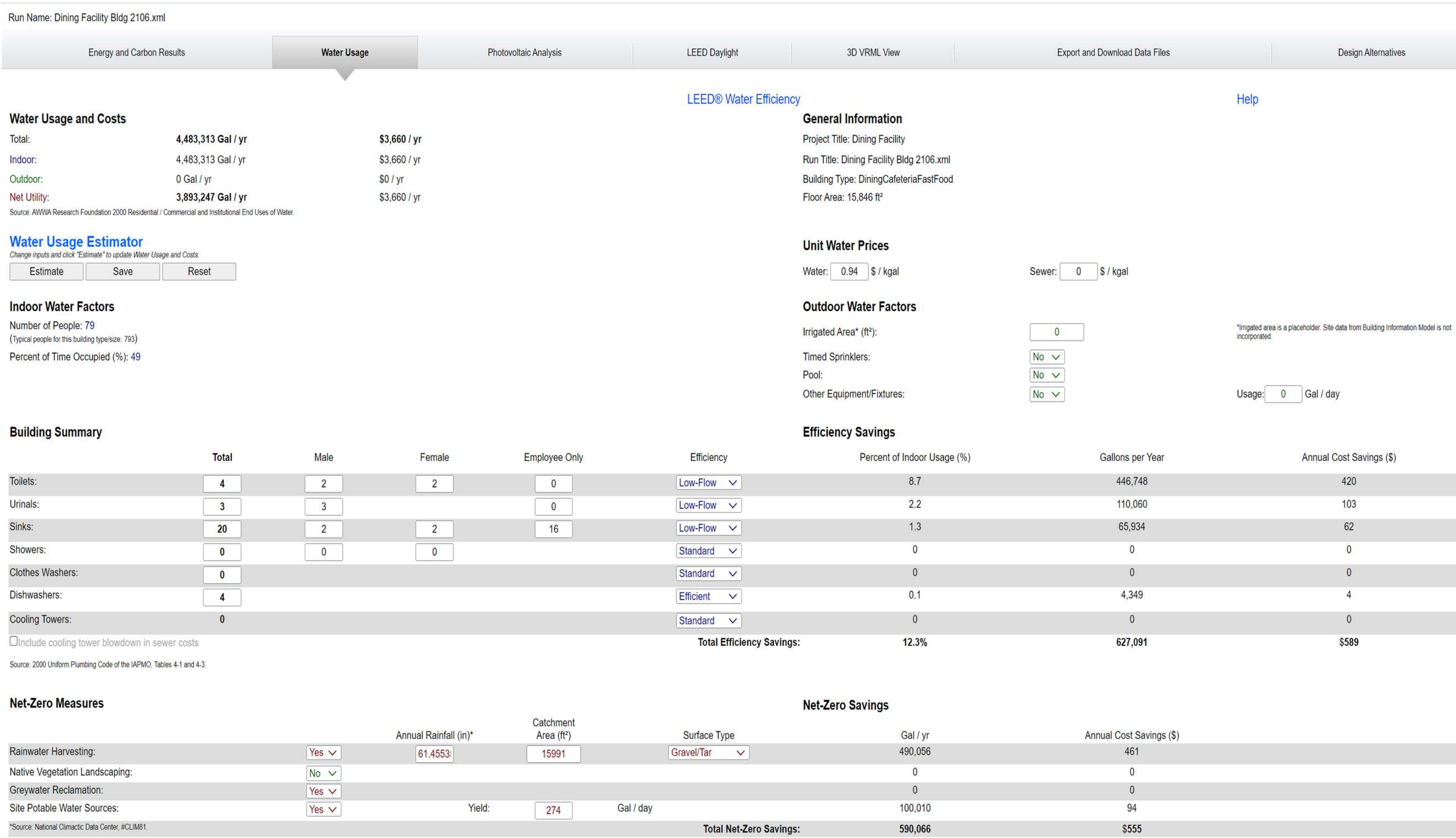


Figure 44: Green Building Studio Results for Air Traffic Control Tower at Eglin AFB, FL

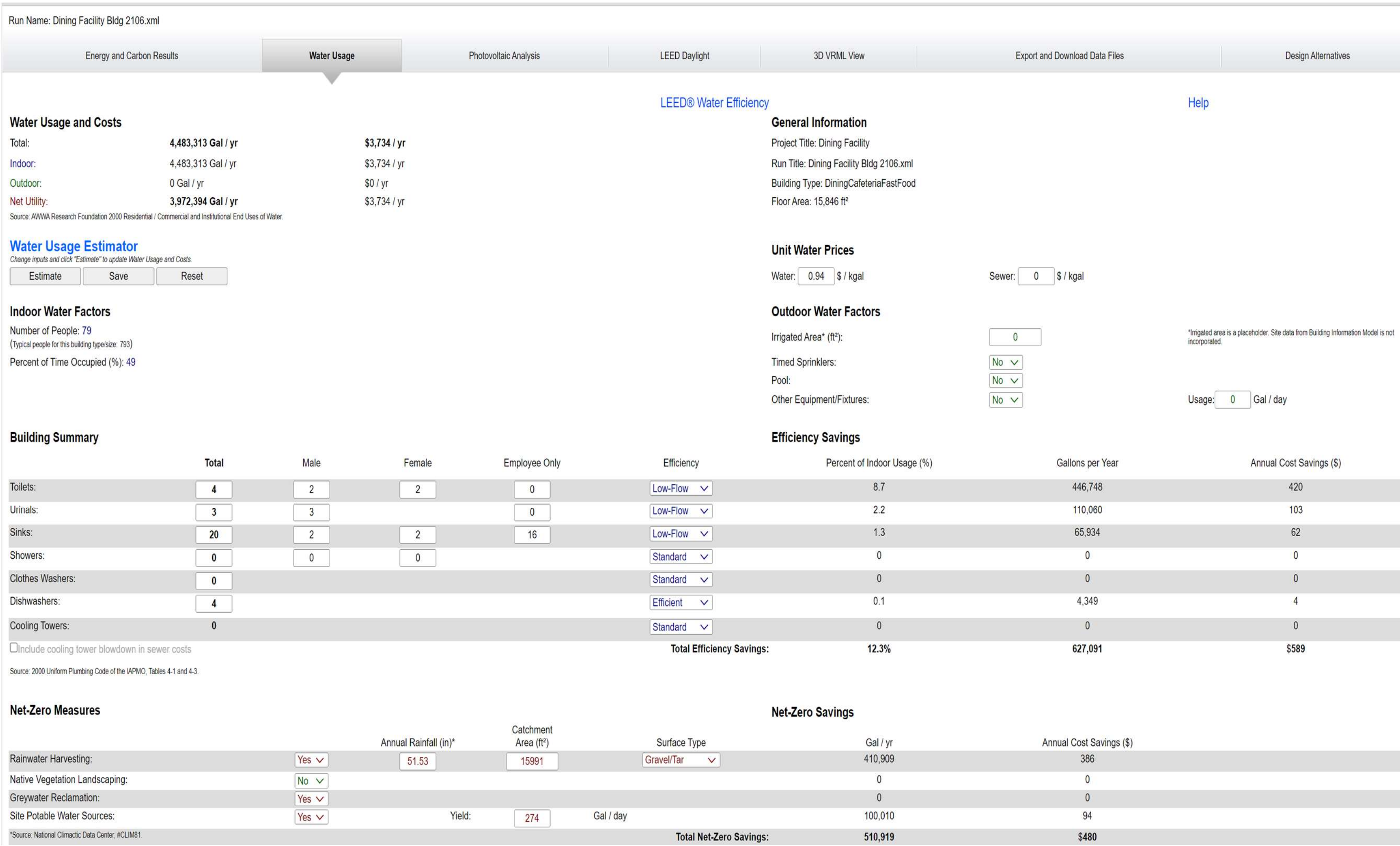


Figure 45: Green Building Studio Results for Air Traffic Control Tower at JB Charleston, SC

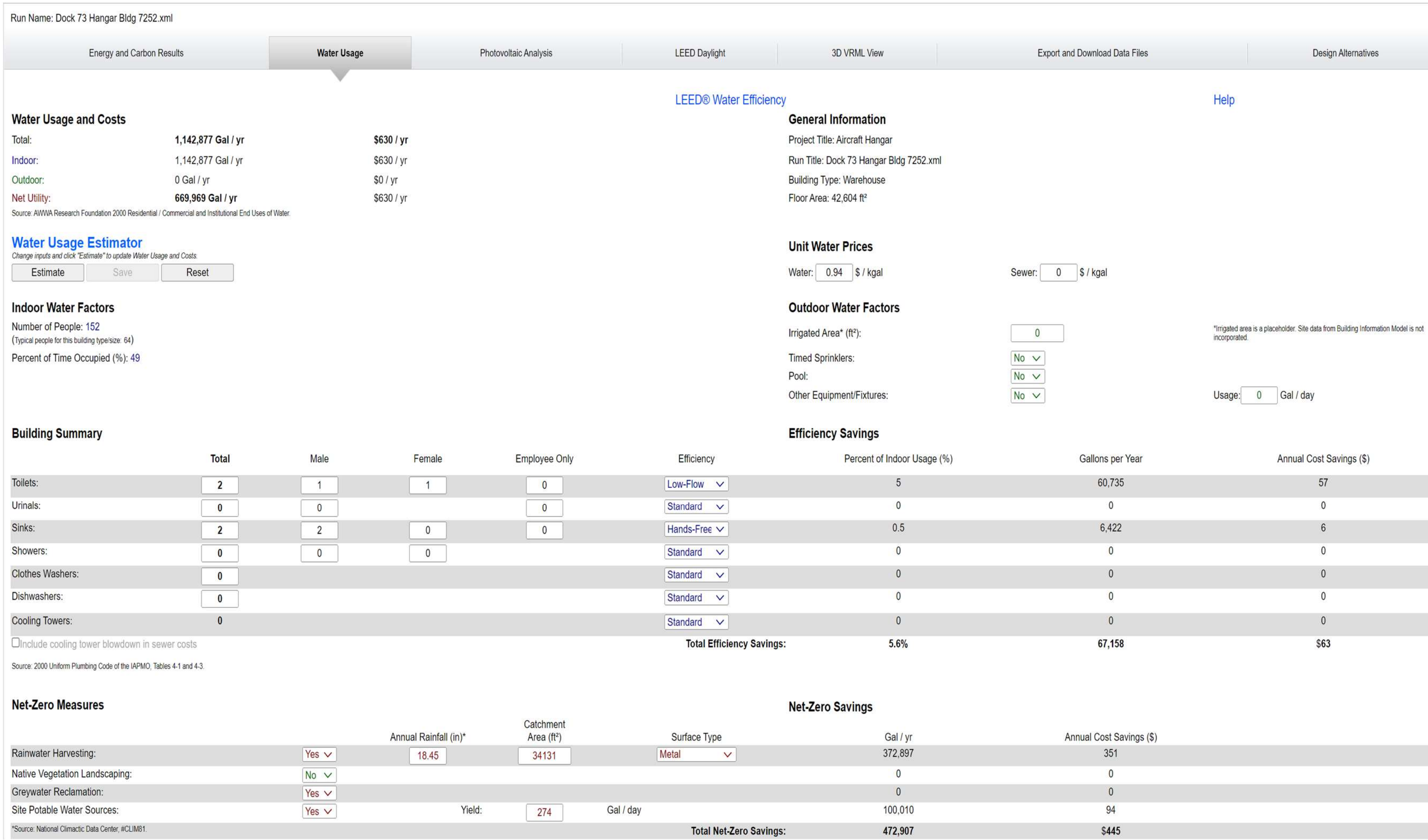


Figure 46: Green Building Studio Results for Aircraft Hangar at Ellsworth AFB, SD

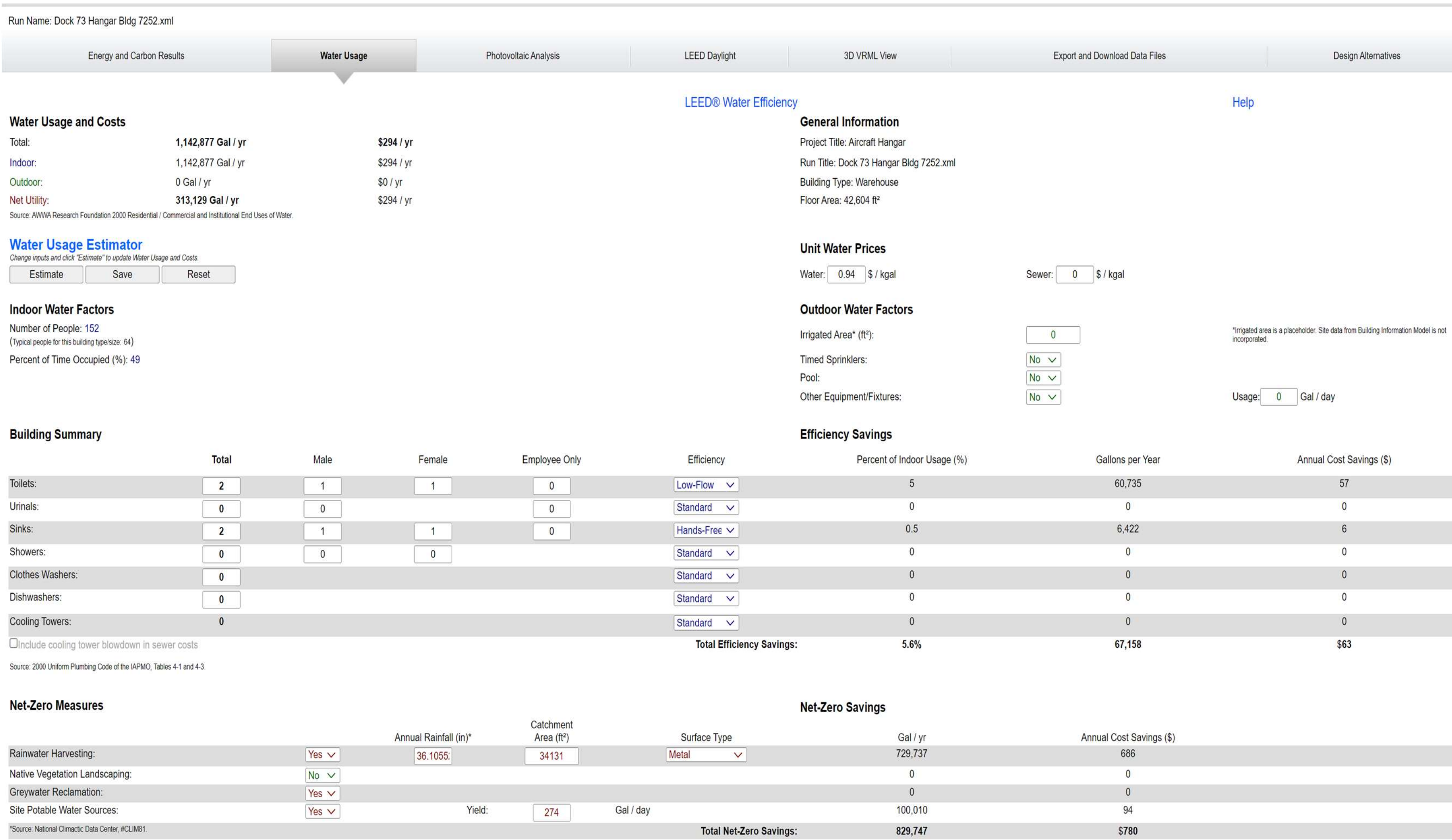


Figure 47: Green Building Studio Results for Aircraft Hangar at Wright-Patterson AFB, OH

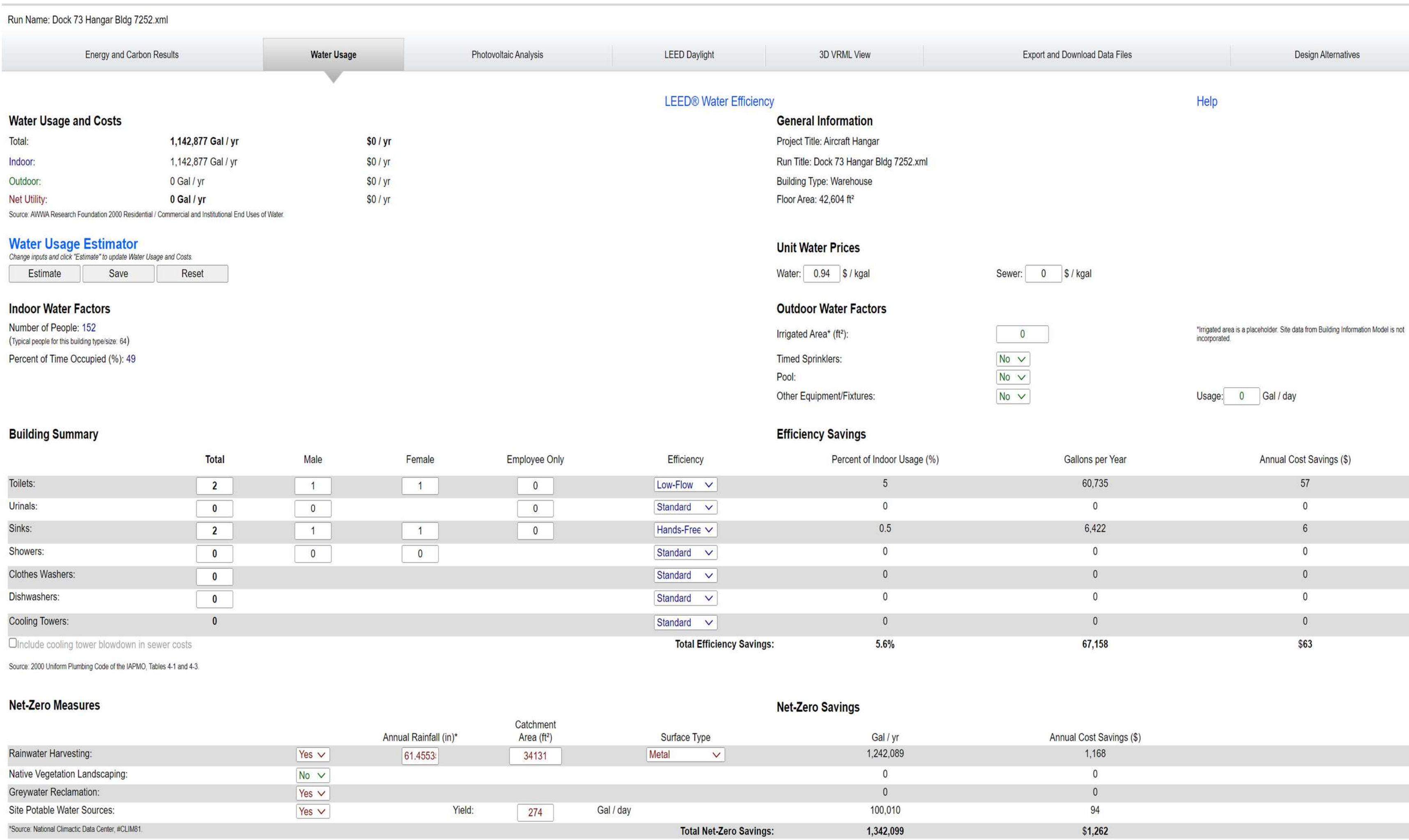
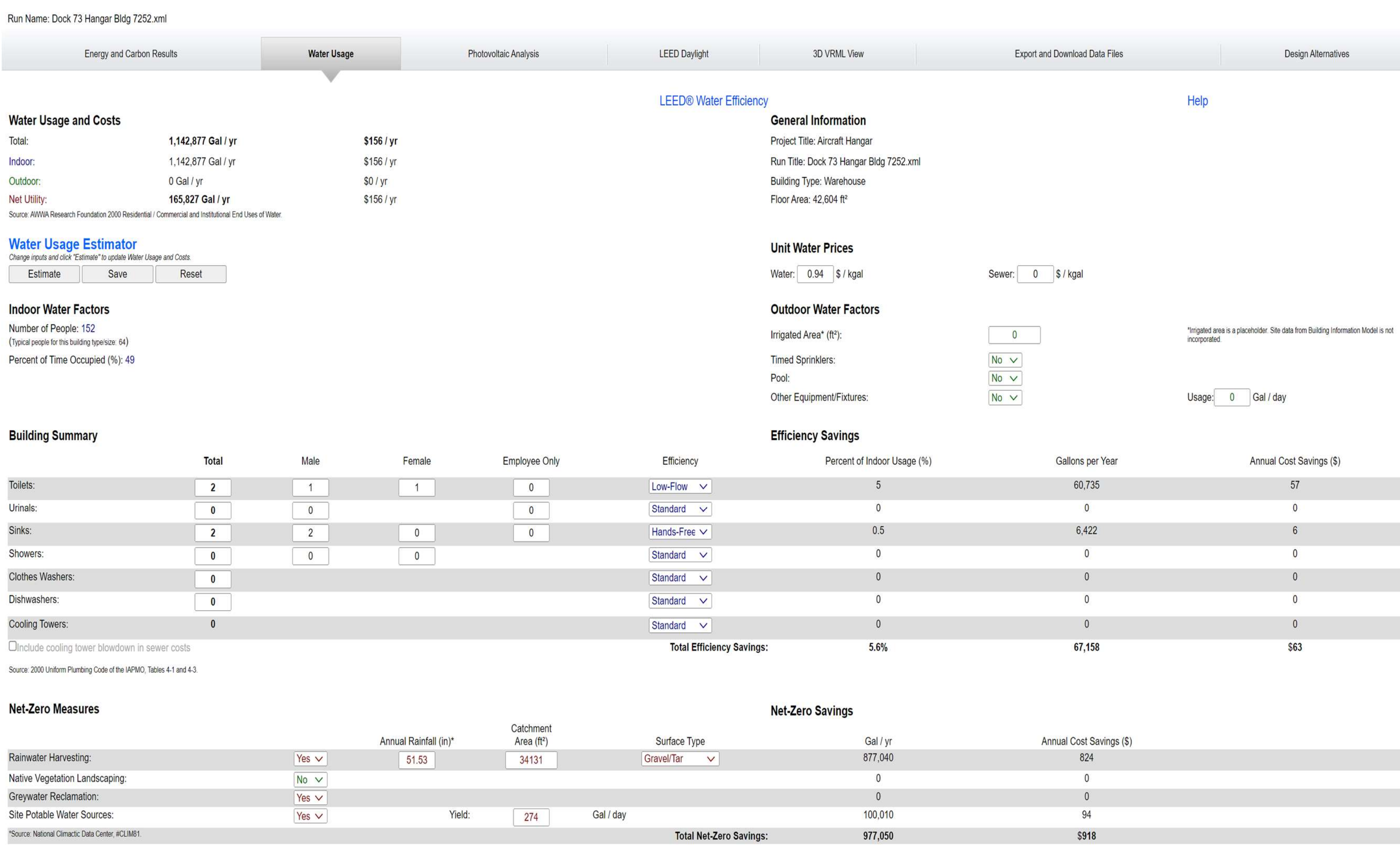


Figure 48: Green Building Studio Results for Aircraft Hangar at Eglin AFB, FL



Run Name: Dock 73 Hangar Bldg 7252.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**1,142,877 Gal / yr**	**$156 / yr**
Indoor:	1,142,877 Gal / yr	$156 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**165,827 Gal / yr**	$156 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Aircraft Hangar

Run Title: Dock 73 Hangar Bldg 7252.xml

Building Type: Warehouse

Floor Area: 42,604 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 152

(Typical people for this building type/size: 64)

Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	2	1	1	0	Low-Flow	5	60,735	57
Urinals:	0	0		0	Standard	0	0	0
Sinks:	2	2	0	0	Hands-Free	0.5	6,422	6
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**5.6%**	**67,158**	**$63**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	51.53	34131	Gravel/Tar	877,040	824
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**977,050**	**$918**

Figure 49: Green Building Studio Results for Aircraft Hangar at JB Charleston, SC

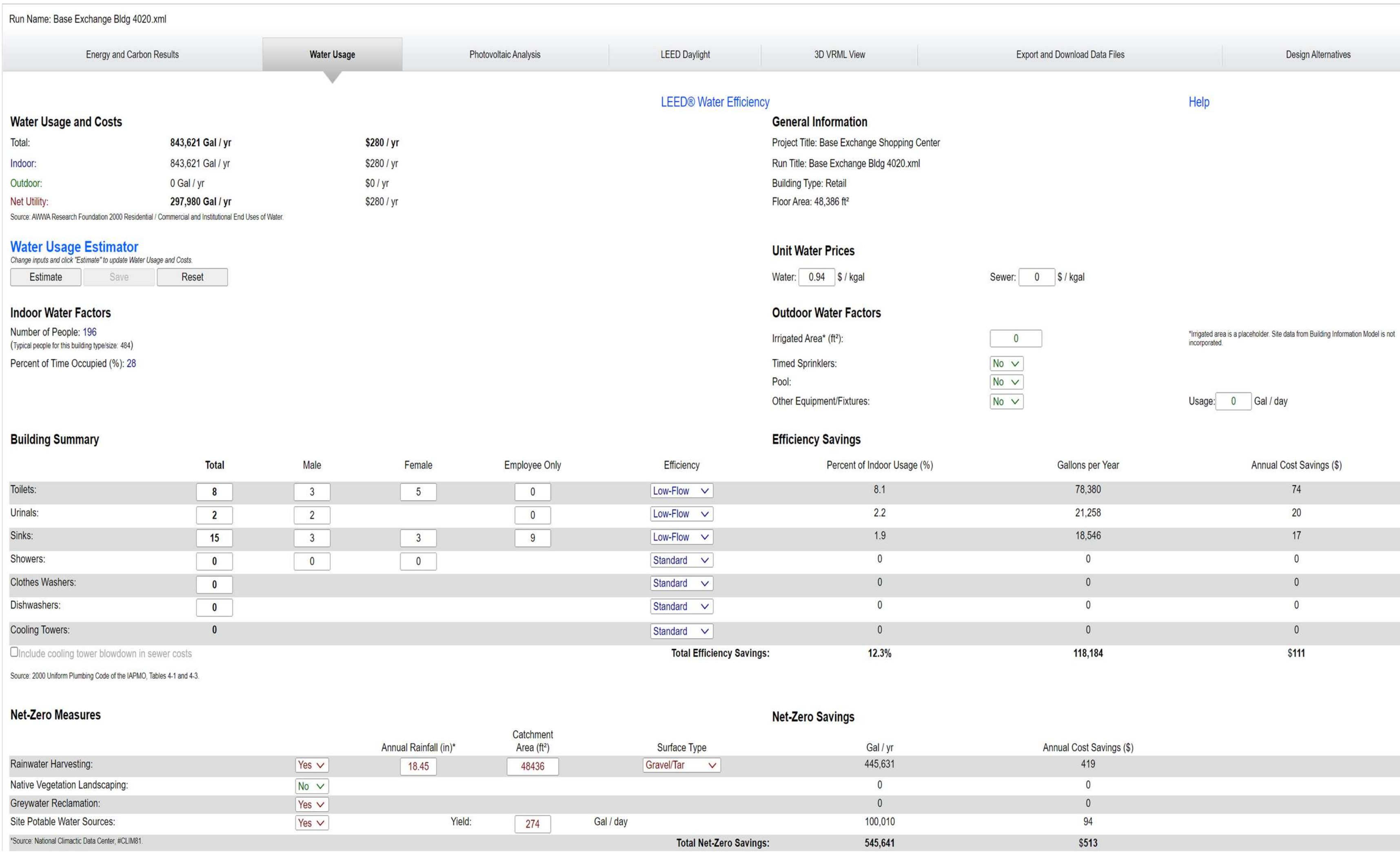


Figure 50: Green Building Studio Results for Base Exchange Shopping Center at Ellsworth AFB, SD

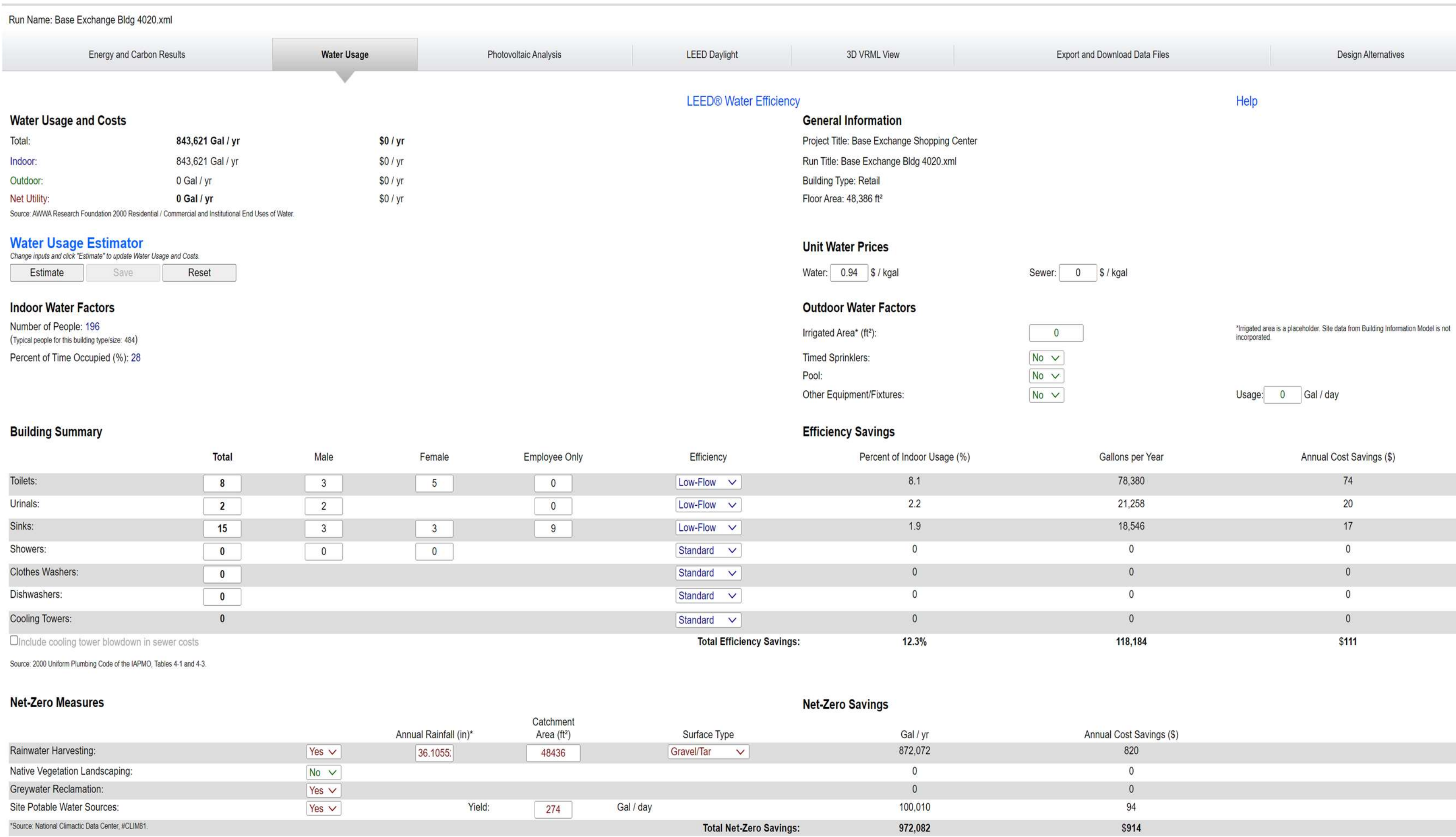
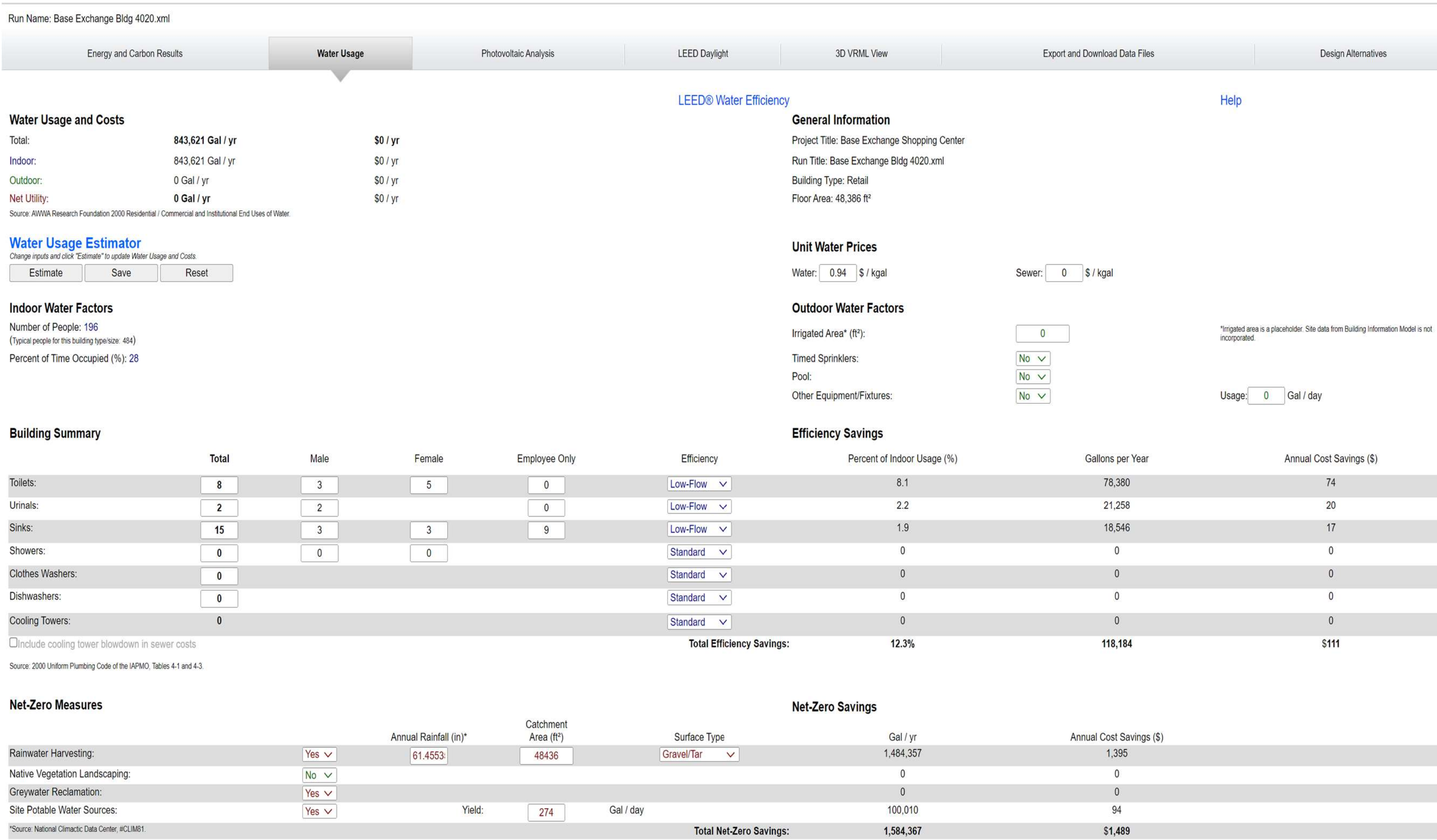


Figure 51: Green Building Studio Results for Base Exchange Shopping Center at Wright-Patterson AFB, OH



Run Name: Base Exchange Bldg 4020.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency | Help

Water Usage and Costs

Total:	**843,621 Gal / yr**	**$0 / yr**
Indoor:	843,621 Gal / yr	$0 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**0 Gal / yr**	**$0 / yr**

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Base Exchange Shopping Center
Run Title: Base Exchange Bldg 4020.xml
Building Type: Retail
Floor Area: 48,386 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 196
(Typical people for this building type/size: 484)
Percent of Time Occupied (%): 28

Outdoor Water Factors

Irrigated Area* (ft²): 0
*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.
Timed Sprinklers: No
Pool: No
Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	8	3	5	0	Low-Flow	8.1	78,380	74
Urinals:	2	2		0	Low-Flow	2.2	21,258	20
Sinks:	15	3	3	9	Low-Flow	1.9	18,546	17
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**12.3%**	**118,184**	**$111**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	61.4553	48436	Gravel/Tar	1,484,357	1,395
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**1,584,367**	**$1,489**

Figure 52: Green Building Studio Results for Base Exchange Shopping Center at Eglin AFB, FL

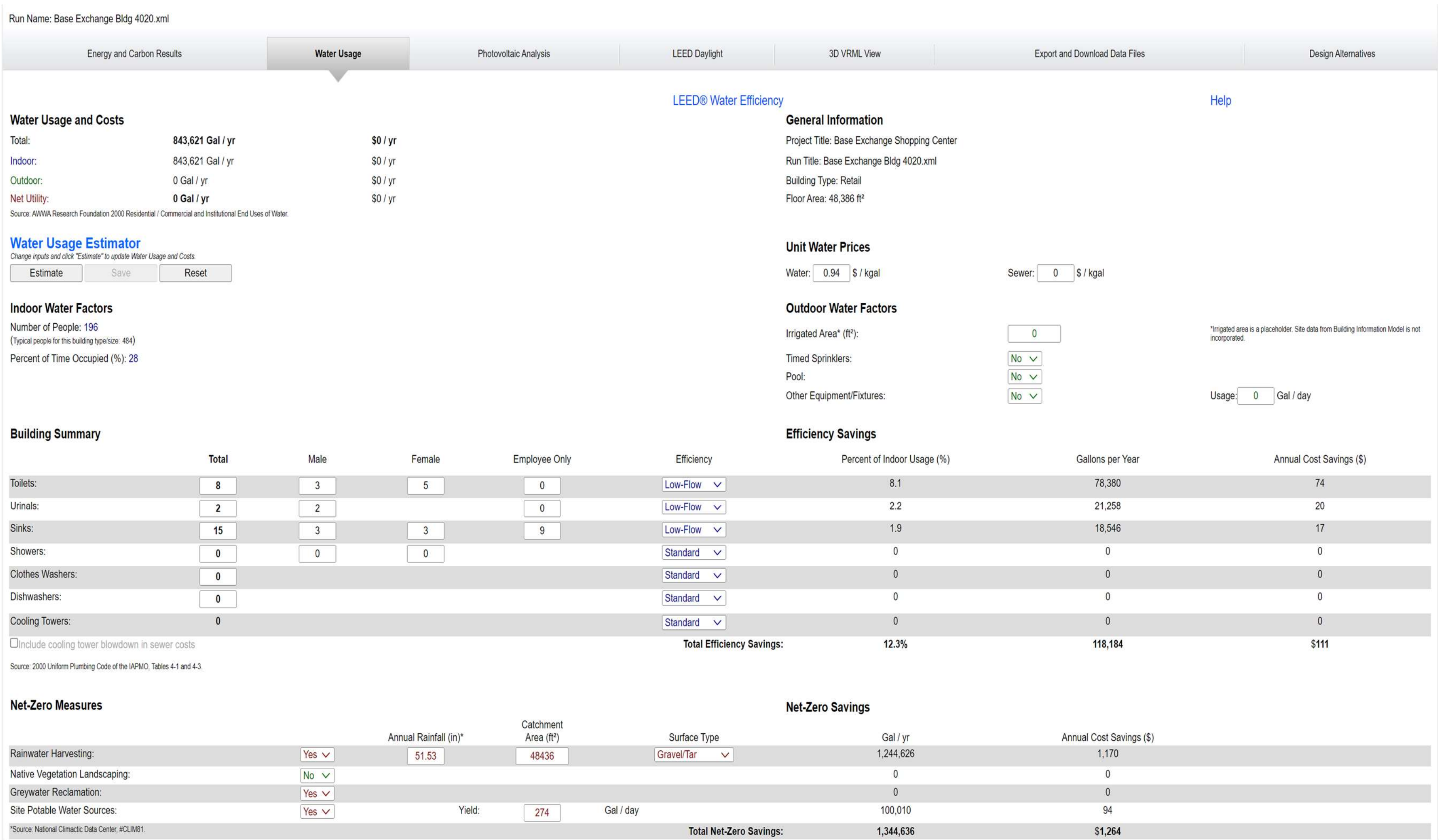
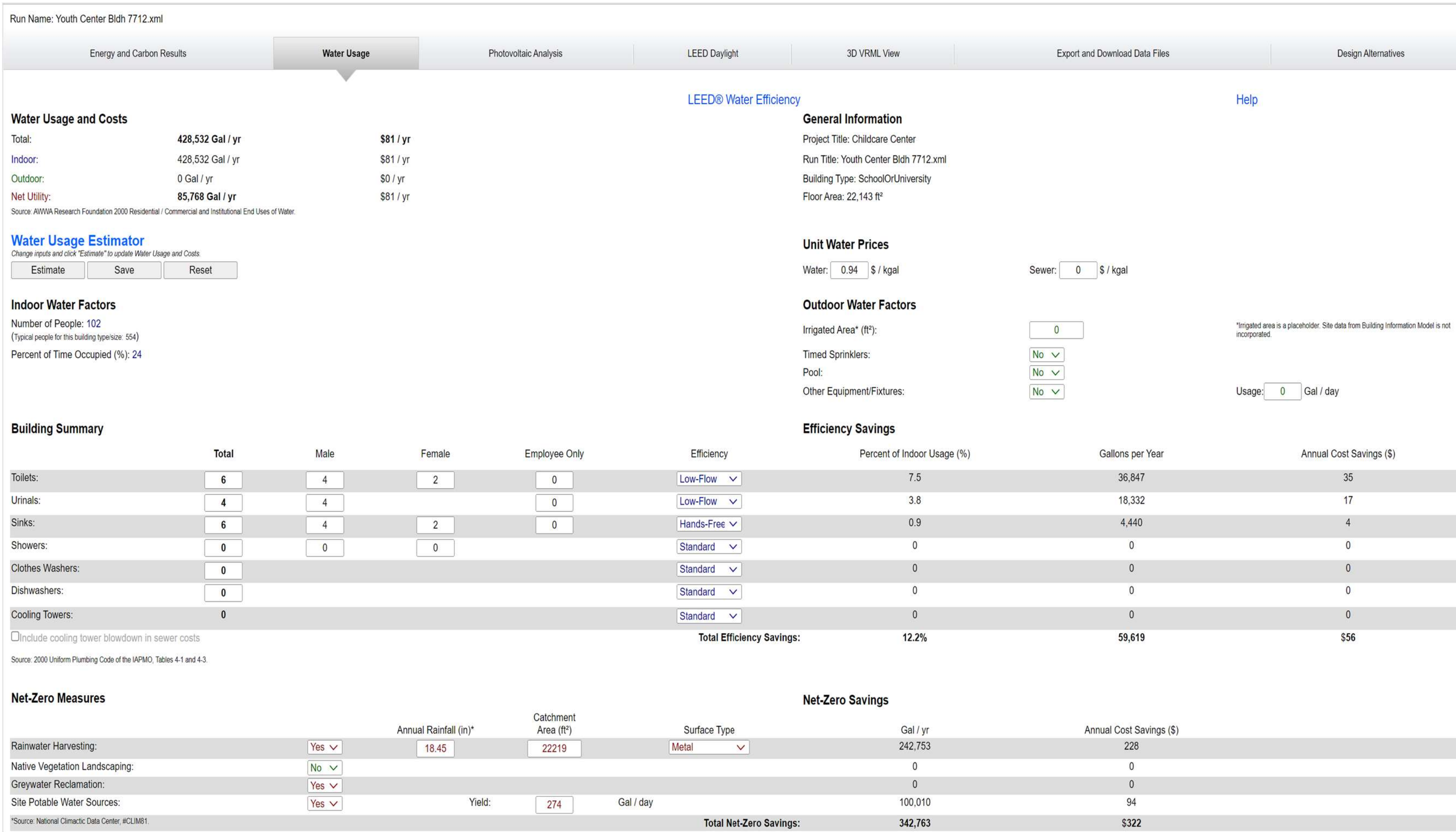


Figure 53: Green Building Studio Results for Base Exchange Shopping Center at JB Charleston, SC



Run Name: Youth Center Bldh 7712.xml

Energy and Carbon Results | **Water Usage** | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency   Help

Water Usage and Costs

Total:	**428,532 Gal / yr**	**$81 / yr**
Indoor:	428,532 Gal / yr	$81 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**85,768 Gal / yr**	$81 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Childcare Center

Run Title: Youth Center Bldh 7712.xml

Building Type: SchoolOrUniversity

Floor Area: 22,143 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 102

(Typical people for this building type/size: 554)

Percent of Time Occupied (%): 24

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	6	4	2	0	Low-Flow	7.5	36,847	35
Urinals:	4	4		0	Low-Flow	3.8	18,332	17
Sinks:	6	4	2	0	Hands-Free	0.9	4,440	4
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**12.2%**	**59,619**	**$56**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	22219	Metal	242,753	228
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**342,763**	**$322**

Figure 54: Green Building Studio Results for Childcare Facility at Ellsworth AFB, SD

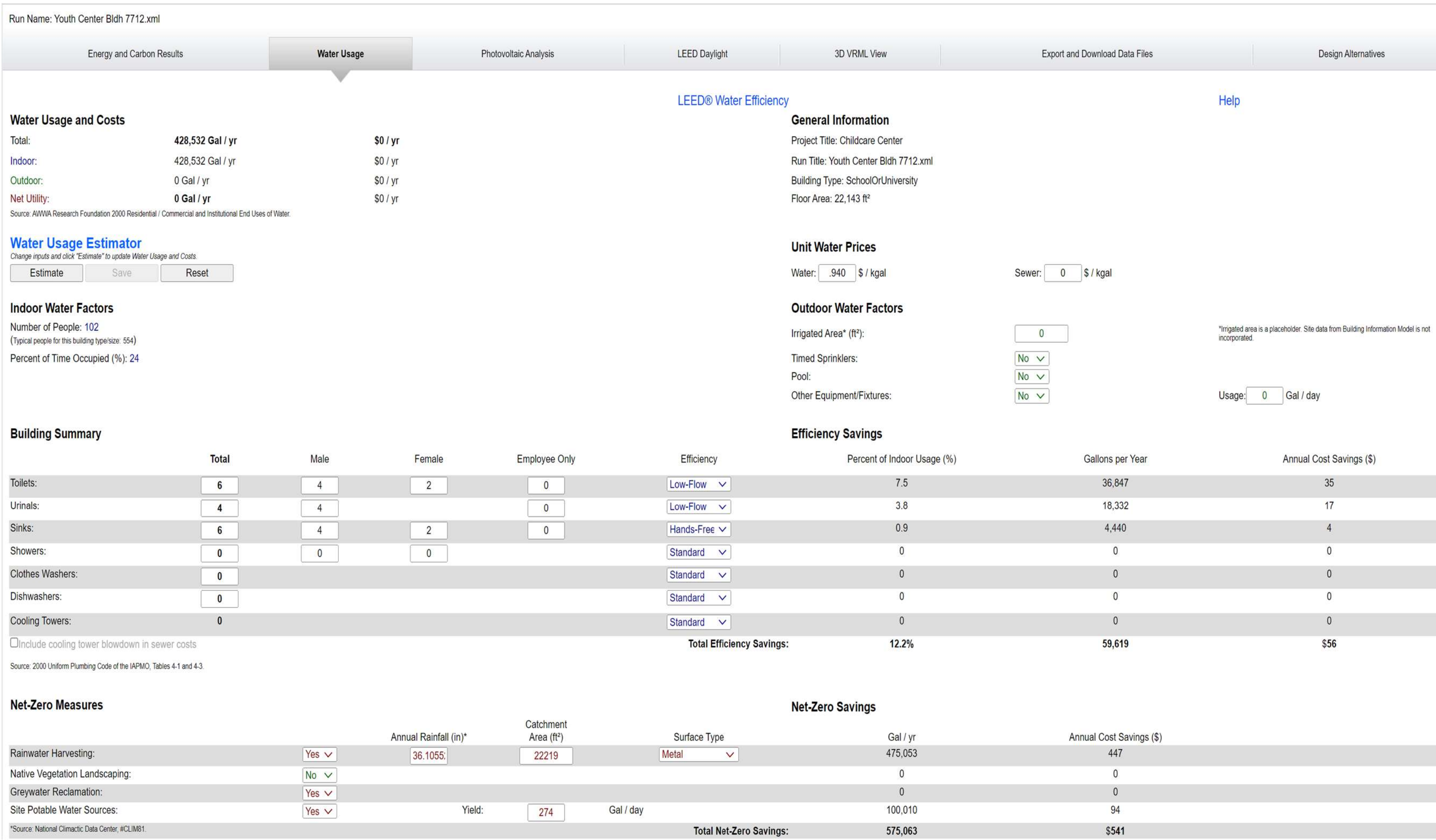
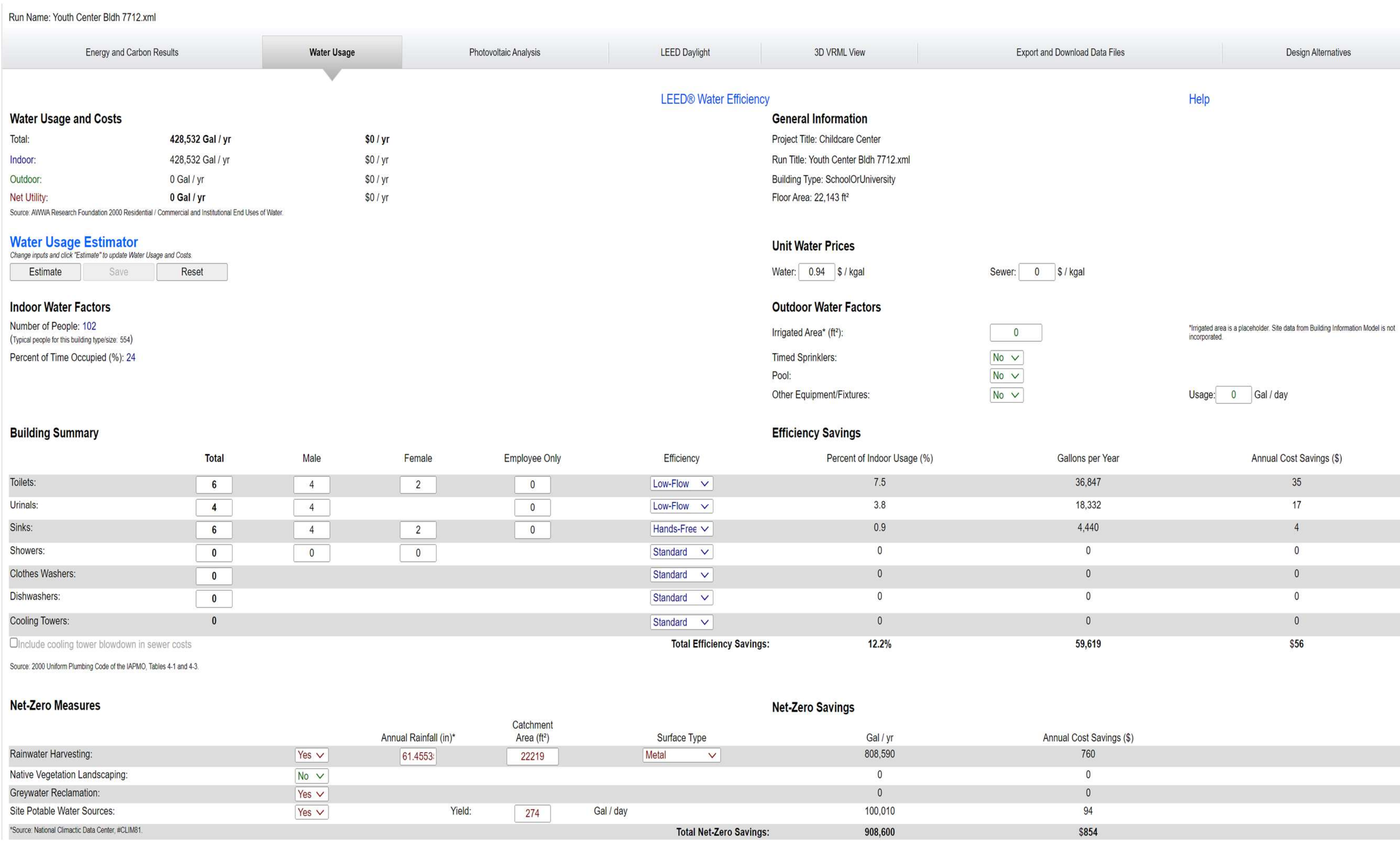


Figure 55: Green Building Studio Results for Childcare Facility at Wright-Patterson AFB, OH



Run Name: Youth Center Bldh 7712.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**428,532 Gal / yr**	**$0 / yr**
Indoor:	428,532 Gal / yr	$0 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**0 Gal / yr**	$0 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Childcare Center

Run Title: Youth Center Bldh 7712.xml

Building Type: SchoolOrUniversity

Floor Area: 22,143 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 102

(Typical people for this building type/size: 554)

Percent of Time Occupied (%): 24

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	6	4	2	0	Low-Flow	7.5	36,847	35
Urinals:	4	4		0	Low-Flow	3.8	18,332	17
Sinks:	6	4	2	0	Hands-Free	0.9	4,440	4
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
					Total Efficiency Savings:	**12.2%**	**59,619**	**$56**

☐ Include cooling tower blowdown in sewer costs

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	61.4553	22219	Metal	808,590	760
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**908,600**	**$854**

Figure 56: Green Building Studio Results for Childcare Facility at Eglin AFB, FL

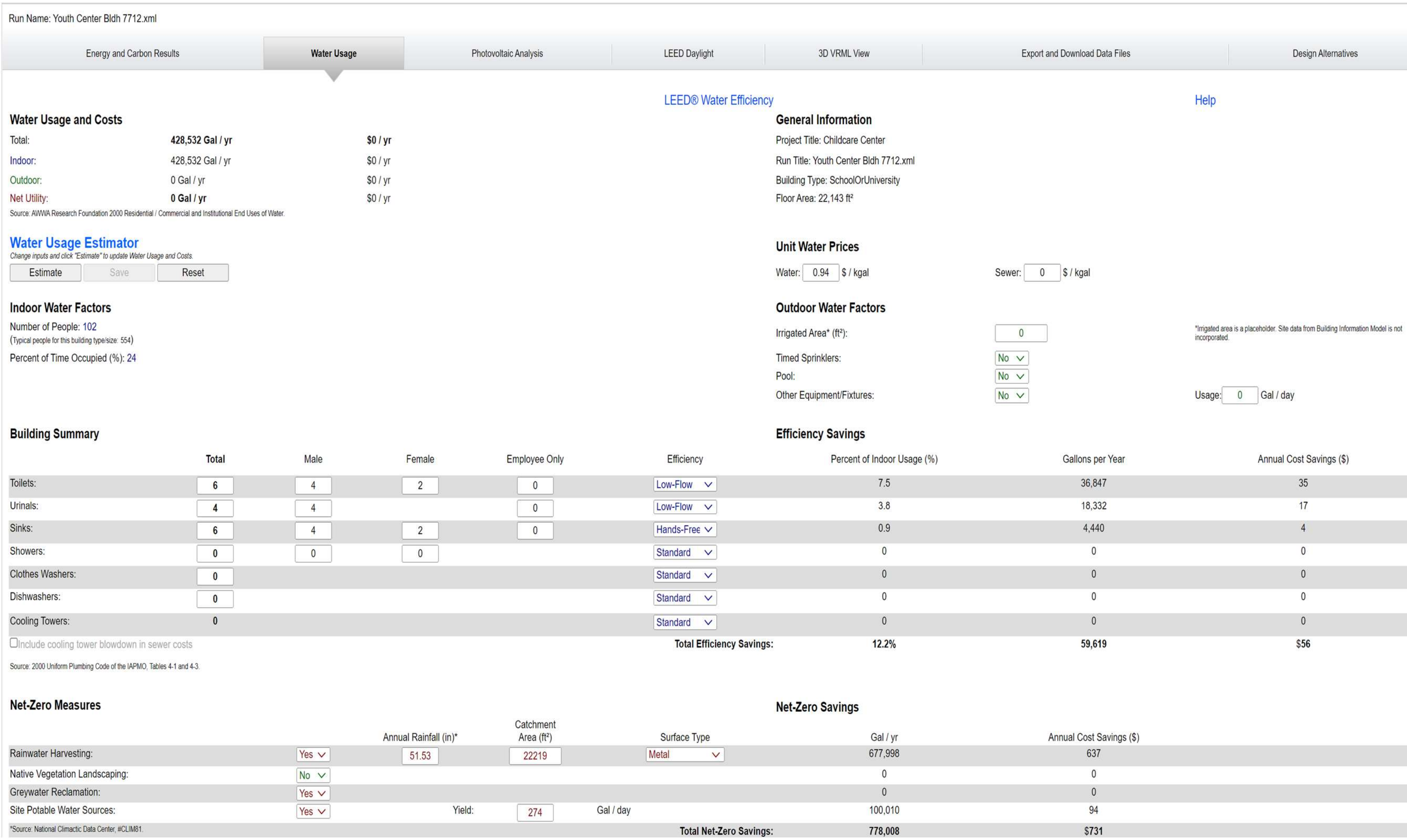


Figure 57: Green Building Studio Results for Childcare Facility at JB Charleston, SC

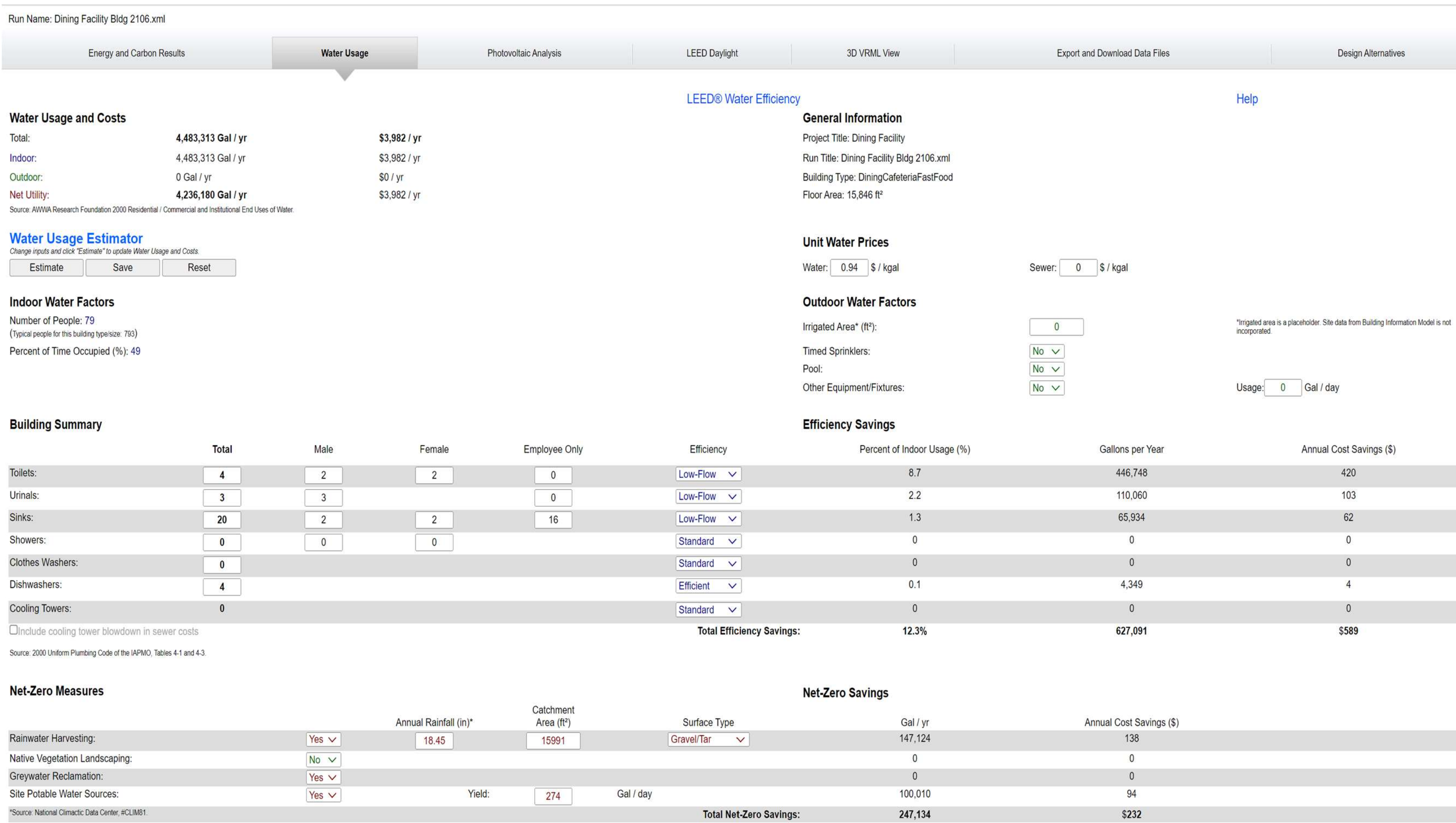


Figure 58: Green Building Studio Results for Dining Facility at Ellsworth AFB, SD

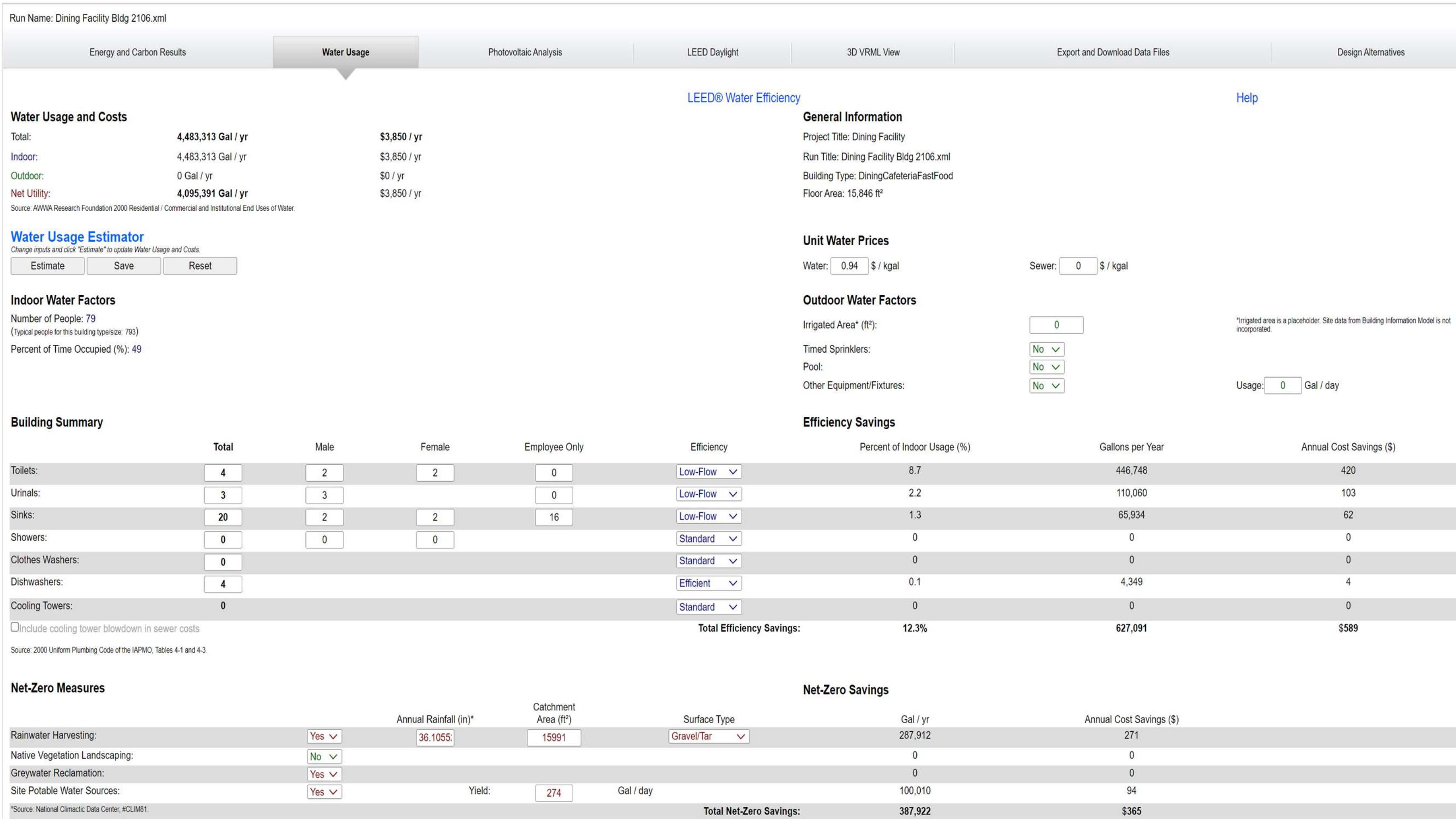


Figure 59: Green Building Studio Results for Dining Facility at Wright-Patterson AFB, OH

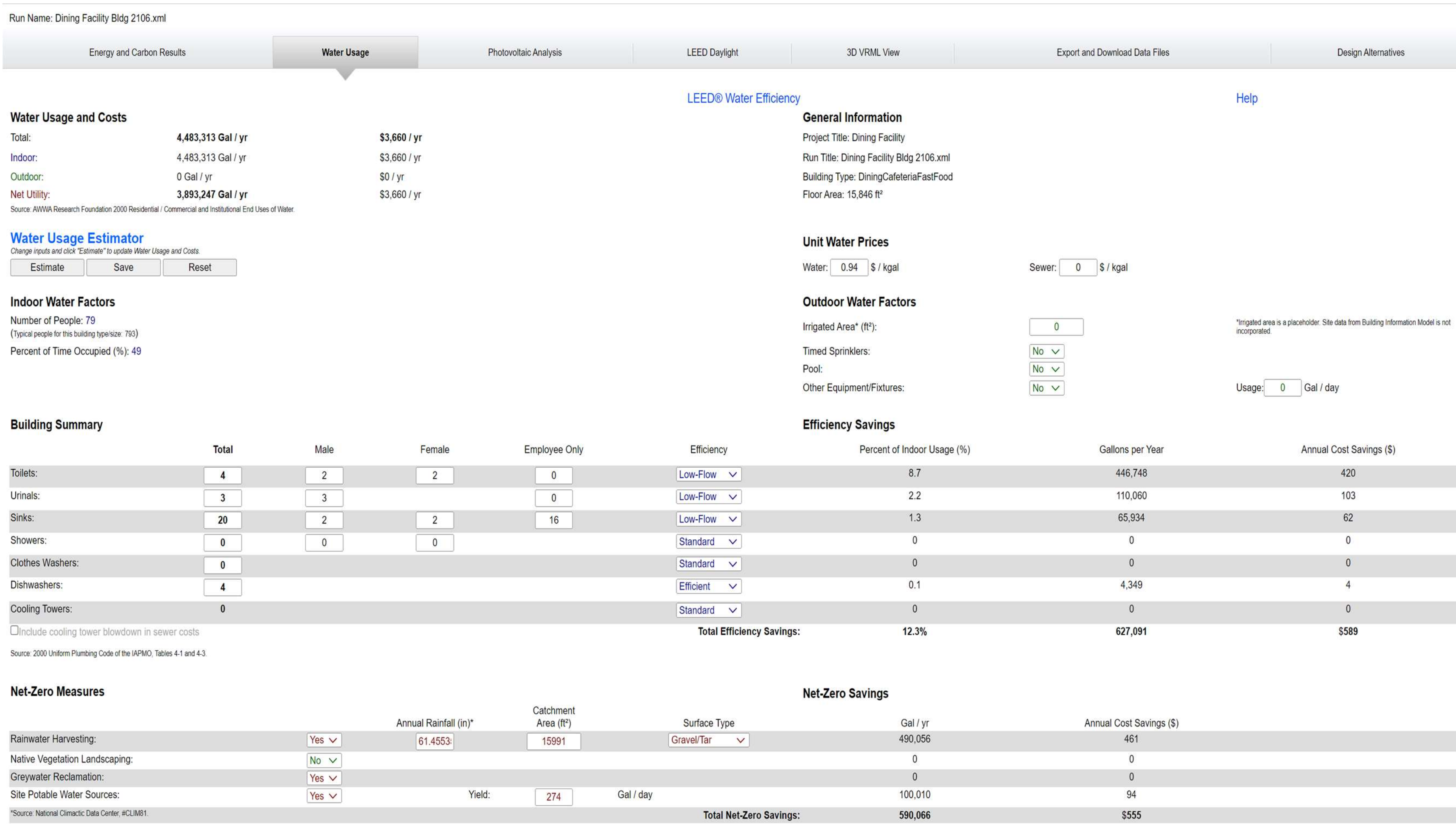


Figure 60: Green Building Studio Results for Dining Facility at Eglin AFB, FL

Run Name: Dining Facility Bldg 2106.xml

Energy and Carbon Results	**Water Usage**	Photovoltaic Analysis	LEED Daylight	3D VRML View	Export and Download Data Files	Design Alternatives

LEED® Water Efficiency   Help

Water Usage and Costs

Total:	**4,483,313 Gal / yr**	**$3,734 / yr**
Indoor:	4,483,313 Gal / yr	$3,734 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**3,972,394 Gal / yr**	$3,734 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Dining Facility
Run Title: Dining Facility Bldg 2106.xml
Building Type: DiningCafeteriaFastFood
Floor Area: 15,846 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 79
(Typical people for this building type/size: 793)
Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²):	0	*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.
Timed Sprinklers:	No	
Pool:	No	
Other Equipment/Fixtures:	No	Usage: 0 Gal / day

Building Summary / Efficiency Savings

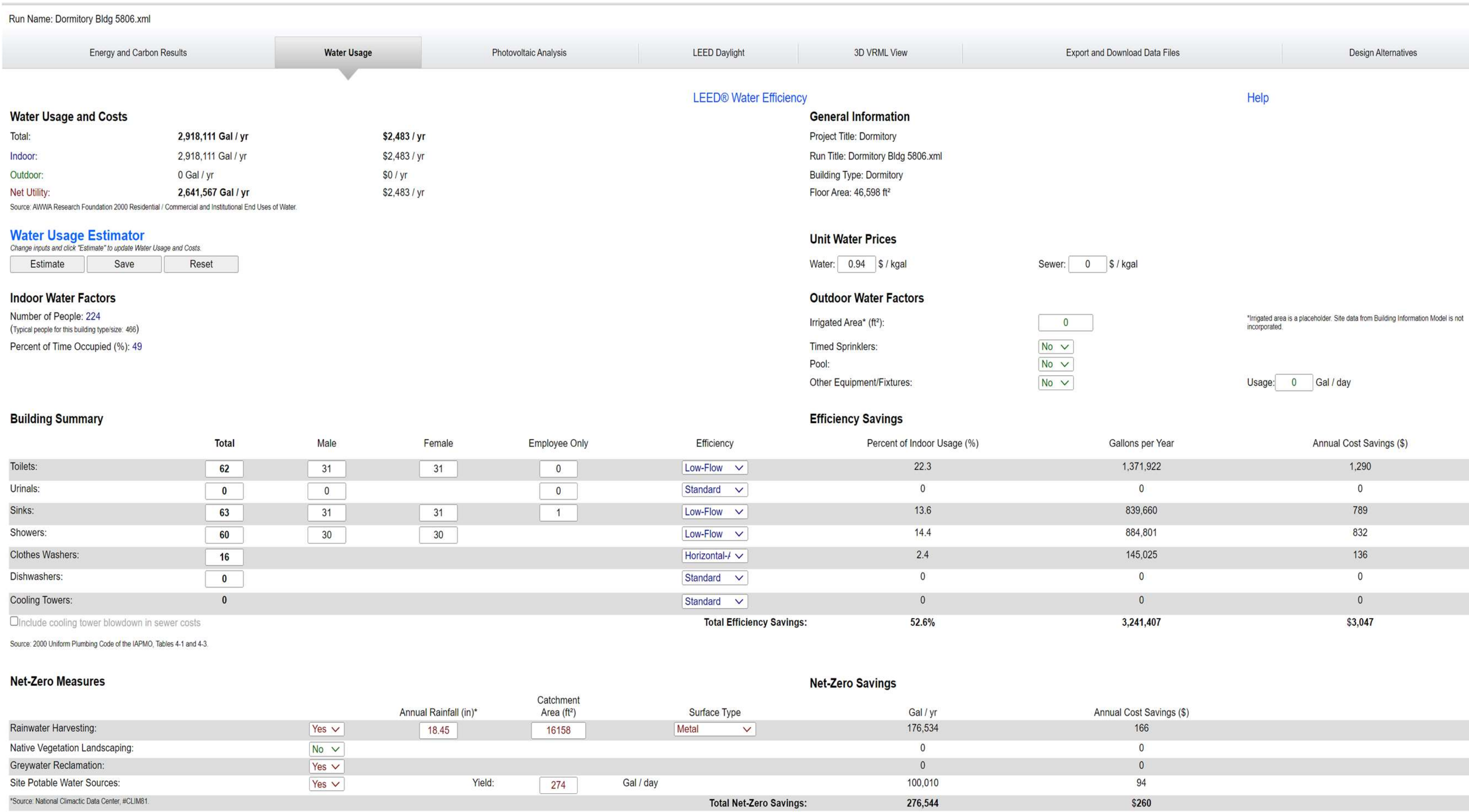
	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	4	2	2	0	Low-Flow	8.7	446,748	420
Urinals:	3	3		0	Low-Flow	2.2	110,060	103
Sinks:	20	2	2	16	Low-Flow	1.3	65,934	62
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	4				Efficient	0.1	4,349	4
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**12.3%**	**627,091**	**$589**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / Net-Zero Savings

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	51.53	15991	Gravel/Tar	410,909	386
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**510,919**	**$480**

Figure 61: Green Building Studio Results for Dining Facility at JB Charleston, SC



Run Name: Dormitory Bldg 5806.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**2,918,111 Gal / yr**	**$2,483 / yr**
Indoor:	2,918,111 Gal / yr	$2,483 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**2,641,567 Gal / yr**	$2,483 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Dormitory
Run Title: Dormitory Bldg 5806.xml
Building Type: Dormitory
Floor Area: 46,598 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 224
(Typical people for this building type/size: 466)
Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0
*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.
Timed Sprinklers: No
Pool: No
Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	62	31	31	0	Low-Flow	22.3	1,371,922	1,290
Urinals:	0	0		0	Standard	0	0	0
Sinks:	63	31	31	1	Low-Flow	13.6	839,660	789
Showers:	60	30	30		Low-Flow	14.4	884,801	832
Clothes Washers:	16				Horizontal-A	2.4	145,025	136
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐ Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**52.6%**	**3,241,407**	**$3,047**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	16158	Metal	176,534	166
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81				**Total Net-Zero Savings:**	**276,544**	**$260**

Figure 62: Green Building Studio Results for Dormitory at Ellsworth AFB, SD

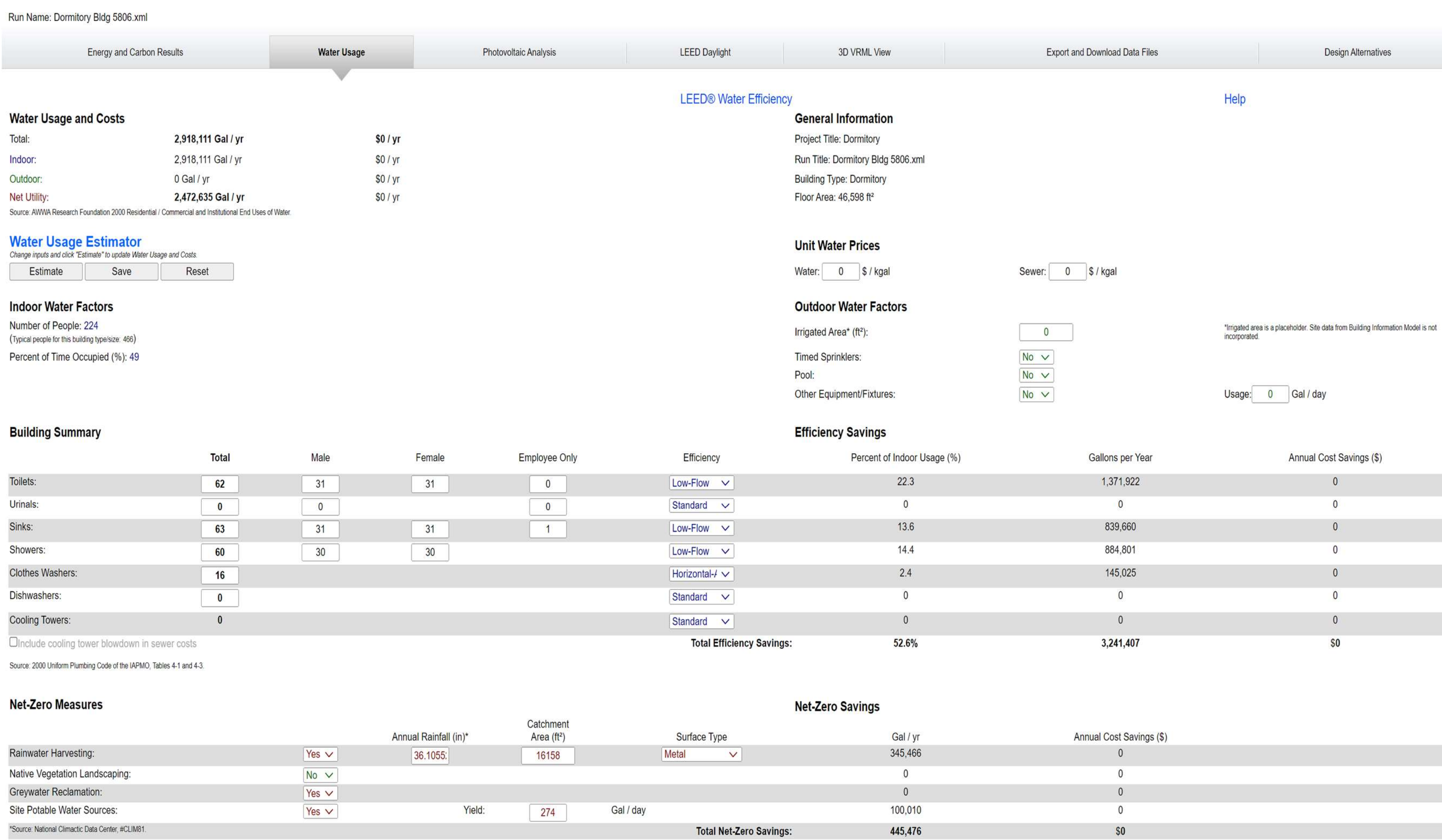


Figure 63: Green Building Studio Results for Dormitory at Wright-Patterson AFB, OH

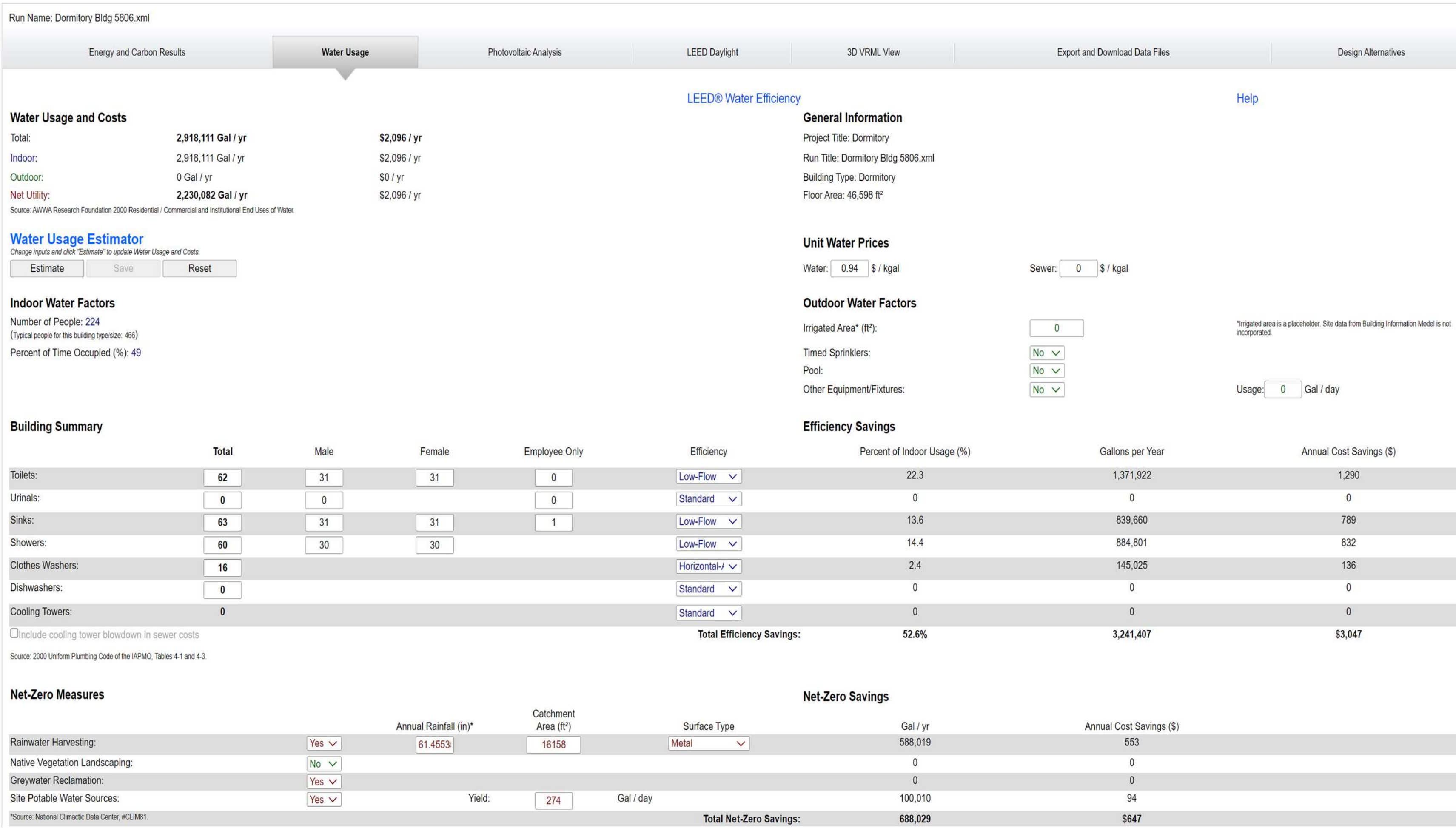
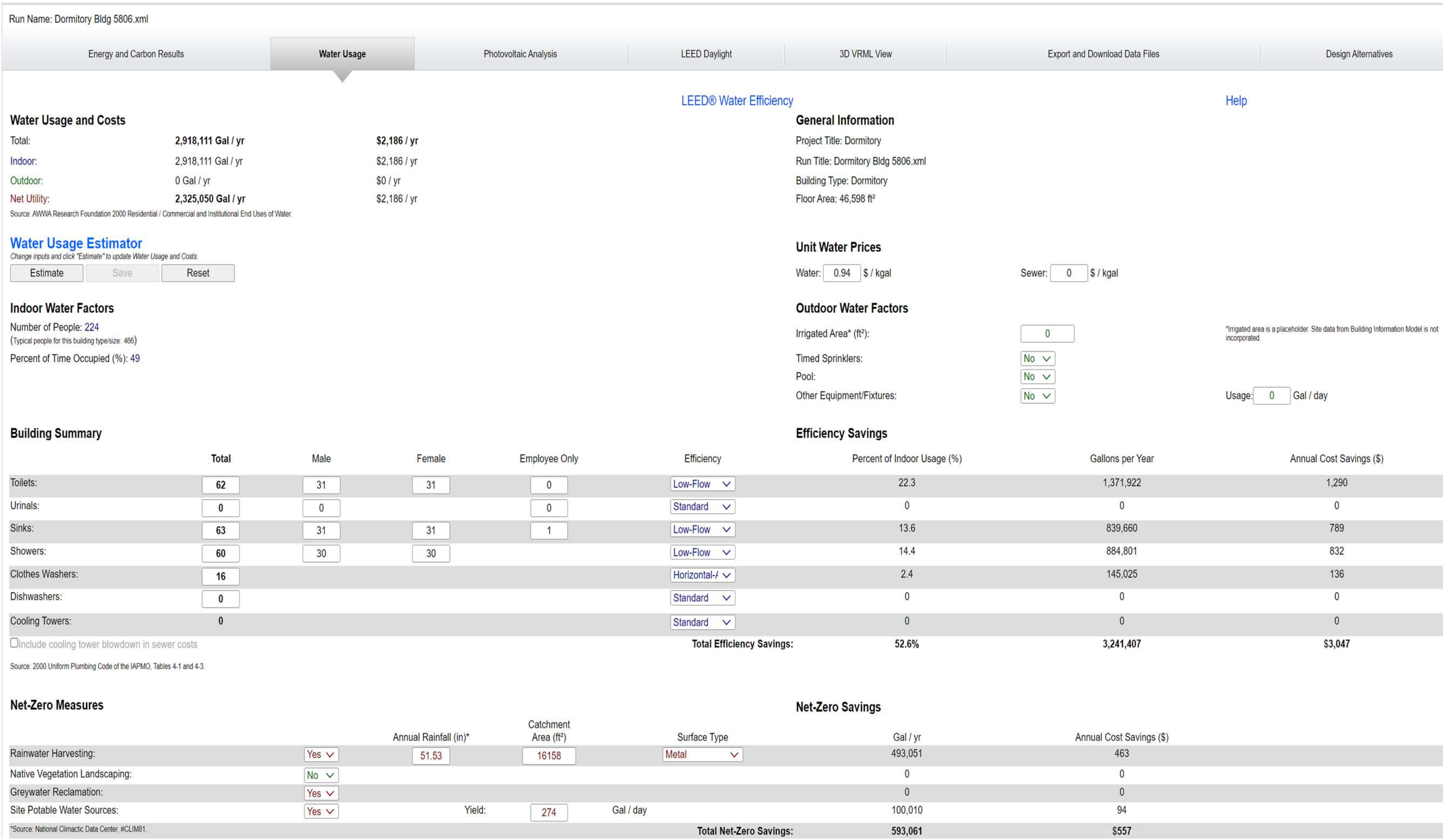


Figure 64: Green Building Studio Results for Dormitory at Eglin AFB, FL


Run Name: Dormitory Bldg 5806.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**2,918,111 Gal / yr**	**$2,186 / yr**
Indoor:	2,918,111 Gal / yr	$2,186 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**2,325,050 Gal / yr**	$2,186 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Dormitory

Run Title: Dormitory Bldg 5806.xml

Building Type: Dormitory

Floor Area: 46,598 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 224

(Typical people for this building type/size: 466)

Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	62	31	31	0	Low-Flow	22.3	1,371,922	1,290
Urinals:	0	0		0	Standard	0	0	0
Sinks:	63	31	31	1	Low-Flow	13.6	839,660	789
Showers:	60	30	30		Low-Flow	14.4	884,801	832
Clothes Washers:	16				Horizontal-/	2.4	145,025	136
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**52.6%**	**3,241,407**	**$3,047**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	51.53	16158	Metal	493,051	463
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
				Total Net-Zero Savings:	**593,061**	**$557**

*Source: National Climactic Data Center, #CLIM81.

Figure 65: Green Building Studio Results for Dormitory at JB Charleston, SC

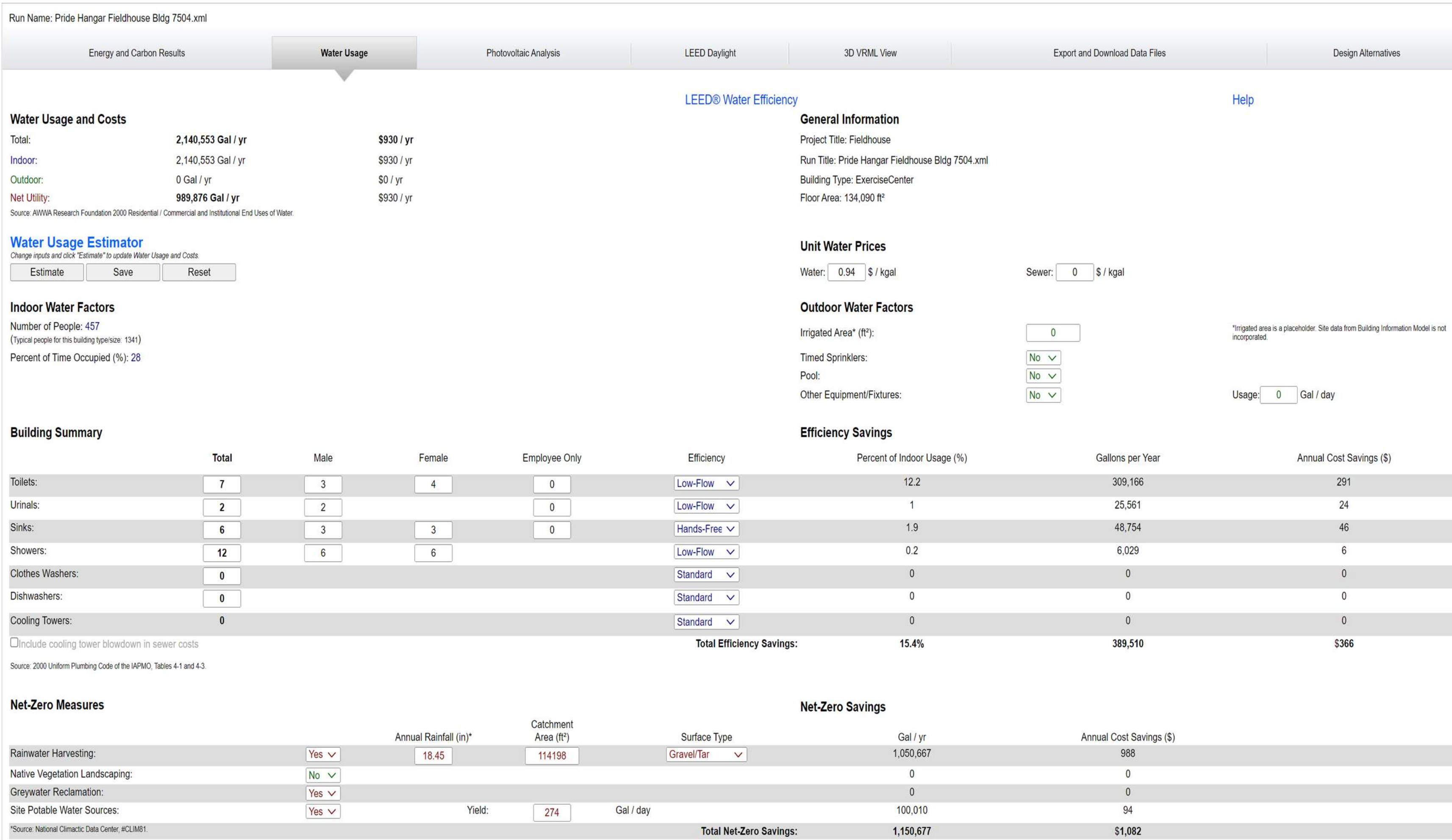


Figure 66: Green Building Studio Results for Fieldhouse at Ellsworth AFB, SD

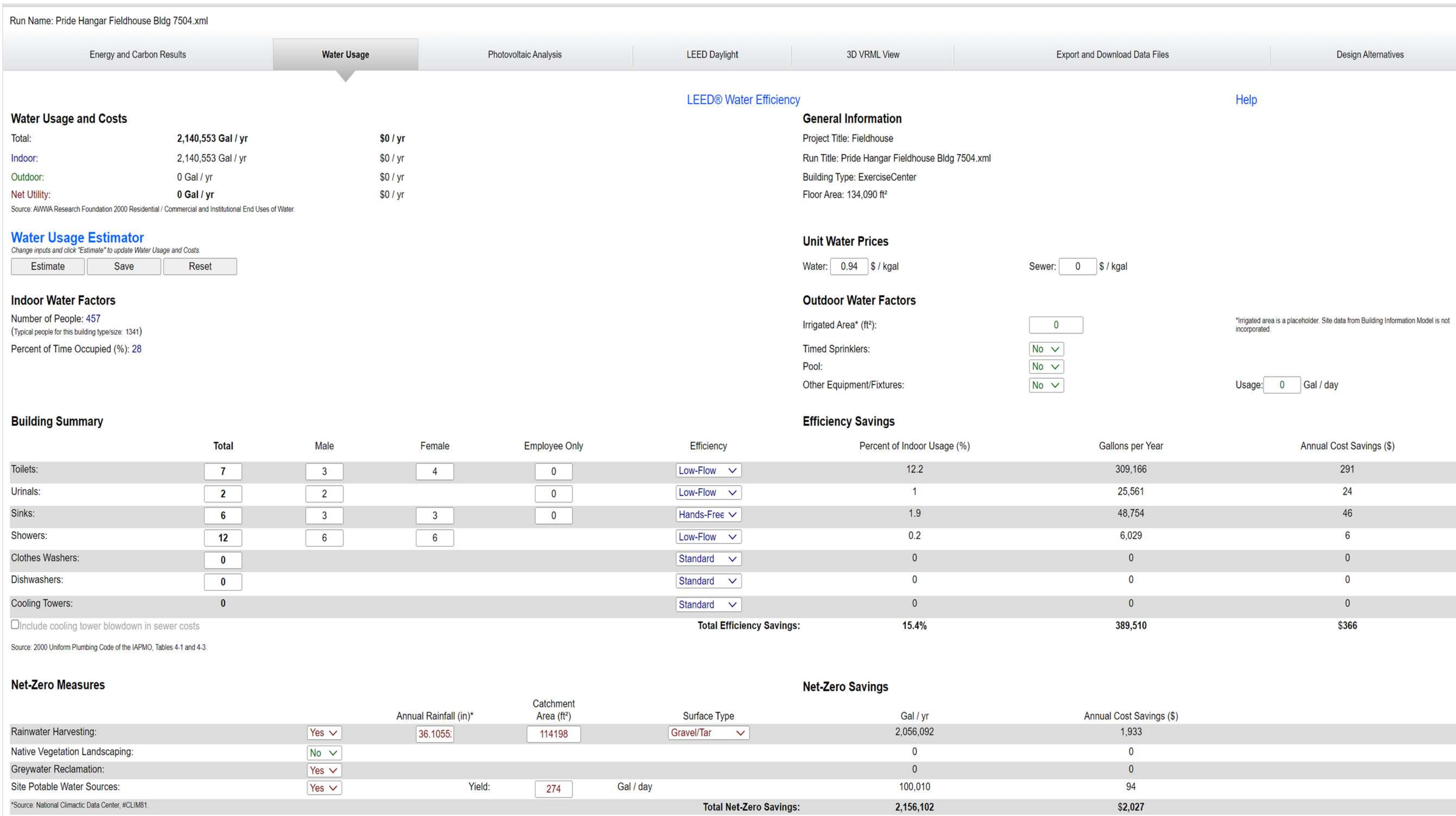
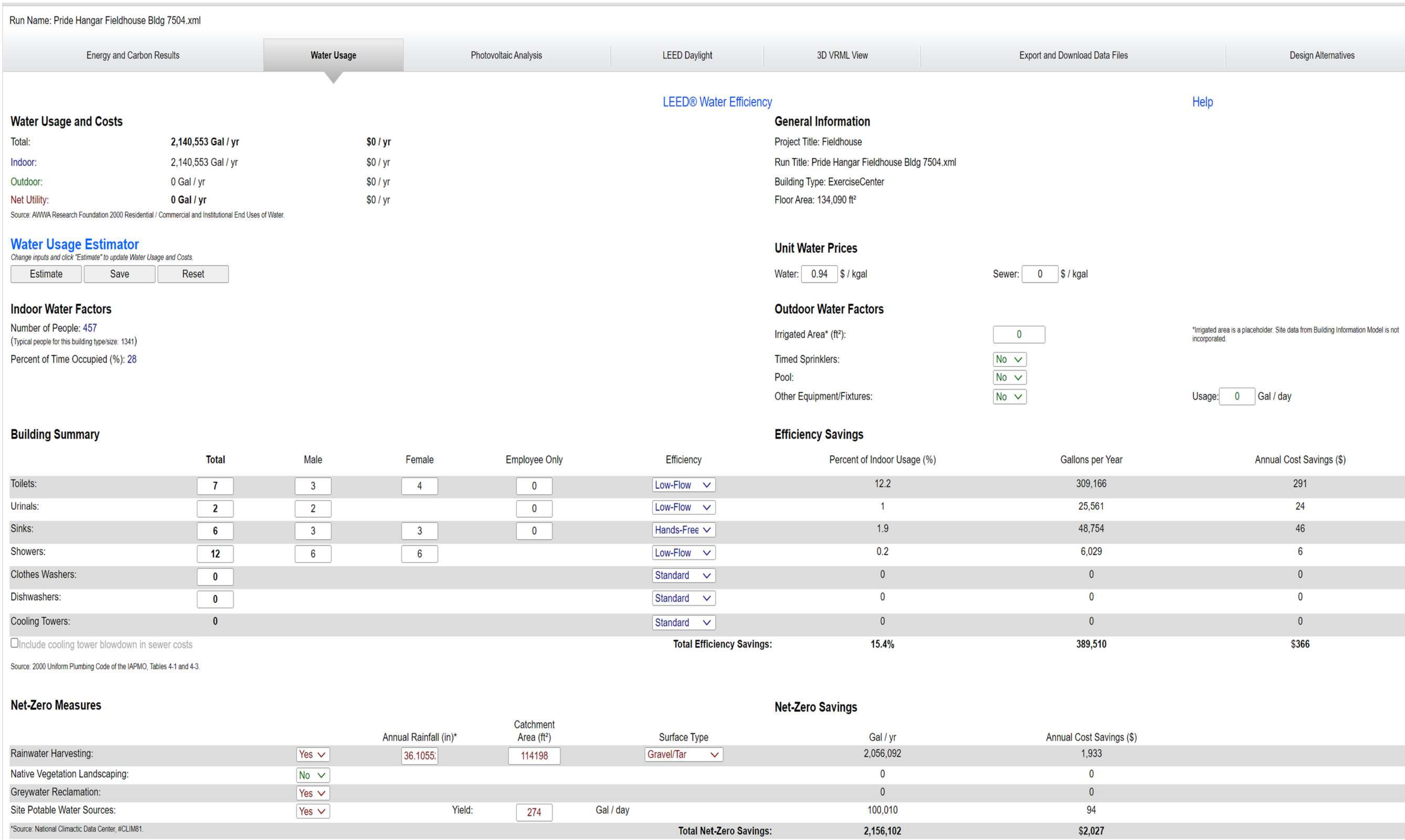


Figure 67: Green Building Studio Results for Fieldhouse at Wright-Patterson AFB, OH



Run Name: Pride Hangar Fieldhouse Bldg 7504.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**2,140,553 Gal / yr**	**$0 / yr**
Indoor:	2,140,553 Gal / yr	$0 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**0 Gal / yr**	$0 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Fieldhouse

Run Title: Pride Hangar Fieldhouse Bldg 7504.xml

Building Type: ExerciseCenter

Floor Area: 134,090 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 457

(Typical people for this building type/size: 1341)

Percent of Time Occupied (%): 28

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

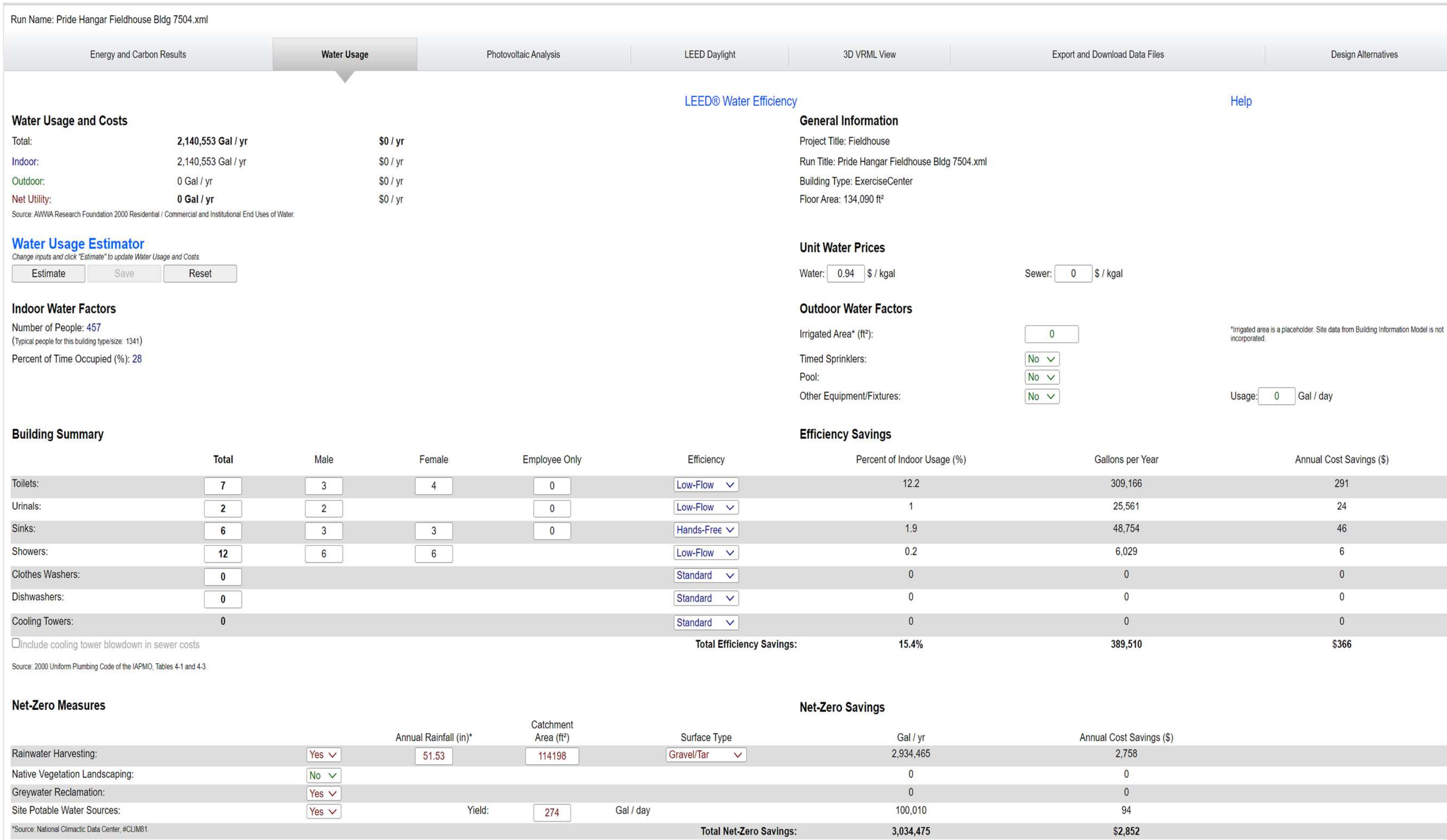
	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	7	3	4	0	Low-Flow	12.2	309,166	291
Urinals:	2	2		0	Low-Flow	1	25,561	24
Sinks:	6	3	3	0	Hands-Free	1.9	48,754	46
Showers:	12	6	6		Low-Flow	0.2	6,029	6
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**15.4%**	**389,510**	**$366**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	36.1055	114198	Gravel/Tar	2,056,092	1,933
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**2,156,102**	**$2,027**

Figure 68: Green Building Studio Results for Fieldhouse at Eglin AFB, FL



Run Name: Pride Hangar Fieldhouse Bldg 7504.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**2,140,553 Gal / yr**	**$0 / yr**
Indoor:	2,140,553 Gal / yr	$0 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**0 Gal / yr**	$0 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Fieldhouse

Run Title: Pride Hangar Fieldhouse Bldg 7504.xml

Building Type: ExerciseCenter

Floor Area: 134,090 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 457

(Typical people for this building type/size: 1341)

Percent of Time Occupied (%): 28

Outdoor Water Factors

Irrigated Area* (ft²): 0   *Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

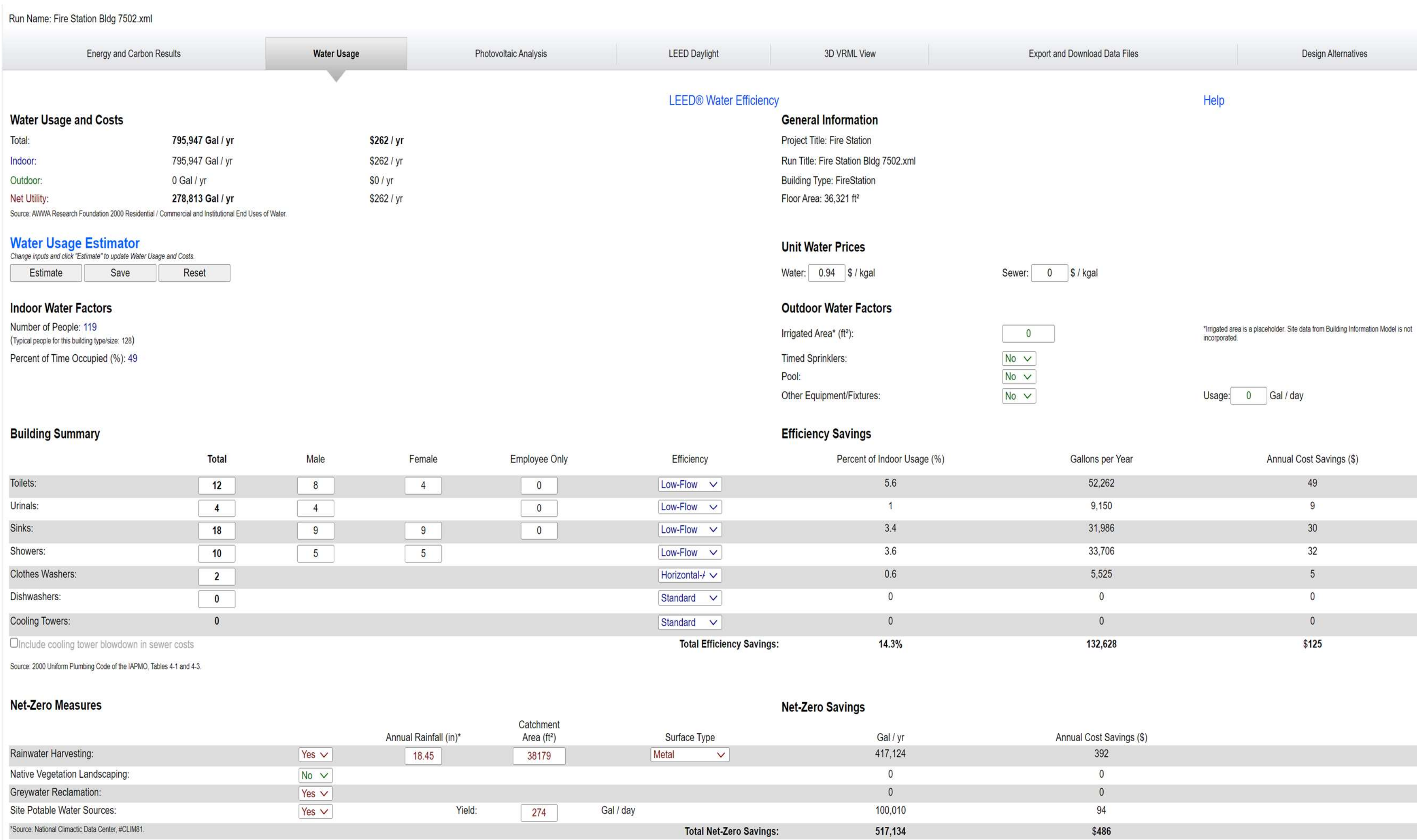
	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	7	3	4	0	Low-Flow	12.2	309,166	291
Urinals:	2	2		0	Low-Flow	1	25,561	24
Sinks:	6	3	3	0	Hands-Free	1.9	48,754	46
Showers:	12	6	6		Low-Flow	0.2	6,029	6
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**15.4%**	**389,510**	**$366**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	51.53	114198	Gravel/Tar	2,934,465	2,758
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**3,034,475**	**$2,852**

Figure 69: Green Building Studio Results for Fieldhouse at JB Charleston, SC



Run Name: Fire Station Bldg 7502.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	795,947 Gal / yr	$262 / yr
Indoor:	795,947 Gal / yr	$262 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	278,813 Gal / yr	$262 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Fire Station
Run Title: Fire Station Bldg 7502.xml
Building Type: FireStation
Floor Area: 36,321 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 119
(Typical people for this building type/size: 128)
Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0
Timed Sprinklers: No
Pool: No
Other Equipment/Fixtures: No   Usage: 0 Gal / day

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	12	8	4	0	Low-Flow	5.6	52,262	49
Urinals:	4	4		0	Low-Flow	1	9,150	9
Sinks:	18	9	9	0	Low-Flow	3.4	31,986	30
Showers:	10	5	5		Low-Flow	3.6	33,706	32
Clothes Washers:	2				Horizontal-A	0.6	5,525	5
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
Include cooling tower blowdown in sewer costs					Total Efficiency Savings:	14.3%	132,628	$125

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	38179	Metal	417,124	392
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				Total Net-Zero Savings:	517,134	$486

Figure 70: Green Building Studio Results for Fire Station at Ellsworth AFB, SD

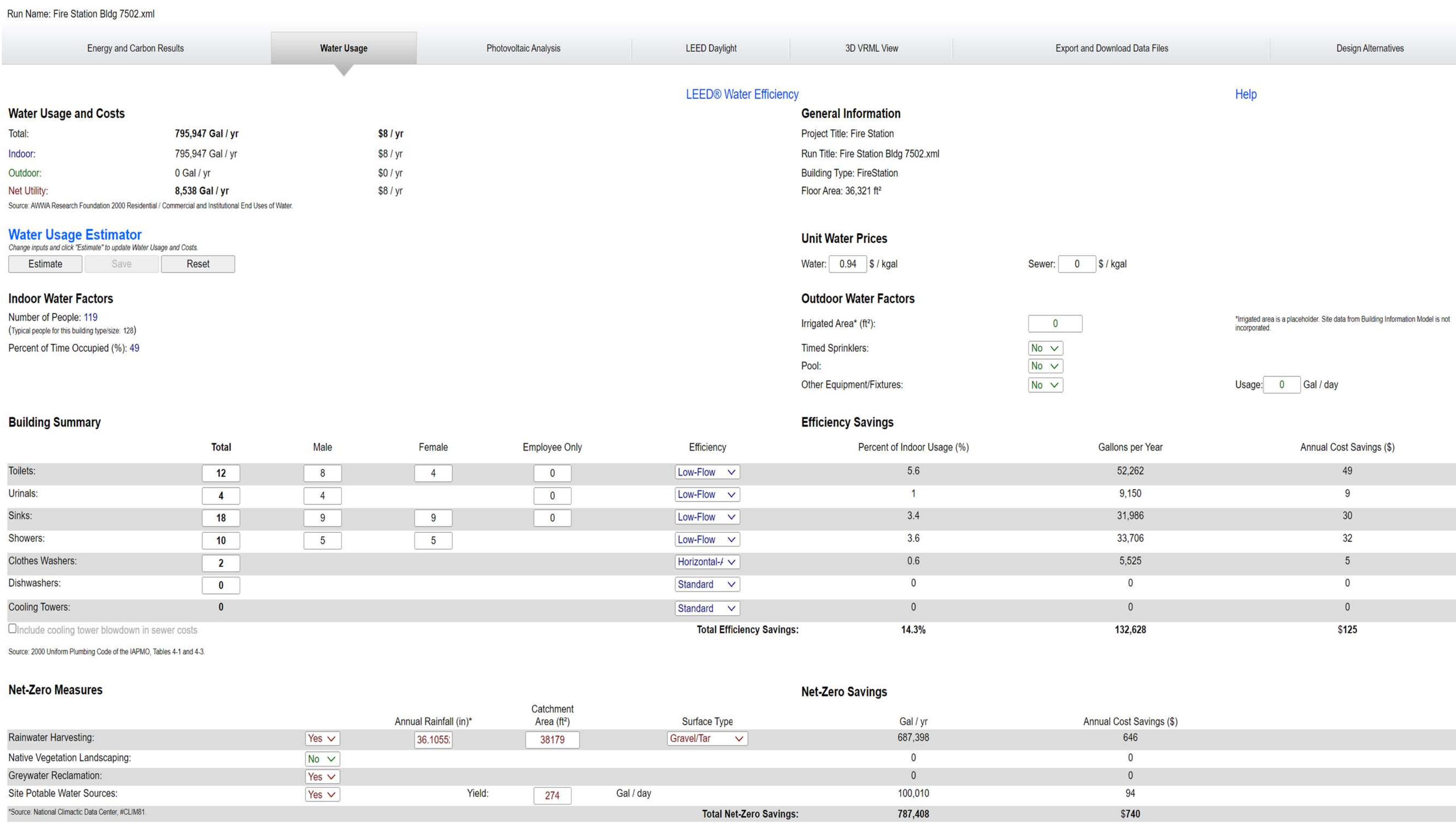


Figure 71: Green Building Studio Results for Fire Station at Wright-Patterson AFB, OH

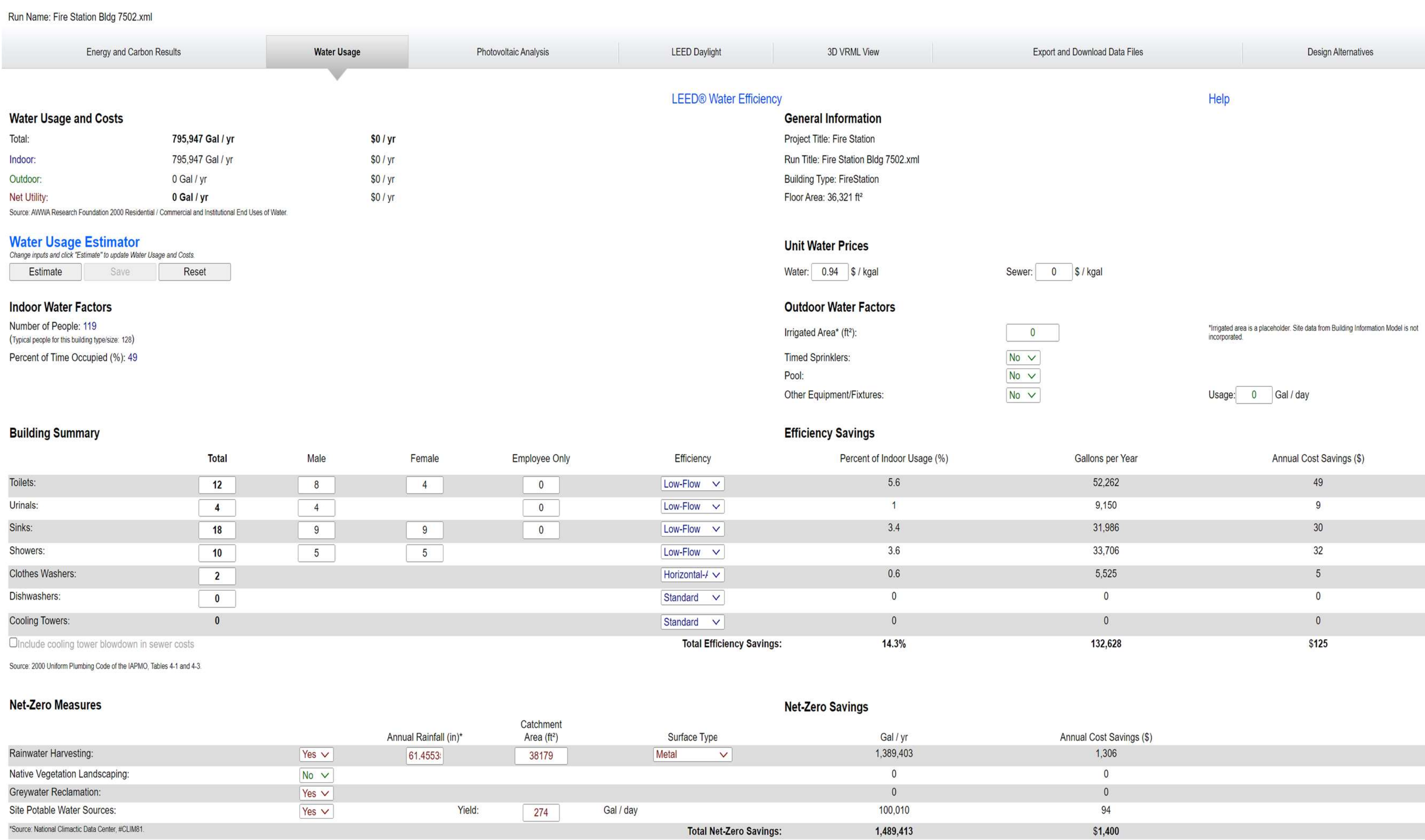
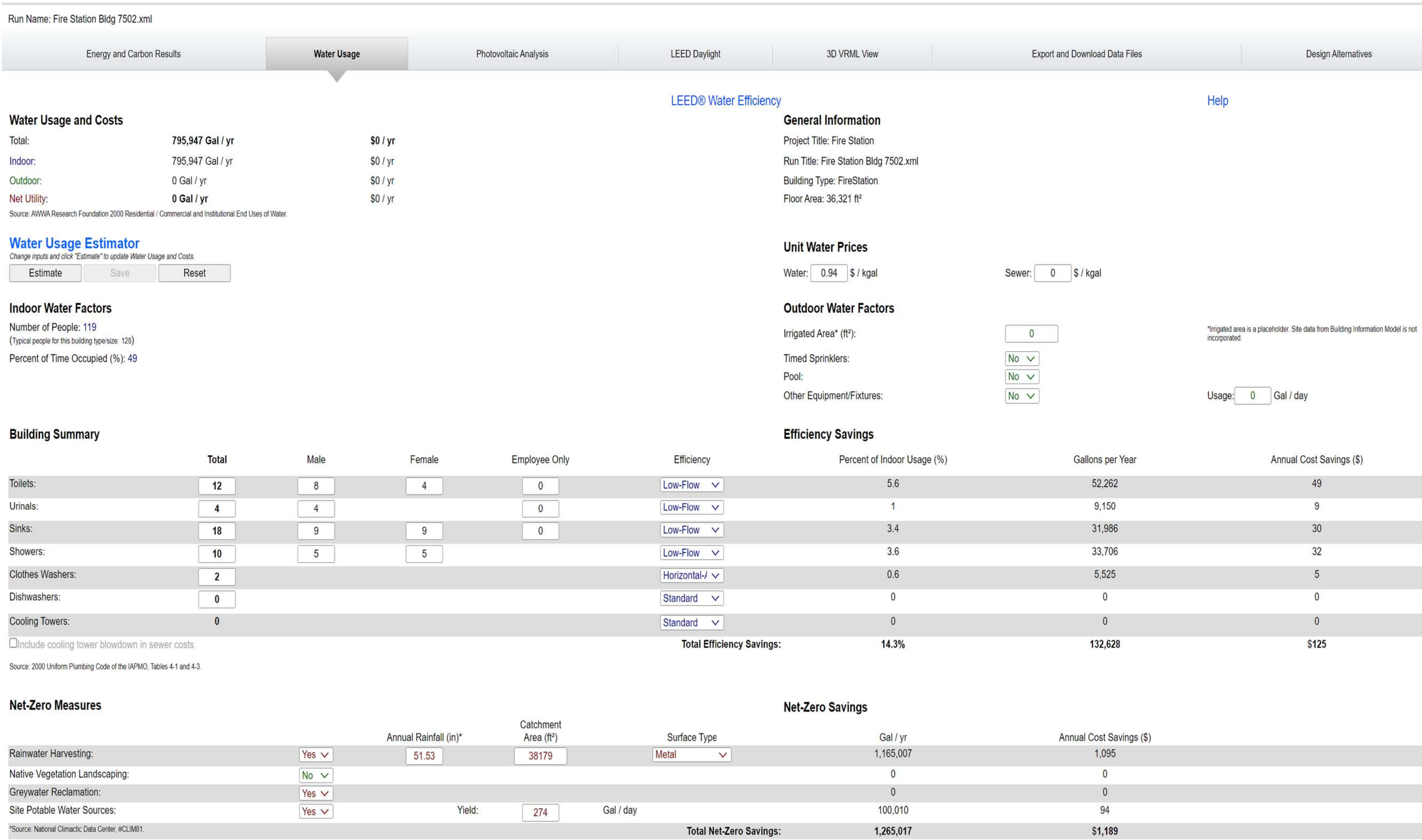


Figure 72: Green Building Studio Results for Fire Station at Eglin AFB, FL



Run Name: Fire Station Bldg 7502.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency   Help

Water Usage and Costs

Total:	795,947 Gal / yr	$0 / yr
Indoor:	795,947 Gal / yr	$0 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	0 Gal / yr	$0 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Fire Station
Run Title: Fire Station Bldg 7502.xml
Building Type: FireStation
Floor Area: 36,321 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 119
(Typical people for this building type/size: 128)
Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0
Timed Sprinklers: No
Pool: No
Other Equipment/Fixtures: No   Usage: 0 Gal / day

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Building Summary / **Efficiency Savings**

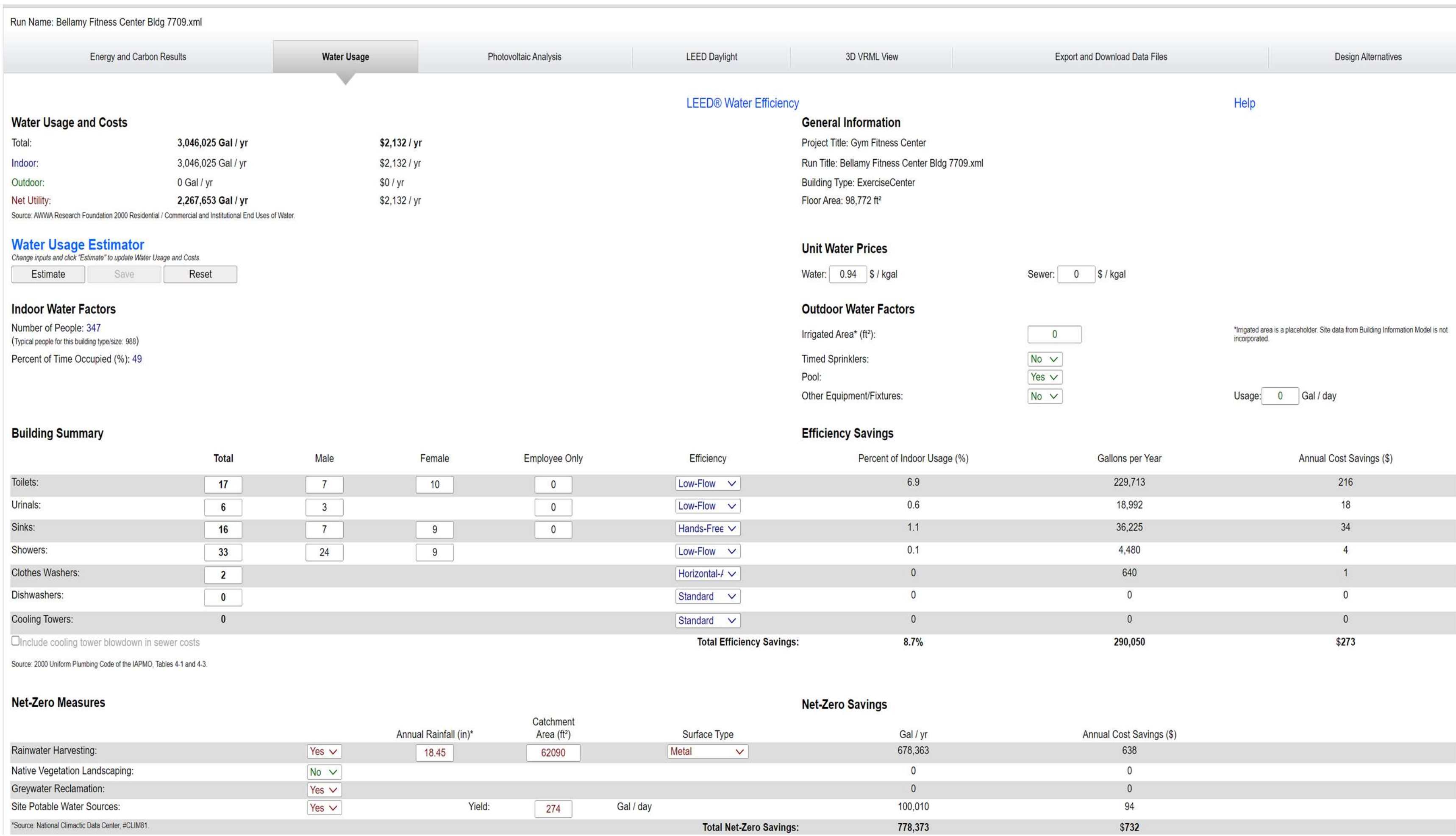
	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	12	8	4	0	Low-Flow	5.6	52,262	49
Urinals:	4	4		0	Low-Flow	1	9,150	9
Sinks:	18	9	9	0	Low-Flow	3.4	31,986	30
Showers:	10	5	5		Low-Flow	3.6	33,706	32
Clothes Washers:	2				Horizontal-A	0.6	5,525	5
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐ Include cooling tower blowdown in sewer costs					Total Efficiency Savings:	14.3%	132,628	$125

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	51.53	38179	Metal	1,165,007	1,095
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				Total Net-Zero Savings:	1,265,017	$1,189

Figure 73: Green Building Studio Results for Fire Station at JB Charleston, SC



Run Name: Bellamy Fitness Center Bldg 7709.xml

Energy and Carbon Results | **Water Usage** | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency　　Help

Water Usage and Costs

Total:	**3,046,025 Gal / yr**	**$2,132 / yr**
Indoor:	3,046,025 Gal / yr	$2,132 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**2,267,653 Gal / yr**	$2,132 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Gym Fitness Center
Run Title: Bellamy Fitness Center Bldg 7709.xml
Building Type: ExerciseCenter
Floor Area: 98,772 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal　　Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 347
(Typical people for this building type/size: 988)
Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0
Timed Sprinklers: No
Pool: Yes
Other Equipment/Fixtures: No　　Usage: 0 Gal / day

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	17	7	10	0	Low-Flow	6.9	229,713	216
Urinals:	6	3		0	Low-Flow	0.6	18,992	18
Sinks:	16	7	9	0	Hands-Free	1.1	36,225	34
Showers:	33	24	9		Low-Flow	0.1	4,480	4
Clothes Washers:	2				Horizontal-A	0	640	1
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**8.7%**	**290,050**	**$273**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	62090	Metal	678,363	638
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**778,373**	**$732**

Figure 74: Green Building Studio Results for Fitness Center at Ellsworth AFB, SD

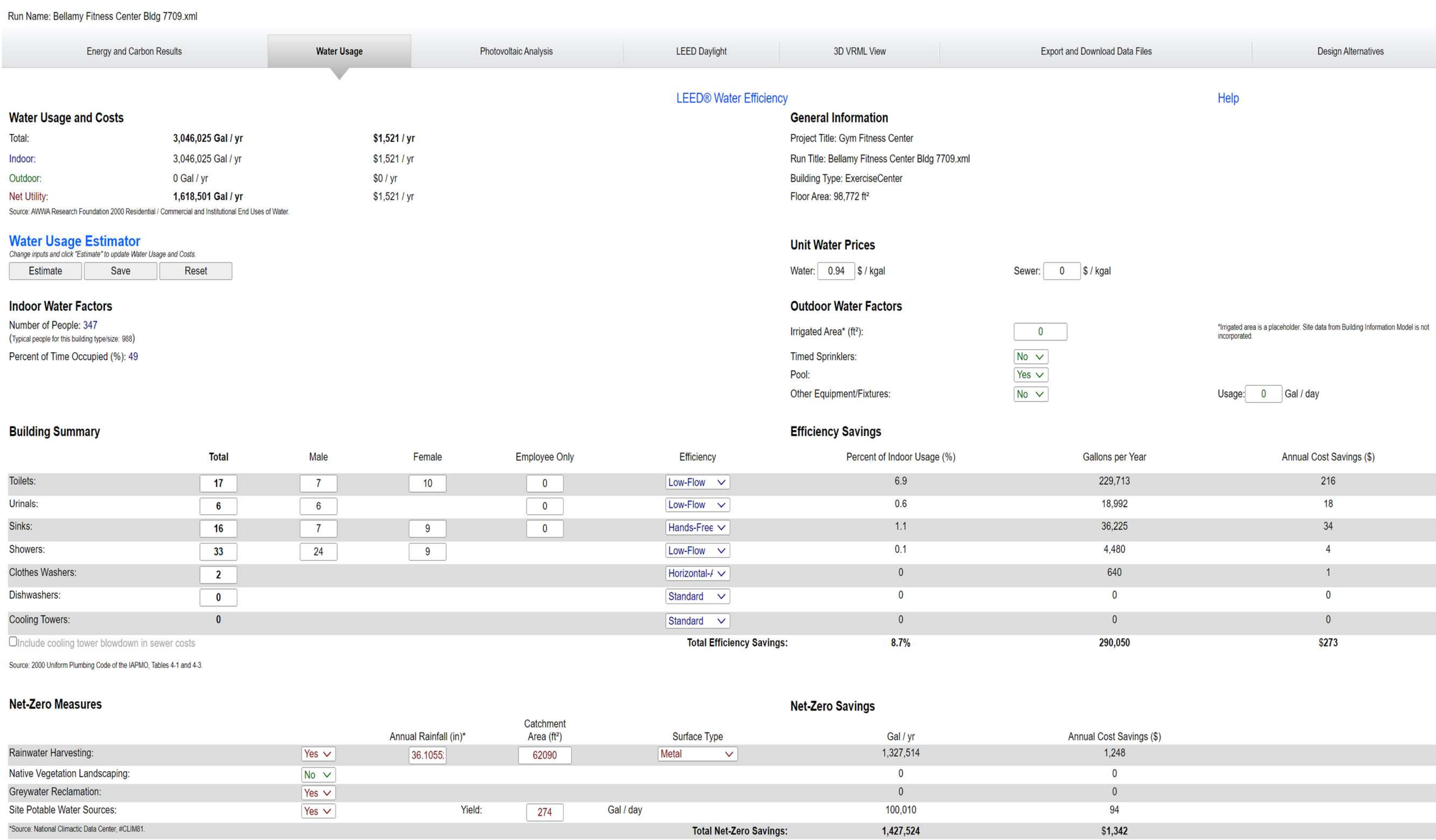


Figure 75: Green Building Studio Results for Fitness Center at Wright-Patterson AFB, OH

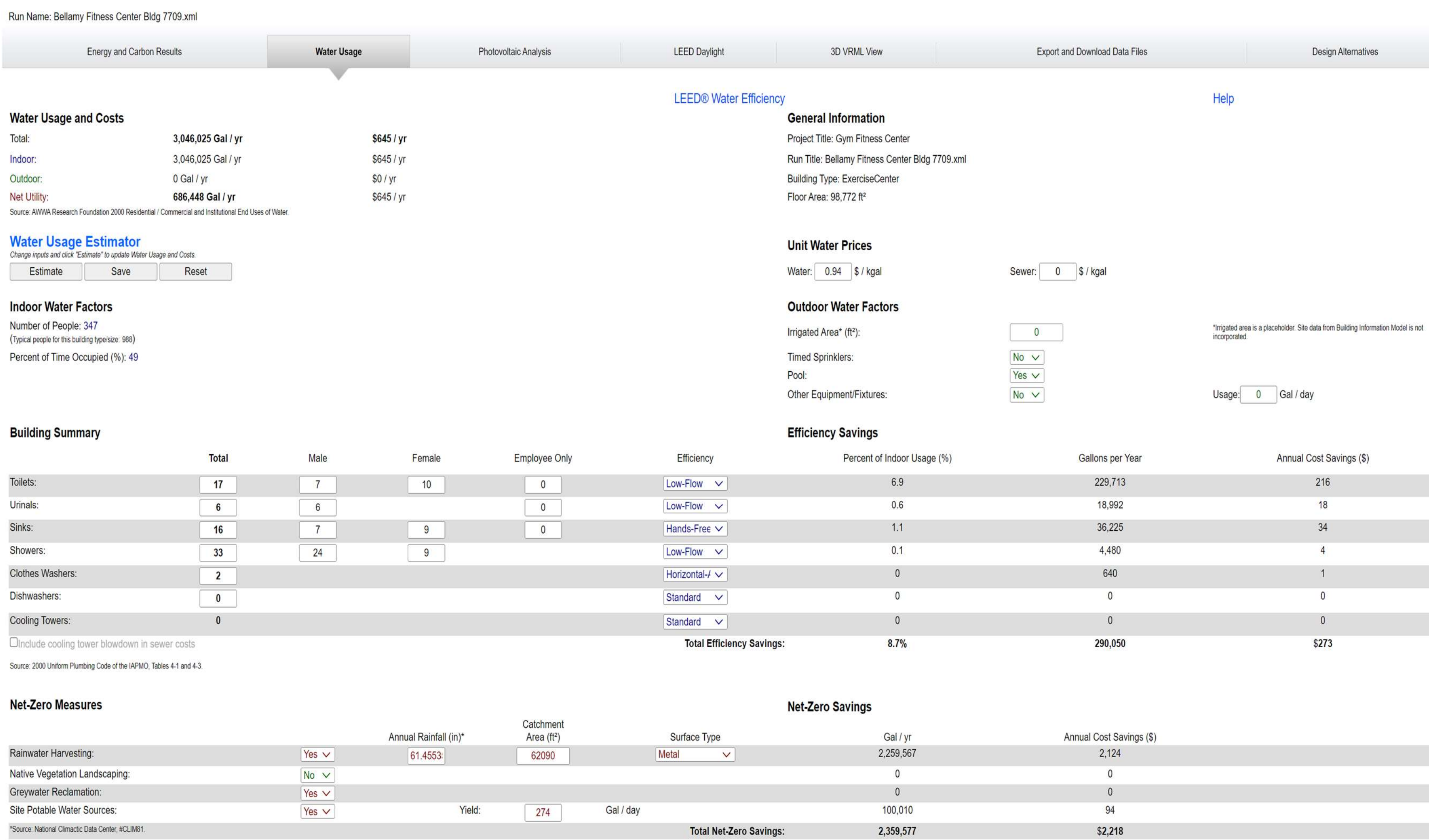


Figure 76: Green Building Studio Results for Fitness Center at Eglin AFB, FL

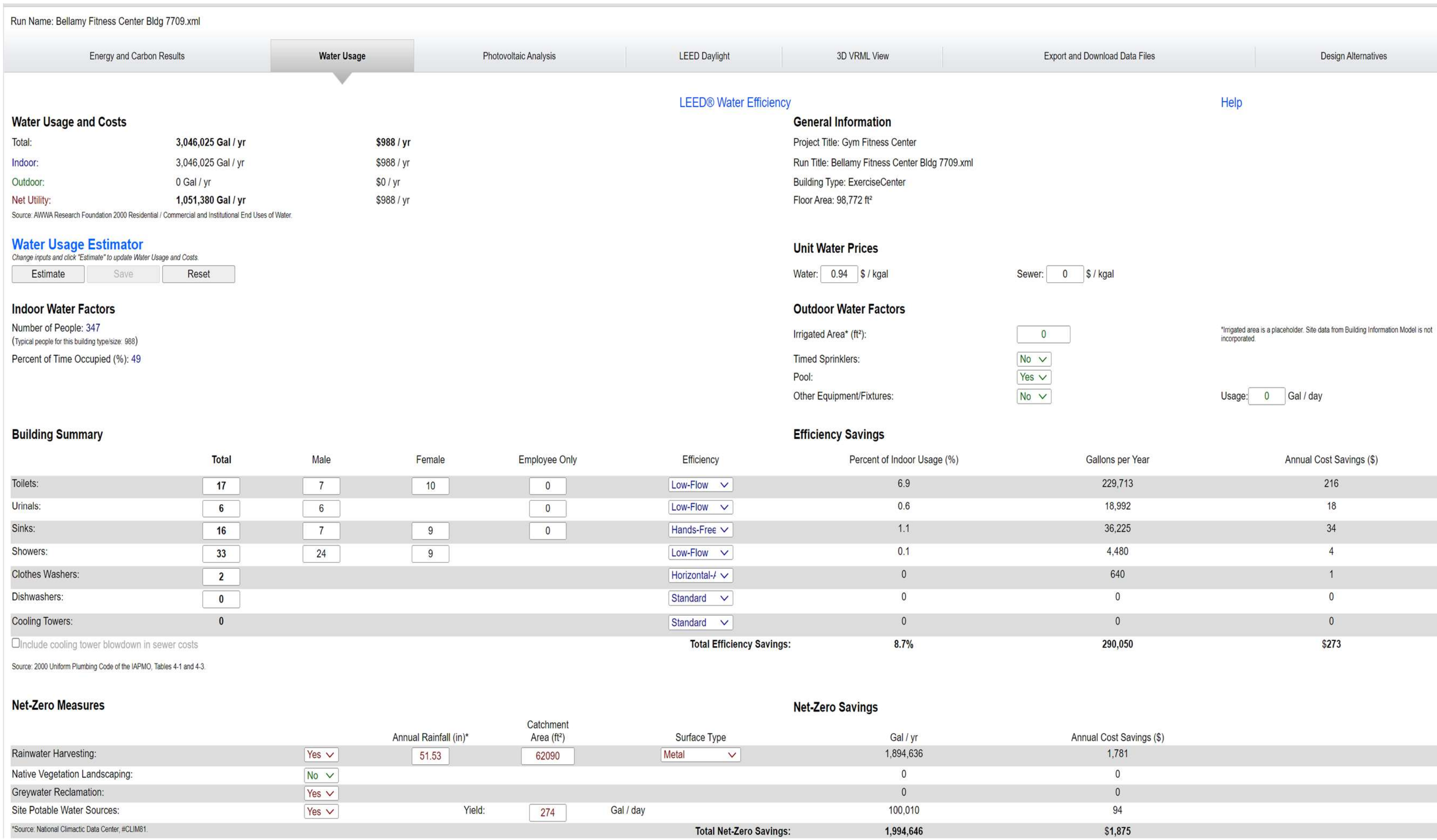
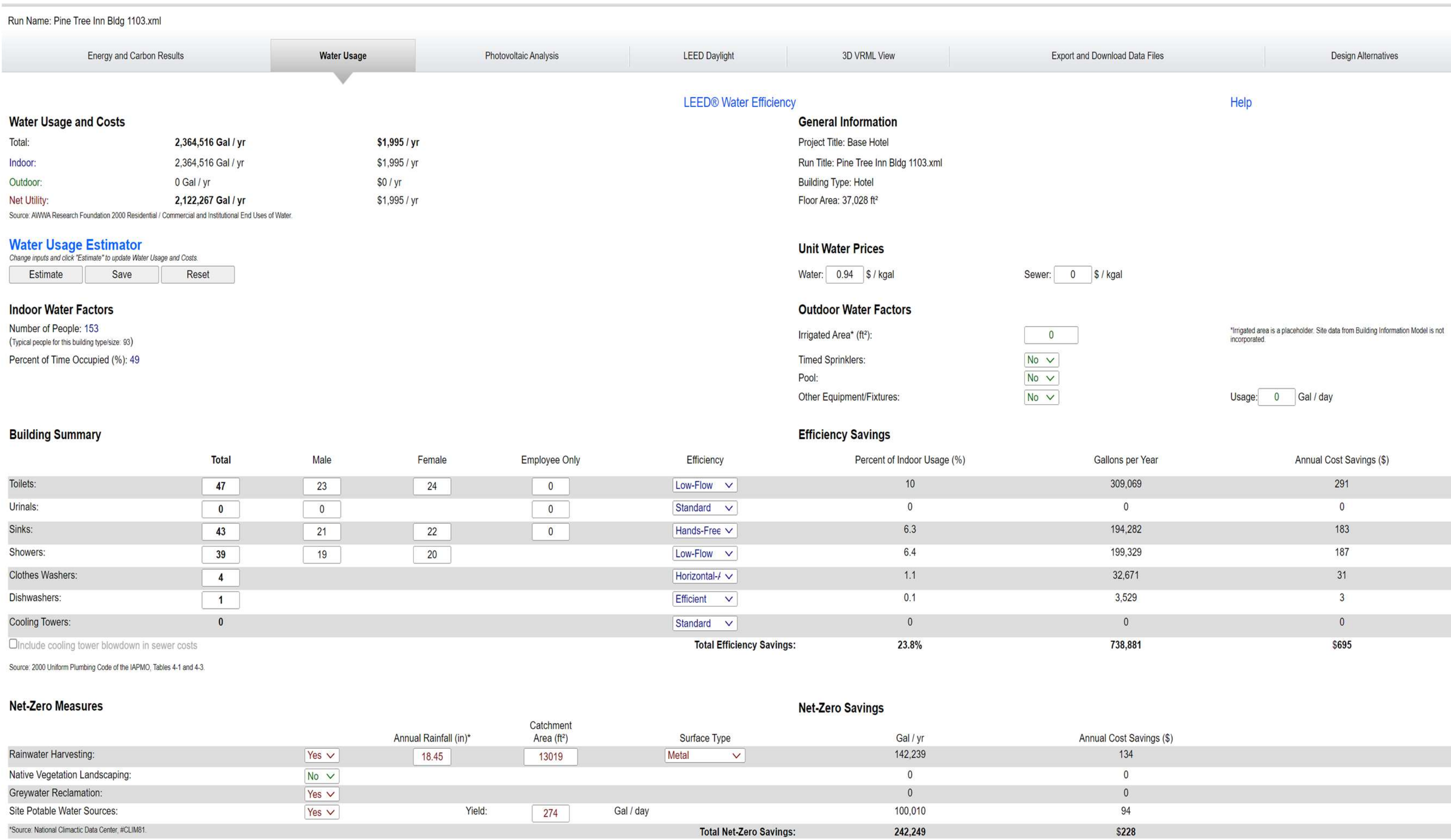


Figure 77: Green Building Studio Results for Fitness Center at JB Charleston, SC



Run Name: Pine Tree Inn Bldg 1103.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

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Water Usage and Costs

Total:	**2,364,516 Gal / yr**	**$1,995 / yr**
Indoor:	2,364,516 Gal / yr	$1,995 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**2,122,267 Gal / yr**	$1,995 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Base Hotel

Run Title: Pine Tree Inn Bldg 1103.xml

Building Type: Hotel

Floor Area: 37,028 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 153

(Typical people for this building type/size: 93)

Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	47	23	24	0	Low-Flow	10	309,069	291
Urinals:	0	0		0	Standard	0	0	0
Sinks:	43	21	22	0	Hands-Free	6.3	194,282	183
Showers:	39	19	20		Low-Flow	6.4	199,329	187
Clothes Washers:	4				Horizontal-A	1.1	32,671	31
Dishwashers:	1				Efficient	0.1	3,529	3
Cooling Towers:	0				Standard	0	0	0
					Total Efficiency Savings:	**23.8%**	**738,881**	**$695**

☐ Include cooling tower blowdown in sewer costs

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	13019	Metal	142,239	134
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
				Total Net-Zero Savings:	**242,249**	**$228**

*Source: National Climactic Data Center, #CLIM81.

Figure 78: Green Building Studio Results for Hotel at Ellsworth AFB, SD

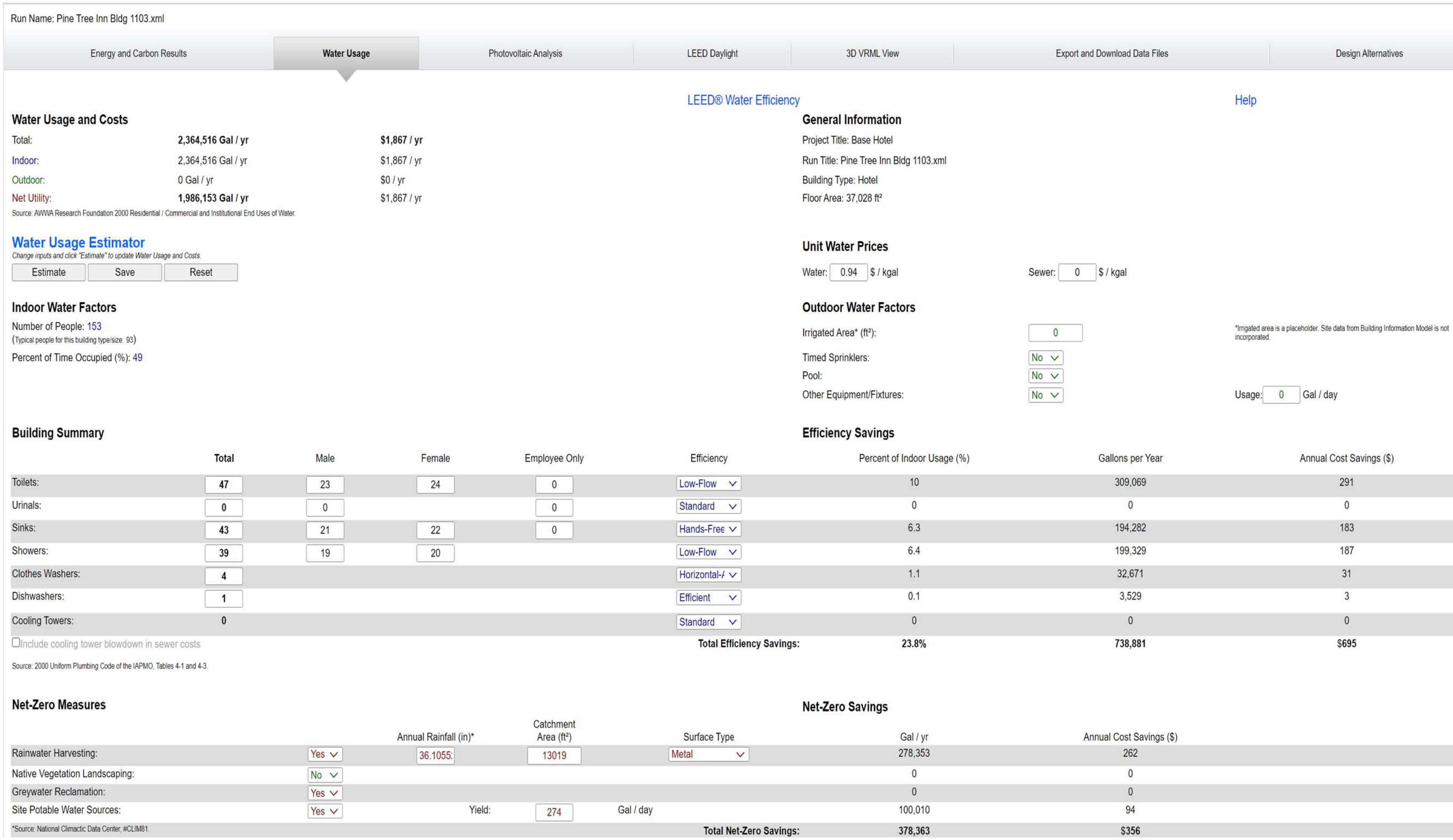
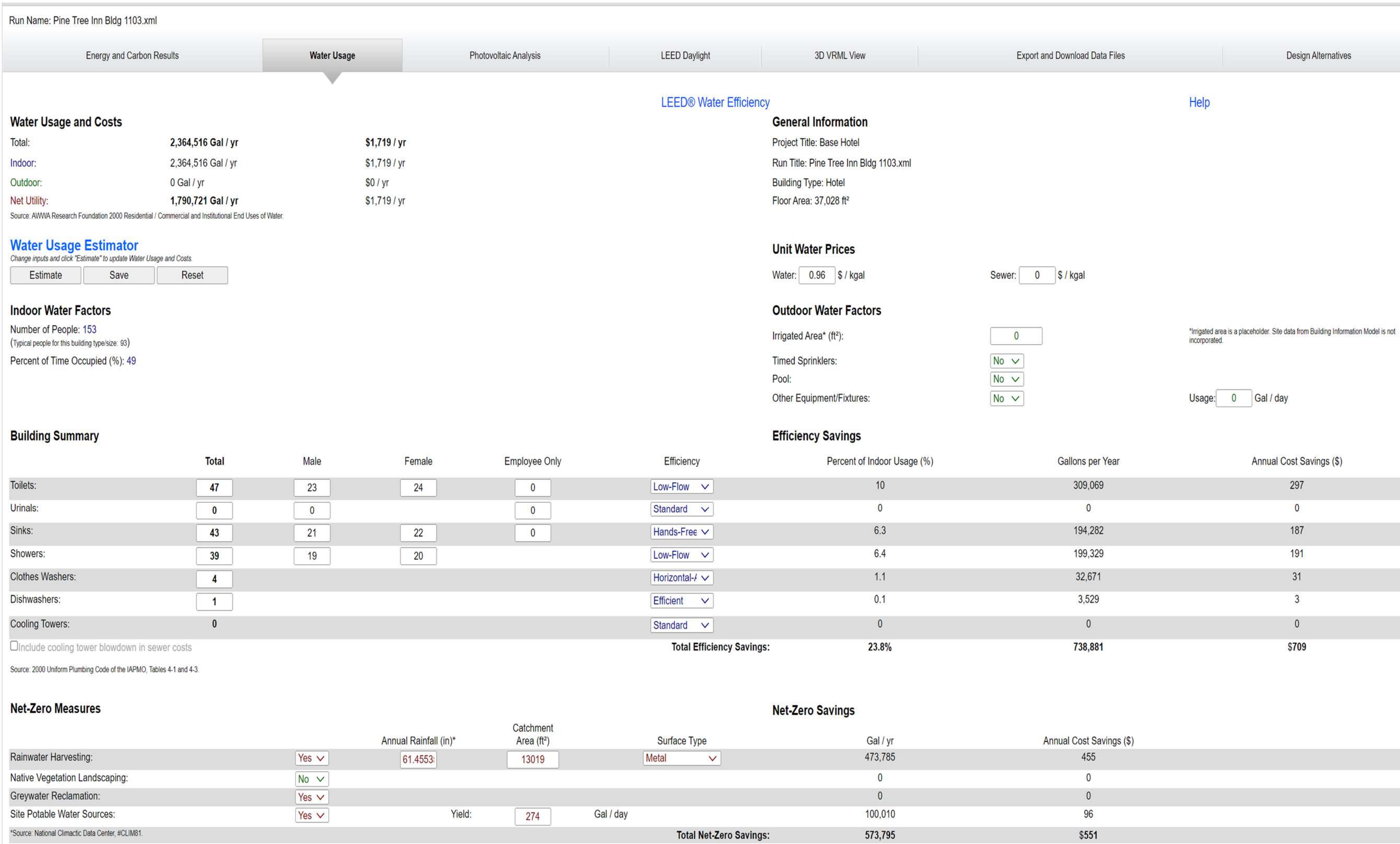


Figure 79: Green Building Studio Results for Hotel at Wright-Patterson AFB, OH



Run Name: Pine Tree Inn Bldg 1103.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

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Water Usage and Costs

Total:	**2,364,516 Gal / yr**	**$1,719 / yr**
Indoor:	2,364,516 Gal / yr	$1,719 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**1,790,721 Gal / yr**	$1,719 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Base Hotel
Run Title: Pine Tree Inn Bldg 1103.xml
Building Type: Hotel
Floor Area: 37,028 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.96 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 153
(Typical people for this building type/size: 93)
Percent of Time Occupied (%): 49

Outdoor Water Factors

Irrigated Area* (ft²): 0
*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.
Timed Sprinklers: No
Pool: No
Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	47	23	24	0	Low-Flow	10	309,069	297
Urinals:	0	0		0	Standard	0	0	0
Sinks:	43	21	22	0	Hands-Free	6.3	194,282	187
Showers:	39	19	20		Low-Flow	6.4	199,329	191
Clothes Washers:	4				Horizontal-/	1.1	32,671	31
Dishwashers:	1				Efficient	0.1	3,529	3
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**23.8%**	**738,881**	**$709**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	61.4553	13019	Metal	473,785	455
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	96
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**573,795**	**$551**

Figure 80: Green Building Studio Results for Hotel at Eglin AFB, FL

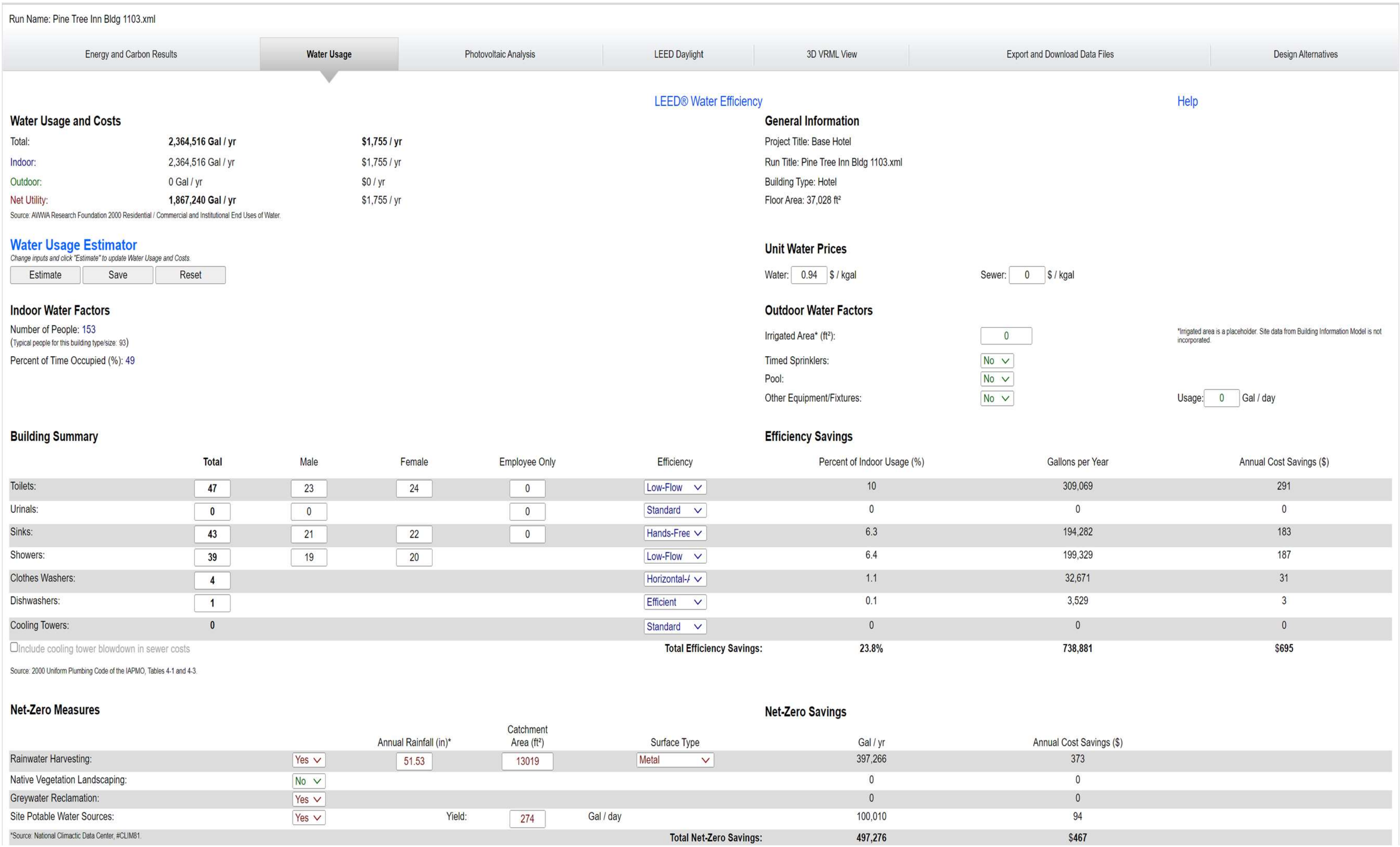


Figure 81: Green Building Studio Results for Hotel at JB Charleston, SC

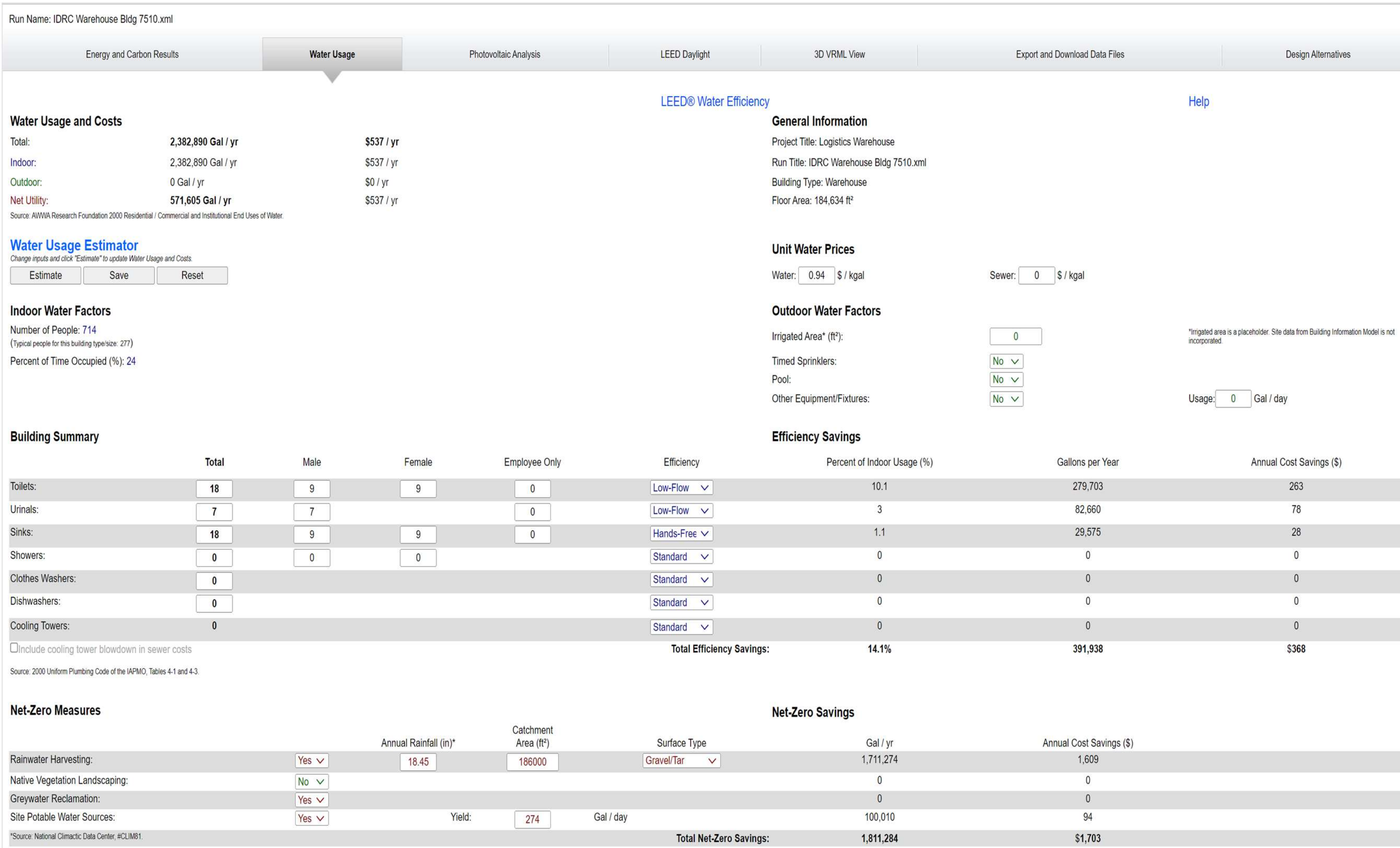


Figure 82: Green Building Studio Results for Large Warehouse (Logistics) at Ellsworth AFB, SD

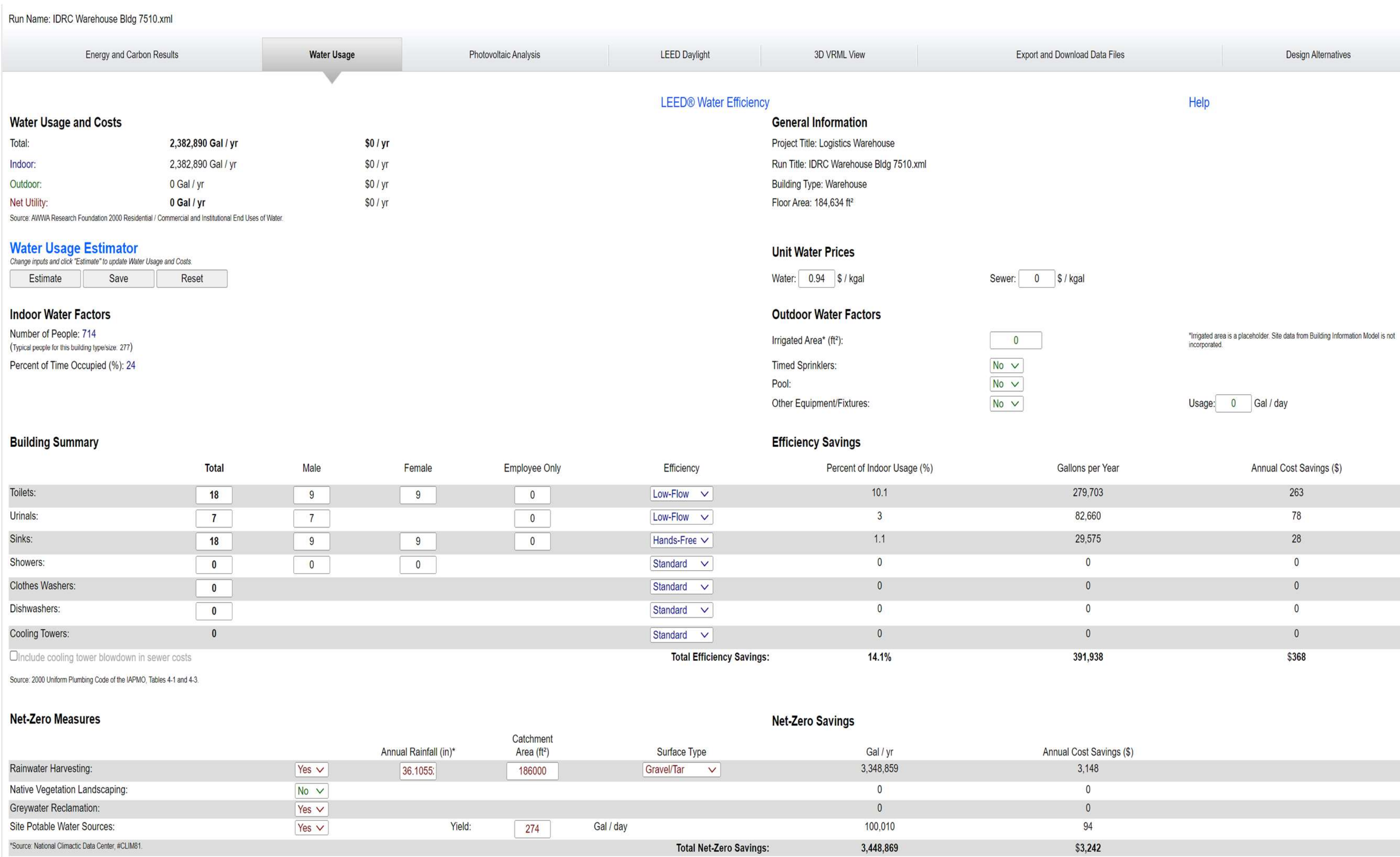


Figure 83: Green Building Studio Results for Large Warehouse (Logistics) at Wright-Patterson AFB, OH

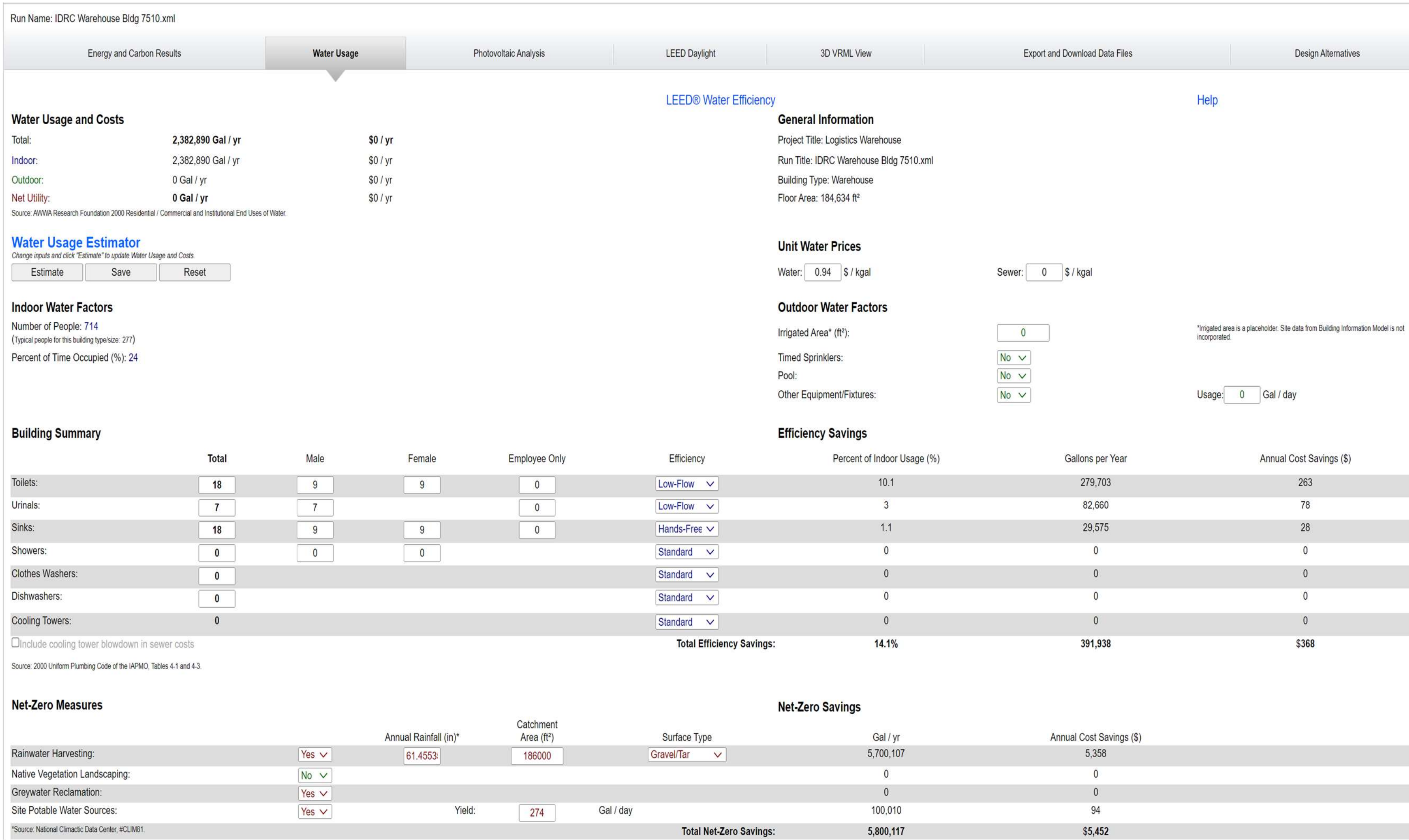


Figure 84: Green Building Studio Results for Large Warehouse (Logistics) at Eglin AFB, FL

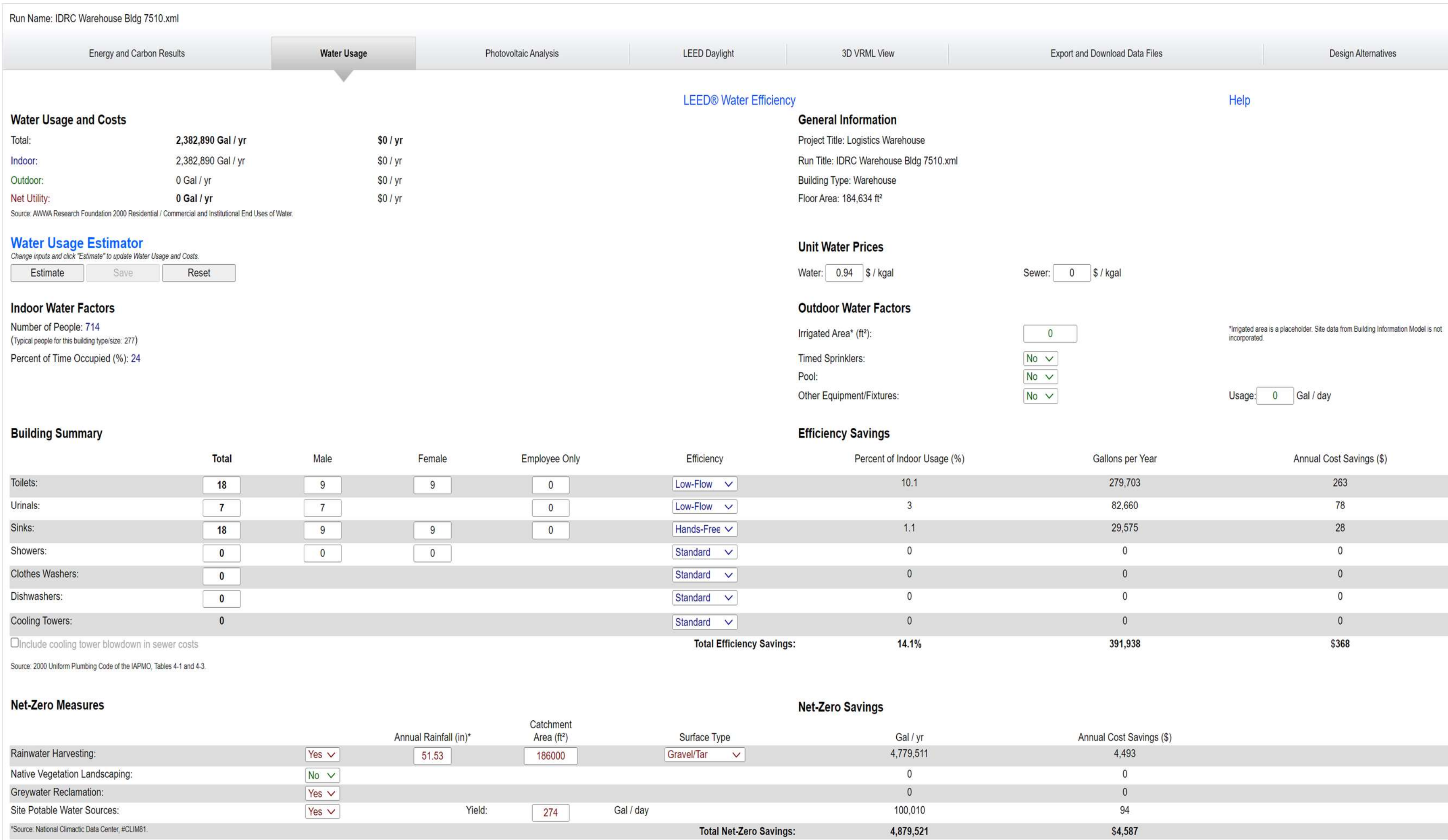


Figure 85: Green Building Studio Results for Large Warehouse (Logistics) at JB Charleston, SC

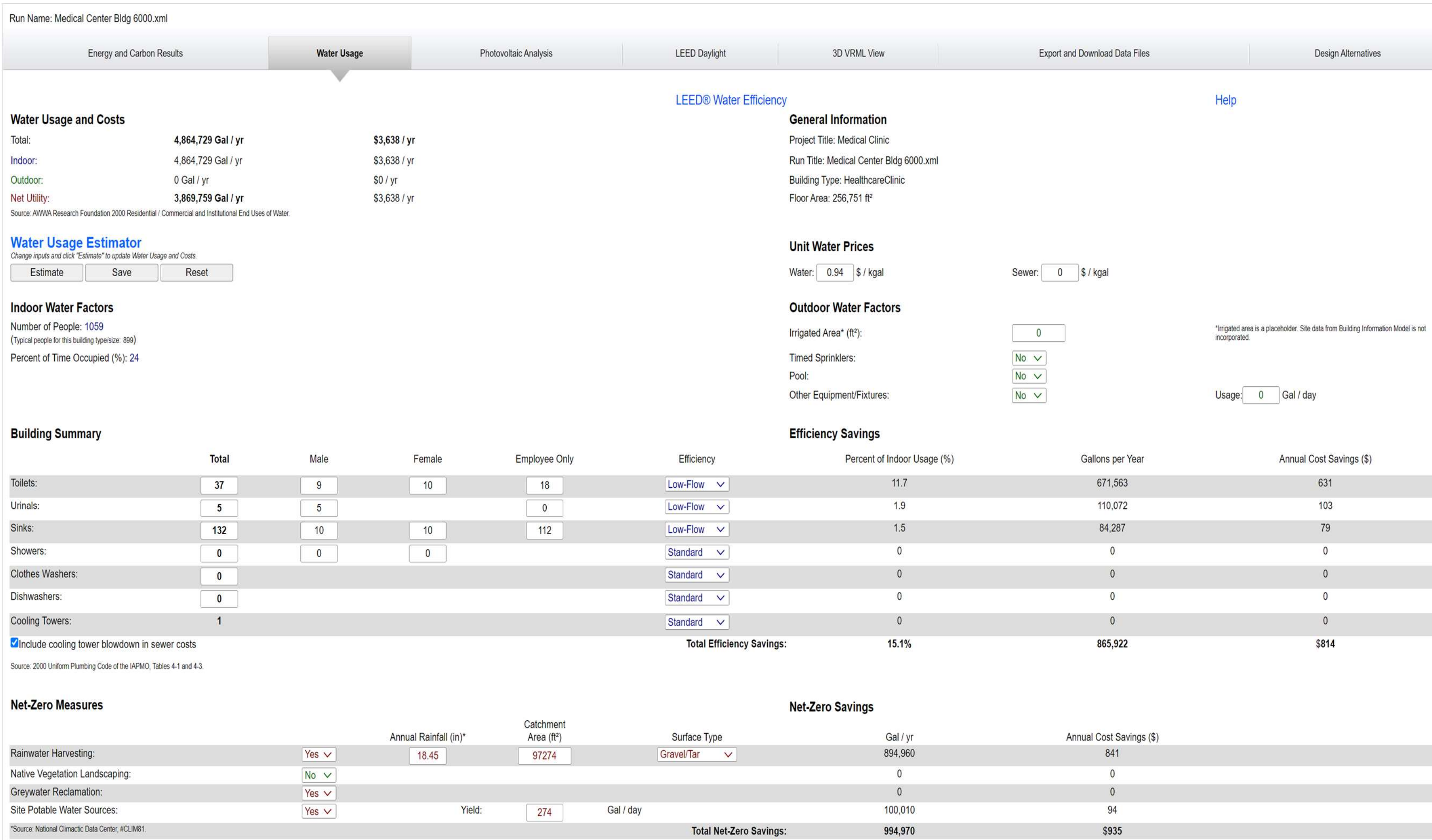
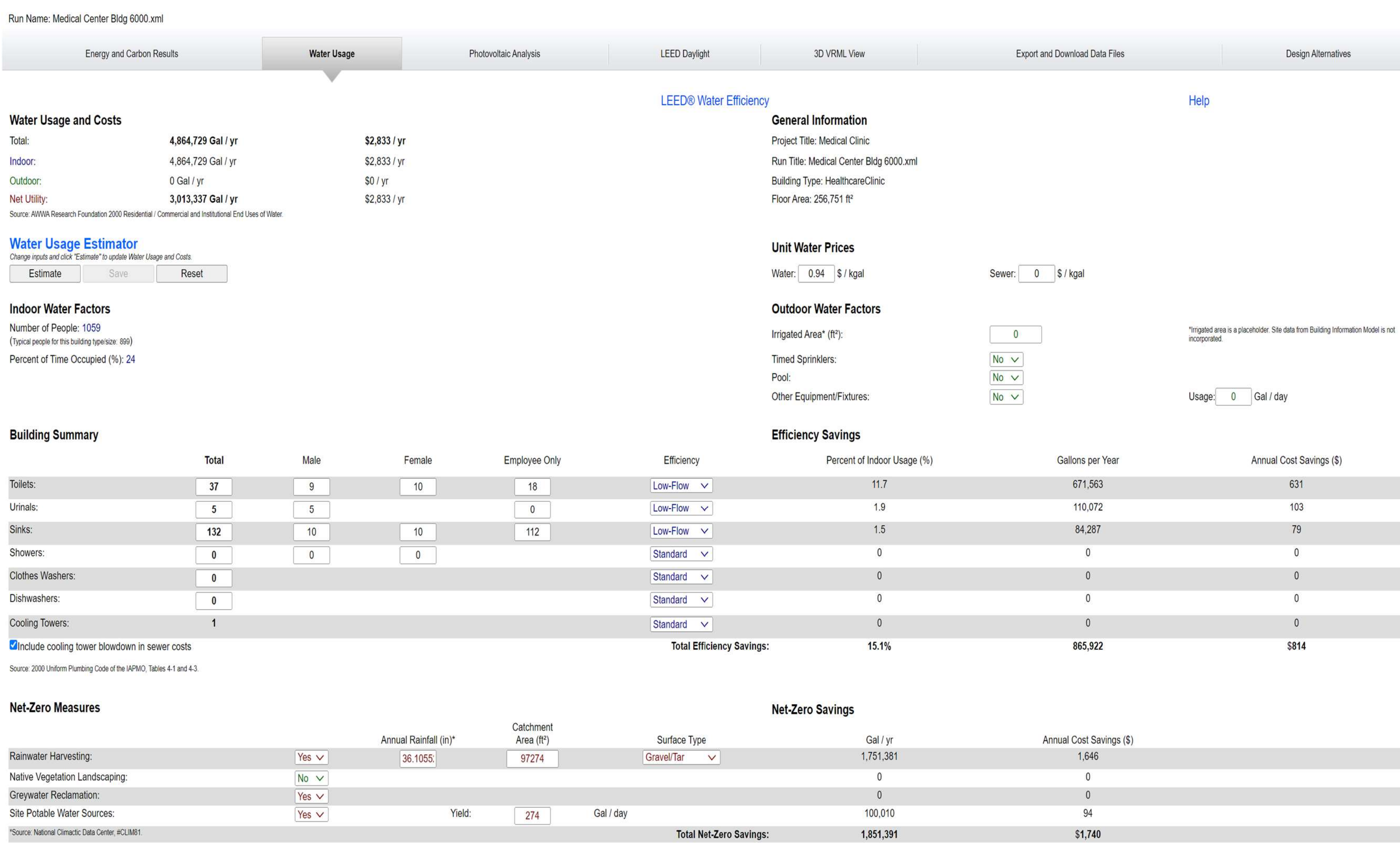


Figure 86: Green Building Studio Results for Medical Center at Ellsworth AFB, SD


Run Name: Medical Center Bldg 6000.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

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Water Usage and Costs

Total:	**4,864,729 Gal / yr**	**$2,833 / yr**
Indoor:	4,864,729 Gal / yr	$2,833 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**3,013,337 Gal / yr**	$2,833 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Medical Clinic

Run Title: Medical Center Bldg 6000.xml

Building Type: HealthcareClinic

Floor Area: 256,751 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 1059

(Typical people for this building type/size: 899)

Percent of Time Occupied (%): 24

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No   Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	37	9	10	18	Low-Flow	11.7	671,563	631
Urinals:	5	5		0	Low-Flow	1.9	110,072	103
Sinks:	132	10	10	112	Low-Flow	1.5	84,287	79
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	1				Standard	0	0	0
Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**15.1%**	**865,922**	**$814**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	36.1055	97274	Gravel/Tar	1,751,381	1,646
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**1,851,391**	**$1,740**

Figure 87: Green Building Studio Results for Medical Center at Wright-Patterson AFB, OH

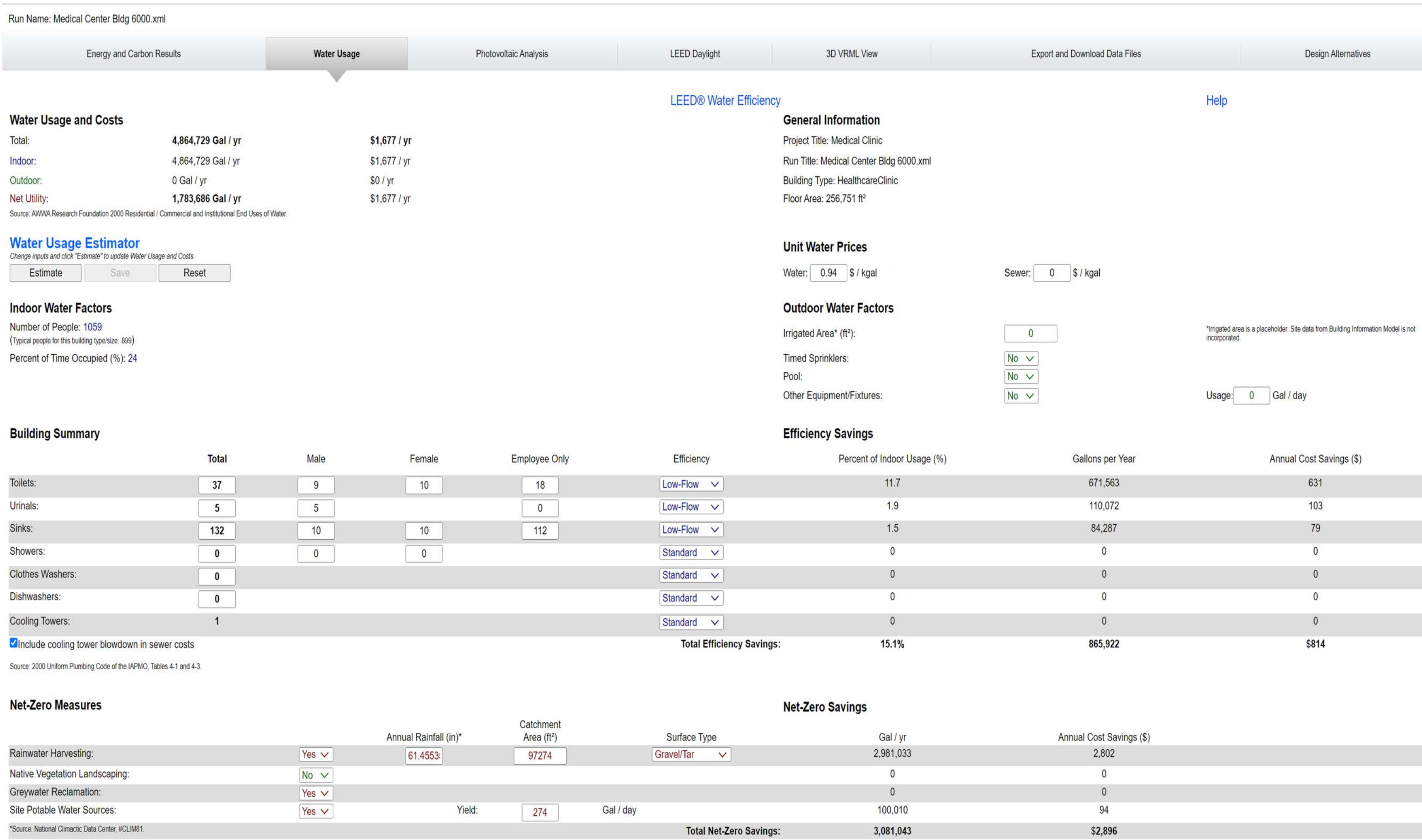


Figure 88: Green Building Studio Results for Medical Center at Eglin AFB, FL

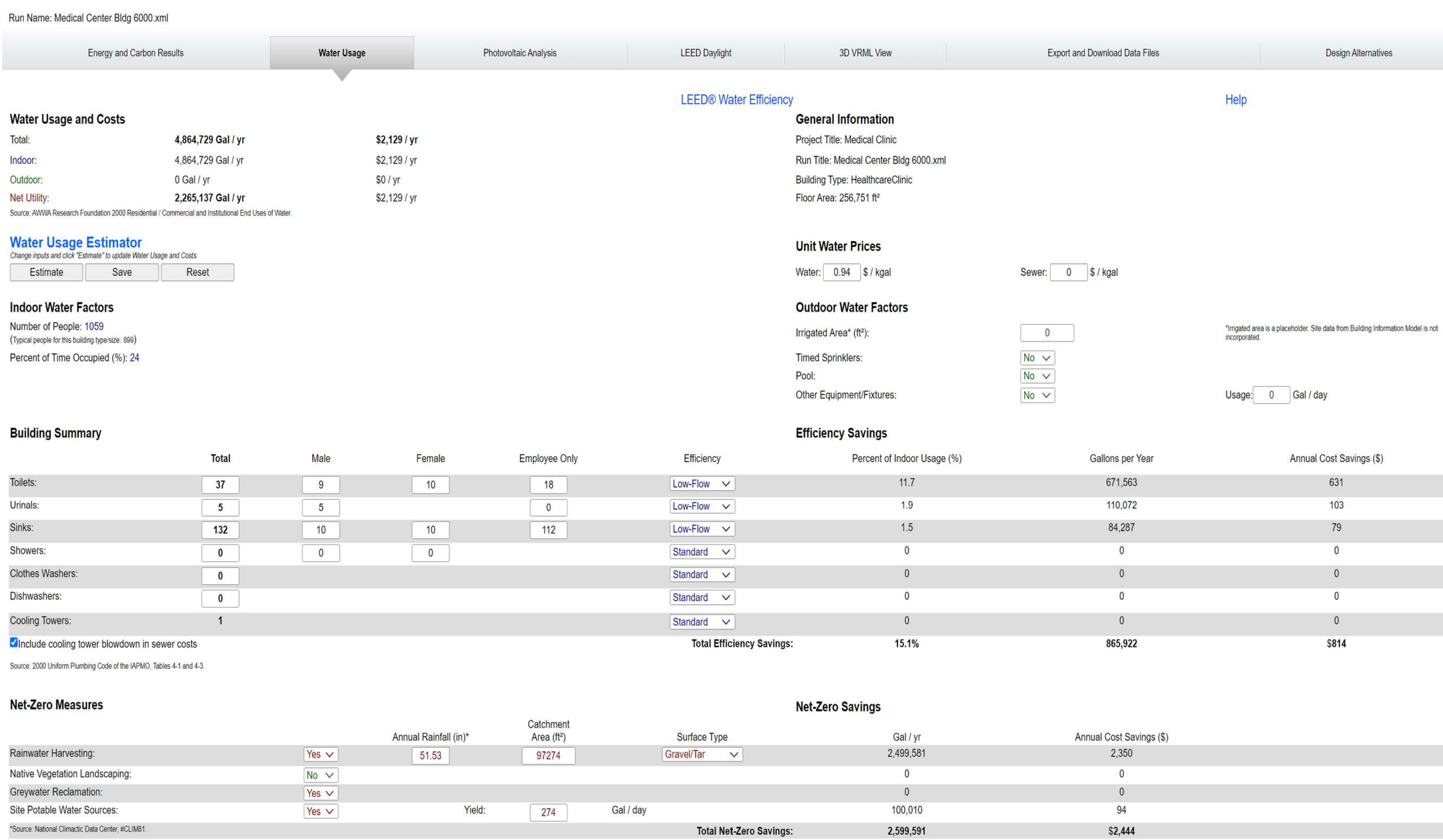
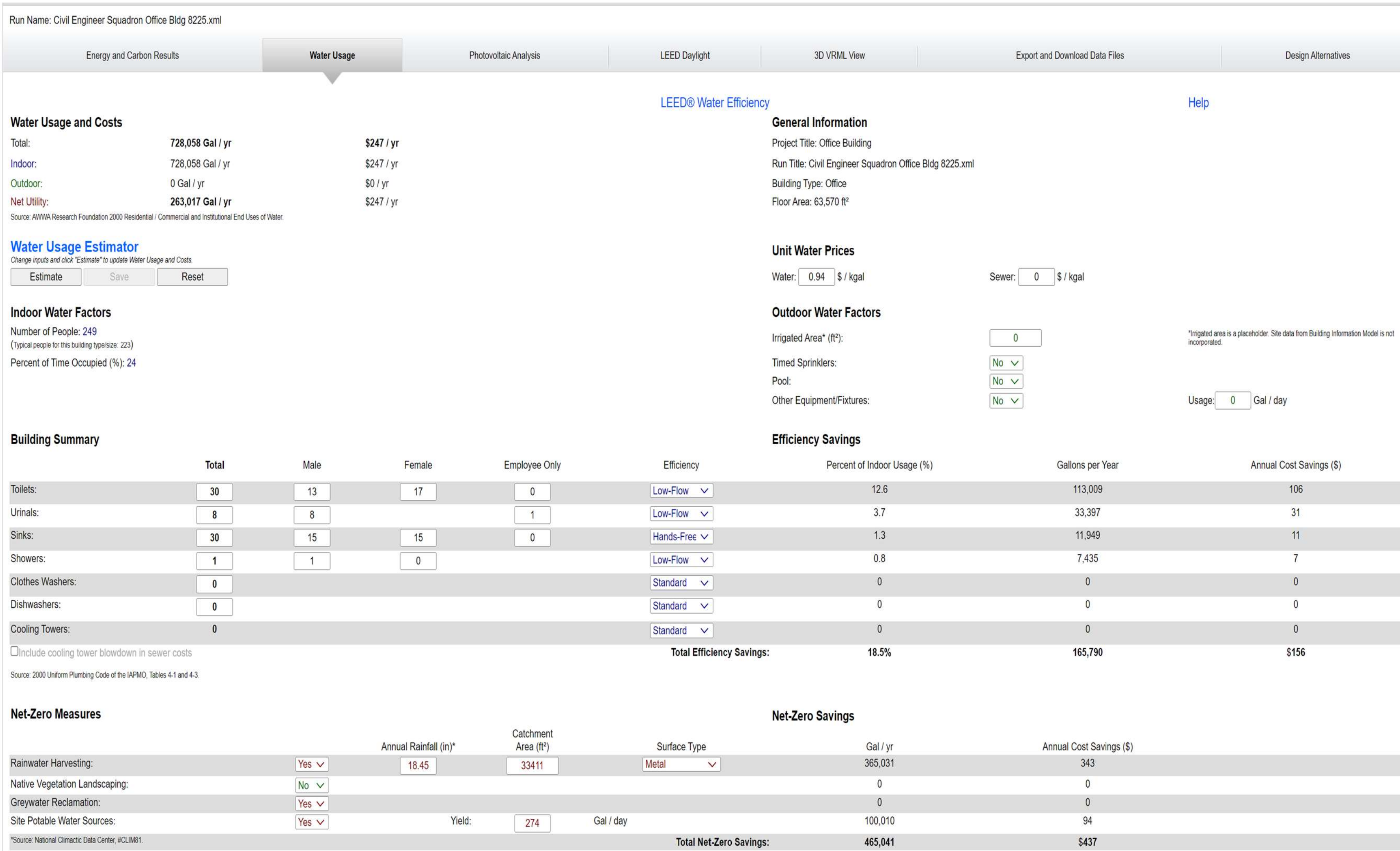


Figure 89: Green Building Studio Results for Medical Center at JB Charleston, SC



Run Name: Civil Engineer Squadron Office Bldg 8225.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

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Water Usage and Costs

Total:	**728,058 Gal / yr**	**$247 / yr**
Indoor:	728,058 Gal / yr	$247 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**263,017 Gal / yr**	$247 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Office Building

Run Title: Civil Engineer Squadron Office Bldg 8225.xml

Building Type: Office

Floor Area: 63,570 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal   Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 249

(Typical people for this building type/size: 223)

Percent of Time Occupied (%): 24

Outdoor Water Factors

Irrigated Area* (ft²):	0	*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.
Timed Sprinklers:	No	
Pool:	No	
Other Equipment/Fixtures:	No	Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	30	13	17	0	Low-Flow	12.6	113,009	106
Urinals:	8	8		1	Low-Flow	3.7	33,397	31
Sinks:	30	15	15	0	Hands-Free	1.3	11,949	11
Showers:	1	1	0		Low-Flow	0.8	7,435	7
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
☐Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**18.5%**	**165,790**	**$156**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)	Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	33411	Metal	365,031	343
Native Vegetation Landscaping:	No				0	0
Greywater Reclamation:	Yes				0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day	100,010	94
*Source: National Climactic Data Center, #CLIM81.				**Total Net-Zero Savings:**	**465,041**	**$437**

Figure 90: Green Building Studio Results for Office Building at Ellsworth AFB, SD

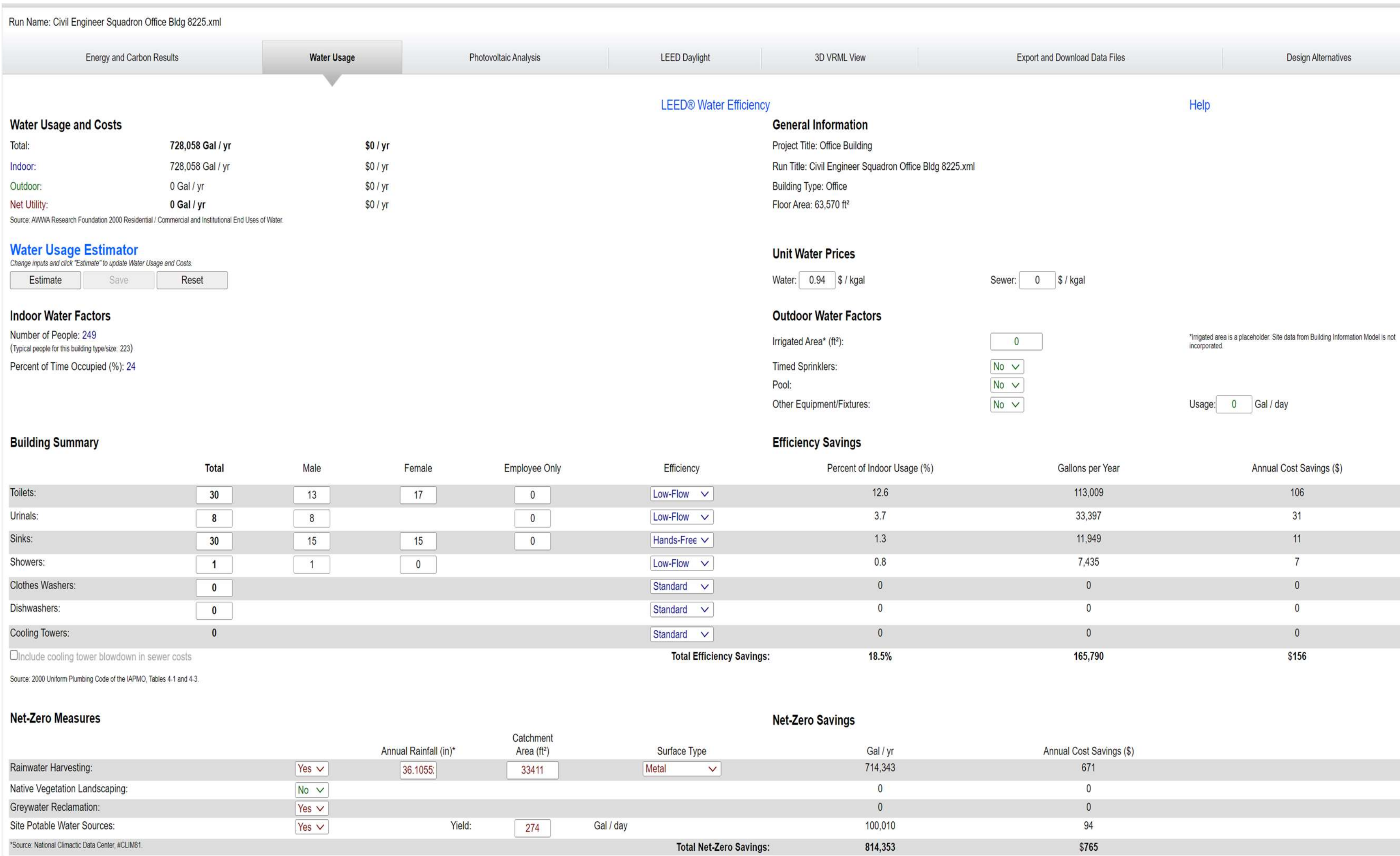


Figure 91: Green Building Studio Results for Office Building at Wright-Patterson AFB, OH

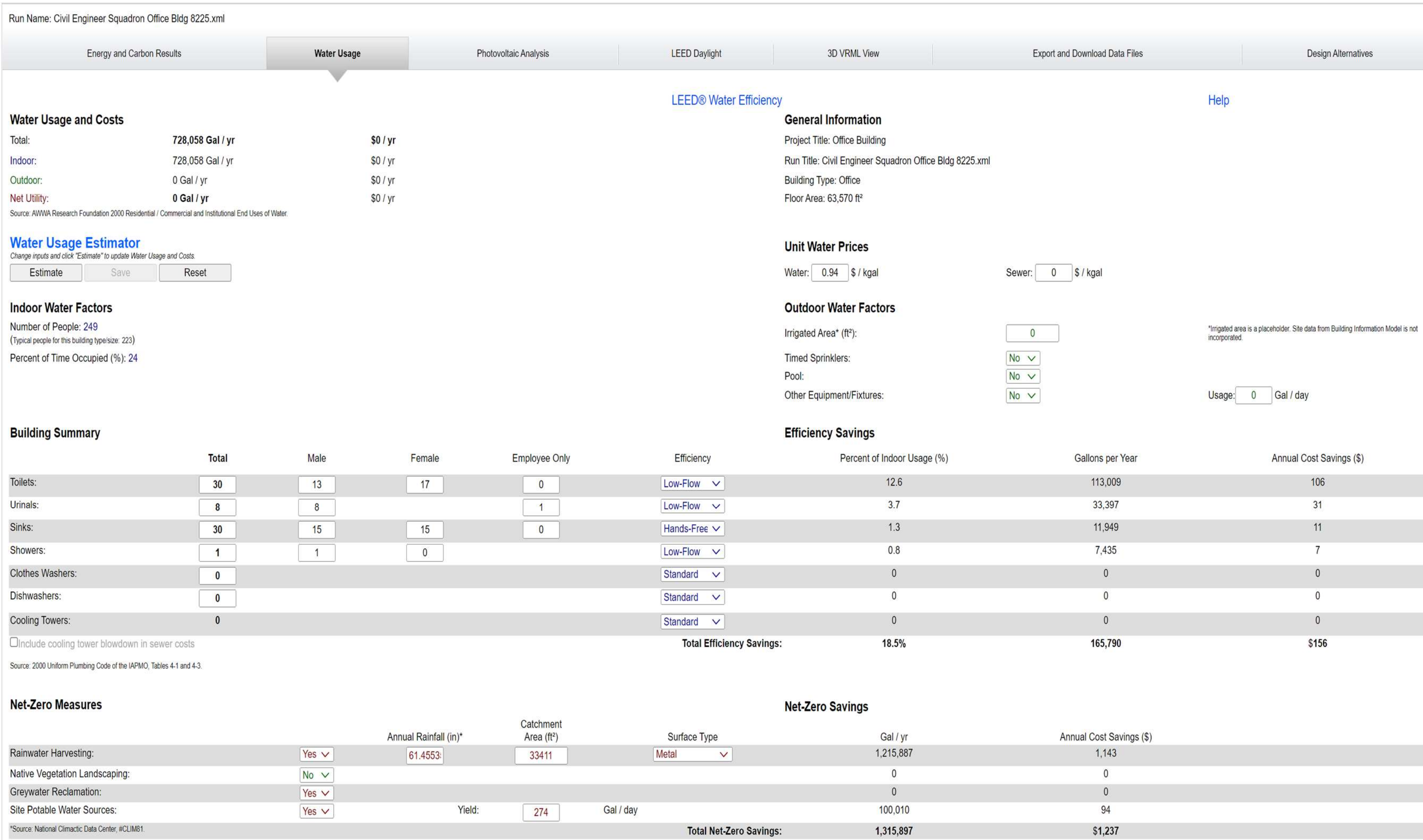


Figure 92: Green Building Studio Results for Office Building at Eglin AFB, FL

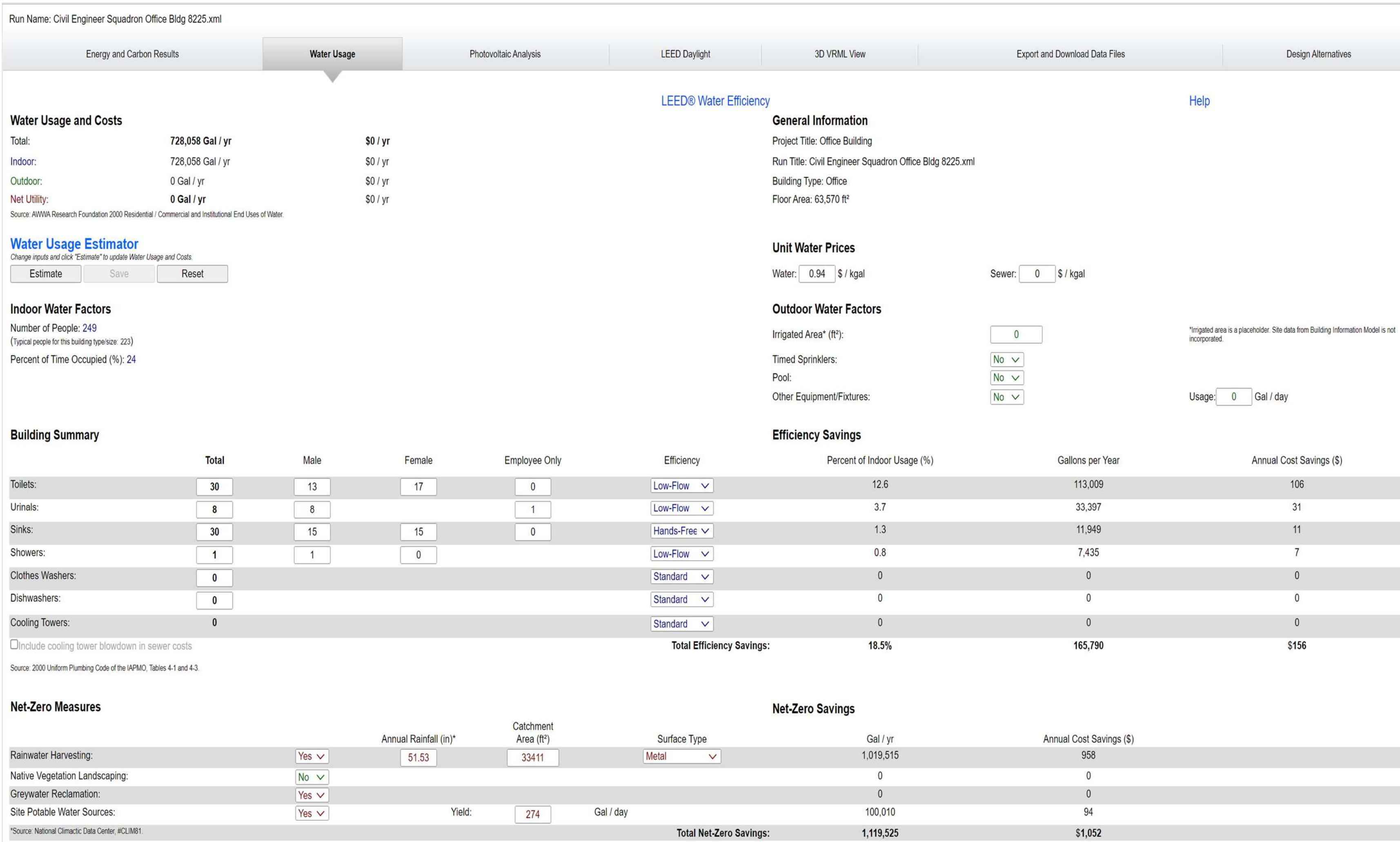
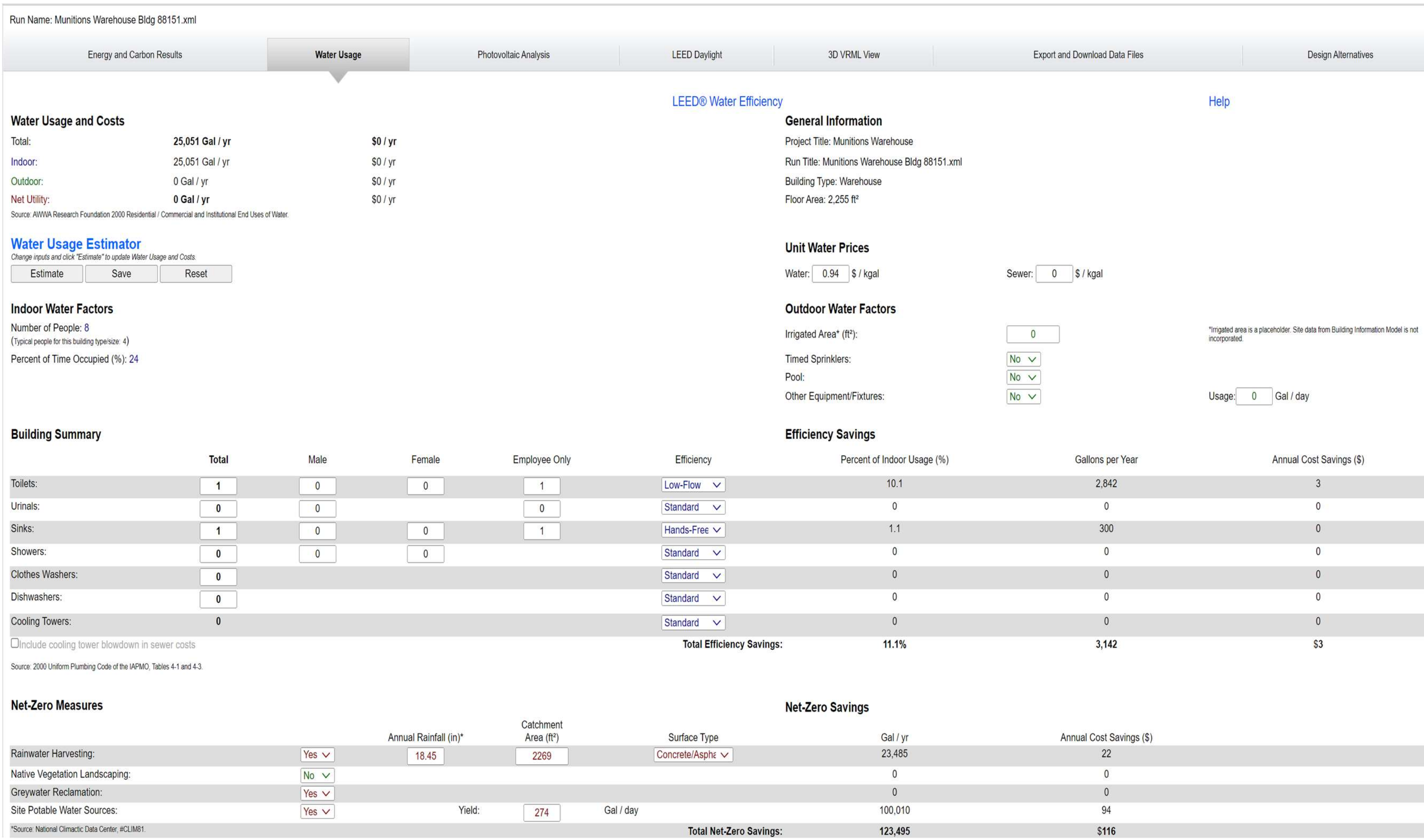


Figure 93: Green Building Studio Results for Office Building at JB Charleston, SC



Run Name: Munitions Warehouse Bldg 88151.xml

Energy and Carbon Results | Water Usage | Photovoltaic Analysis | LEED Daylight | 3D VRML View | Export and Download Data Files | Design Alternatives

LEED® Water Efficiency

Help

Water Usage and Costs

Total:	**25,051 Gal / yr**	**$0 / yr**
Indoor:	25,051 Gal / yr	$0 / yr
Outdoor:	0 Gal / yr	$0 / yr
Net Utility:	**0 Gal / yr**	$0 / yr

Source: AWWA Research Foundation 2000 Residential / Commercial and Institutional End Uses of Water.

General Information

Project Title: Munitions Warehouse

Run Title: Munitions Warehouse Bldg 88151.xml

Building Type: Warehouse

Floor Area: 2,255 ft²

Water Usage Estimator

Change inputs and click "Estimate" to update Water Usage and Costs.

Estimate | Save | Reset

Unit Water Prices

Water: 0.94 $ / kgal Sewer: 0 $ / kgal

Indoor Water Factors

Number of People: 8

(Typical people for this building type/size: 4)

Percent of Time Occupied (%): 24

Outdoor Water Factors

Irrigated Area* (ft²): 0

*Irrigated area is a placeholder. Site data from Building Information Model is not incorporated.

Timed Sprinklers: No

Pool: No

Other Equipment/Fixtures: No Usage: 0 Gal / day

Building Summary / **Efficiency Savings**

	Total	Male	Female	Employee Only	Efficiency	Percent of Indoor Usage (%)	Gallons per Year	Annual Cost Savings ($)
Toilets:	1	0	0	1	Low-Flow	10.1	2,842	3
Urinals:	0	0		0	Standard	0	0	0
Sinks:	1	0	0	1	Hands-Free	1.1	300	0
Showers:	0	0	0		Standard	0	0	0
Clothes Washers:	0				Standard	0	0	0
Dishwashers:	0				Standard	0	0	0
Cooling Towers:	0				Standard	0	0	0
Include cooling tower blowdown in sewer costs					**Total Efficiency Savings:**	**11.1%**	**3,142**	**$3**

Source: 2000 Uniform Plumbing Code of the IAPMO, Tables 4-1 and 4-3.

Net-Zero Measures / **Net-Zero Savings**

		Annual Rainfall (in)*	Catchment Area (ft²)		Surface Type	Gal / yr	Annual Cost Savings ($)
Rainwater Harvesting:	Yes	18.45	2269		Concrete/Asphalt	23,485	22
Native Vegetation Landscaping:	No					0	0
Greywater Reclamation:	Yes					0	0
Site Potable Water Sources:	Yes	Yield:	274	Gal / day		100,010	94
*Source: National Climactic Data Center, #CLIM81.					**Total Net-Zero Savings:**	**123,495**	**$116**

Figure 94: Green Building Studio Results for Small Warehouse (Munitions) at Ellsworth AFB, SD

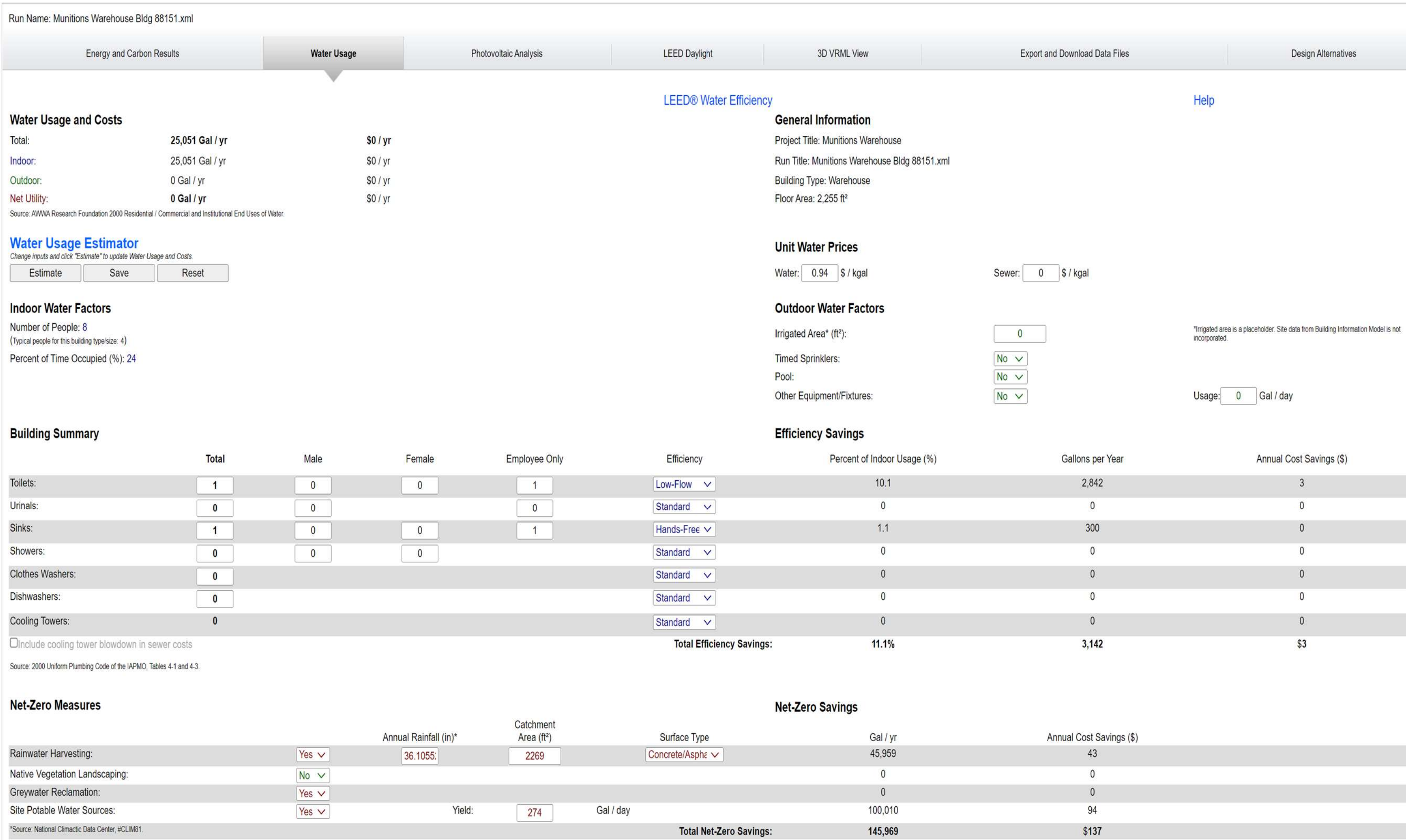


Figure 95: Green Building Studio Results for Small Warehouse (Munitions) at Wright-Patterson AFB, OH

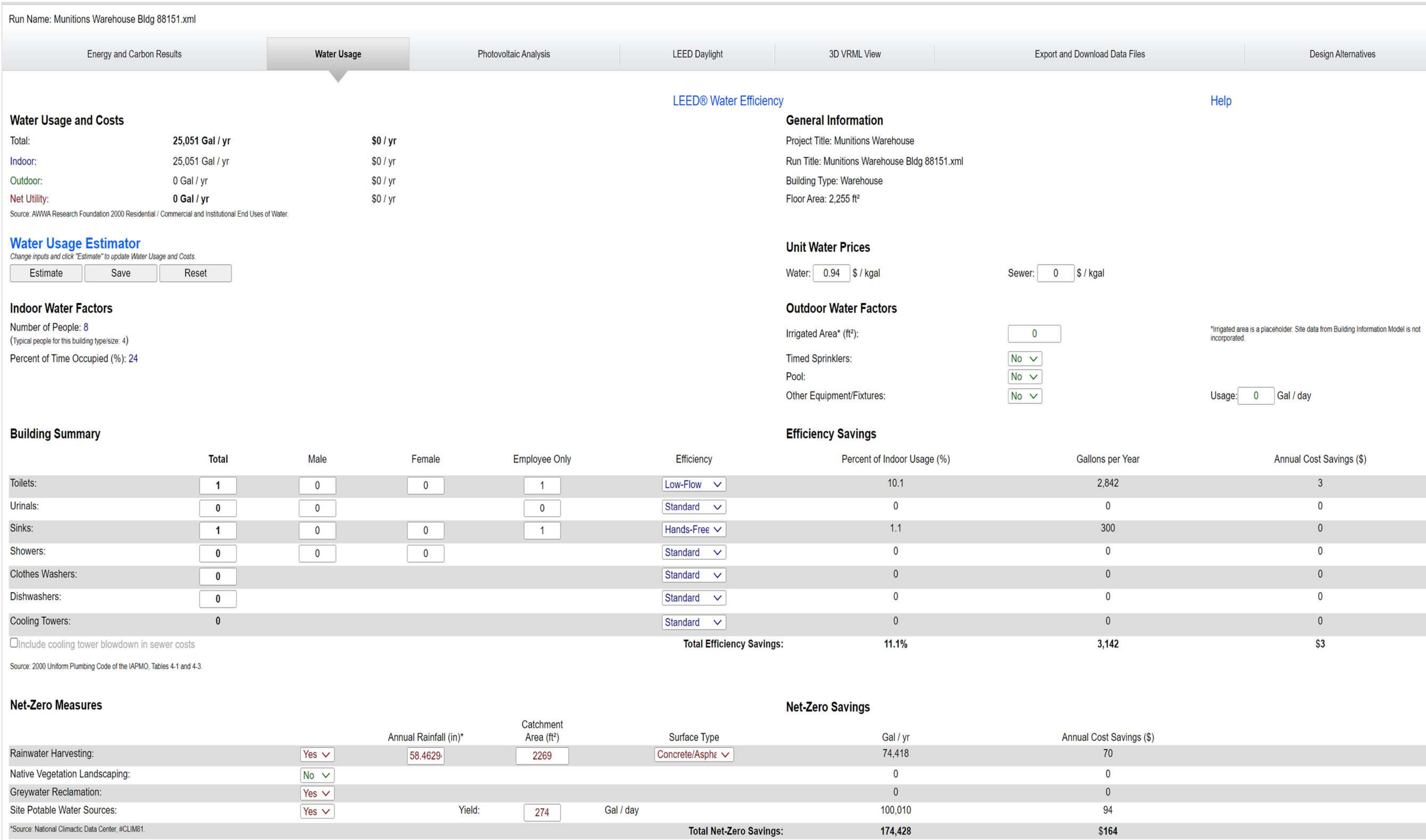


Figure 96: Green Building Studio Results for Small Warehouse (Munitions) at Eglin AFB, FL

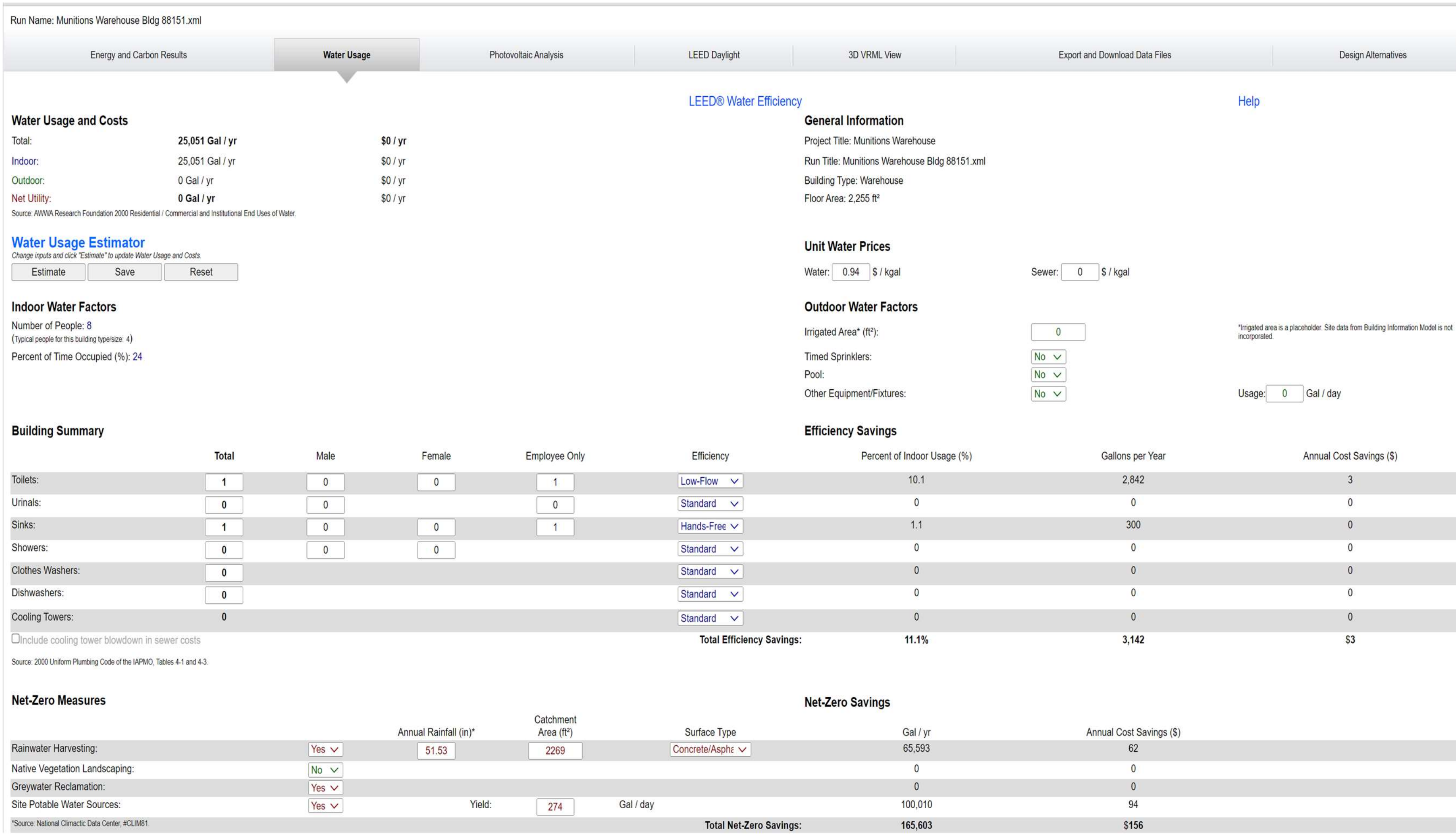


Figure 97: Green Building Studio Results for Small Warehouse (Munitions) at JB Charleston, SC

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