ABSTRACT

Title of Thesis:	SIMULATION AND ANALYSIS OF ENERGY CONSUMPTION FOR TWO COMPLEX AND ENERGY INTENSIVE BUILDINGS ON UMD CAMPUS
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The Physical Sciences Complex and Eppley Recreational Center are multi-purpose buildings which are complex in functionality and are among the highest consumers of energy on the UMD campus. Building energy analyses used to identify energy efficiency measures to optimize energy efficiency in the buildings. Detailed building energy models were developed in EnergyPlus and OpenStudio that sought to mimic current operations of the buildings. PSC model results deviated respectively -1.05%, 1.19%, and 5.27% for electricity, steam, and chilled water. ERC model results deviated respectively 0.47%, 5.3%, and 2.2% from annual electricity, hot water, and gas. Four energy efficiency measures for the Physcial Sciences Complex provided energy model predicted energy savings of 3,757 MMBtu or 7.5% of the building's energy

consumption. Four efficiency measures were identified for the Eppley Recreation Center with energy model predicted energy savings of 3,390 MMBtu or 8.4% of the building's energy consumption.

SIMULATION AND ANALYSIS OF ENERGY CONSUMPTION FOR TWO COMPLEX AND ENERGY INTENSIVE BUILDINGS ON UMD CAMPUS

by

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Chapter 1: Introduction

1.1 Project Background and Goals

1.1.1 Project Background

This work is in conjunction with the University of Maryland Energy Sustainability Office and Facilities Management's goals of reducing energy and water consumption of the campus. The UMD Sustainability Office has set 2020 goals of reducing potable water and electricity use by 20% while decreasing carbon emissions by 50% with the goal of being a net-zero carbon emissions campus by 2050. To realize these goals, the Office of Sustainability has high level strategies including "conducting existing building retrofit and making research-related resources that relate to energy efficiency and economic and environmental sustainability available to campus." (UMD Climate Action Plan, 2009) To keep with the spirit of these strategies, the UMD Facilities Management supports student-lead research for energy audits of selected high energy consuming buildings on campus. These energy audits use building energy modeling to identify potential building retrofits for building energy reduction. As a product of this research, research-related resources are created and stored that relate to energy conservation for the selected buildings on campus which contribute to the economic and environmental sustainability to the campus.

The two buildings included in the scope of this work are the Physical Sciences Complex (PSC) and Eppley Recreational Center (ERC), both are located on the University of Maryland's (UMD) College Park campus.

1.1.2 Project Goals

The main purpose of this project was to produce building energy models for the Physical Sciences Complex and Eppley Recreation Center that accurately predict the energy consumption of each building. Each of these multi-purpose buildings are complex and major energy consumers on the UMD campus.

A comprehensive model for each building can be used for a variety of different benefits to a building owner. These benefits include the ability to simulate energy consumption changes with building operational changes and renovations, identify temperature changes with operational changes, determine cost effectiveness of planned renovations and equipment replacements, and assess economic and operational changes to a building due to changes in climate conditions.

A second goal of this project was to develop a series of no to low cost Energy Efficiency Measures (EEMs) which will reduce the overall energy consumption of each building. Completion of this goal will have a two-fold benefit: decrease in the overall utility costs associated with building operations and a lowered Energy Use Index (EUI), the standard benchmark of building energy usage.

Preceding this work, four independent energy audits have been conducted by CEEE members including Levy (2013), Bangerth (2014), and Savage (2017).

Building functions for these energy audits varied from dining services to biological laboratories. Results from these energy audit projects include combined energy savings opportunities of 25,860 MBtu with an estimated annual cost savings of $573,132.

1.2 Building Energy Modeling

1.2.1 Building Energy Modeling Overview

According to the 2016 U.S. Energy Information Administration's (EIA) report on international energy consumption, global energy consumption reached 572.8 Quadrillion BTUs. The United States had the second highest energy consumption at 97.5 Quadrillion BTUs, with China being the highest energy consumer and India being the third highest consumer. Total global energy consumption is projected to grow 739 Quadrillion BTUs by 2040 or a 29% increase from 2016 figure. During this same time period, United States' energy consumption is expected to grow to 106.5 Quadrillion BTUs, or a 9.2% increase from 2016 values (EIA).

In the United States, 39% of the total energy consumption or 38 Quadrillion BTUs is used in buildings. Commercial buildings use approximately 17 Quadrillion BTUS while residential buildings use about 21 Quadrillion BTUs. Due to climate and change and concerns about energy costs, debates about building energy efficiency have become more mainstream. (Kneifel, 2010) The Pacific Northwest National Laboratory identified most commercial buildings can obtain energy savings of 10-20%. (Belzer, 2009) As a result many organizations have come to the forefront identifying ways in which building energy usage can be made more efficient. Programs such as the Better Building Challenge, Energy Star Program, and Leadership in Energy and Environmental Design (LEED) have brought energy efficiency to the limelight for new and existing buildings. Incentives such as tax incentives and rebate programs have made it more financially viable to improve overall energy efficiency in buildings. One of the tools engineers have to improve building energy efficiency is building energy modeling software.

Building energy modeling started to develop in the early 1960s with the advent of the first building energy modeling program, BRIS, which was first introduced in 1963. Hundreds of other programs have been developed since then to meet engineering needs with general building development and energy efficiency. Building energy simulation software can provide the user with energy usage and energy demand data when given a complete set of building characteristics. (Crawley, 2008) This complete set of building characteristics includes building geometry, HVAC systems, internal loads, wall construction, and weather conditions. A visual representation of a generic workflow of a building energy simulation can be seen in Figure 1. (Maile, Fischer, and Bazajanac, 2007)

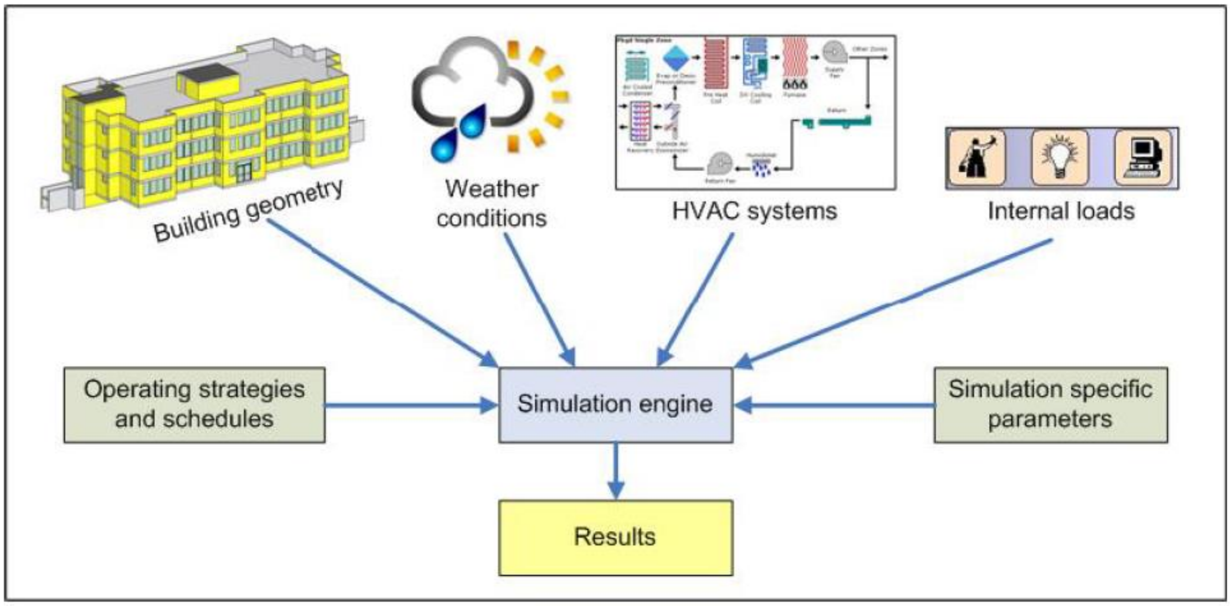


Figure 1: Building Energy Simulation Workflow

For some programs such as LEED, building energy modeling which assesses a building's energy efficiency and details energy savings is required to obtain certification. Building energy modeling is used for a variety of purposes, but for this thesis, it is used to improve energy efficiency in already existing buildings.

Primarily, there is one applications of building energy modeling software for improving energy efficiency in already existing buildings: building retrofit analysis. Accurate building energy models can predict new energy usage and energy demand in buildings when planning a major change in a building such as HVAC replacement and construction replacement or upgrades. Large retrofits done to a building can be quite difficult and time consuming to accurately calculate leading to a preference for using building energy simulation. A building energy simulation easily takes into account all of the different variables within a building environment and their interdependencies on each other. Therefore, using building energy simulations is not only time efficient, but more accurate.

1.2.2 Building Energy Modeling Approach

For both buildings presented by the author, the building energy simulation software used was EnergyPlus version 8.3.0. EnergyPlus is a combination of two already existing programs development by the U.S. government, DOE-2 and BLAST. DOE-2's development was supported by the U.S. Department of Energy (DOE), dating to the 1960s and continuing for multiple decades. BLAST was a Department of Defense (DOD) initiative dating to the 1970s and also supported for many decades. EnergyPlus' creation started in 1996 with a purpose to combine the best features and capabilities of the two programs. EnergyPlus was development in cooperation between the U.S. Army Construction Engineering Research Laboratories (CERL), Lawrence Berkeley National Lab (LBNL), University of Illinois, Oklahoma State University, and Department of Energy. (Crawley, 2001) Figure 2 shows the workflow structure and different parameters used in an EnergyPlus simulation.

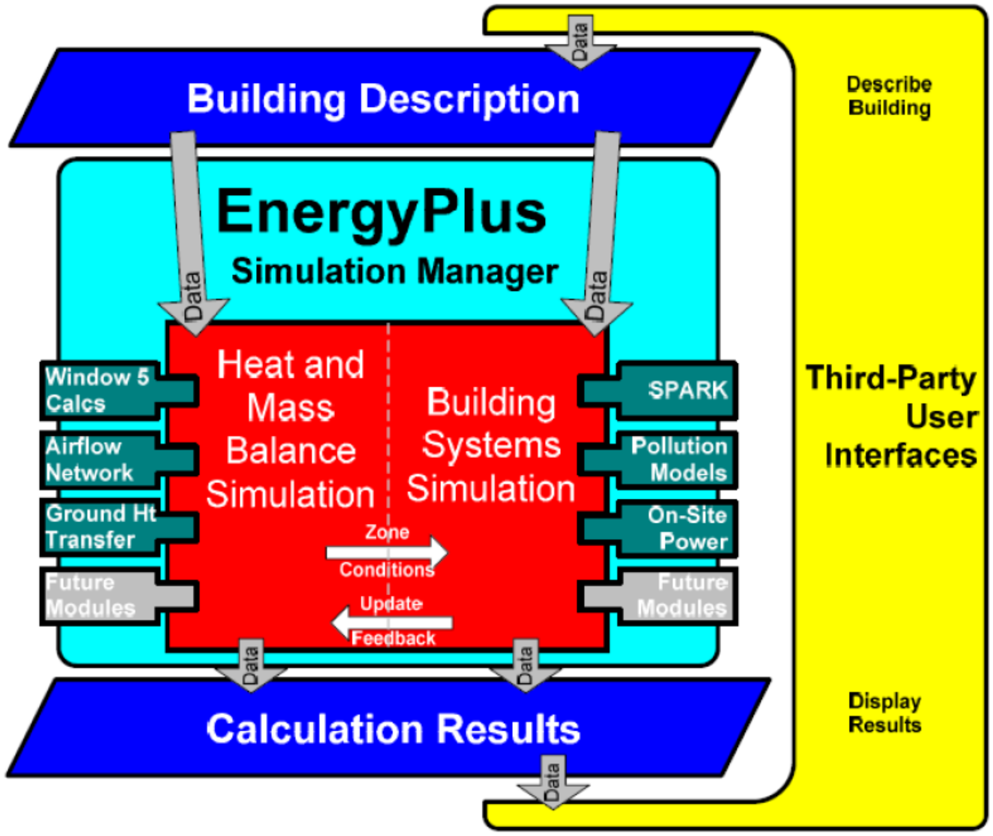


Figure 2: EnergyPlus Workflow Structure

EnergyPlus is primarily a text-based program and is somewhat cumbersome to operate. Luckily, there are programs that interface with EnergyPlus to make building and running a building energy simulation much easier and intuitive. For this project, two open sourced software programs were used to complete both building energy models. SketchUp is an open source program developed by Trimble which primarily is used in modeling building architecture. Building surfaces (walls, doors, and windows) and their corresponding nodes were created in SketchUp. OpenStudio is the second program that was used to define building constructions, internal loads, weather, HVAC systems, and other building parameters. OpenStudio was developed by the National Renewable Energy Laboratory (NREL) and is described as "a cross-platform collection of software tools to support whole-building energy modeling using EnergyPlus." (NREL) OpenStudio is constantly in development with new features being added for each new version. It can be used for almost any building project due to its vast array of features. OpenStudio works in conjunction with SketchUp through a OpenStudio plugin in SketchUp which allows both programs to be used simultaneously. Figure 3 and Figure 4 show the interfaces of the SketchUp and OpenStudio programs respectively.

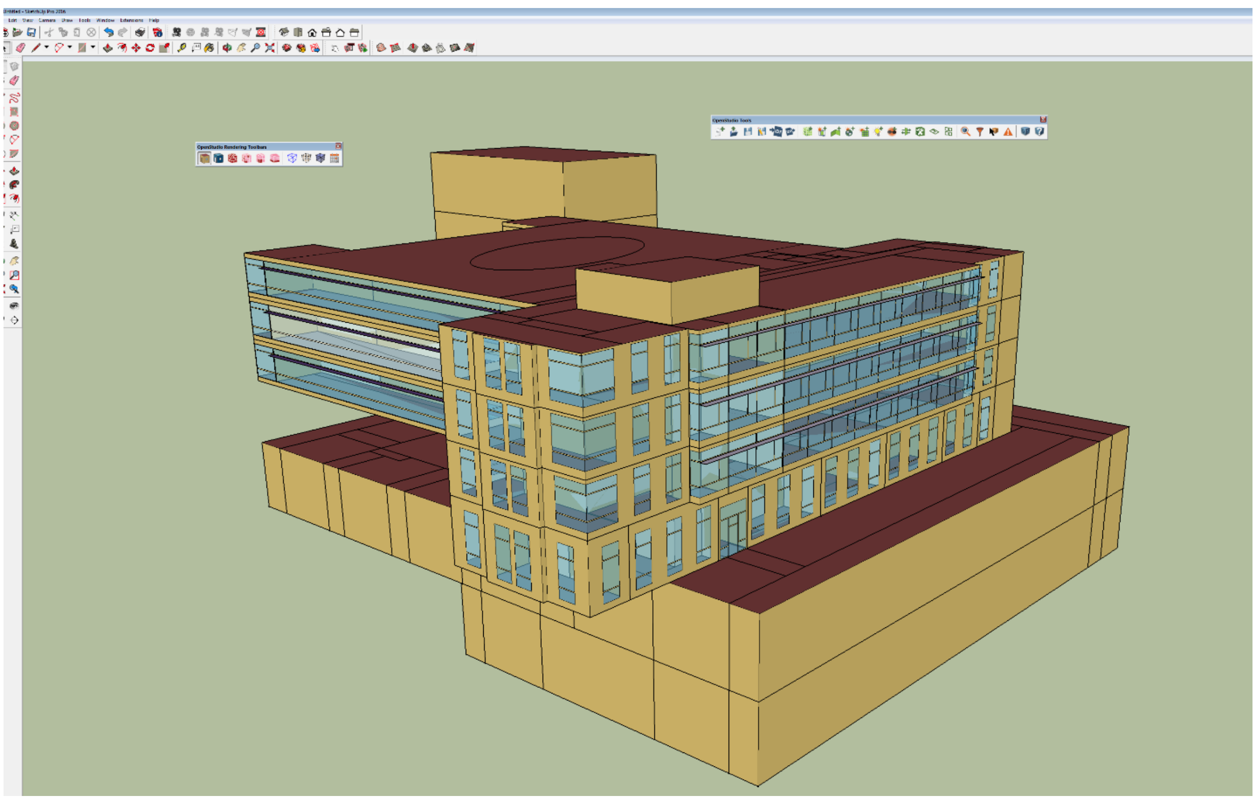


Figure 3: SketchUp Interface with OpenStudio Plugin

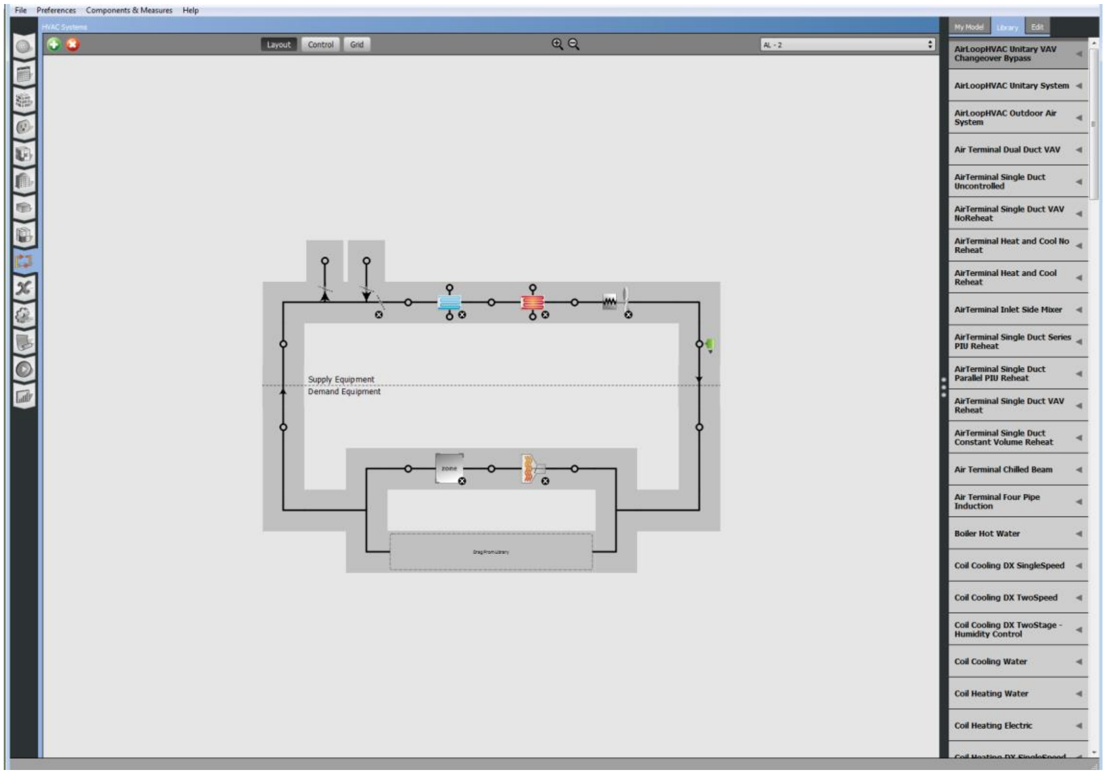


Figure 4: OpenStudio HVAC Interface

Chapter 2: Literature Review

2.1 Energy Savings and Sustainability on U.S. Academic Campuses

Energy sustainability and environmental awareness is an ever growing topic on U.S. campuses across the country. Climate change and energy supplies are some of the big drivers for the acceleration of energy sustainability conversations across U.S. campuses. The American College and University Presidents' Climate Commitment (ACUPCC) is one of the biggest initiatives taken across campuses. It is described as a "high-visibility effort to address global warming by creating a network of colleges and universities that have committed to neutralize their greenhouse gas emissions and accelerate the research and education efforts of higher education to equip society to re-stabilize the earth's climate." (ACUPCC) Currently, the ACUPCC has 435 colleges and universities who have pledged to reduced their greenhouse gas emissions with the University of Maryland, College Park (UMCP) being one of them.

Along with being signatory to the ACUPCC, UMCP has a list of President's energy initiatives which aim to lower energy usage across the campus. The three main energy initiatives set forth by the UMCP president are energy conservation, carbon-neutral new construction, and purchased power. (UMD Sustainability Office) Energy conservation aims to reduce electricity usage 20% by 2020 through energy efficiency upgrades and building operations improvements. Carbon-neutral new buildings revolve around building new buildings that are highly energy efficient and offset energy usage by using renewable energy sources. Purchasing power means purchasing electricity from renewable energy sources, therefore offsetting carbon emissions.

2.2 Energy Savings in Gymnasiums and Natatoriums

There has not been much research published in the field of energy savings in gymnasiums and natatoriums specifically. Natatoriums are by far the most energy consuming spaces in a gymnasium due to the large ventilation and dehumidification and pool heating loads typically needed to run the space comfortably. (Zucarri, et al, 2017) A visual of the heat transfer within a pool system is shown in Figure 5. In an indoor pool, typically radiation loads can be ignored. Improving energy efficiency involves improving heat transfer parameters within the pool system.

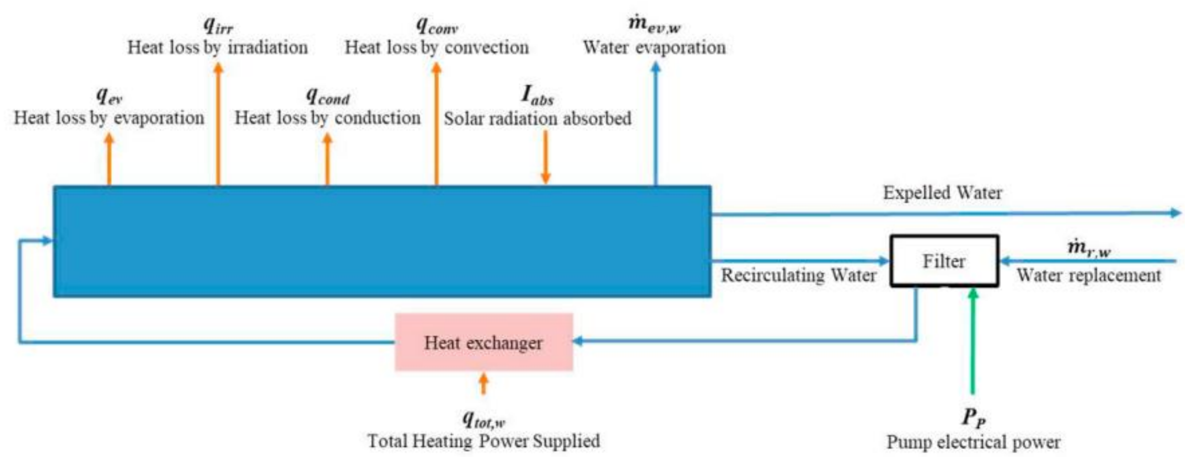


Figure 5: Energy Balance of a Pool System

Although there is few research that has been done on the subject, there have been many ideas on how to save energy within a natatorium. Brambley and Wells concluded that installing pool covers significantly limits the evaporation of pool water into the natatorium. (Brambley and Wells, 1983) The decrease in water evaporation decreases the humidity in the air which leads to a decrease in dehumidification and ventilation load within the space. It was estimated through case studies done by the Energy Efficiency Best Practice Programme in England that a pool cover can save up to 22% of total energy costs within a natatorium. (Best Practice Programme, 1998)

Energy recovery systems are another excellent way to improve energy efficiency within the natatorium area. Essentially, energy recovery transfer the latent and sensible heat from exhaust air into the supply air. If the supply air is cold, energy recovery will humidify and increase the temperature of the supply air and vice versa for supply air that is hot from the outside. Zuccari et al estimated total reduction of heating needs by about 50% with energy recovery systems installed. (Zucarri et al, 2017). Pool covers and heat recovery are some of the main energy efficiency measures specifically for natatoriums.

Demand controlled ventilation (DCV) has become more recently popular in gymnasiums due to the unique occupancy loads of typical gyms. DCV utilizes CO_2 sensors to avoid over ventilation of spaces with outside make up air. Essentially, DCV controls the amount of outside make-up air brought into the gym by keeping outside make-up air in line with safe CO_2 limits inside the building. A case example of a DCV system is Georgia Tech's gymnasium which was retrofitted with CO_2 sensors and variable frequency drive (VFD) fans on the Air Handling Units (AHUs) and air terminals. (Georgia Tech) The project cost $800,000 with an estimated savings of $102,000.

A smaller but more mainstream energy efficiency measure is exercise equipment that produces energy. This is essentially equipment that generates electricity when a person is exercising on the equipment. Typically, energy generating equipment uses micro-inverters to convert the DC power created by the person into AC power that can be used by the gymnasium. One such device is a treadmill created by SportArt which is claimed to be able to generate roughly 200 Watts per hour. (Green Matters)

2.3. Energy Savings in Laboratories

Laboratories pose a unique challenge in the realm of energy conservation in that they are one of the most energy intensive. Typical ventilation rates of laboratories are about 3-4 times that of normal spaces in addition to the high ventilation rates of fume hoods that are typically located in laboratories. As part of an effort to make laboratories more energy efficient, the Lawrence Berkeley National Lab (LBNL) was established through funding by the Department of Energy (DOE) and Environmental Protection Agency (EPA). LBNL runs a program called Laboratories for the 21st century (Labs21), described as "providing facility designers, engineers, owners, and facility managers with tools, resources, and innovative solutions for designing, constructing, and maintaining sustainable laboratory facilities" (Labs21, 2003).

Labs21 has a list of tools that serve as guide for improving energy efficiency in laboratories displayed in Figure 6.

Tool	Purpose
Design process tools:	
Labs21 Process Manual	Guidance for sustainable design process.
Design Intent Tool	Documentation of design intent – objectives, strategies, metrics.
Environmental Performance Criteria	Point-based rating system for sustainability, based on LEED™.
Core information resources:	
Design Guide	Reference manual on energy efficiency features in laboratories.
Best Practice Guides	Information on design, construction and operation of specific technologies and strategies.
Case Studies	Whole building case studies of high-performance laboratories.
Energy Benchmarking	Energy use data for laboratory systems and buildings.
Overview resources:	
Intro to Low-Energy Design	Overview of key strategies for high performance labs.
Labs21 Video	Examples of high performance labs.

Figure 6: Lab21 List of Tools for Lab Energy Efficiency Improvement

During the course of the PSC energy audit, this list was consulted many times to brainstorm EEMs for the PSC building. I2SL studied lab retrofits in the Lab21 database from 1999 to 2010 which added energy efficiency sustainability. A graph of the frequency of a project retrofit is given in Figure 7. (I2SL, 2010)

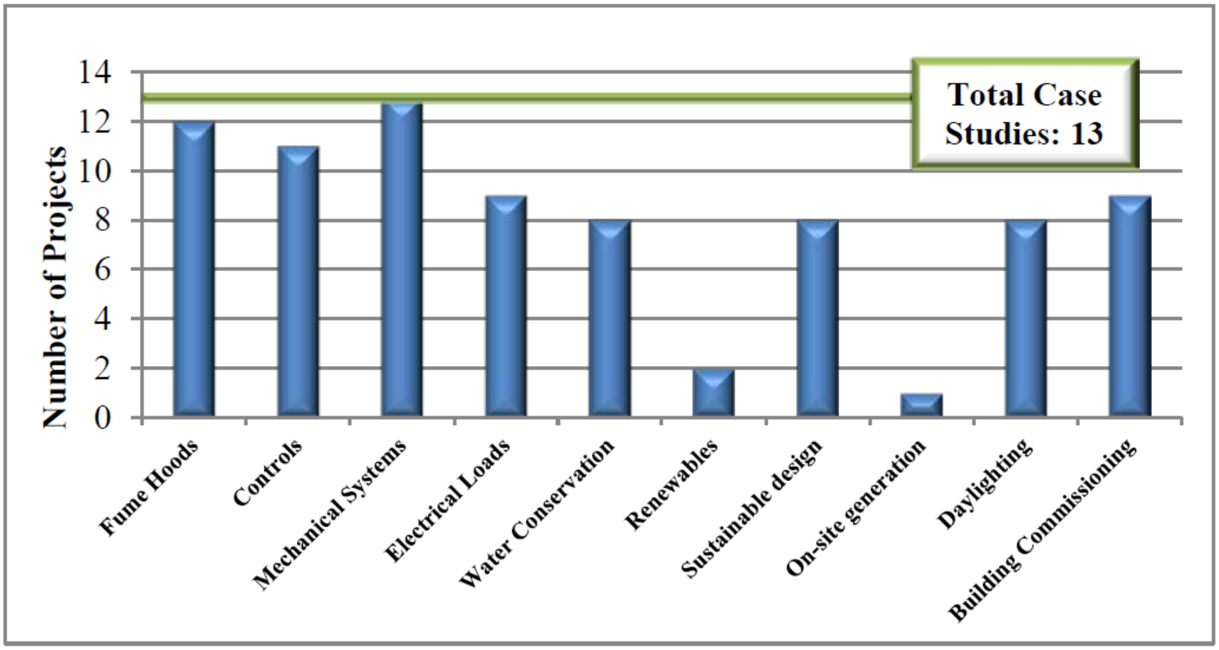


Figure 7: Lab21 Case Studies of Energy Efficiency Retrofits

Controls systems (BAS), fume hoods, and mechanical room were cited as the most frequently done.

Chapter 3: Building Descriptions

3.1 Physical Sciences Complex (PSC) Building Overview

The Physical Sciences Complex Building (PSC), Build 415 at UMD, is a mixed-use research, café, and office facility. Phase 1 construction was completed in 2013 and the doors of PSC were open to students and faculty in May 2013. Figure 8 shows the main entrance of the Physical Sciences Complex, which faces south.

Figure 8: The Physical Sciences Complex

PSC, although new, has undergone one renovation which cost $2,991,716 according to the UMD facilities management building inventory. PSC is four stories tall with two basements which are mainly used for laboratories. The building houses an array of research laboratories including Type 2A Laser, Type 2A Condensed Matter, and Type 2A Biophysics labs, which are located in the basement. PSC has a total replacement value which is defined as the total design and construction cost to replace the building to modern codes and standards of $149,585,813. Including the basement total gross floor area of PSC is 171,772 ft^2 with a net assignable floor area, which is defined as “the sum of all floor area assigned to or available to, an occupant or specific use” (NCES) of 90,150 ft^2.

The primary functions of PSC serve as office space and laboratory space for UMD’s Department of Physics which can be seen from floor to floor. Basement levels one and two in the building contain entirely laboratory, storage, and mechanical space. Offices are found from the ground level to the third level with a copious amount of common areas and collaboration spaces on each floor, while the Quantum Café is on the ground floor. Figure 9 shows the floor plan of the first floor in PSC which were obtained from UMD’s facility management (FM).

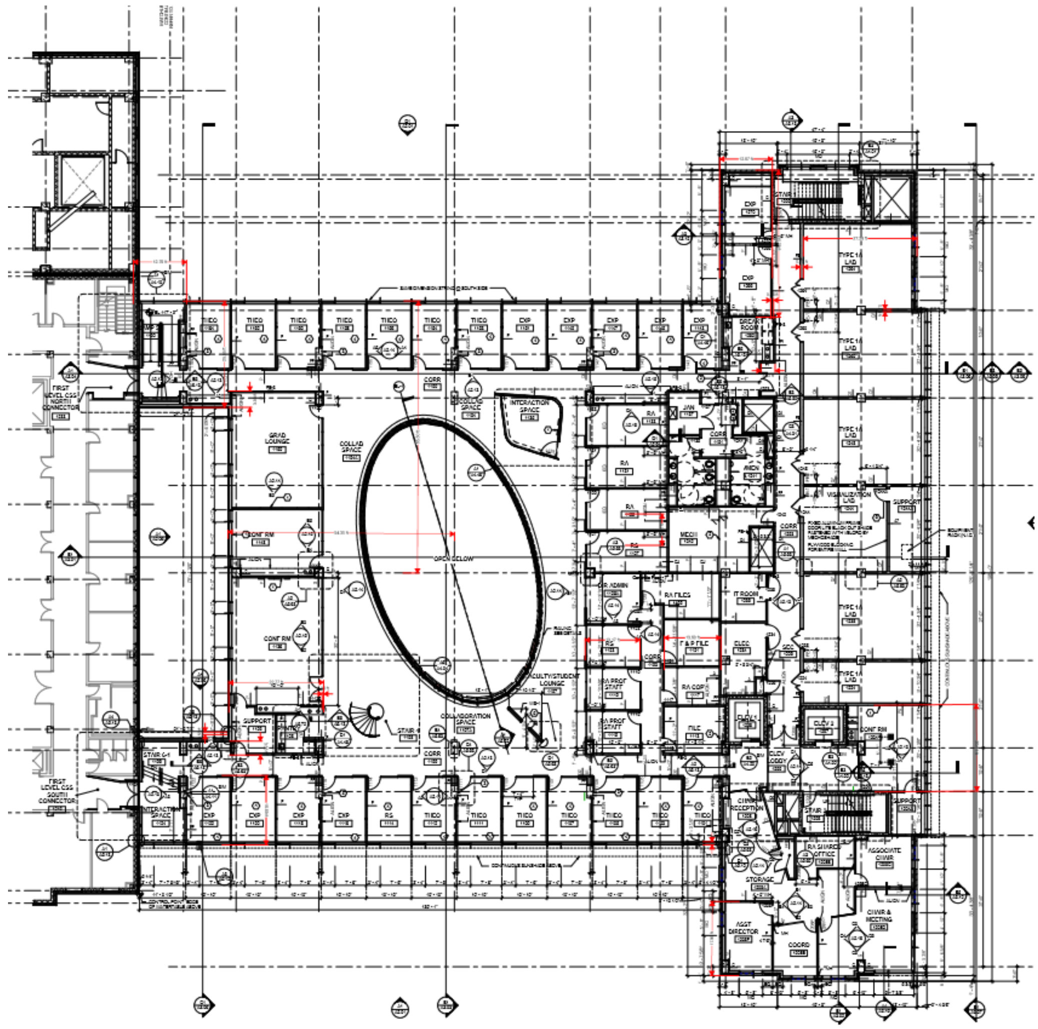


Figure 9: PSC Floor Layout, First Level

Table 1: Floor Space Allocation in PSC by Function

Function	Floor Area (ft^2)	Percentage of Gross Floor Area (ft^2)
Type 2A Labs	31,778	18.5%
Type 1 Labs	9,788	5.7%
Offices	34,173	19.9%
Mechanical/Storage	29,021	16.9%
Common Areas	15,627	9.1%
Corridors	51,688	30.1%
Café	687	0.4%
Total	**171,722**	**100%**

PSC is open to the public from 7:30am to 10:00pm throughout the week except on weekends and open 24 hours to students and research staff with proper card access. Occasionally, students will occupy the building after normal public hours, but typical occupancy schedules correlate mostly with the public opening hours. The Building Automation System (BAS) HVAC schedules closely resemble those of the public hours except in a few instances which will be discussed alter in this paper.

3.2 Physical Sciences Complex Building Details

3.2.1 Architecture and Lighting

Space lighting in PSC is comprised mostly of 32W T8 Bulbs and 32W Compact Fluorescent Lamps (CFL) which is the original lighting of the building. The majority of offices and common areas utilize lighting occupancy controls to save electricity when unoccupied. The common areas and lobby areas utilize daylight controls to turn off lighting when enough natural sunlight has illuminated a room. The lighting sensors were found to be somewhat effective with some lights still turned on even when there was significant daylighting in an area. Average lighting densities for different space types in PSC were calculated using the lighting drawings obtained for PSC and shown in Table 2.

Table 2: Lighting densities of PSC

Space Type	Lighting Density (W/ft^2)
Type 2A Labs	0.786
Type 1 Labs	1.078
Offices	0.883
Mechanical/Storage	0.334
Common Areas	0.866
Corridors	0.492
Café	2.147

The architecture design drawings for PSC show wide varying use of construction types throughout the building, but there are two main designs which can be differentiated between below construction and above ground construction. Essentially all of the windows were double pane with an array of different window glazings which helps mitigate solar loading on the south side of the building particularly. The two main designs of walls, ceilings, and roofs are summarized in Table 3 based on the PSC construction documents.

Table 3: PSC Construction Types

Construction Types		
Construction Name	Material	Thickness (in)
Above Ground External Wall	Gypsum Board	0.5
	Steel Frame 4in Studs	16
	Red Brick	4
Above Ground Ceiling/Floor	Acoustic Tile	1
	Air Gap	4
	Concrete	2
Above Ground Internal Wall	Gypsum Wall	1
	Air Gap	4
	Gypsum Wall	1
Above Ground Roof	Acoustic Tile	1
	Air Gap	4

	Concrete	2
Below Ground External Wall	Concrete	8
	Rigid Polystyrene Insulation	2
	Concrete	14
Below Ground Ceiling/Floor	Rigid Polystyrene Insulation	2
	Concrete	8
Below Ground Internal Wall	Gypsum Wall	1
	Air Gap	4
	Gypsum Wall	1

3.2.2 Laboratory Equipment

PSC houses an immense array of laboratories, mostly located in the two basements. Lab equipment varies widely between these labs due to the nature of the research being performed. In the basement labs, there are 51 VAV fume hoods, at least 15 low dilution refrigerators and helium compressors, 5 low temperature freezers, and numerous power supplies. Other equipment include electron microscopes, sputtering machines, and computers. The laboratory areas on the above ground floors do not contain any fume hoods like the basement labs and mostly have computers as the majority of lab equipment

3.2.3 Heating, Ventilation, and Air Conditioning (HVAC)

PSC operates daily by utilizing three different energy commodities: electricity, district steam, and district chilled water. Electricity, like all of the other buildings on the UMD campus, is purchased from the utility company PEPCO which is used throughout the building. These include the laboratory equipment mentioned in the previous section, lighting, cooking equipment in the café, computers, and various other plug loads in the building.

Steam is produced in the University of Maryland's Combined Heat and Power Plant (CHP) and delivered to PSC at saturated conditions under a pressure of

115 psi before being reduced to a lower pressure. Steam is used to produce hot water in the heat exchangers located in the basement mechanical room which then subsequently provides heating to the entire building. Heating coils and reheat coils in the building provide the transmission of heat within the building. Chilled water (CHW) is received from the Satellite Central Utilities Building (SCUB) located in the Atlantic Building, which is next to PSC. The chilled water is circulated to PSC using a closed loop system and is used primarily in cooling the building through the cooling coils in PSC's air handling units (AHU).

PSC utilizes a standard HVAC system with nine air handling units (AHU) with variable air volume (VAV) reheat capabilities for most of the terminal units. All of the AHUs utilize return/makeup air mixing, therefore none of the systems are 100% dedicated outside air. All nine AHUs have the capability of cooling makeup (outside) air and five contain heating coils to heat the outside air. The majority of hazardous air is exhausted through the fume hoods in the laboratories directly to the outside.

PSC's AHUs are assigned by floor and unique floor area function. AHUs 101, 102, and 103 serve the above ground type 1 laboratories on the first floor, second floor, and third floor respectively. The terminal units for these areas contain reheat coils to closely control the temperature in these spaces. AHUs 201 and 202 are the largest of the AHUs which serve the type 2 laboratories in the basements, whose terminal units also contain reheat coils for precise temperature control. AHUs 301, 302, and 303 serve the underfloor HVAC systems on the first floor, second floor, and third floor respectively. The underfloor HVAC systems primarily serve the offices, corridor, and common areas on the first, second, and third floors. AHU 401 serves only the main mechanical wing in PSC. AHU allocation makes sense for the building functionality, and diagram of the AHU allocation is shown in Figure 10.

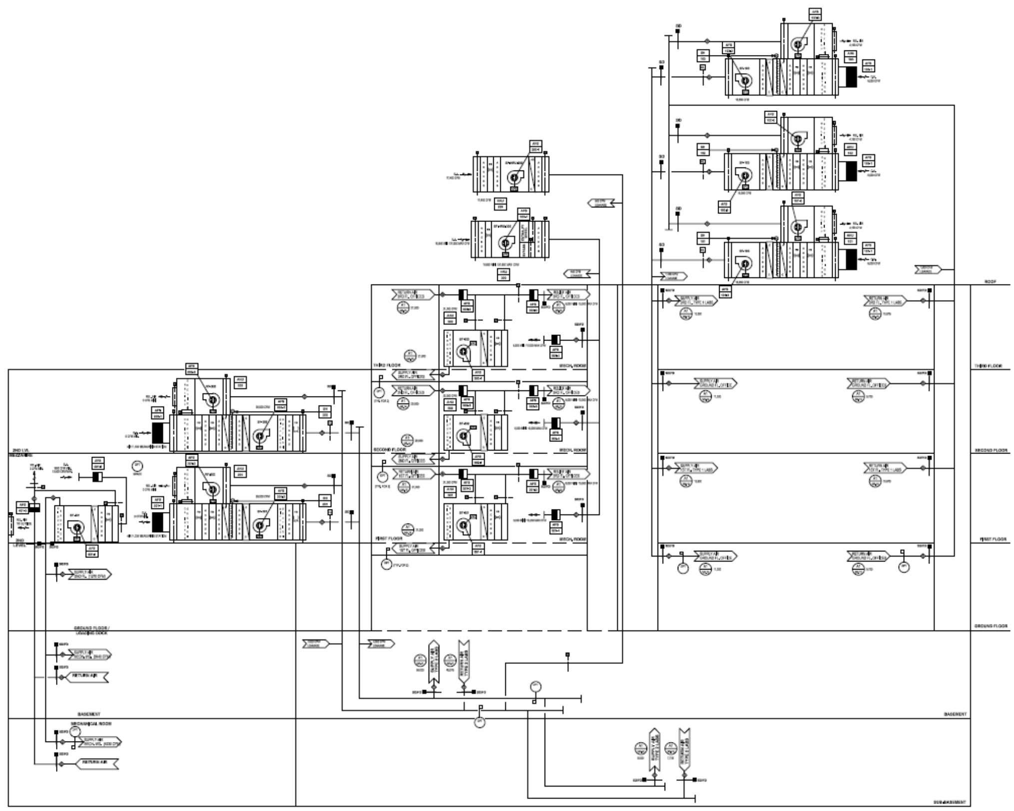


Figure 10: PSC Air Handling Unit Allocation Diagram

All of the AHUs in PSC mostly follow the same configuration. They all contain a outdoor air damper, supply fan, return fan, coiling coil, heating coil (except for AHUs 301, 302, 303, and 401), and air filter. The capacities of the fans, cooling coils, and heating coils vary based on the design loads expected for each AHU which is combination of AHU set point temperatures and thermal zone loads. After the AHU discharges the air, supply air travels through the ducts to the VAV terminal units, which mostly all have hot water reheat coils to change the discharge temperature to meet the thermostat settings within the designated space. A summary of PSC's AHU design specifications is given in Table 4. Note that the design specifications for AHUs 101, 102, and 103 are the same, design specifications for AHUs 201 and 202 are the same, and also for AHUs 301, 302, and 303.

Table 4: PSC AHU Design Specification Summary

	AHU-101,102,103	AHU-201,202	AHU-301,302,303	AHU-401
Location	Rooftop	Mechanical Wing	Respective Floors	Rooftop
Service Area	Type 1 Labs	Type 2 Labs	Above Ground Offices	Mechanical Wing
VFDs	Yes	Yes	Yes	Yes
Energy Recovery Loop	No	Yes	Yes	No
Design CFM	23,000	48,000	21,000	13,500
Total Static Pressure (in H_2O)	2.0	4.0	1.0	2.7
Supply Fan HP	50	100	40	20
Return Fan HP	25	60	None	None
CHW Cooling GPM	225	454	118	106
HW Pre-Heating GPM	500	500	None	None

3.2.4 Building Automation System (BAS)

PSC utilizes the Automated Logic (AL) Building Automation System (BAS) developed by United Technologies for the entire building. The BAS system automates many of the HVAC controls in PSC and contributes to the overall efficiency of the HVAC system. PSC's BAS system monitors the AHU systems, thermal zones, lighting, steam loops, chilled water loops, hot water loops, and air terminal units for reheat. Access to AL BAS system was granted by facilities management and was utilized effectively to gather data about building HVAC performance and scheduling. Figure 11 shows an example of an AHU in the AL BAS, clearly identifying heating and cooling coils. Figure 12 represents the typical thermal zone visualization in the BAS for the third floor of PSC in the afternoon.

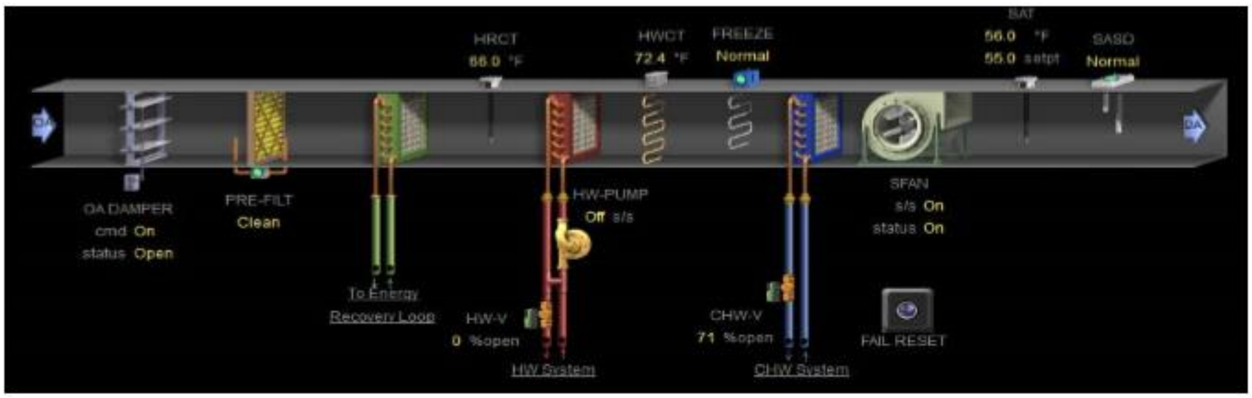


Figure 11: Example of AHU in AL BAS

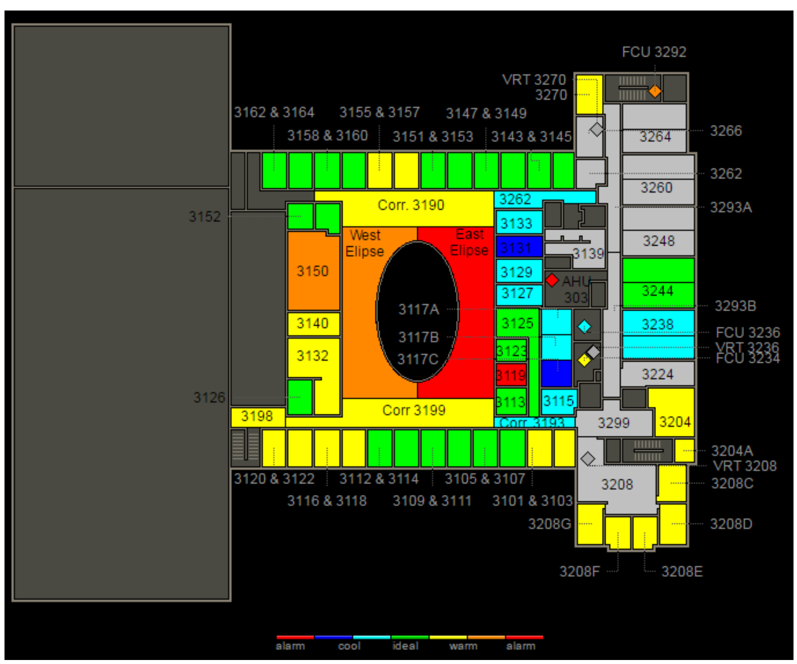


Figure 12: AL BAS representation of Third Floor in PSC

3.2.5 Energy Recovery System

There are two heat recovery units in PSC, one glycol loop system, HRU-200, and one enthalpy wheel system, HRU-300. HRU-200 is connected to AHUs 301, 302, and 303 to recycle sensible heat from the exhaust air from the underfloor HVAC systems. HRU-300 works in tandem with AHUs 201 and 202 which recycles both sensible and latent heat from the type 2 laboratory exhaust air. HRU-200 utilizes a 24,000 CFM supply fan while HRU-300 utilizes a 30,000 CFM supply fan. Both HRUs are in operation, however due to HRU-300's inefficient exhaust design, it is only operated infrequently on extremely hot days (>94°F) and cold days (sub 20°F) due to the fan power required to transfer air to and from the HRU located on the roof. Subsequently HRU-200 is operated when outside temperatures are 84°F for hot conditions and 40°F for cold conditions.

3.3 Eppley Recreational Center (ERC) Building Overview

Eppley Recreational Center (ERC), Building 068 on the UMD campus is a mixed-use building with exercise facilities and offices. Construction on ERC was completed in 1998 and serves as the main gymnasium for the campus student body. Figure 13 shows the main entrance of (south facing) of ERC.

Figure 13: Eppley Recreational Center South Facing Side (Building 068)

Many renovations have been completed on ERC since it opened its doors in 1998 which have since totaled to $24,231,112. The building houses the one of the SCUBs on campus, various exercise rooms and studios, offices, indoor natatorium, and outdoor pool area. ERC has a replacement value of $96,924,449. The gross floor area in this four story building is 233,421 ft^2 with a net assignable floor area of 150,281 ft^2.

The majority of the used space in ERC is dedicated to exercise functionality with exercise rooms taking up the majority of all the floors. Office space is found mostly on the 2nd floor and a small portion of the 1st floor. Figure 14 shows the floor plan for the first floor in ERC taken from documents obtained from FM. Table 5 details the floor space allocation by functionality in ERC.

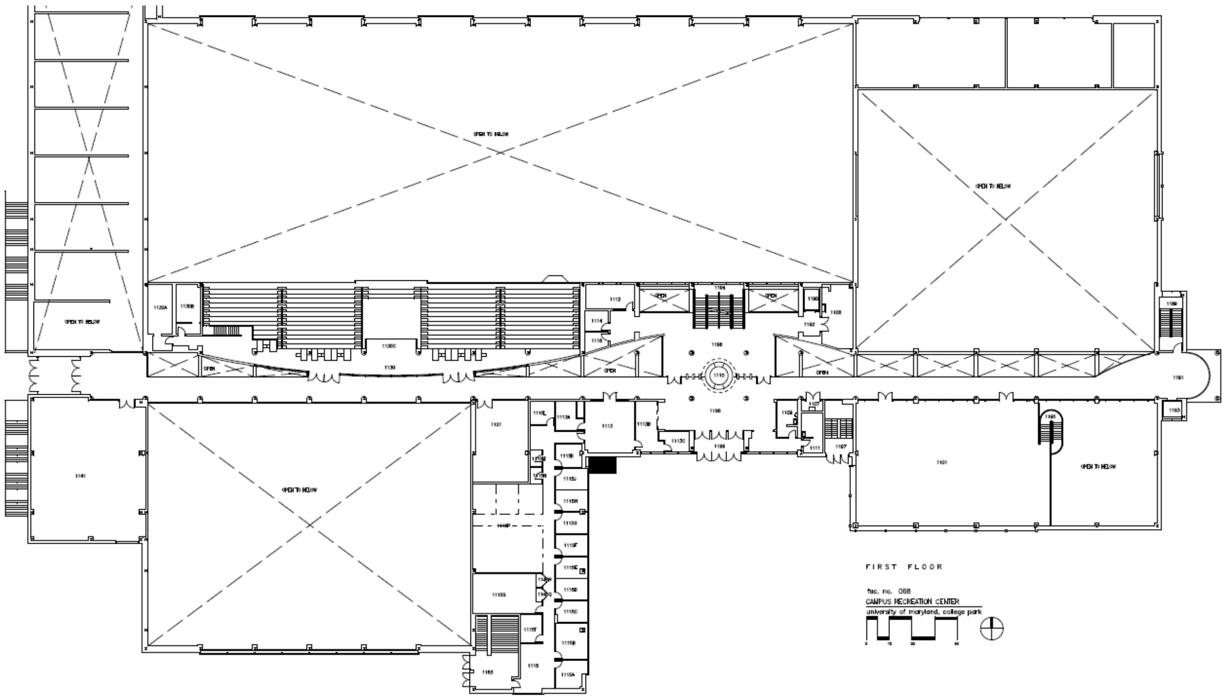


Figure 14: First Floor Plan of ERC

Table 5: Floor Space Allocation in ERC by Space Functionality

Function	**Floor Area (ft^2)**	**Percentage of Gross Floor Area (ft^2)**
Natatorium	44,117	18.9%
Outdoor Pool Area	13,072	5.6%
Mechanical Rooms	23,109	9.9%
Basketball/Racquetball Courts	40,849	17.5%
Weight Rooms/Studio/Exercise Rooms	35,713	15.3%
Locker Rooms	17,740	7.6%
Storage	9,337	4.0%
Offices/Conference Rooms	16,106	6.9%

Corridors/Lobby	30,812	13.2%
Bathrooms	1,634	0.7%
Café	934	0.4%
Total	**233,421**	**100%**

ERC has extensive operating hours, open to the public from 6:00am-12:00am on weekdays, 8:00am-10:00pm on Saturdays, and 10:00am-12:00am on Sundays. A private swim team occupies the Natatorium most weekdays starting at 5:00am which further increases operational hours. Based on occupancy tables recorded by the ERC staff, peak occupancy occurs from midafternoon to closing with moderate occupancy during the morning and early afternoon timeframes. Due to these extensive hours, the building uses a 24/7, always on operating conditions.

3.4 Eppley Recreational Center Details

3.4.1 Architecture and Lighting

ERC has been steadily upgraded to an LED lighting system from the previous fluorescent lighting system through the use of PEPCO's rebate program. This has undoubtedly saved the building in a significant amount of electricity usage. In the majority of ERC's large spaces, such as the basketball court areas and natatorium, high intensity LED lights are used to illuminate the spaces. Throughout the corridors and smaller spaces such as locker rooms and office spaces, normal LED lighting is used. During the building walk-through, it was noticed that some lights were on in the corridors and larger spaces even though there was sufficient daylight entering the areas. Therefore, greater use of daylighting would help lower electricity costs. As contrasted with PSC, ERC is more developed in terms of energy savings when it comes to lighting.

According to ERC construction documents, the building as a wide array of wall constructions and windows used throughout the building. ERC utilizes different window shadings to mitigate solar loading on the building. For example, highly shaded windows are used on the south side of the building since this is where the highest solar insolation on the building occurs. On the other sides of the building, normal clear windows are used. Table 8 lists the common construction types used in ERC.

Table 6: ERC Construction Types

Construction Types		
Construction Name	Material	Thickness (in)
Above Ground External Wall	Gypsum Board	.5
	Wall Insulation	1.5
	Concrete	8
	Stucco	1
Above Ground Ceiling/Floor	Concrete	4
	Air Space	8
	Acoustic Tile	1
Above Ground Internal Wall	Gypsum Board	1
	Air Space	8
	Gypsum Board	1
Above Ground Roof	Acoustic Tile	1
	Roof Insulation	1.5
	Concrete	8

3.4.2 Heating, Ventilation, and Air Conditioning (HVAC)

As mentioned earlier, ERC uses three commodities to operate the building: gas, steam, and electricity. Electricity and gas is received by PEPCO and steam is received from the College Park power plant. Electricity is used to power all of the mechanical systems, exercise equipment, office equipment, laundry equipment, and lighting systems.

Steam is used to produce hot water through two shell and tube heat exchangers in the ERC SCUB. Some of the hot water produced is then transported to the neighboring Public Health building, while the rest is used in ERC. In ERC, hot water is used to condition the building and used for the shower systems. For conditioning the building, hot water is pumped directly into the heating coils in the AHUs and in the majority of the air terminal units in the office areas. Hot water produced in the SCUB is too hot to be used directly in the shower systems, so it is tempered with cold water to reach the correct temperature before being delivered to the shower systems in the locker rooms.

Chilled water is also produced in the SCUB by the three electrically powered chillers. Some of the chilled water produced in ERC is also delivered to the neighboring Public Health building. Chilled water is predominately used to condition the building by pumping the chilled water through cooling coils in the AHUs. Cooling towers are used in conjunction with the chillers to cool down the water from the condenser cycle.

ERC operates on a four pipe system, meaning there are separate pipes for hot and cold water supply and return. To condition this enormous building, ERC utilizes twelve AHUs, nine of which are constant volume (C.V.) and three are variable air volume (VAV). Constant volume AHUs supply a constant amount of supply air into the building, whereas VAV AHUs supply a variable amount of air depending on the demand. All of the AHUs in ERC have the capability of mixing return air back into the supply air, which saves a significant amount of energy.

The majority of the air terminals in ERC are constant volume terminals which do not have reheat. These air terminals primarily service all of the non- office areas in the building including locker rooms and exercise areas. VAV air terminal units are used in the office areas of the building. These terminal units have reheat coils in them to control the temperature of the spaces more precisely.

The zoning of the AHUs in ERC can be seen in Figure 15.

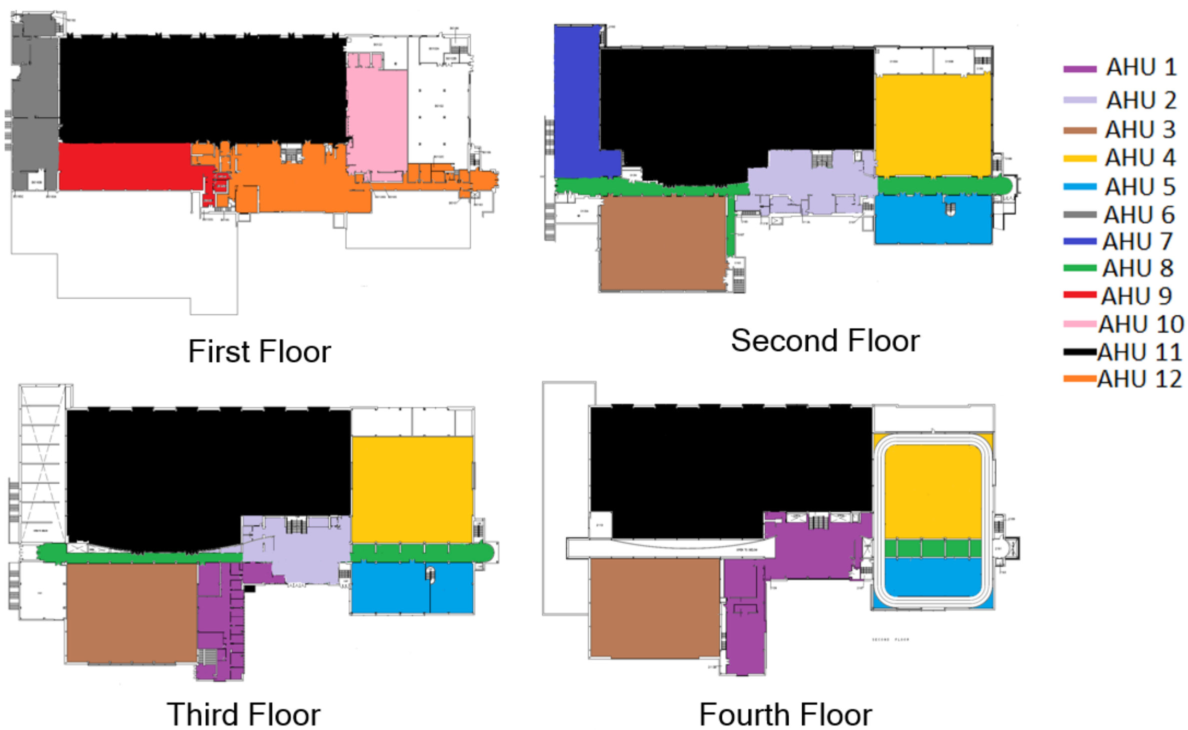


Figure 15: ERC AHU Zoning Designations

AHU 1 utilizes a VAV system and predominately services the third and fourth floor offices. AHU 2 is also a VAV system which conditions the atrium space/entrance area on the third floor of the building. AHU 3 is a constant volume system that services the basketball courts on the west end of the building which occupy the second, third, and fourth floors. AHU 4 is also constant volume and services the basketball courts on the east side of the gym. AHU 5 is constant volume and services the weight room which is located on the second and third floor on the south-eastern side of the building. AHU 6 is the CV AHU that services the storage area of the natatorium on the first floor. AHU 7 is a VAV system which services the racquetball area on the second floor, the terminal units for these areas are constant volume with no reheat in contrast to the office VAV terminal units. AHU 8 conditions the spine of ERC or the main corridor in the middle of the building, this AHU is constant volume. AHU 9 and AHU 10 are both constant volume systems which serve the men's and women's locker rooms respectively located on the first floor. AHU 11, normally called the Pool Paks, services the natatorium, it is by far the largest AHU in the building. It is a constant volume AHU which was recently replaced about a year ago. The Pool Pak system will be discussed in detail later in this chapter. AHU 12 is constant volume and serves the storage and laundry services on the first floor of the building.

All of the AHUs in ERC follow the same configuration. They all contain an outdoor air damper, supply fan, return fan, coiling coil, heating coil, and air filter. The capacities of the fans, cooling coils, and heating coils vary based on the design loads expected for each AHU which is combination of AHU set point temperatures and thermal zone loads. After the AHU discharges the air, supply air travels through the ducts to the air terminal units. Unlike PSC, air temperature is mostly controlled in the AHUs for the spaces since the air terminal units do not have any form of reheat. A summary of ERC's AHU design specifications is given in Table 7. Note, M.E.R. stands for Mechanical Room.

Table 7: ERC AHU Design Specification Summary

	AHU 1	AHU 2	AHU 3	AHU 4	AHU 5	AHU 6
Location	M.E.R 5	M.E.R 5	M.E.R 6	M.E.R 2	M.E.R 2	M.E.R 3
Service Area	Offices	Atrium	Gym A	Gym B	Weight Room	Pool Storage
VFDs	Yes	Yes	No	No	No	No
Energy Recovery Loop	No	No	No	No	No	No
Design CFM	22,500	26,000	11,750/23,500	18,500	20,300	1,900
Total Static Pressure (in H_2O)	3.76	4.03	3.63	2.86	3.40	1.79
Supply Fan HP	25	30	25	20	25	1.5
CHW Cooling GPM	115	168	247	118	119	10.1
HW Heating GPM	62	70	99	55	75.2	7.0
	AHU 7	**AHU 8**	**AHU 9**	**AHU 10**	**AHU 11**	**AHU 12**
Location	M.E.R 6	M.E.R 6	M.E.R 1	SCUB	M.E.R 7	SCUB
Service Area	Racquetball	Spine	Men's Locker Room	Women's Locker Room	Natatorium	Floor 1 Maint
VFDs	Yes	No	No	No	Yes	No
Energy Recovery Loop	No	No	No	No	Yes	No
Design CFM	2,800	12,000	14,500	14,500	25,000	1,585
Total Static Pressure (in H_2O)	2.56	3.00	3.33	3.03	2.60	2.70
Supply Fan HP	3	15	20	20	25	2
CHW Cooling GPM	17	72	69.8	69.8	164	8.2
HW Heating GPM	8	30.3	72.7	72.7	114.6	3.6

3.4.3 Building Automation System (BAS)

ERC runs on the Siemens Talon System and Staefa MS-1800 system, two of four BAS systems that is used on the UMD campus. Like PSC's BAS system, ERC's

BAS system automates many of the day to day functions within the HVAC system. The Talon system uses control points which are either derived through equations are given as a hard set point such as a set point temperature of a room. These control points can be room temperature, valve positions, fan speed for VAV AHUs, and many more mechanical points of interest within the HVAC system.

An example of how the BA system works is if a room's temperature exceeds its high set point temperature; which is read by a thermostat, a control point in the BAS system. Then the BAS system would automate an increase in the chilled water flow rate in the cooling coil of the AHU that services the room which in turn decreases the temperature in the room. Visuals of the ERC BAS system are similar to those seen in the PSC BAS section.

3.4.4 Natatorium Pool Pak Systems and Pool Heating Systems

The most complex Air Handling Unit is the Natatorium Pool Pak system. This AHU is responsible for conditioning and dehumidifying the natatorium in both competition and non-competition times. Due the immense amount of activity, there is a much higher load placed on the AHU system. The AHU was replaced in the 2017 as part of a renovation done to ERC. The old AHU was a constant volume AHU with no energy recovery systems was replaced with the new AHU which is a VAV system with energy recovery. Adding sensible and latent heat recovery within an AHU system for a pool is one of the largest ways to save energy. (Zuccari, Santiangeli and Orecchini, 2017) With the addition of this energy recovery system, ERC's total energy consumption is expected to decrease from its already low energy consumption figures.

All of the inside and outside pools at ERC are heated. Generally the outside pools are heated in April, September, and October months due to the hot temperatures in the summer. ERC's two indoor pools are heated year round, one pool being an Olympic sized pool (660,000 gallons) and the other being a smaller training pool. The pools are heated using gas fired boilers which are rated at 1 MMBTU each. The boiler is a closed system in which the water returned from the pools is filter, reheated, and pumped back into the pools.

Chapter 4: Audit and Energy Modeling Methodology

As is necessary with most complex projects, a detailed and thorough approach was taken to develop the building energy model of PSC and ERC. The main areas the projects were divided into are: Building Comprehension, Baseline Building Energy Model Development, and Energy Efficiency Measures (EEM). Figure 16 highlights the workflow organization used throughout both projects which has helped the author maintain time efficiency and accuracy during the project time period. This workflow chart was developed by a previous student. (Levy, 2014)

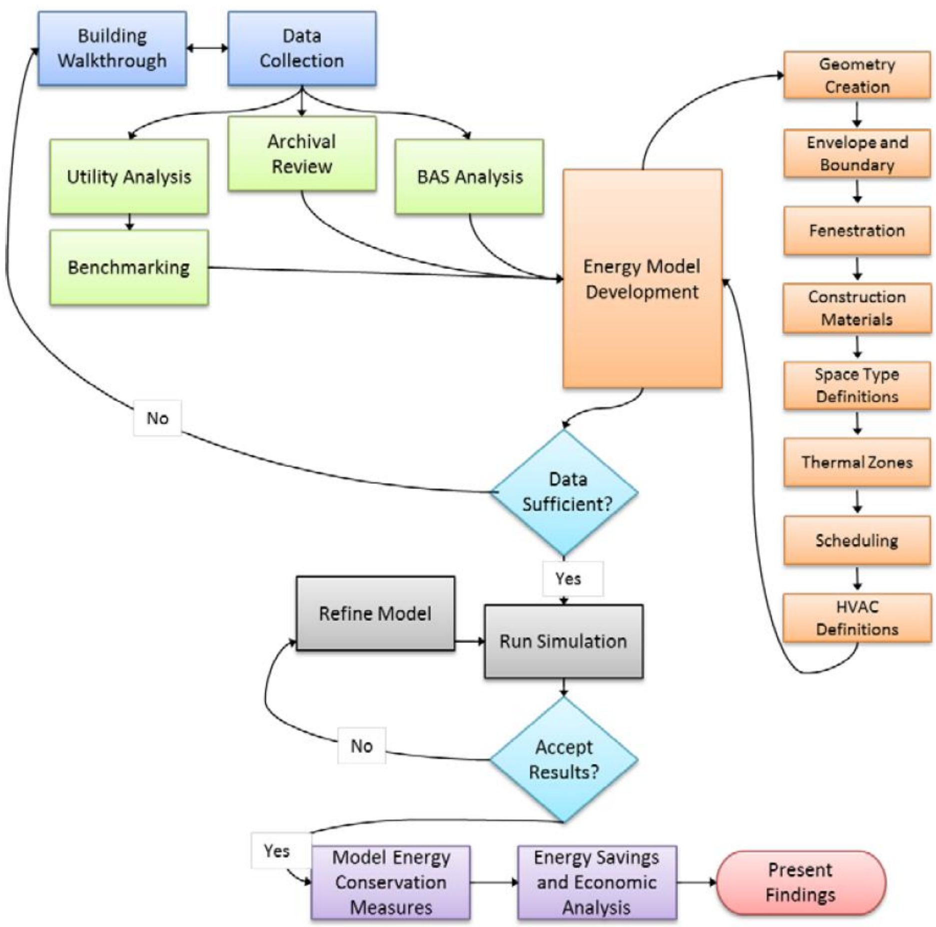


Figure 16: Energy Audit Project Flow Chart

4.1 Building Comprehension

The first step in the energy audit process is to understand the building being audited in order to accurately model the building. Understanding the building consists of four aspects: utility analysis, building walkthrough, building drawings review, and BAS analysis. The utility analysis is one of the most important aspects of the energy audit procedure and therefore will be covered in the next chapter. A procedure developed by a former student to organize the building comprehension aspect of the project can be seen in Figure 17 (Savage, 2017).

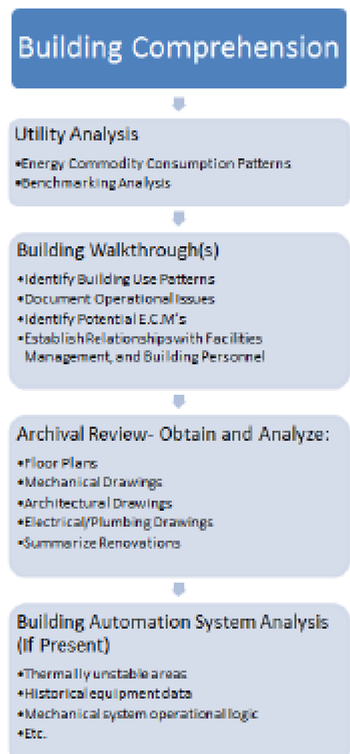


Figure 17: Building Comprehension Details

4.1.1 Building Walkthrough

The first building walkthrough is usually performed in the beginning stages of the energy audit project. It is essentially a walkthrough of the entire building with a facility manager of the building with a focus on mechanical rooms and mechanical equipment. This is the first opportunity to get a day by day understanding of the building's functions and problems through observation and interviews with facility personnel. An example of a problem found during a walkthrough was a hole in one of AHU supply ducts shown in Figure 18.

Ideally, each space within a room will be inspected to identify any potential issues that building might be having. In addition to potential problems, other variables such as plug loads and people loads are mainly identified during the walkthrough. For both PSC and ERC, multiple walkthroughs were conducted to obtain complete comprehension of the building. Typically, a temperature sensor and light meter were taken on the building walkthrough along with a notebook for taking notes. About four walkthroughs were performed in each building.

Figure 18: Issue Found during Building Walkthrough

4.1.2 Building Drawings Review

A drawing review is very important for building the building energy model in that the building drawings discuss everything about the building. For both PSC and ERC, the author used drawings to create the geometry of the building, HVAC systems, building constructions, plumbing system, and electrical systems. For PSC and ERC, building drawings were obtained from the university's facilities management department.

The most important drawings that are reviewed are the floor plans, architectural, mechanical, electrical, and plumping (MEP) drawings. Both PSC and ERC underwent renovations before the project was performed, so the author also had to read the renovation drawings and update any building configuration accordingly from the original drawings. An example of a building drawing from ERC can be seen in Figure 14.

4.1.3 BAS Analysis

The Building Automation System (BAS) is the brain of the building as has been described in the previous chapter. Access was granted to PSC and limited access was granted to ERC during the projects. The BAS generally provides crucial information on the day to day HVAC operations in the building that is used to modify ideal HVAC operations (from drawings) to realistic HVAC operations.

The data from the PSC BAS was vital in creating the PSC building energy model due to the immense amount of data the BAS provided. Current and historical data were available for a wide array of variables such as thermal zone makeup, HVAC schedules, zone temperature set points, and other relevant control points. The author continuously monitored the BAS to identify any issues with the building. One such issue the author found was an immense amount of chilled water being used to dehumidify the basement labs to low levels.

The ERC BAS was much more difficult to access than the PSC BAS. Access for the Talon System was granted to the author which controlled the SCUB in ERC. Data was taken from this BAS to gain a better understanding of how the SCUB operated and any issues in the SCUB operation. Based on observation, there were no significant issues that were identified in the ERC SCUB operations. Access to the MS-1800 BAS system, which controlled all non SCUB related HVAC systems in ERC, was very limited. The author would have to view the BAS from a designated computer in the FM department, which made real time viewing very difficult. Historical data points in the MS-1800 system were also not readily available so many of the parameters easily obtained for PSC were not available for ERC.

4.2 Baseline Building Energy Model Development

After the building walkthrough and building drawings analysis were completed, preliminary building modeling took place. The building drawings play an integral role in the creation of the model with the building walkthroughs and BAS analysis providing the details necessary to complete the model. Figure 19 provides the relationship between the building drawings review (titled archival review), building walkthroughs, and BAS analysis developed by Savage (2017).

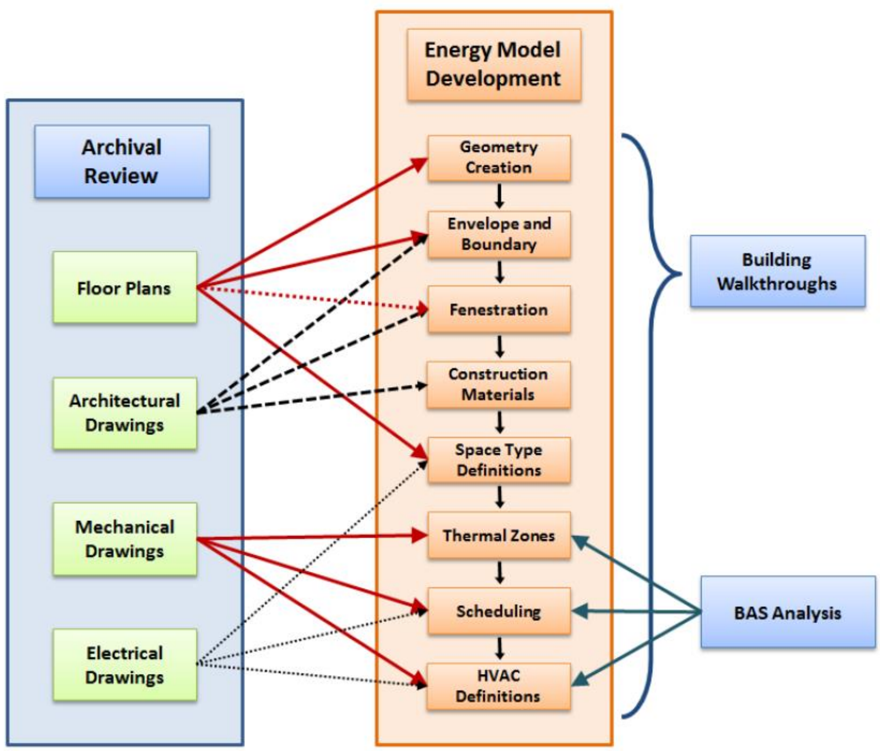


Figure 19: Development Flow of Building Energy Model

As discussed previously EnergyPlus software in combination with OpenStudio and SketchUp were used to generate the building energy model.

SketchUp was used to build the building geometry for both PSC and ERC. The geometry was refined multiple times to lower the node and surface count in the model in order to improve calculation run time. Space types, thermal zones, and building constructions were created and assigned using the OpenStudio plugin in SketchUp.

After the geometry was completed in SketchUp, the model was moved into the OpenStudio software program to complete the building model. Due to the immense amount of options in OpenStudio, HVAC systems in both PSC and ERC were modeled exclusively in OpenStudio with relatively little need to use the EnergyPlus model editor. Internal loads, HVAC loops, plant loops, HVAC schedules, and weather data were inputted using the OpenStudio program. Once completed, initial runs of the building energy model were done using EnergyPlus and compared to actual utility data. If the simulation results did not match with actual utility data, more refinement of the model was done to accurately capture day to day operations.

Due to the immense amount of data from the building energy model, data reduction was key to efficiently assessing simulation results. All results from the EnergyPlus simulation were exported into excel spreadsheet for a more manageable format. This streamlined the analysis of the results obtained from the simulation.

4.3 Energy Efficiency Measures

The fundamental goal for an energy audit is to present Energy Efficiency Measures (EEM) to reduce energy usage and improve energy efficiency within a building. Two the characterizations of an EEM is that it is cost efficient and appropriate for the building the EEM is for and it does not affect occupants residing within a space negatively. During the lifetime of the PSC and ERC project, numerous EEMs were proposed for each building to save on energy consumption.

Unfortunately, many of these EEMs were not cost efficient for UMD's FM to undertake and were then scraped for more cost efficient EEMs with lower payback periods that are comparable to the lifetime of the building. An of a cost inefficient EEM was relocating AHU 201 and 202 in PSC so they are closer to their heat recovery unit which would incur hundreds of thousands of dollars with a small amount of energy savings. The EEMs proposed for PSC are lower cost with limited amount of retrofit due to the high cost, low return financial characteristics for the more extensive EEMs the author proposed. EEMs for ERC are both low cost and high cost EEMs and are categorized as "As-Designed" for lower cost ECMs and "energy efficiency measures" (EEMs) for the higher cost EEMs.

Chapter 5: Utility Analyses

Before the building models were created, a detailed analysis of the historical energy use patterns was conducted to have a fully developed understanding of how each building was performing. This is a crucial piece of the energy auditing process for all levels of energy auditing per the ASHRAE standard (levels 1, 2, and 3). Once calculated, the building energy use profiles are compared with benchmark energy use for similar buildings to determine the building's relative performance. The annual and monthly utility data from the years 2013-2016 are presented for the Physical Sciences Complex in the first section of this chapter along with an analysis of its performance based on benchmark data. A similar process will be done for the Eppley Recreation Center in the second section of this chapter.

5.1 Physical Sciences Complex Utility Analysis

5.1.1 Physical Sciences Complex Historical Energy Consumption

Monthly utility data for electricity and steam was acquired for 2013-2016 using UMD's Enterprise Energy Management (EEM) Suite; monthly chilled water usage was only retrieved for 2015 and 2016 due to chilled water usage values not being recorded prior to this year. The data from the EEM suite software is represented in kWh, pounds, and ton-hour for electricity, steam, and chilled water respectively. Since the outside weather has a strong influence on the energy consumption profile of a building, the monthly utility usage for each year is visualized and then analyzed based on the monthly heating degree days (HDD) and cooling degree days (CDD). The utility usage for electricity, steam, and chilled water can be seen in Figure 20 through Figure 22. The monthly HDD and CDD for the College Park area can be seen in Figure 23 and Figure 24, respectively.

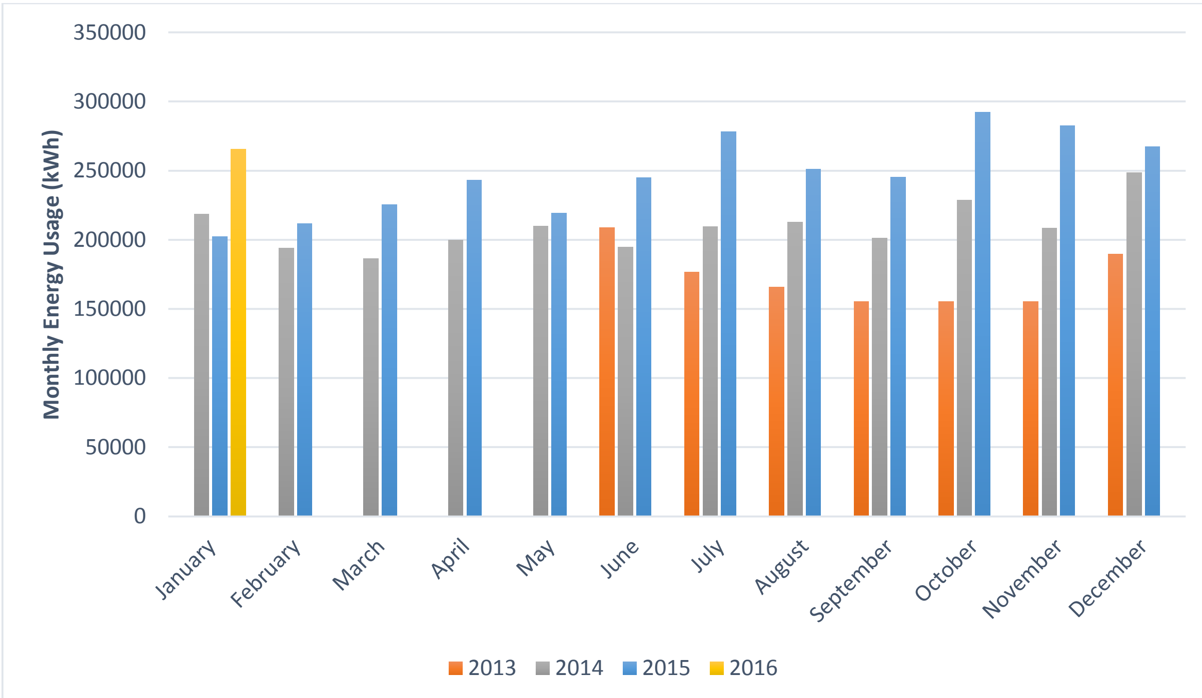


Figure 20: PSC Historical Monthly Electricity Usage

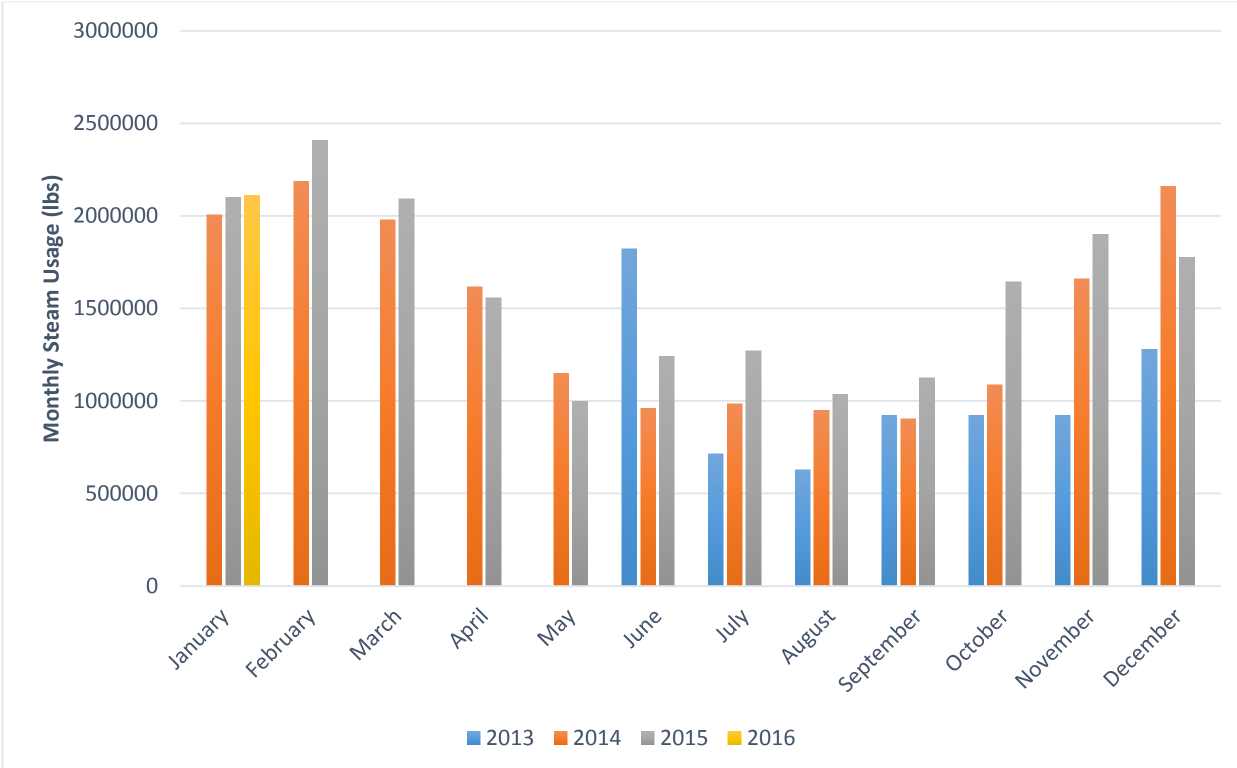


Figure 21: PSC Historical Monthly Steam Usage

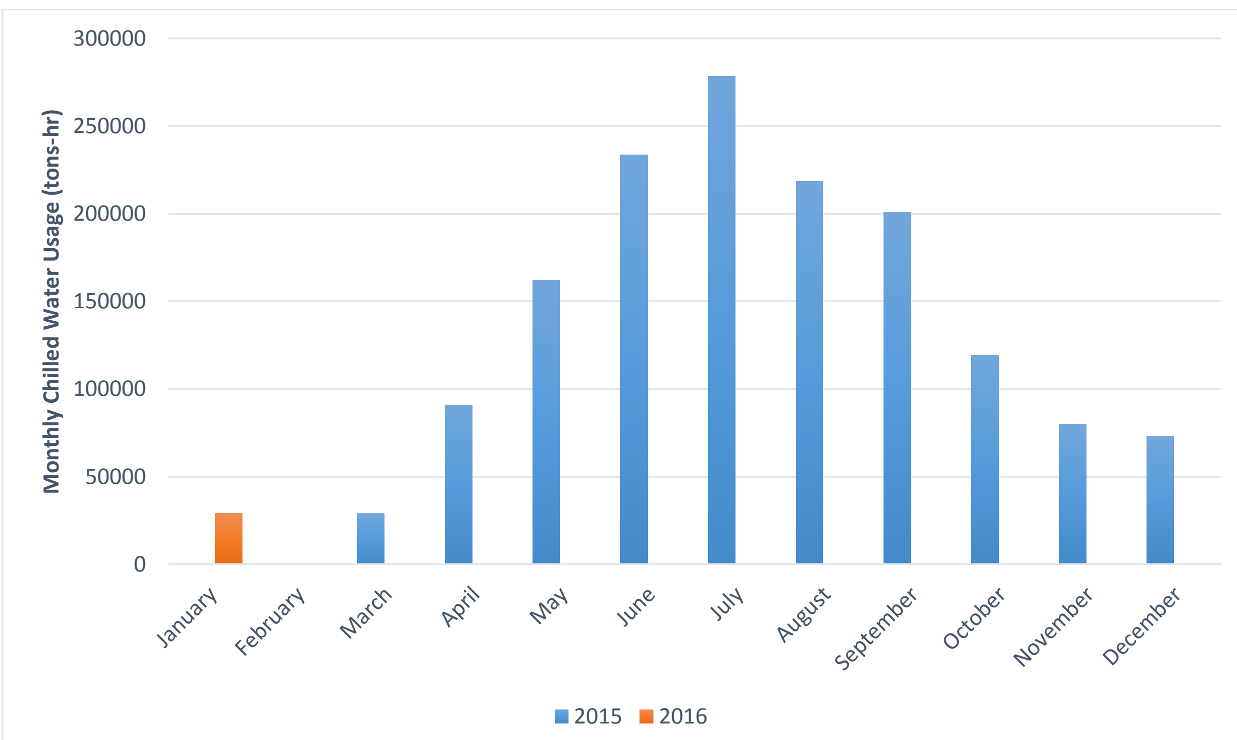


Figure 22: PSC Historical Chilled Water Usage

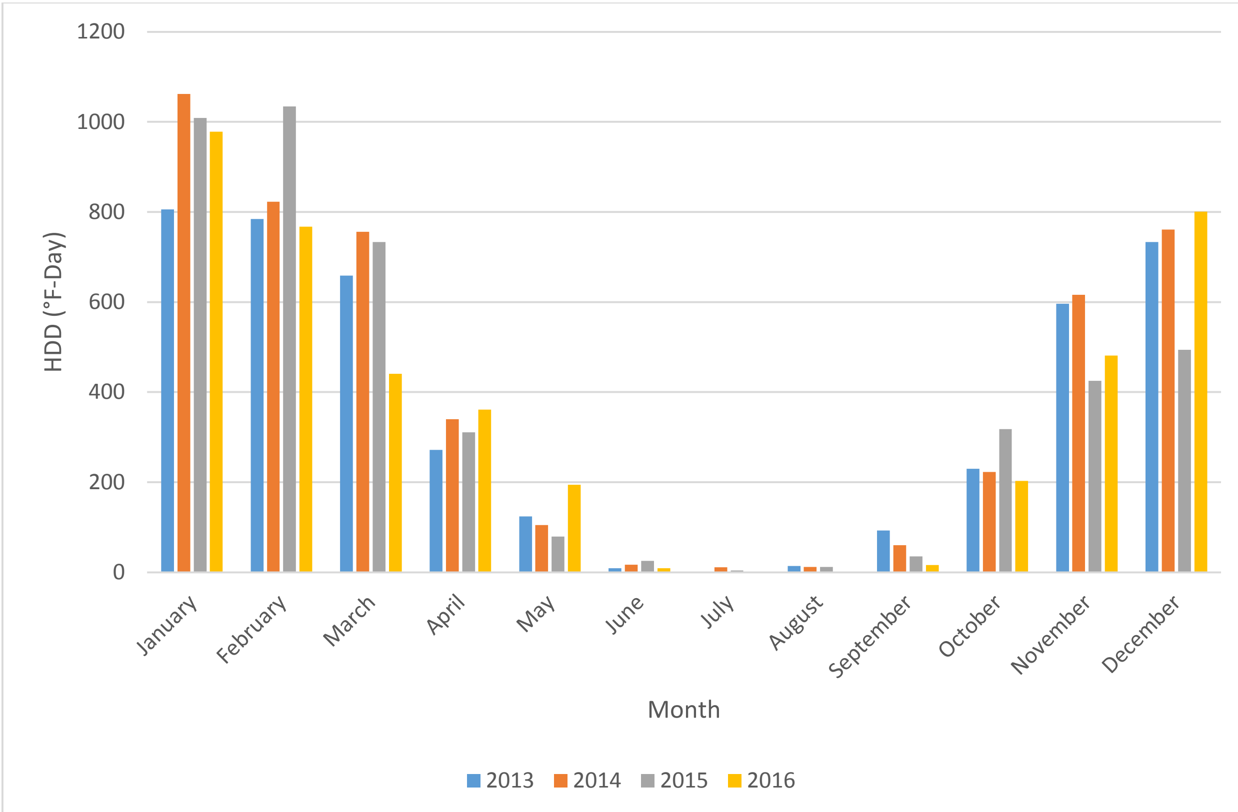


Figure 23: Monthly Heating Degree days for College Park, MD

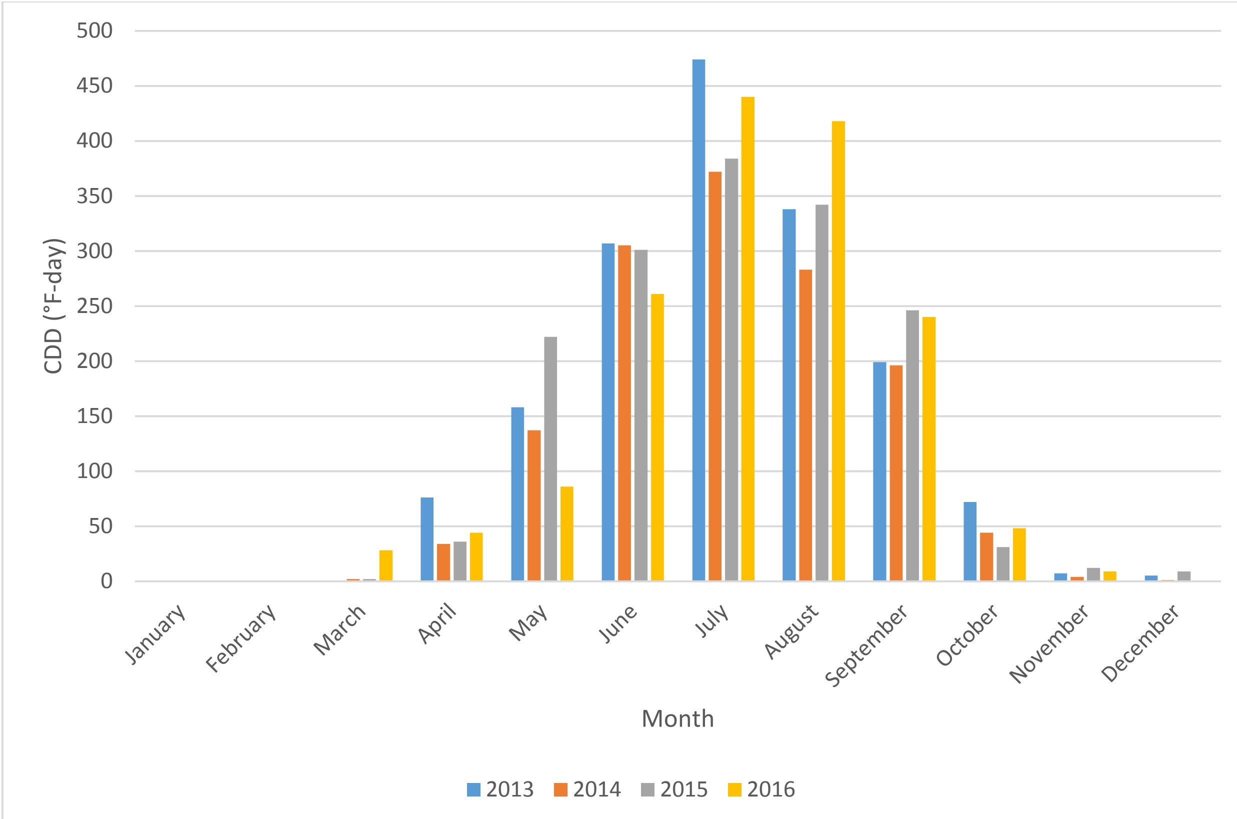


Figure 24: Monthly Cooling Degree days for College Park, MD

As can be clearly seen in Figure 20, electricity consumption in the Physical Sciences Complex increased significantly over the 2013-2016 period. From the beginning of the building's operation in mid-2013 to 2015, the average monthly electricity increased by 43%. The main reason for this significant increase in year over year electricity usage is the fact that the Physical Sciences Complex is a new building and the laboratories are gradually adding more equipment to reach their full operational capability. Once the laboratories reach their full operational capability, the year over year electricity usage comparison is expected to be approximately equal. Although the electricity usage is constantly changing year over year, the monthly electricity usage profile for each year is uniform across the months. This is compatible with the fact that electricity is not used for direct cooling or heating of the building since there are no seasonal variations in the electricity consumption. Monthly average electricity values varied from 175 MWh in 2013 to 250 MWh in 2015.

Steam usage follows a seasonal trend with the highest usage in the winter months and lowest usage in the summer months as can be seen in Figure 21. This trend is normal for a building in College Park, MD due to the cold winters and hot summers since the building is heated through hot water produced from steam in the heat exchangers located in the building. However, there is still significant steam consumption in the summer months although the heating degree days are essentially zero. This summer steam usage is due to the reheating of the supply air with hot water through reheat coils in the majority of the sub-basement and basement labs. Since the supply air is maintained at a constant 55°F all year round to maintain humidity levels in the labs, the room temperature in these labs can become considerably low due to the natural insulation of the ground. Once the zone temperature reaches 68°F, the 55°F supply air must be reheated to meet the zone temperature demands.

Unfortunately, there is not enough data to make any substantial conclusions about the chilled water usage in PSC. Chilled water usage is lowest in the winter months and highest in the summer months for 2015 which is to be expected based on the CDD profile.

Since utility cost is also an important factor when analyzing building energy use, it is worthwhile to perform a brief cost analysis for the Physical Sciences Complex. Auxiliary utilities rates from the UMD Facilities Management team were used to calculate the total cost of utilities for PSC, which can be seen in Table 8. The total utility cost of PSC in 2015 was $1,044,316.

Table 8: Utility Rates and Unit conversion Factors

Utility	**Unit**	**Price per Unit**	**Conversion Factor to kBtu**
Electricity	kWh	$0.1025	3.412
Steam	lb	$0.0298	1.194
Chilled Water	Ton-hr	$0.1700	12

5.1.2 Physical Sciences Complex Benchmarking Study

A benchmark study is a comparison of energy performance of the building being studied and other buildings with similar functions. This is an important component of the energy audit process as it answers the question of "How are we doing in energy performance?" There are many benchmarking databases that are used to compare energy performance of buildings including Department of Energy's Energy Star Portfolio Manager and ASHRAE Standard 100. Due to the numerous functions of PSC, a hybrid approach needed to be developed to accurately assess a proper benchmark for the building. As stated before, PSC is comprised of laboratories, offices, common areas, and a café, therefore the Energy Star Portfolio Manager could not be utilized effectively to provide a benchmark analysis. Instead data was taken directly from the Commercial Building energy Consumption Survey (CBECS), which is the crux of where the Portfolio Manager's data comes from. The Energy Information Agency describes CBECS as the following:

The Commercial Buildings Energy Consumption Survey (CBECS) is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures). Commercial buildings include all buildings in which at least half of the floor space is used for a purpose that is not residential, industrial, or agricultural. By this definition, CBECS includes building types that might not traditionally be considered commercial, such as schools, hospitals, correctional institutions, and buildings used for religious worship, in addition to traditional commercial buildings such as stores, restaurants, warehouses, and office buildings.

ASHRAE Standard 100 is also another useful tool in benchmarking as it highlights both normal and energy efficient building performance. ASHRAE Standard 100 was used to benchmark for both normal and energy efficient building performance for some more common spaces, such as offices, in conjunction with the CBECS database.

Lastly, since the CBECS database and ASHRAE Standard 100 database both have limited data on laboratories, so another resource was needed to identify an appropriate benchmark for the laboratories in PSC. The Lab21 benchmarking tool was developed by Lawrence Berkeley National Laboratory (LBNL) and has a data base of 760 laboratory buildings around the United States as of the data of this paper's publication (I2SL, 2010). LBNL describes their sources in their database as follows:

The data in the Labs21 tool was provided by a wide range of laboratory owners and operators in the United States, including federal government agencies, universities, pharmaceutical companies, and other organizations. Identities of the buildings and organizations in the database are masked for confidentiality. The Lab21 database also includes 14 buildings from the U.S. Department of Energy's CBECS dataset.

Only laboratory buildings having occupancy hours of 80 hours or less, in ASHRAE climate zone 4A, with physical lab type were considered from the Lab21 database. The definition of a physical space according to Lab21 is "Since the total lab space was calculated at 23.2% of the entire building space, laboratory buildings with a lab area ratio to gross area of 0.0 - 0.3 were considered. Seven laboratory buildings fit the above criteria; taking the mean average of the dataset resulted in a EUI of 357.5 kBtu/ft^2-yr.

Taking PSC's space types into consideration, the overall calculated benchmark EUI for PSC is 233 kBtu/ft^2-yr. PSC's EUI, calculated from utility data from 2015, is 294 kBtu/ft^2-yr. Based off of this benchmark study, PSC has some room to become more energy efficient.

5.2 Eppley Recreational Center Utility Analysis

5.2.1 Eppley Recreational Center Historical Energy Consumption

Monthly utility data for electricity, gas, and hot water was acquired for 2013-2016 using UMD's Enterprise Energy Management (EEM) Suite. The data from the EEM suite software is represented in kWh, pounds, and therms for electricity, steam, chilled water, and gas respectively. Steam is also measured in ERC, but since some of the hot water produced by the steam is delivered to the Public Health building, steam consumption does not reflect actual steam usage by ERC. Chilled water usage is also metered in ERC, but it does not account for efficiency losses in the chillers, therefore chilled water usage is also not presented.

Since the outside weather has a strong influence on the energy consumption profile of a building, the monthly utility usage for each year is visualized and then analyzed based on the monthly heating degree days (HDD) and cooling degree days (CDD). The utility usage for electricity, heated water, and gas can be seen in Figure 25 through Figure 27. The monthly HDD and CDD for the College Park area can be seen in Figure 23 and Figure 24, respectively.

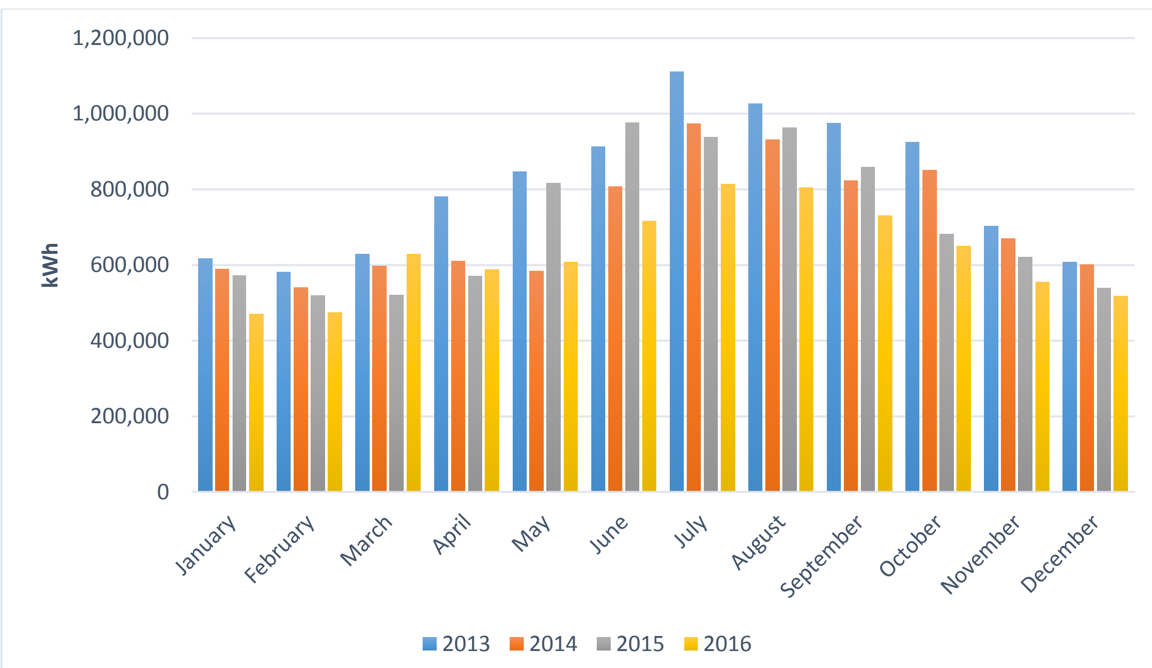


Figure 25: ERC Historical Monthly Electricity Usage

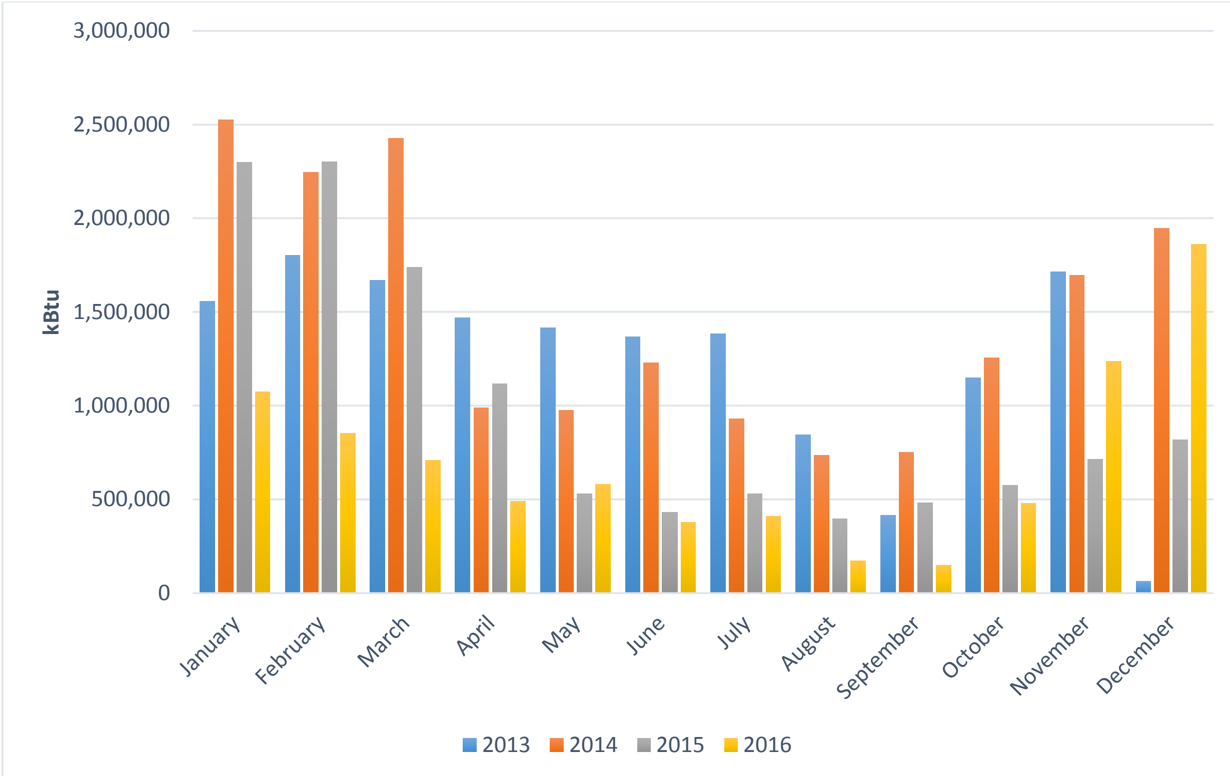


Figure 26: ERC Historical Monthly Hot Water Usage

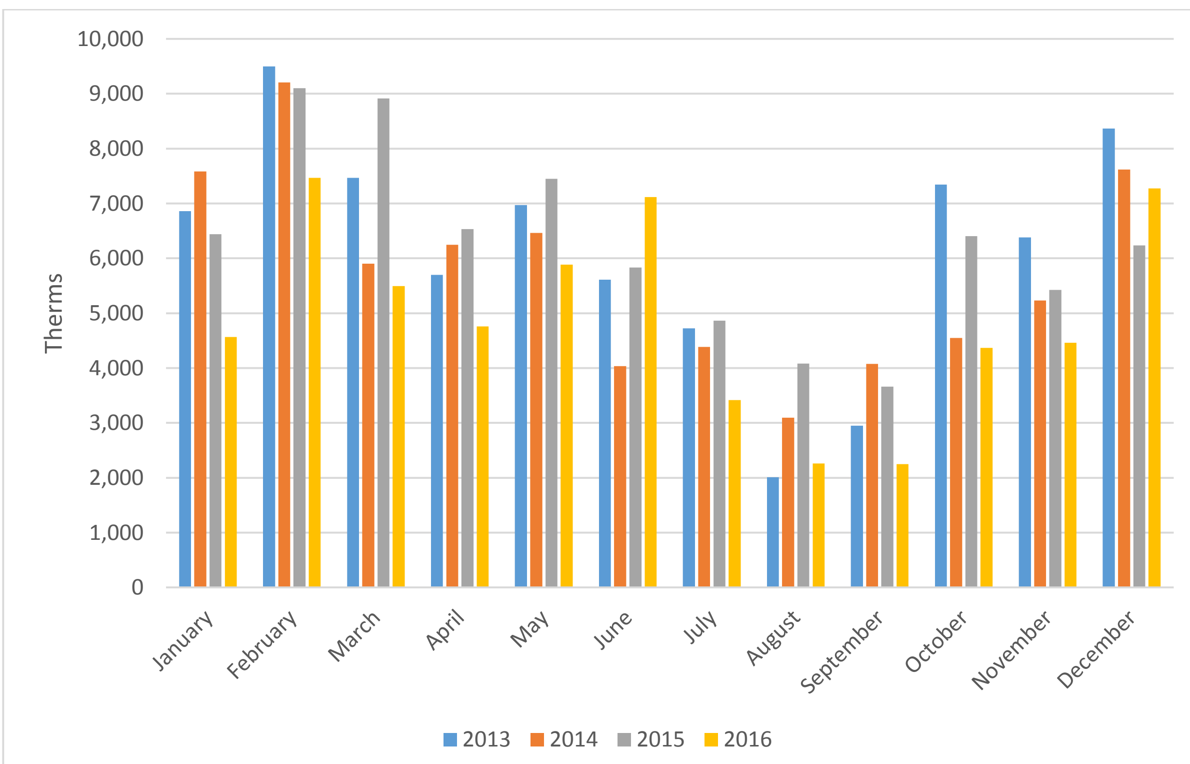


Figure 27: ERC Historical Gas Usage

As can be seen in Figure 25, electricity usage in ERC is highest in the summer months and lowest in the winter months. This is due to the higher chilled water production needed to condition ERC in the summer months. Electricity demand from 2013 to 2016 has decreased from month to month on an average rate of 21%. This is not attributable due to a change in the weather since the total cooling degree days is only 3% higher in 2013 compared to 2016. The decrease in electricity is due to an optimization in the chiller BAS algorithm that took place in the 2014-2015 time period. The change in algorithm optimized the way in which the chillers share the load. Instead of one chiller taking the full load until it is maxed out, the algorithm takes advantage of the chiller's part loading. This significantly saves on electricity consumed by the chillers. In the winter months, the electricity consumption is around 450MWh, which correlates to the non-cooling electricity load of the building. This can be verified by looking at the chilled water consumption and comparing it to the electricity consumption. Figure 28 shows the chilled water consumption of ERC from 2013 to 2016. During the January and February months, it is evident that there is no chilled water usage, which confirms that 450MWh is ERC's non-cooling electricity usage.

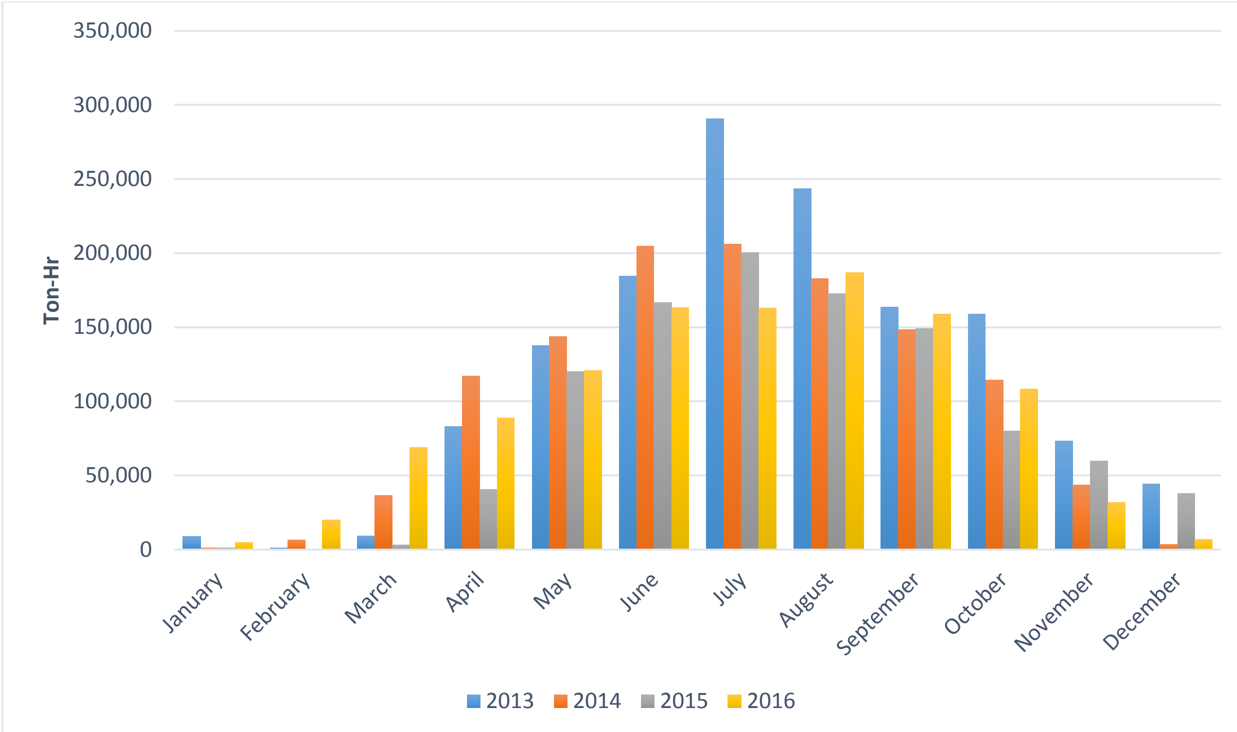


Figure 28: ERC Chilled Water Usage

Hot water usage correlates to the heating demand in ERC which is seen in Figure 26. It can be seen very clearly that from 2013 to 2016, hot water usage decreased significantly month over month. This decrease in the hot water usage does not correlate with the weather since the heating degree days from 2013 to 2016 does not change significantly. Assuming that the shower load maintains a constant demand throughout the years, the reduction in hot water usage correlates to less hot water being used for conditioning the building. The author has tried to understand on numerous attempts by interviewing facilities management personnel why this hot water reduction occurred. However, the author failed to find the reasoning for this reduction.

Gas is primarily used to fuel the pool water heaters. Gas consumption fluctuates throughout the year which is characteristic of the pool water heating demand. Typically during swimming meets, this demand is much higher than normal which is evident in the drastic changes of gas consumption month to month.

Since utility cost is also an important factor when analyzing building energy use, it is worthwhile to perform a brief cost analysis for the Eppley Recreational Center. Auxiliary utilities rates from the UMD Facilities Management team were used to calculate the total cost of utilities for ERC, which can be seen in Table 8. The total utility cost of ERC in 2016 was $2,034,767

5.2.2 Eppley Recreational Center Benchmarking Study

The CBECS database that was used to compute a benchmark EUI for PSC was not sufficient in itself to calculate a bench mark EUI for ERC. Data on gymnasiums was limited to typical commercial gyms that did not contain large natatoriums. Also the sample size for the EUI data on gymnasiums in CBECS was small and was not ideal for use in this analysis.

The UK government created a building energy efficiency program called the "Best Practice Programme". The program has an excellent database on gymnasiums and was used to calculate benchmark EUIs for the gymnasium aspects of ERC. In its white paper titled "Energy Use in Sports and Recreation Buildings", multiple types of gym layouts including natatoriums, exercise studios, weight rooms, and basketball court areas are discussed; all of which were used in the calculation of the ERC EUI benchmark. The paper details EUI benchmarks of typical gymnasiums and high performing gymnasiums to distinguish normal gyms and state of the art gyms that have invested heavily in energy efficiency. In addition to energy efficiency classification, usage levels for these spaces were also classified. For example, a gym that is only open 8-10 hours a day with minimal usage would be classified as a low usage level. A gym which is open 18 hours a day with high usage would be classified as very high usage. Based on gym usage data and statistics given to the author by RecWell, ERC is classified as a very high usage gym. Therefore, EUI values for high usage spaces from the report were used to calculate the benchmark EUI.

As highlighted before, ERC also contains typical office spaces. The CBECS database was used to calculate a benchmark EUI for the office spaces. Based on ERC's building layout, a benchmark EUI was calculated at 301.78 kBtu/ft^2 for a typical gym and 156.86 kBtu/ft^2 for a high performing gym. The EUI calculated based off of 2016 utility data for ERC was 243.67 kBtu/ft^2. Based off this benchmark study, ERC is energy efficient given its functionality and building age.

Chapter 6: Energy Models

6.1 Physical Sciences Complex Baseline Energy Model

6.1.1 Energy Model Overview

The geometry of PSC was modeled in Sketchup using an Open Studio toolbox plugin to the program; PSC construction drawings were used as reference in modeling the building. Wall, door, and window dimensions were taken directly from the construction drawings using the reference scale. All dimensions were measured to the nearest inch to capture the building volume accurately. Internal doors and windows were not modeled since they would not contribute much value to the results and would only lengthen run times. External window areas were calculated for each area of the six floor modeled to accurately capture solar loading into the building. Figure 29 shows the 3-D rendered version of the PSC energy model.

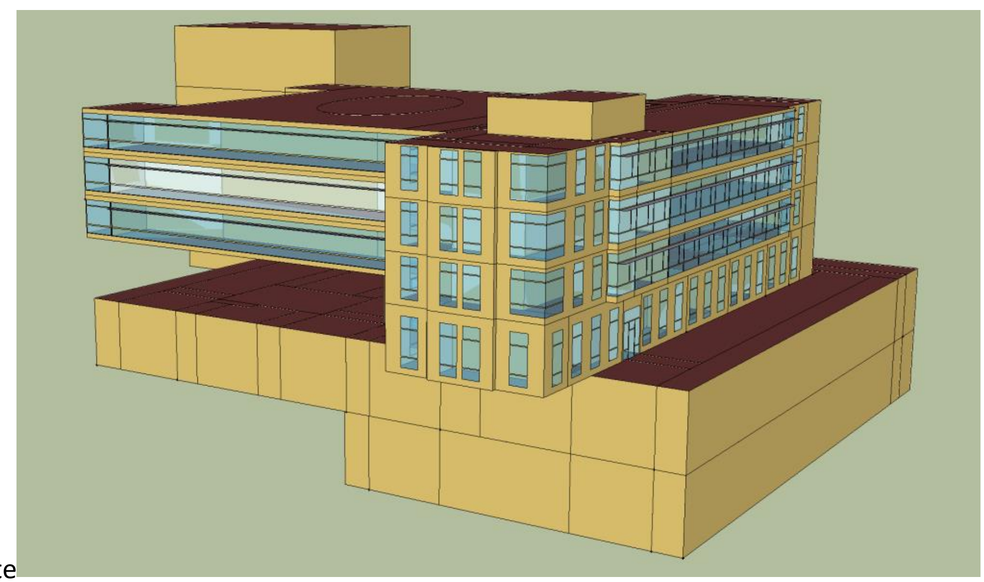
ste

Figure 29: PSC Energy Model rendered in Sketchup

Some of the areas within the building were simplified in order to reduce the calculation time while running the model. For example a group of offices would be simplified into one room instead of modeling each room separately. These grouped rooms would inherit the temperature set points, internal loads, occupancy loads, and daylighting characteristics.

PSC has over 300 thermal zones, each zone having a VAV box controlling air flow into the space that is linked to its own thermostat. The PSC energy model was simplified into 105 thermal zones with its own VAV box and thermostat settings. Space types characterize occupancy loads, plug loads, air infiltration rates, and other associated schedules that define spaces. Space types were created for PSC through interviews, observations, analysis of the drawings, and ASHRAE standards. Twenty space types were used in the PSC model. Each wall was assigned a construction based on review of construction documents. Figure 30 through Figure 32 show the second floor of the PSC model rendered by space type, boundary condition, and construction respectively.

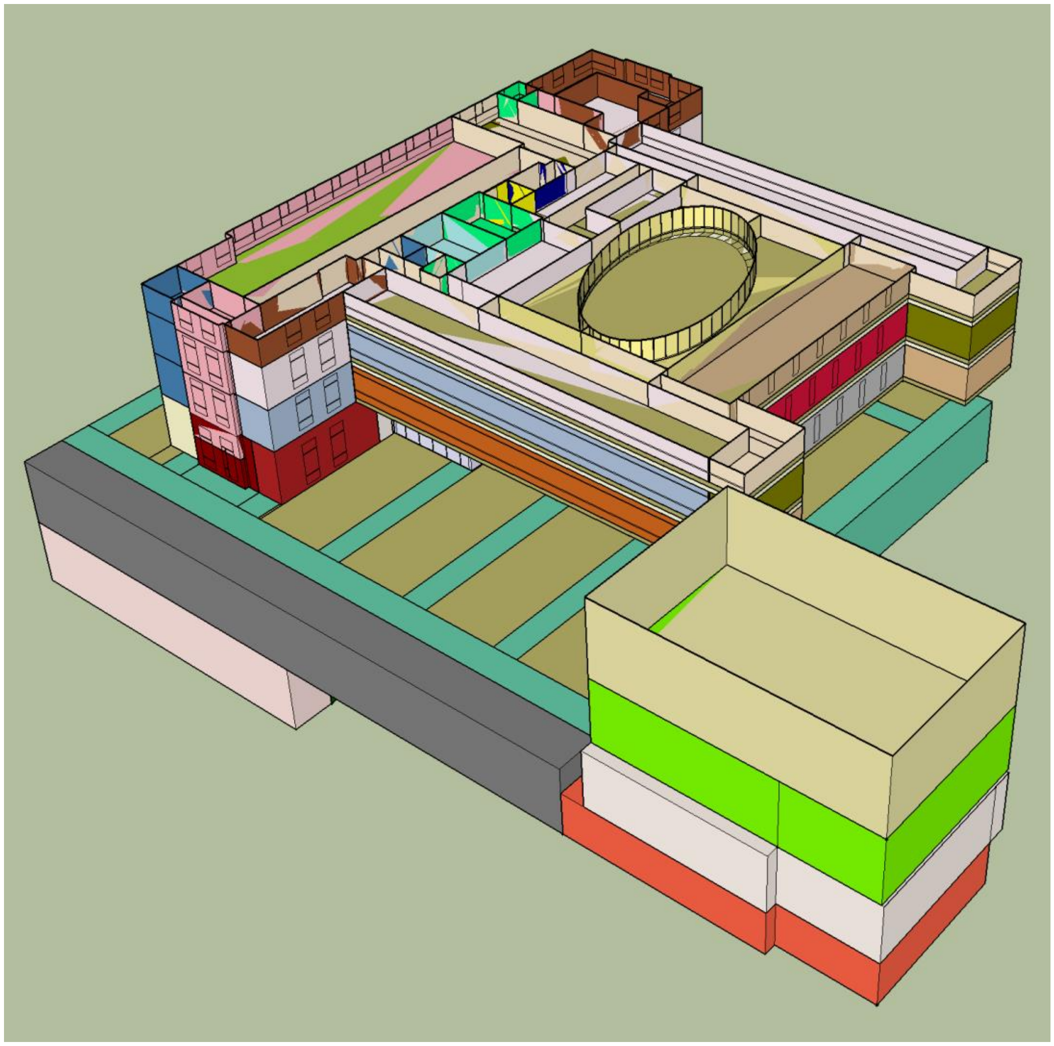


Figure 30: PSC energy model rendered by space type

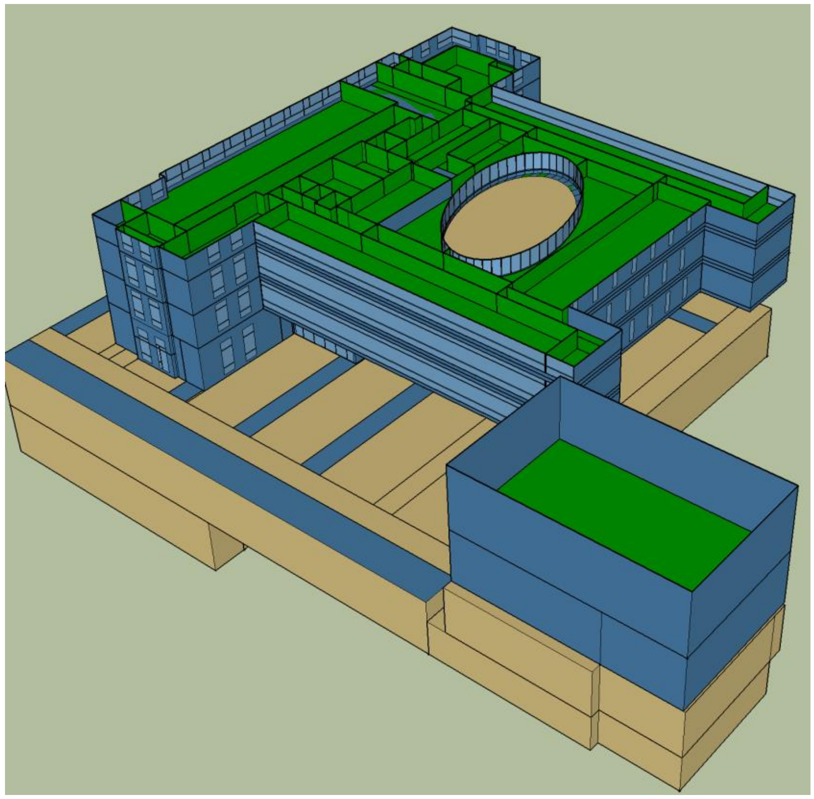


Figure 31: PSC energy model rendered by boundary condition

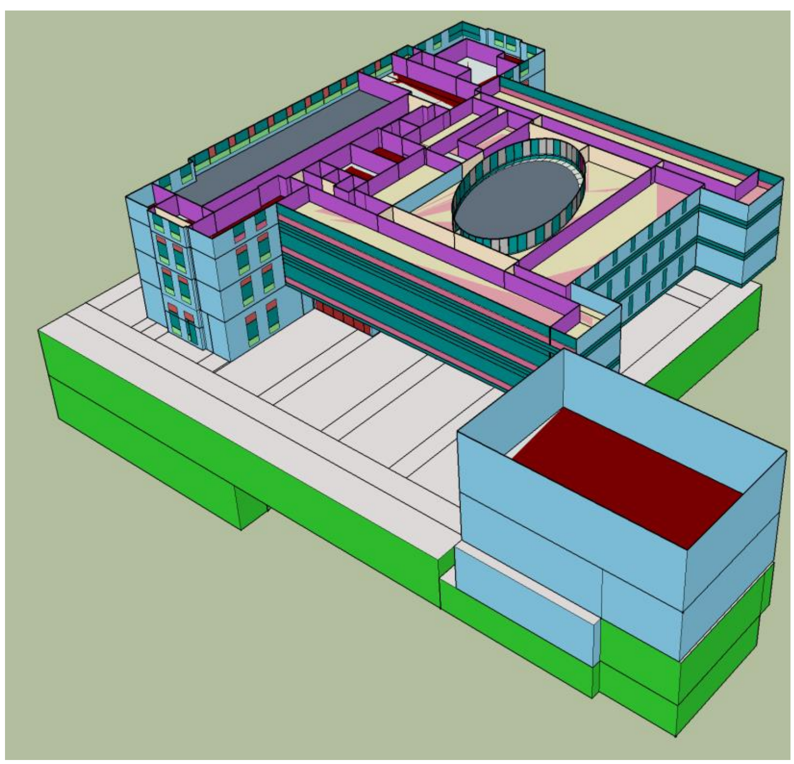


Figure 32: PSC energy model rendered by construction

6.1.2 Energy Model Results

In order to make predictions based on the energy model, the model must first be calibrated to actual utility data. As discussed in Chapter 3, PSC receives electricity, district chilled water, and district steam. Monthly data for each of these commodities for 2016 were compared to the model results for each month. 2016 was picked as the year to compare due to the continually increasing occupancy and building usage since it's a new building with tenants still moving in. The baseline energy model closely resembles that of the actual utility data will be discussed further.

Figure 33 shows the comparison of electricity from the utility data given and model predicted. Total annual electricity consumption deviates -1.05% from the actual electricity of PSC. Slightly higher electricity usage values were predicted in the winter months whereas slightly lower electricity usage rates were predicted in the fall months.

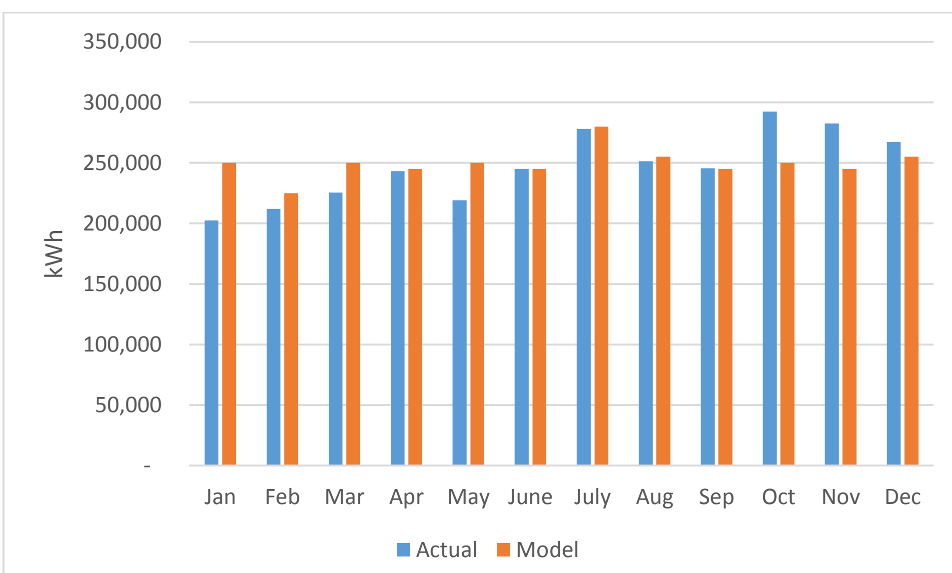


Figure 33: Electricity data comparisons between utility bills and model

The main inputs for electricity rates were lighting loads, plug loads, and HVAC equipment. Not all of the plug loads were known for all of the spaces in the building, so discrepancies between the actual usage and predicted usage should be expected.

Figure 34 shows the side by side comparison for steam usage in PSC for actual utility data and energy model predicted usage. As can be seen in the figure, steam was highly overestimated during the summer months and overestimated in the winter months. As will be discussed later, there is a significant heating load in the basement labs during the summer due to substantial cooling to maintain a low humidity level in the basement laboratories. Much effort was spent trying to capture this phenomenon, however this effect could not be adequately captured in Open Studio. The annual energy model steam consumption deviates by 1.19% compared to the actual utility usage.

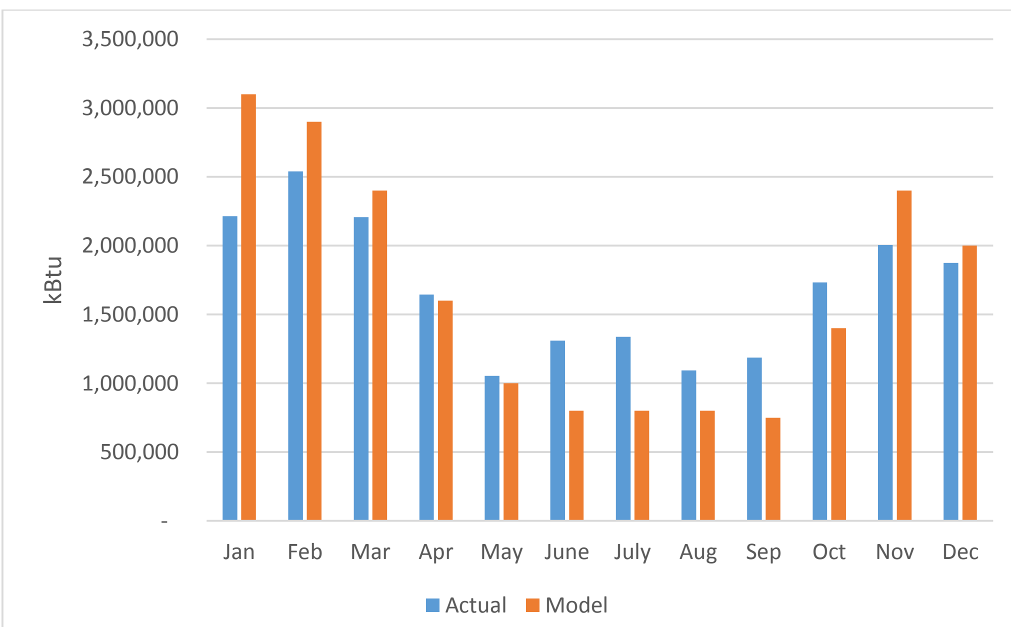


Figure 34: Steam data comparisons between utility bills and model

Figure 35 shows the comparison between the actual utility usage and energy modeled predicted usage for chilled water (CHW). CHW consumption was underestimated during the winter months and overestimated in the summer months. Total annual deviation of the predicted CHW consumption to the actual CHW usage was 5.27%.

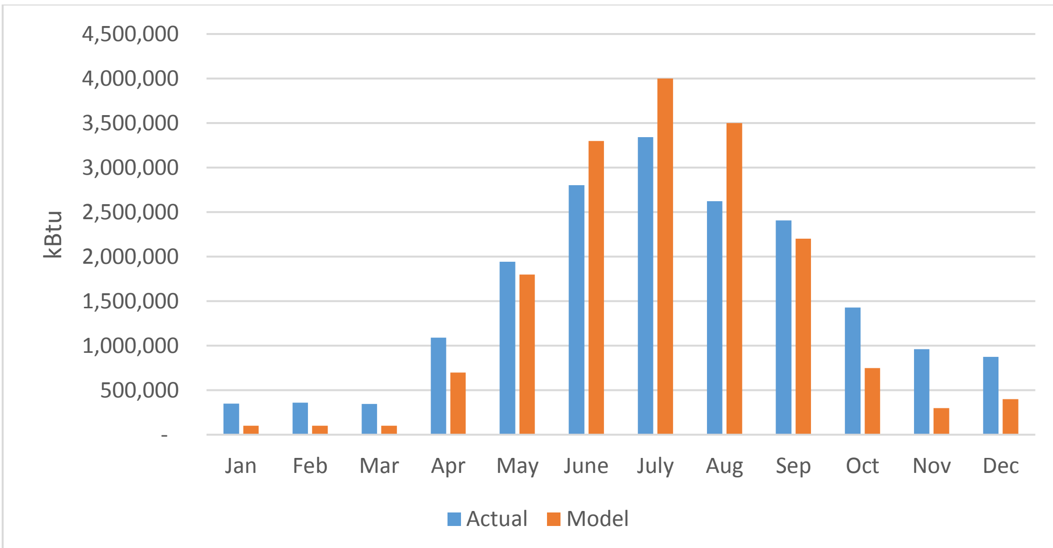


Figure 35: Chilled water data comparisons between utility bills and model

Figure 36 shows the breakdown of the PSC energy model results by end use. From the utility analysis in Chapter 5, it was determined that 41.3% of total energy use was used for heating, 38% for cooling, and 20.7% for electricity based equipment like the lighting systems. Model discrepancies based on end use vary by at most 3% from utility data.

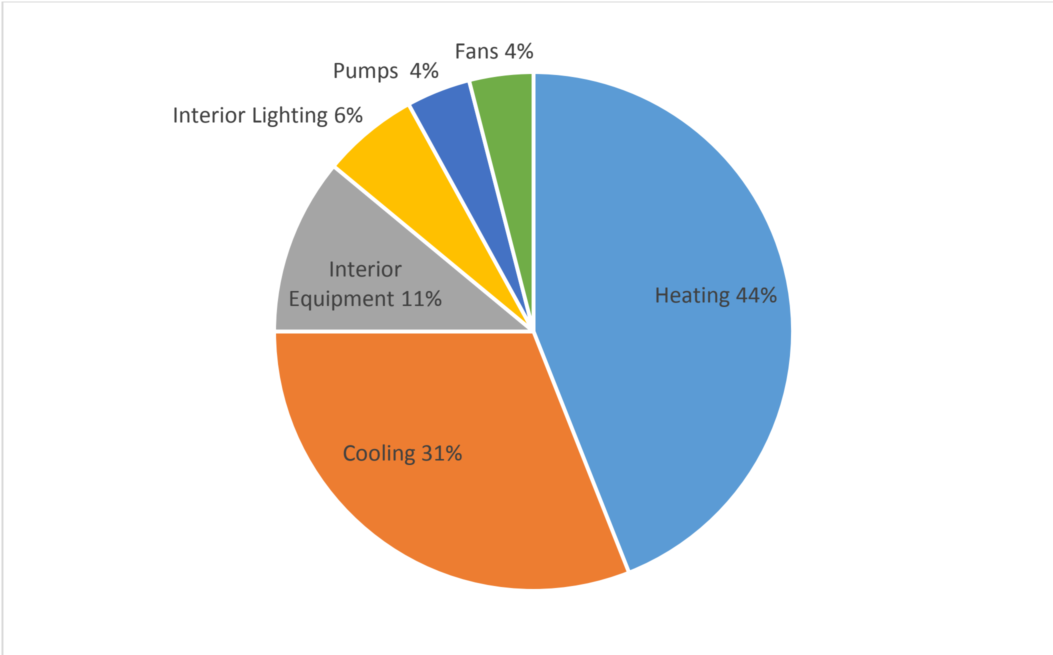


Figure 36: PSC Simulation Energy Use by End-Use

6.1.3 Uncertainty Analysis

An important component of building energy modeling is calibrating and performing sensitivity testing of the model to determine model uncertainty. An uncertainty analysis was performed varying eight parameters. The parameters were chosen based on how influential they are to the thermal model. Table 9 lists the parameters that were used in the sensitivity analysis and their respective low and high values. Figure 37 shows the results from the sensitivity analysis performed on the PSC building energy model.

Table 9: PSC Energy Model Sensitivity Analysis Parameters

Parameter	Unit	Baseline Value	Low Value	High Value
Infiltration	cfm/ft^2	0.12	0	0.25
Lighting Intensity	W/ft^2	0.844	0.5	1.5
Plug Load Intensity (PSC Labs)	W	35000	20000	50000
Zone Cooling Setpoint Temperature	°F	68	64	72
AHU Supply Fan Pressure Rise	inH20	2	0	4
Above Ground Window Thermal Conductivity	Btu-in/ft^2-h-R	0.71178	0.25	1.25
Occupant Density	People/ft^2	0.1	0	0.3
Weather File Location	N/A	Washington DC	Dulles	Philadelphia

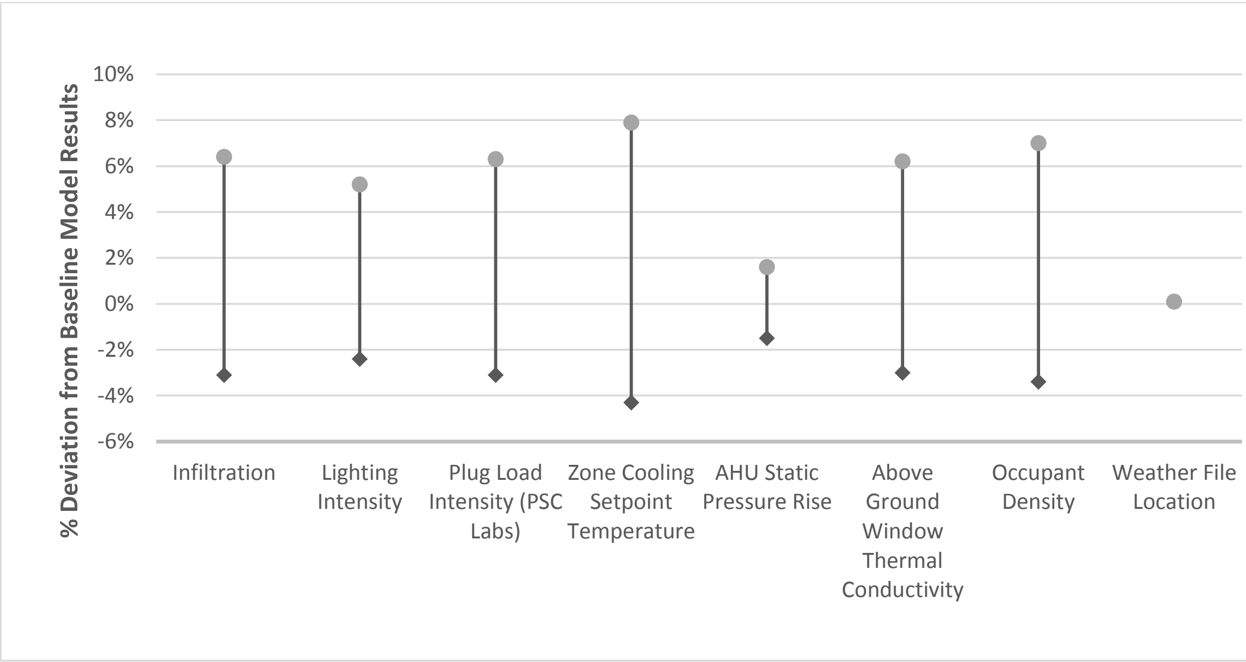


Figure 37: PSC Energy Model Sensitivity Analysis Results

6.2 Physical Sciences Complex Energy Efficiency Measures

Energy efficiency measures (EEMs) were identified for PSC which were deemed economically feasible with sufficient payback periods comparable to the lifetime of the building and did not impede on building functionality. Other EEMs were identified that did not meet this criteria, therefore they were will not be wholly detailed in this paper. These EEMs include the following:

- Moving AHU 201 and 202 closer to their heat recovery unit (HRU) to reduce fan energy consumption (too expensive)
- Raising temperature set point in basement labs (humidity levels are required to be very low for optics labs)

6.2.1 PSC EEM #1 – Ground Floor and Type 2 Lab Schedule Changes

Through numerous walk-throughs of PSC, the occupancy profiles of each of the spaces, except for the basement labs which required special access. Occupancy schedules were compared to the BAS schedules that were implemented in the building. Based on this research, it was determined that the HVAC schedule for the first floor type 2 lab schedules was not in line with occupancy patterns. Second and third floor HVAC schedules were set to be on during weekdays from 6am-8pm.

Typical occupancy patterns for the first floor type 2 labs were from 8am-8pm with HVAC scheduling implemented in these spaces on a 24/7 basis. Based on interviews conducted with facilities management staff and lab occupants, there are no temperature or humidity sensitive equipment in the labs. Therefore a schedule change for the type 2 labs would not impact functionality of the spaces. A proposed schedule change from 24/7 to weekdays 6am-8pm was analyzed using the PSC building energy model.

In addition to changing the HVAC schedule for the first floor type 2 labs, changes to the ground floor HVAC schedule have also been identified. The ground floor HVAC schedule is set to operate from 6am-10pm for weekdays and weekends.

Based on occupancy inspections, the building is normally closed on the weekends with no occupants on the ground floor. Therefore, the HVAC schedule for the ground floor can be changed to "unoccupied" during the weekend. A summary of the planned HVAC schedule changes can be seen in Table 10. Energy savings resulting from this EEM are shown in Table 11.

Table 10: PSV HVAC Schedule Changes Description

Space Type	WD Morning	WD Afternoon	WD Night	Weekend
1st Floor Type 2 Labs	Occupied	Occupied	Unoccupied	Unoccupied
Ground Floor	Occupied	Occupied	Unoccupied	Unoccupied

Table 11: PSC EEM #1 Energy Savings

	CHW (MMBTU)	ELECTRICITY (MMBTU)	STEAM (MMBTU)	TOTAL ENERGY SAVED (MMBTU)
ANNUAL ENERGY SAVED	370	30	390	790
% REDUCTION	1.9%	0.2%	1.9%	1.6%
ANNUAL COST REDUCTION	$5.241	$901	$8,800	$14,942

It should be noted that HVAC scheduling changes for the type 1 labs in the basement were assessed, but due to the sensitive nature of the instruments, a 24/7 HVAC schedule is necessary to maintain functionality of the spaces.

6.2.2 PSC EEM #2 - Ventilation Reduction in PSC Offices

During the BAS analysis, air change rates per hour (ACH) were calculated for all spaces and compared with ASHRAE 62.1-2010 standards. The average office ACH was calculated to be about 3.07 changes per hour while the minimum ACH according to ASHRAE 62.1-2010 is 1.2 changes per hour. Air ventilation rates can be changed for the office spaces through changing control set points for the VAV air terminal units in the offices. Reducing the air change rate will reduce the make-up air needed for the offices which saves on energy by reducing make-up air conditioning. This EEM was simulated by changing the air supply rates from the air terminal units in the office spaces. Table 12 shows the energy consumption reduction in relation to this EEM.

Table 12: PSC EEM #2 Energy Savings

	CHW (MMBTU)	ELECTRICITY (MMBTU)	STEAM (MMBTU)	TOTAL ENERGY SAVED (MMBTU)
ANNUAL ENERGY SAVED	420	40	270	730
% REDUCTION	2.1%	0.4%	1.3%	1.4%
ANNUAL COST REDUCTION	$5,950	$1,201	$6,148	$13,299

6.2.3 PSC EEM #3 – LED Lighting Replacement

As has been described in PSC's lighting description, T8 fluorescent lighting is predominantly used in the building. LED lighting is quickly becoming a more viable lighting source with decreases in price which make it more comparable to fluorescent lighting. Typically there are two ways of converting a fluorescent lighting system into an LED one: replacing fluorescent light bulbs with LED ballast compatible bulbs or rewiring the ballast fixture to install typical LED lamps. For PSC, both options are compared and assessed.

PSC has approximately 3,000 lighting fixtures that can be converted into LED lighting systems. Due to UMD building standards, an LED replacement should replace the fluorescent bulb with comparable lighting temperature, lighting levels, and color rendering index (CRI). Table 13 shows the option of replacing the fluorescent bulbs with comparable LED bulbs.

Table 13: PSC Lighting Summary

Lamp Types	Number of Fixtures	Wattage	LED Replacement Wattage (W)
T8 (4' and 3')	93	57	25.
T8 (4')	2724	32	1
T5HO	222	54	2
CFL	520	32	1
CFL	42	26	[illegible]
CFL	48	42	1
NFL (café)	10	35	1

The benefit of rewiring the lighting fixture to bypass the ballast is that the electricity draw from the lighting ballast is removed. Typically lighting ballast consume about 3-7W of power per lighting fixture, therefore electricity reduction will be more with this option. Table 14 details the energy savings and cost for each option. The higher cost associated with rewiring the ballast is due to added material and labor cost needed.

Table 14: LED Lighting Replacement Energy Savings and Cost

	ELECTRICITY (MWH)	INITIAL COST	ANNUAL COST SAVINGS	PAYBAC PERIOD
OPTION 1 – REPLACE FLOURESCENT LIGHTS	346.3	$76,122	$35,500	2.14 year
OPTION 2 – REWIRE LIGHTING FIXTURES FOR LED	371.1	$157,642	$38,038	4.14 year

6.2.4 PSC EEM #4 – Type 1 Labs Unoccupied Ventilation Rate Setback

During unoccupied hours, air change rates in the type 1 labs maintains the same ventilation rates as occupied hours. The air change rates per hour during occupied and unoccupied hours averages around 4.6 per hour for the type 1 labs. Typically, laboratory ventilation rates are much higher than that of normal spaces due to hazardous chemicals that could potentially be used in the laboratory. For the type 1 labs in PSC, based on interviews with facilities management personnel, hazardous chemicals are not permitted in these labs due to their classification. Therefore, the ventilation rates of these labs can be reduced during the unoccupied hours without compromising the lab's functionality.

Per ASHRAE 62.1-2010, minimum ventilation rates in university laboratories is 0.18 cfm/ft^2 which corresponds to a minimum ACH rate of the type 1 labs of about 2 changes per hour. This EEM was simulated using the PSC building energy model by changing the ventilation schedule of the VAV air terminal units during the unoccupied hours. Table 15 shows the energy and cost savings associated with EEM.

Table 15: Type 1 Labs Unoccupied Ventilation Adjustment Savings

	CHW (MMBTU)	ELECTRICITY (MMBTU)	STEAM (MMBTU)	TOTAL ENERGY SAVED (MMBTU)
ANNUAL ENERGY SAVED	327	94	550	971
% REDUCTION	1.5%	0.9%	2.6%	1.9%
ANNUAL COST REDUCTION	$4,630	$2,822	$12,671	$20,123

6.3 PSC Savings Summary

The majority of EEMs proposed for PSC have a reality low cost associated with except for the LED lighting replacement. Therefore, upon implementation, the university will see an immediate return on investment. Table 16 shows the summary of EEMs proposed for PSC. The second option for the LED replacement EEM was chosen over the first option due to higher energy savings associated with it.

Table 16: PSC EEM Summary

EEM	CHW (MMBtu)	Electricity (MMBtu)	Steam (MMBtu)	Total (MMBtu)	Energy Savings %	Utility Savings ($)
EEM #1	370	30	390	790	1.6%	14,942
EEM #2	420	40	270	730	1.4%	13,299
EEM #3	0	1,266	0	1,266	2.6%	38,038
EEM #4	327	94	550	971	1.9%	20,123
Total	1,117	1,430	1,210	3,757	7.5%	86,402

6.4 Eppley Recreational Center Baseline Energy Model

6.4.1 Energy Model Overview

The geometry of ERC was modeled in Sketchup using an Open Studio toolbox plugin to the program; ERC construction drawings were used as reference in modeling the building. Wall, door, and window dimensions were taken directly from the construction drawings using the reference scale. All dimensions were measured to the nearest inch to capture the building volume accurately. Internal doors and windows were not modeled since they would not contribute much value to the results and would only lengthen run times. External window areas were calculated for each area of the six floor modeled to accurately capture solar loading into the building. Figure 38 shows the 3-D rendered version of the ERC energy model.

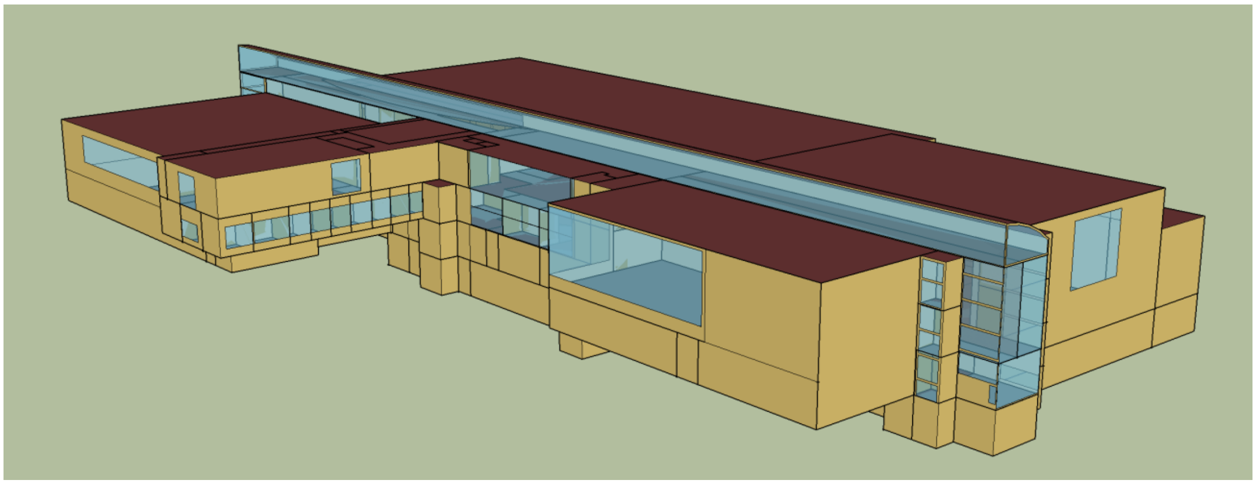


Figure 38: ERC Building Energy Model Rendered in SketchUp

Since the spaces in ERC are very big, the spaces were kept as is and not combined like the PSC model. The spaces' temperature set points, internal loads, occupancy loads, and daylighting characteristics were set based on research in the building and on the BAS. Since BAS information was limited for temperature set points, the author used ASHRAE standards of 68°C for the heating set point and 72°C for the cooling set point.

ERC has 12 thermal zones which correlate to the 12 AHUs that service the building. Since most of the spaces did not utilize reheat to alter the supply air temperature from the AHU, the author didn't find it necessary to divide the building into more thermal zones like PSC. The majority of spaces in ERC are relatively the same, so space types were not used in the ERC model. Each wall was assigned a construction based on review of construction documents. Figure

39 and Figure 40 show the exterior of the ERC model rendered by boundary condition and construction respectively.

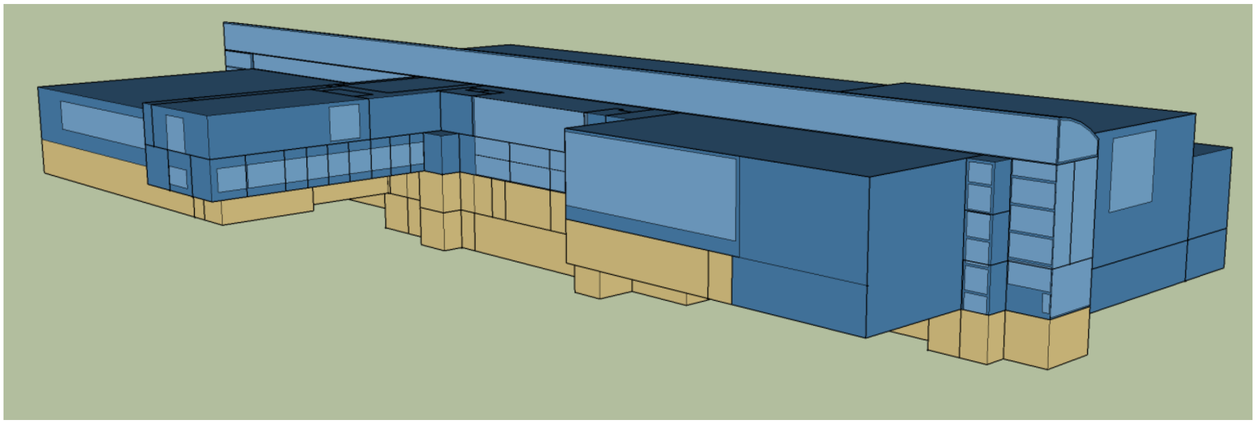


Figure 39: ERC Energy Model Rendered by Boundary Condition

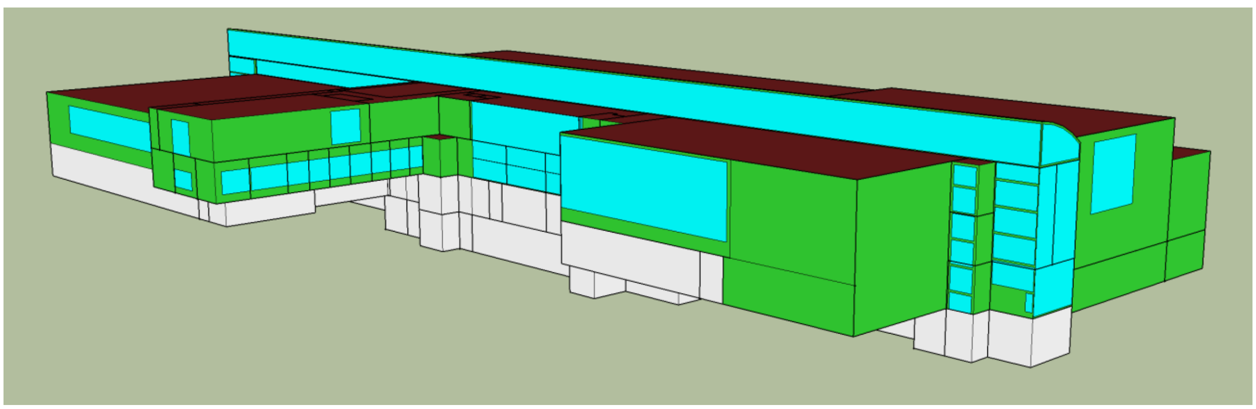


Figure 40: ERC Energy Model Rendered by Construction Type

6.4.2 Energy Model Results

As discussed in Chapter 3, ERC receives electricity, gas, and district steam. For the model comparison, the metered values of electricity, gas, and hot water from the utility data were used to verify model results.

Figure 41 shows the comparison of electricity from the utility data given and model predicted. Total annual electricity consumption deviates 0.47% from the actual electricity of ERC. Slightly lower electricity usage values were predicted in the winter months whereas slightly higher electricity usage rates were predicted in the fall months. This correlates with the model's tendency to over predict cooling load in the summer months while under predicting in the winter months.

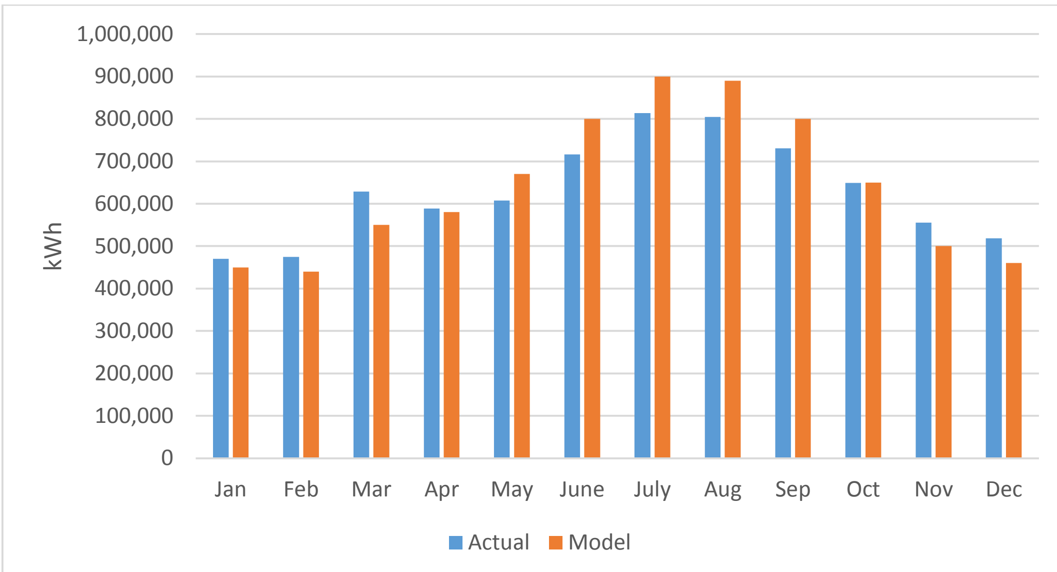


Figure 41: Electricity data comparisons between utility bills and ERC model

The main inputs for electricity rates were chillers, lighting loads, plug loads, and HVAC equipment.

Figure 34 shows the side by side comparison for hot water usage in ERC for actual utility data and energy model predicted usage. As can be seen in the figure, hot water is overestimated in the winter months and under predicted in the summer months. Total annual hot water consumption deviates 5.3% from actual ERC hot water consumption. The main inputs for hot water were the locker room show systems and HVAC equipment.

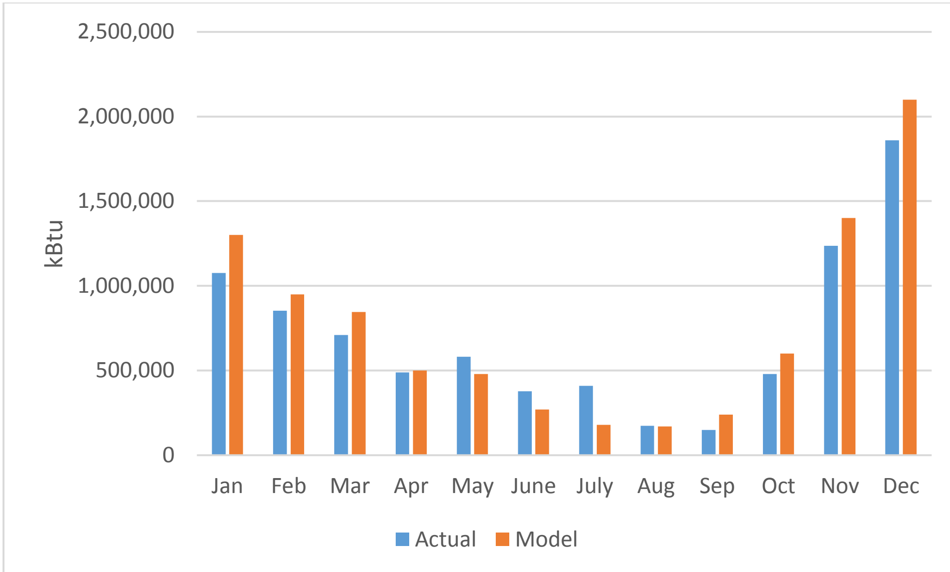


Figure 42: Steam data comparisons between utility bills and model

Figure 35 shows the comparison between the actual utility usage and energy modeled predicted usage for gas. Actual gas consumption varied wildly as a result of highly varying demand in the natatorium which the author was not able to capture accurately. Therefore, model predicted gas savings values were not used in evaluating EEMs for ERC. Total annual deviation of the predicted gas consumption to the actual gas usage was 2.12%.

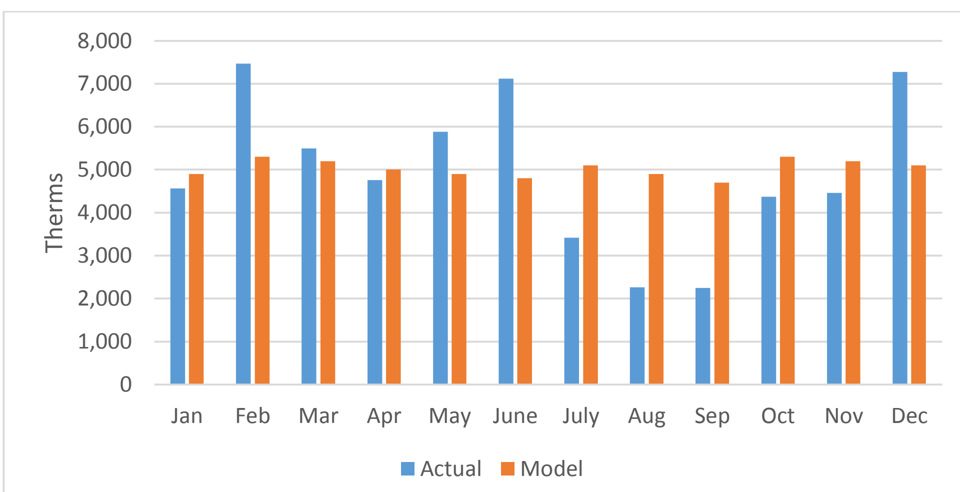


Figure 43: Chilled water data comparisons between utility bills and model

Figure 44 shows the breakdown of the PSC energy model results by end use. From the utility analysis in Chapter 5, it was determined that 41.3% of total energy use was used for heating, 38% for cooling, and 20.7% for electricity based equipment like the lighting systems. Model discrepancies based on end use vary by at most 3% from utility data.

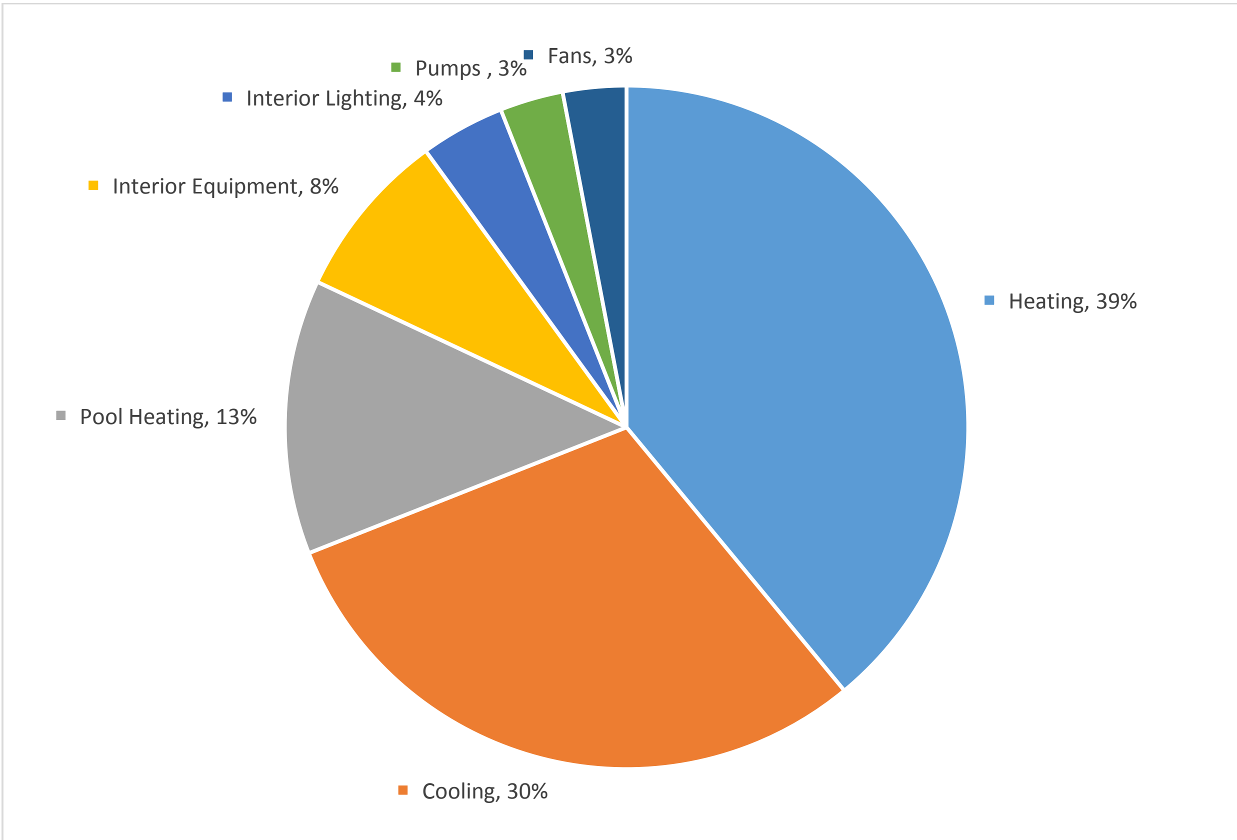


Figure 44: ERC Simulation Energy Use by End-Use

6.4.3 Uncertainty Analysis

An uncertainty analysis was also performed on ERC by varying eight parameters within the energy model. The parameters were chosen based on how influential they are to the thermal model. Table 17 lists the parameters that were used in the sensitivity analysis and their respective low and high values. Figure 45 shows the results from the sensitivity analysis performed on the ERC building energy model.

Table 17: ERC Energy Model Sensitivity Analysis Parameters

Parameter	Unit	Baseline Value	Low Value	High Value
Infiltration	cfm/ft^2	0.15	0	0.30
Chiller COP	N/A	5.5	3	8
Chiller Pump Motor Efficiency	%	90%	70%	100%
Zone Cooling Setpoint Temperature	°F	68	64	72
AHU Supply Fan Pressure Rise	inH20	2	0	4
Chiller Water Outlet Temperature	°F	44	40	48
Occupant Density	People/ft^2	0.05	0	0.15
Weather File Location	N/A	Washington DC	Dulles	Philadelphia

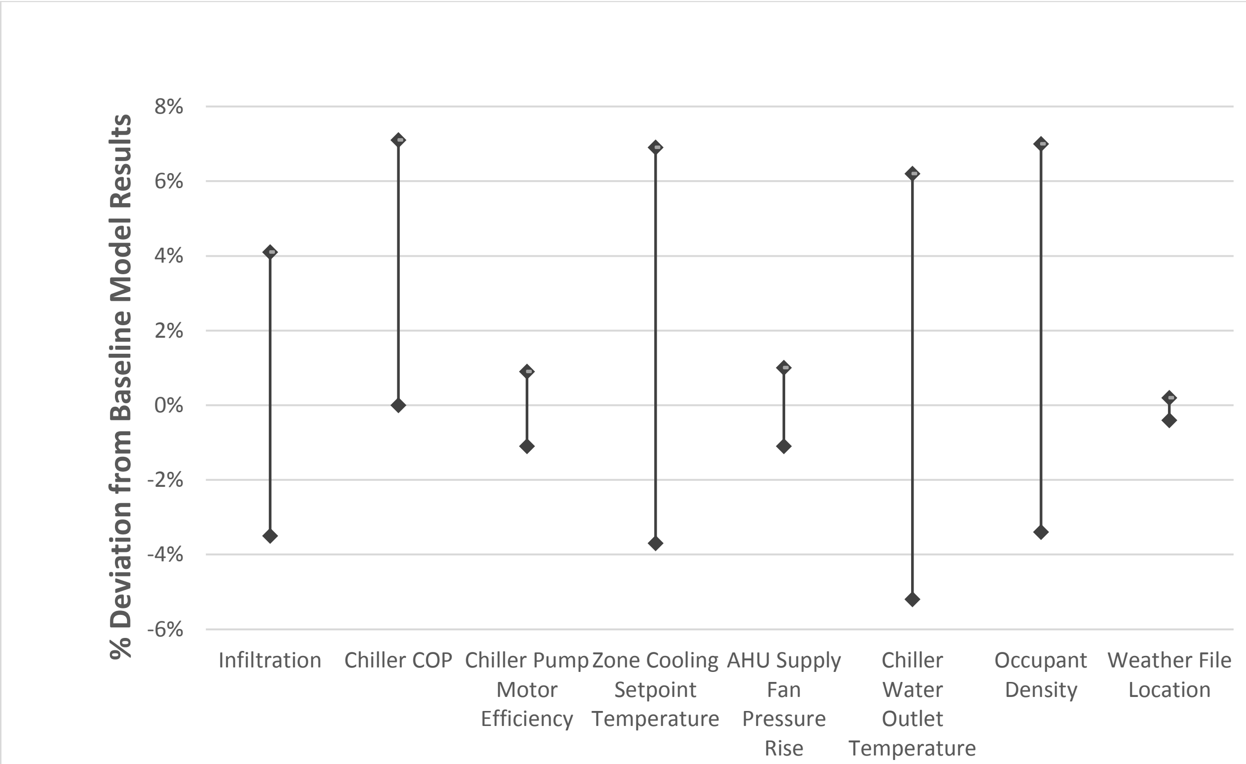


Figure 45: ERC Energy Model Sensitivity Analysis Results

6.5 Eppley Recreational Center Energy Efficiency Measures

Energy efficiency measures (EEMs) were identified for ERC which were deemed economically feasible with sufficient payback periods comparable to the lifetime of the building and did not impede on building functionality. Other EEMs were identified that did not meet this criteria, therefore they were will not be wholly detailed in this paper. These EEMs include the following:

- Replacing old AHUs that service the majority of the building. These AHUs are over 20 years old, which when the recommended replacement is.

- Installing pool covers while the natatorium pools are not in use. Pool use is from 4am-12am daily so cost of installing pool cover is economically feasible given cost savings.

- Decreasing pool water temperature set points in order to reduce pool water evaporation rates.

- Replacing exercise equipment with energy producing exercises equipment. Energy producing equipment is still not cost effective, but could be an option for replacing older, broken-down equipment.

6.5.1 ERC EEM #1 – Sphagnum Moss Usage in Cooling Towers

ERC uses three cooling towers in order to cool the condenser water from the chillers. These cooling towers typically build up bacteria, algae, fungus, mold, and scale formations that must be cleaned in order to maintain proper hygiene in the system.

During the cleaning process, the water in the cooling tower loop is removed and harsh chemicals are used to treat the residues in the tower. This results in a lot of wasted water and man hours each time the cooling towers have to be cleaned.

Sphagnum moss is naturally occurring moss that has been growing steadily in the HVAC maintenance realm. When installed in a system such as a cooling tower, it inhibits growth of residues as mentioned above and also removes scales by stabilizing the pH of the water. (Knighton and Fiegel) This results in less chemical usage in the cooling tower, decreased water usage, and reduced maintenance time. Although this EEM does not directly save on energy, it is still a good way to save water and money.

6.5.2 ERC EEM #2 - Pool Heat Recovery

This EEM has already been implemented in the ERC natatorium with the 2016 natatorium renovation. Since this EEM has been installed recently, utility data has not been documented to show actual utility savings from the renovation. Therefore, the ERC EUI value does not reflect this addition and is therefore being considered to calculate predicted EUI values with the pool heat recovery addition.

Natatorium HVAC systems constantly need to supply and fraction of outside air into the space so pool chemicals in the air do not reach uncomfortable levels. Conditioning this outside air normally takes a significant amount of energy. Pool heat recovery is essentially an energy recovery device that transfers sensible and latent heat from the hot and humid exhaust air to the colder and less humid outside air. To simulate this, the natatorium AHUs were updated to have an energy recovery unit. Figure 46 shows an example of a pool heat recovery system. (Best Practice Programme)

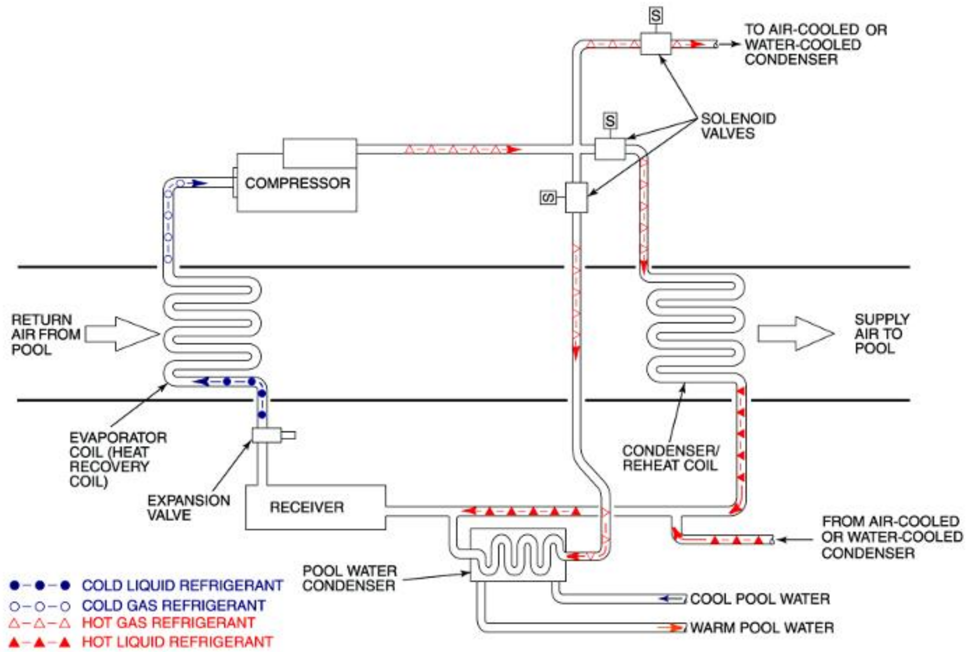


Figure 46: Example of Pool Energy Recovery

The expected savings from the AHU improvement is shown in Table 18.

Table 18: ERC EEM #2 Pool Heat Recovery Savings

	HOT WATER (MMBTU)	**ELECTRICITY (MMBTU)**	**GAS (MMBTU)**	**TOTAL ENERGY SAVED (MMBTU)**
ANNUAL ENERGY SAVED	567	2,201	0	2,303
% REDUCTION	6.8%	8.5%	0%	5.7%
ANNUAL COST REDUCTION	$14,056	$66,166	$0	$80,222

6.5.3 ERC EEM #3 – Reduced HVAC Night Time Schedule

ERC HVAC equipment runs on a 24/7 occupied schedule despite being closed from 12am to 6am. HVAC to areas such as offices, basketball courts, and weight lifting areas could be reduce during this time with minimal loss to building functionality.

This would not include the natatorium HVAC equipment since it constantly needs to maintain certain humidity levels despite not having occupants in the area.

ERC staff typically come before 6am and stay after 12am to open and shut down the gym. HVAC systems could be conservatively set into unoccupied mode from the 1am-5am time frame for the areas mentioned above. In order to simulate this in the ERC building model, unoccupied heating and cooling set points of 65°C and 75°C were used from 1am to 5am to simulate unoccupied mode.

Table 19: Reduce HVAC Night Time Schedule Savings

	HOT WATER (MMBTU)	ELECTRICITY (MMBTU)	SGAS (MMBTU)	TOTAL ENERGY SAVED (MMBTU)
ANNUAL ENERGY SAVED	364	723	0	1,087
% REDUCTION	4.3%	2.8%	0%	2.7%
ANNUAL COST REDUCTION	$9,024	$21,735	$0	$30,759

6.5.4 ERC EEM #4 – Demand Control Ventilation/VAV Upgrade

Occupancy schedules were closely examined from the 2015-2016 timeframe by time of day and day of the week. Occupancy patterns varied greatly in the two basketball court areas and the weight room which correspond to AHU-3, AHU-4, and AHU-5. Typically, these spaces are empty from the late morning to mid-afternoon. After mid-afternoon to night, these spaces see very high occupancy levels. Due to this high variation of occupancy in these areas, demand control ventilation is recommended to improve energy efficiency and air quality.

Carbon dioxide demand control ventilation (CO_2 DCV) varies the ventilation rate based on the amount of CO_2 in the air through the use of CO_2 sensors and VAV

AHUs and VAV terminal units. Typically VAV is used in spaces that have highly carrying occupancy schedules, so these areas in ERC are great candidates to upgrade to a VAV system. CO_2 DCV has been studied for rooms with highly carrying occupancy schedules with high reductions in fan energy and ventilation heat losses. (Merema et al, 2018) CO_2 DCV lowers ventilation rates in periods of low occupancy since there is less CO_2 being exhaled into the air. During high ventilation rates, the constant volume AHUs serving these areas may not be able to supply enough outside air to keep CO_2 concentrations low.

Prominent schools such as Indiana University and Georgia Tech have also upgraded their gymnasiums to CO_2 DCV system with excellent results. Georgia Tech upgraded its Campus Recreational Center (CRC) to a CO_2 DCV system for a capital cost of $800,000 with annual utility savings of around $102,000. (Georgia Tech Faculties Management) Georgia Tech's CRC has a similar functionality and greater floor area than Eppley (300,000 ft^2).

Since CO_2 DCV could not be modeled accurately in OpenStudio, the case study from Georgia Tech has used to estimate annual utility savings of an ERC CO_2 DCV retrofit. The retrofit would replace current constant volume AHUs and air terminal units with VAV comparable designs. Also, CO_2 sensors would be added in the spaces of interest to monitor CO_2 levels. The author conservatively estimated an annual utility savings of around $81,000 for a CO_2 DCV retrofit to ERC.

6.6 Eppley Recreational Center Savings Summary

The EEMs for ERC vary in cost with the CO_2 DCV retrofit being the most expensive. However, given the utility savings for each of the EEMs, payback times within 10 years are expected. Table 20 shows the summary of EEMs proposed for ERC.

Table 20: ERC EEM Summary

EEM	Hot Water (MMBtu)	Electricity (MMBtu)	Gas (MMBtu)	Total (MMBtu)	Energy Savings %	Utility Savings ($)
EEM #1	0	0	0	0	0%	TBD
EEM #2	567	2,201	0	2,303	5.7%	$80,222
EEM #3	364	723	0	1,087	2.7%	$30,759
EEM #4	TBD	TBD	0	TBD	TBD	$81,000
Total*	931	2,924	0	3,390	8.4%	$191,981

*Energy totals exclude EEM #4 since precise energy savings are not known currently

Chapter 7: Conclusions, Recommendations, and Future Work

7.1 Physical Sciences Complex Project Conclusions and Recommendations

Creating an accurate model of PSC required a significant amount of time planning, selecting modeling strategies, and obtaining resources. Fine tuning the models through constant information gathering and updating of the energy model proved to be the most time consuming aspect of the project. Once the PSC energy model was baselined, scenarios for energy conservation were simple to simulate and did not require much time at all. Therefore the PSC energy model could be used in future decisions regarding building retrofits for energy conservation.

The baseline energy model deviated respectively -1.05%, 1.19%, and 5.27% from annual electricity, steam, and chilled water use from 2015 utility data. Based on the predictions of the PSC energy model, 41.3% of total energy use was used for heating, 38% for cooling, and 20.7% for electricity based equipment like the lighting systems. Space conditioning accounted for almost 80% of the energy consumption in PSC. This is due to design issues with one of the HRU units, poor HVAC scheduling in some areas, and large dehumidification requirements in the type 1 basement labs. One of the key takeaways from the PSC energy audit were that there are not always solutions to energy inefficiencies, as is the case with the dehumidification loads in the basement labs.

However, despite some issues not able to be resolved, energy saving strategies were still identified for PSC. No cost EEMs such as reducing ventilation rates and modifying temperature set back schedules were great strategies to reduce energy consumption in the building. These no cost EEMs saved approximately 2,500 MMBtus of energy or about 5% of PSC's energy consumption which have an immediate payback period. LED lighting upgrades are an easy way for PSC to save on electricity use. With energy savings of 1,266 MMBtu or 2.6% of the building energy consumption, LED lighting retrofitting has a low payback period of around 4 years.

7.2 Eppley Recreational Center Conclusions and Recommendations

Like the PSC building energy model, creating the ERC building energy model was time consuming and complex task. Much of the information relating to the BAS and HVAC controls was unknown for this project due to the lack resources and control points monitored in the building. Therefore, fine-tuning the ERC model involved numerous interviews with facilities management staff in order to capture details of the building operation. Pool modeling was limited to a basic schedule due to a lack of knowledge of the competition schedules.

The baseline energy model deviated respectively 0.47%, 5.3%, and 2.2% from annual electricity, hot water, and gas use from 2016 utility data. Based on the predictions of the ERC energy model, 39% of total energy use was used for heating, 30% for cooling, 13% for pool heating, and 18% for electricity based equipment like the lighting systems. Space conditioning accounted for almost 69% of the energy consumption in PSC. With the HVAC renovations in the natatorium, space conditioning energy use will decrease. As seen in the benchmark analysis, it was determined that ERC energy efficiency is very high for a building of its functionalities.

Even though ERC is performing very well, EEMs were still identified to bring ERC to a higher performing level. The no-cost EEM identified reduced energy use by 1,087 MMBtu or 2.7% of the building's energy use. Higher cost EEMs such as adding pool heat recovery and CO_2 DCV were estimated to save a considerable amount of energy totaling up to about $160,000 in utility savings. Payback periods for these higher cost EEMs vary, but both are estimated to be within the building's lifetime. Therefore, all EEMs proposed for ERC are recommended to be implemented.

7.3 Project Comparisons and Lessons Learned

PSC and ERC were two unique buildings on the UMD campus that each posed different challenges in modeling the buildings and generating EEMs for them. The building functionalities, age, HVAC systems, BAS systems, and occupancy loads all varied considerably. PSC is largely a research and office building with several different types of high energy consuming labs. ERC is a gymnasium that houses basketball courts, a large natatorium, other exercise room, and offices.

Building energy modeling wise, both buildings were modeled using the same programs: EnergyPlus and OpenStudio. Modeling details such as HVAC schedules and definitions were largely similar between the two buildings. A custom module code was developed in Ruby which was added into the ERC OpenStudio model to accurately model the natatorium pool heating system.

Despite the differences in the two buildings, common energy efficiency measures were developed for both buildings. EEMs such as setting back HVAC schedules and upgrading to LED lighting were common to both buildings despite their differences in functionality.

7.4 Future Work

Although much work was done to create accurate building energy models an identify energy efficiency measures, additional energy savings opportunities could still be identified. Most of the EEMs discussed in this thesis were conventional and mostly related to improving or fine-tuning HVAC systems. Newer technologies such as renewables were not investigated for this project and could be sources of higher energy reductions in the buildings.

In ERC, examination of solar water heating or geothermal water heating could prove to have high energy savings by replacing the gas boilers with renewable fuels. Other technologies such as solar windows which are windows that can generate electricity from solar power could also be viable options for reducing the carbon footprint of the buildings.

The building energy models themselves could also be improved to more closely resemble that of day to day operations. Due to the immense amount of information and details (PSC) or lack of information (ERC), the building energy models predictions could improve to have a more accurate assessment of actual energy consumption and energy savings. For example, the pool occupancy schedule was set constant throughout the day due to the limitation in the pool module the author created.

The next phase of the project would include implementation of the no-cost EEMs and post-implementation analysis to verify predicted model results. Other high cost EEMs should be reviewed and inspected by the UMD facilities management department to determine their viability and implementation.

Appendices

PSC EEM #3a – LED Lighting Retrofit Calculations

Lamp Types	Number of Fixtures	Wattage	LED Replacement Wattage (W)	Wattage Difference	kW Difference
T8HO	93	57	25.5	31.5	2.9295
T8 (4')	2724	32	15	17	46.308
T5HO	222	54	24	30	6.66
CFL	520	32	13	19	9.88
CFL	42	26	9	17	0.714
CFL	48	42	15	27	1.296
NFL (café)	10	35	13	22	0.22
Total					68.0075

Assuming the lights are on 14 hours a day, the total energy saved would be:

68.0075kW*14hours/day*365days/year = 346.3MWh

Bibliography

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ASHRAE. (2004). *Thermal Environment Conditions for Human Occupancy.* Atlanta, GA: American Society of Heating Redrigeration and Air Conditioning Engineers, Inc.

ASHRAE. (2011) *Energy Standards for Buildings Except Low-Rise Residential Buidings (I-P Edition ed.).* Atlanta, GA: ANSI/ASHRAE/IESNA

ASHRAE. (2016). *Ventilation for Acceptable Indoor Air Quality*

ASHRAE. (2017). *ASHRAE Advanced Energy Design Guides*. Retrieved June 2018 from http://aedg.ashrae.org/Default.aspx

Bangerth, S., Ohadi, M.M., and Jenkins, C.A. (2017). *Energy Analysis of LEED Silver Certified Dining Hall on an Academic Campus – A Revisit Three Years After its Initial Certification*. Ashrae Transactions, 123, Part 1, 129-139.

Belzer, D.B. (2009). *Energy Efficiency Potential in Existing Commercial Buildings*: Review of Selected Recent Studies. Richland, WA: Pacific Northwest National Laboratory.

Best Practice Programme. *Energy Use in Sports and Recreation Buildings*. Retrieved September 2017 from http://www.cibse.org/getmedia/34def23a-c65b-405e-9dff-ce181c0b1e0d/ECG78-Energy-Use-in-Sports-and-Recreation-Buildings.pdf.aspx

Brambley, M.R., and Wells, S.E. (1983). *Energy Conservation measures for indoor swimming pools.* Energy Elsevier, 8(6), 403-418.

CBECS. (2012). 2012 *Commercial Building Energy Consumption Survey: Energy Usage Summary*. Retrieved July 2017 from https://www.eia.gov/consumption /commercial/

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Glazer, J. (2001). *EnergyPlus Creating a New-generation Building Energy Simulation Program.* Energy and Buildings, 33.4, 319-331.

EnerData. (2016). *Global Energy Statistical Yearbook*. Retrieved June 2018 from https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

EnergyStar. *Benchmarking Energy Use*. Retrieved on July 2017 from https://www.energystar.gov/buildings/about-us/how-can-we-help-you/benchmark-energy-use?s=mega

Georgia Tech Facilities Management. *CRC Demand Control Ventilation.* Retrieved July 2018 from https://facilities.gatech.edu/crc-demand-control-ventilation

Hunt, Kristin. (2018). *This Treadmill Generates Electricity as you Jog. Green Matters*. Retrieved December 2018 from https://www.greenmatters.com/news/2018/11/13/Z1axDvg/sportsart-verde-energy-generating-treadmill

I2SL. (2010). *Labs21 Case Studies: Featured Concepts table.* Retrieved February 2018 from http://www.i2sl.org/documents/toolkit/cs_contents_tracking_chart_508.pdf

Kaplowitz, M.D., Thorp, L., Coleman, K., Yeboah, F.K. (2012) *Energy conservation attitudes, knowledge, and behaviors in science laboratories.* Energy Policy. 50, 581-598. doi: https://doi.org/10.1016/j.enpol.2012.07.060

Kneifel, J. (2010). *Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings.* Energy and Buildings. 42.3, 333-340.

Knighton, David, and Fiegel, Vance. (2012, September) *Making the Most of Moss*. Retrieved January 2019 from https://sgcweb.s3.wasabisys.com/wqp/s3fs-public/12_tu_cws_0912WQP.pdf

Levy, J.M. (2014). *Simulation and Analysis of Energy Consumption for an Energy-Intensive Academic Research Building.* College Park: University of Maryland

Maile, T., Fischer, M., and Bazajanac, V. (2007) *Building Energy Performance Simulation Tools – a Life-Cycle and Interoperable Perspective*. Stanford, CA: Stanford University Center for Integrated Facility Engineering.

Mathew, P.A., Sartor, D.A., Bell, G.C., Drummond, D. (2007) *Major energy efficiency opportunities in laboratories – Implications for health and safety.* Journal of Chemical Health and Safety. 14.5, 31-39. doi: https://doi.org/10.1016/j.jchas.2007.01.002

Merema, B., Muhannad, D., Sourbron, M., and Breesch, H (2018). *Demand controlled ventilation (DCV) in school and office buildings: Lessons learnt from case studies.* Energy and Buildings, 172, 349-360. doi: 10.1016/j.enbuild.2018.04.065

Mills, E., Sartor, D. (2005) *Energy Use and savings potential for laboratory fume hoods*. Energy. 30.10, 1859-1864. doi: https://doi.org/10.1016/j.energy.2004.11.008

National Renewable Energy Laboratory. *OpenStudio.* Retrieved July 2017 from https://openstudio.nrel.gov

Savage, Dana. (2017). *Simulation and Analysis of Energy Consumption for Two Complex and Energy Intensive Buildings on UMD Campus*. College Park: University of Maryland

Second Nature. (2015). *The Presidents' Climate Leadership Commitments*. Retrieved January 2018 from http://secondnature.ord/what-we-do/climate-leadership/

University of Maryland Facilities Management. Building Inventory. Retrieved June 2018 from https://facilities.umd.edu/facilities-info/building-inventory

University of Illinois Facility Management. (2016) *Activities and Recreation Center #0118*. Retrieved July 2017 from https://www.fs.illinois.edu/docs/default-source/Utilities-Energy/0118-arc_report.pdf?sfvrsn=3835feea_0

U.S. DOE. (2013). *EnergyPlus Energy Simulation Software*. Retrieved November 2017 from http://apps1.eere.energy.gov/buildings/energyplus/openstudio.cfm

U.S. Energy information Administration. *What is the United States' share of world energy consumption*? Retrieved July 2017 from https://www.eia.gov/tools/faqs/faq.php?id=87andt=1

U.S. Energy Information Administration. (2016) *International Energy Outlook 2016*. DOE/EIA-0484

Zuccari, F., Santiangeli, A., Orecchini, F. (2017). *Energy analysis of swimming pools for sports activities: cost effective solutions for efficiency improvement.* Energy Procedia. 126. 123-130.