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Capturing, Mapping, and Analyzing Clemson University's Academic Building Utility Consumption

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CAPTURING, MAPPING, AND ANALYZING CLEMSON UNIVERSITY'S ACADEMIC BUILDING UTILITY CONSUMPTION

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ABSTRACT

Clemson University has set sustainability goals in 2007 for the years 2020, 2025, and 2030. This research works in conjunction with Clemson University Facilities (CUF) to take strides towards these goals. The academic buildings on campus are metered monthly for their utility use (electricity, steam, chilled water, water, sewer, and natural gas). The patterns for all of the academic building utility use for the 2017 calendar year were captured with the use of Tableau. A foundational meter billing database was created to streamline the monthly billing process within CUF and a tool was created to analyze the resulting data. Further, this data was analyzed on an individual building basis, as well as by Clemson's disciplinary colleges. Utility intensity (utility use per gross square foot) was projected onto a heat map within Tableau to visually see which buildings were the most intensive. Buildings that CUF should prioritize investigating retrofit applications include Hunter Hall, Godley Snell, Biosystems Research Complex, Fluor Daniel, Rhodes Engineering Hall and Annex, Earle Hall, and Olin Hall.

Additionally, a framework used by Clabeaux (2017) to calculate the carbon footprint associated with Clemson University was utilized to calculate the environmental impact of each academic building's operation phase. The total carbon footprint for the academic buildings totaled 40,722 metric tons CO_2-e. Scope 1, 2, and 3 emissions totaled 6,609, 32,104, and 2,009 metric tons respectively. Further, the largest flows attributing to the carbon footprint of all academic buildings were purchased electricity (Scope 2), steam generation (Scope 1), and electricity used at the chilled water plants on campus (Scope 2). These values accounted for 67%, 16%, and 11% of the total carbon footprint for the academic buildings.

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1. INTRODUCTION

1.1 Problem Statement

Decreasing energy use to reduce environmental impact has become a major interest of many organizations, governments, and higher education institutions in recent decades. Motivating energy engineers and managers at such institutions to implement energy efficiency projects and to analyze the system they are dealing with. Thus, there is a need for an analytical tool with a user-friendly interface that captures utility use in Clemson University's academic buildings. This tool will be able to target specific buildings on campus to focus sustainability efforts, observe utility use trends, as well as quantify the carbon footprint of academic buildings on Clemson University's main campus based on the 2017 calendar year. Although the billing of utilities at Clemson is unique, the general framework of the tool and carbon footprinting method can be applied to other higher educational institutions to assist in targeting areas to decrease their energy use and impact.

1.2 Motivation

Increased energy use entails increased environmental impacts including, but not limited to, natural resource depletion, ozone layer depletion, global warming, and consequently, associated climate change [1]. Higher education campuses, such as Clemson University's, can be considered small cities or "microcosms" of society and a drive to make these campuses "greener" is becoming a global objective [2]–[7]. Clemson's main campus covers an area roughly the size of 1,400 acres and hosts more than 23,000 total students. The student population and building gross square footage (GSF) are growing more and more each year, as administration has set a goal to reach 30,000 students by 2030.

In 2007, Clemson University's administration set long-term sustainability goals to motivate the campus to reduce energy use and environmental impact. These goals are: 1) Reduce energy consumption 20% by the fiscal year 2020 according to the 2000-year baseline, 2) Increase renewable energy sourcing 10% by 2025, and 3) become carbon neutral by 2030 [8]. As these deadlines are quickly

approaching, Clemson University Facilities (CUF) is looking for opportunities to help propel the university towards these goals. With growing infrastructure and student population, both building GSF and energy use will increase. However, with emerging technologies and the sustainability goals in mind, CUF has the opportunity to ensure efficient energy and utility use to drive the emissions per GSF of Clemson's main campus down.

The main motivation behind this report is to target building utility consumption patterns and to analyze how much energy and resources each building on campus uses. Additionally, being able to capture and calculate the carbon footprints of each academic building's operation phase will be helpful in the efforts to reduce energy use and greenhouse gas emissions. It will also give insight into the effects of operating a university building by providing a transparent methodology to the public. Approximately 40% of energy use and carbon dioxide equivalent (CO_2-e) emissions in America is through building use [9], [10], of which 18% is commercial and 22% is residential [1]. Therefore, capturing and analyzing Clemson's academic building utility use will help reduce costs for CUF and achieve the goals that Clemson administration has set on a small scale, while also helping to mitigate the total energy use of the building sector on a national level.

Clemson University also commissions a sustainability reasearch firm, Sightlines, to produce a report of Clemson's greenhouse gas (GHG) emissions and comparisons to other universities with comparable metrics (size, technical complexity, climate zone, and percent of residential students) [11]. Sightlines receives information from Clemson staff and analyzes the information that is given. However, there is speculation as to the accuracies of the findings, largely because a university like Clemson is very complex and the data is not necessarily organized when delivered to Sightlines, potentially leading to a misinterpretation of the data. Furthermore, the methodology that Sightlines uses is confidential, leading to conjectures. As such, there is a desire to utilize CUF staff expertise to improve reporting, billing, and analysis of building utility use. For example, the meter data that has been used for at least a decade had numerous errors and did not accurately reflect the actual utility use

in some of the affected buildings. By analyzing the building consumption internally, a more focused and accurate report can be produced and publicized for transparency. Brinkhurst et al. (2011) discusses the importance of university faculty and staff (i.e. CUF) to spearhead sustainability initiatives in order to achieve sustained and impactful progress towards campus sustainability [6].

Along with capturing total utility use within the buildings, the corresponding carbon footprint (CF) will be calculated and reported. By quantifying and publicizing these carbon footprints, CUF, students, faculty, and staff at Clemson can be motivated to reducing the impact that each building has on the environment. This will bring real data and metrics to the public to incorporate a bottom-up approach to sustainability. Brinkhurst et al. (2011) and Owens & Halfacre-Hitchcock (2006) mention that bottom-up, or student led, initiatives towards campus sustainability are helpful and encouraged, however they often lose momentum over time and do no reach administration. Also mentioned is a top-down method, or administration led, where initiatives are effective, but don't happen as often as desired. These initiatives can include statements and policy changes followed by necessary resources provided to individuals to carry out these sustainability motives [6], [7]. With CUF and Clemson faculty as the spearhead for this project, it will bring together the "top" and "bottom" of the university to achieve a prolonged and much needed sustainability tool on campus. The students, faculty, and staff will be able to see how they can directly reduce the impact in the academic building they occupy, and administration will be able to fund and make policy changes based on the findings of this report.

1.3 Goals and Objectives

This research will produce a tool to allow CUF, as well as administration, to target academic buildings on campus to focus sustainability efforts. With the use of the data analysis software Tableau, a multi-faceted workbook will be constructed and presented with a user-friendly interface that will be shared with the public to allow them to understand how consumption trends, and their implications, are spread across campus.

Objectives

- Quantify utility use and intensity, respective to utility type for each building for the 2017 calendar year
- Create a dashboard to visually show consumption patterns on campus
- Quantify carbon footprint of academic buildings to assess environmental impact severity for the 2017 calendar year
- Quantify total energy use (kBTU) in Clemson University's main campus academic buildings for the 2017 calendar year
- Create a heat map of energy use to focus sustainability efforts from the 2017 calendar year
- Streamline the consumption and billing process within CUF

1.4 Organization of Thesis

This thesis will be organized to allow the reader to understand the current status and basic operation of Clemson University's utilities and why it is necessary to analyze the historical data as well as set CUF up to target buildings on campus to focus on. Chapter 2 discusses the details of Clemson University's current operation, the building landscape, resource and utility background, the environmental impacts that are associated with this research, lifecycle assessment, and finally carbon footprinting. Chapter 3 describes the methodology of how the data was collected, organized, and analyzed, as well as the lifecycle assessment design. The carbon footprinting process and calculations will be outlined and described in this chapter, too. The results of the analysis of the academic buildings on campus will be reported and discussed in Chapter 4. Recommendations and an analysis of the effects of the different heating, ventilation, and air conditioning systems, water systems, electricity efficiency methods, and building age are presented in Chapter 5. Final concluding remarks sum up this report in Chapter 6.

2. BACKGROUND

2.1 Overview of Clemson University

The Clemson University Facilities (CUF) department is responsible for the tracking and billing of all utility use of buildings on campus related to: electricity (kWh), natural gas (cu. ft.), water (gal), sewer water (gal), chilled water (kBTU), steam (lbs), and irrigation (gal). Employees within CUF monitor and track consumption of these utilities by collecting data from the meters at specific locations on campus monthly. This data is then manually adjusted within CUF to then be billed out to the various departments within Clemson's resource distribution network. There are seven main departments that CUF works with: Education and General (E&G or academic), Housing, Dining, Athletics, Parking Services, Auxiliary Customers, and External Customers. Auxiliary and External Customers are organizations or establishments that are within the Clemson community, but are privately funded. Furthermore, the data linked to Housing, Dining, and Athletics are private and will not be publicly reported. E&G information is public because Clemson is a public university and will be the concentration of this report. The E&G data involves buildings on campus that are used for academic and faculty use, such as Cooper Library, Fike Recreation Center, and Brackett Hall. The Education (or academic) buildings will be the focus of this report and the meters corresponding to the building is shown in Table 2.

In an effort to focus this research further, the meters that are associated with General areas or buildings on campus, such as the Botanical Gardens, Central Energy Plant, Chilled Water Plants, and Fike Recreation Center, will be excluded. Additionally, the academic buildings will be analyzed in groupings based on what college operates within the building, as shown in 1. There are some buildings (Brackett Hall, Hardin Hall, and Edwards Hall) that share the space with multiple colleges and are described as "Multidisciplinary". Buildings such as Cooper Library, Watt Family Innovation Center, and Academic Success Center are not college specific and are described as "General Academic". The

population, provided by Clemson University's Institutional Research department [12], and number of E&G buildings associated with each college is included and will be used in the analysis.

Table 1. Clemson University college's population [12] and building distribution

College	Acronym	Student Population	Number of Buildings
College of Agriculture, Forestry and Life Sciences	CAFLS	2,137	5
College of Architecture, Arts and Humanities	CAAH	1,944	4
College of Behavioral, Social and Health Sciences	CBSHS	3,632	2
College of Business	CBUS	4,589	2
College of Education	CED	1,509	1
College of Engineering, Computing and Applied Sciences	CECAS	7,056	11
College of Science	CSCI	3,276	6
General Academic	GA	N/A	3
Multidisciplinary	MD	N/A	3

Princeton University's operation is comparable to Clemson, only on a smaller scale (just over 8,000 students), and previously had a similar analytical system in place. A student led team analyzed the building energy use and created a live, public heat map where anyone could interact with the map and view specific details of each building on campus that had relevant data [13]. Furthermore, the transparent methodology to compute Clemson University's total CF has been conducted for the 2014 fiscal year, and that framework will be utilized in this report to add to and support a cohesive methodology for Clemson and other higher education institutions [14].

Table 2. Academic buildings included in this study, corresponding College, and age

Building Name	College	Age
Academic Success Center	GA	5
Barre Hall	CBSHS	42
Life Sciences Building	CSCI	4
Biosystems Research Complex	CSCI	16
Brackett Hall	MD	66
Brooks Center	CAAH	24
Cook Lab	CECAS	52
Cooper Library	GA	51
Daniel Hall/Strode Tower	CAAH	48
Dillard	CECAS	64
Earle Hall	CECAS	58
Edwards Hall	MD	40
Fluor Daniel	CECAS	22
Freeman Hall	CECAS	91
Godfrey Hall	CBUS	119
Godley Snell	CAFLS	22
Hardin Hall	MD	127
Harris A. Smith	CAFLS	8
Holtzendorff Hall	CECAS	102
Hunter Hall	CSCI	31
Jordan Hall	CSCI	40
Kinard Hall	CSCI	56
Lee 1 & 2	CAAH	59
Lee III	CAAH	5
Lehotsky Hall	CBSHS	42
Long Hall	CAFLS	80
Lowry Hall	CECAS	59
Martin Hall	CSCI	55
McAdams Hall	CAFLS	66
Newman Hall	CAFLS	62
Olin Hall	CECAS	64
Poole Agricultural Center	CAFLS	62
Rhodes Engineering	CECAS	48
Rhodes Engineering Annex	CECAS	8
Riggs Hall	CECAS	90
Sirrine Hall	CBUS	79
Tillman Hall	CED	123
Vickrey Hall	GA	26
Watt Family Innovation Center	GA	1

2.2 Clemson's Building Landscape

Although Clemson University has multiple campuses across South Carolina (Clemson, Anderson, Greenville, Charleston, etc.), only the utility use on Clemson's main campus in Clemson, South Carolina will be reported and displayed. The campuses outside of Clemson, SC are smaller in size and their contributions are minimal compared to the bulk of main campus and will be excluded from this report. Figure 1 shows the Academic building landscape on Clemson's main campus, and Table 3 supplements this map with corresponding building names. Some of these academic buildings are open and occupied longer than usual business hours, specifically Cooper Library which is open for more than 5,500 hours each year, including weekends and parts of holiday breaks. The energy demand of each academic building varies based on use (research labs, classrooms, offices, etc.), size, and mechanical systems within each building (lighting fixtures, HVAC systems, etc.).

Table 3. Building names corresponding to Figure 1

Building No.	Building Name	Building No.	Building Name
1	Holtzendorff Hall	21	Rhodes Annex
2	Godfrey Hall	22	Freeman Hall
3	Tillman Hall	23	Watt Family Innovation Center
4	Dillard Building	24	Academic Success Center
5	Brackett Hall	25	McAdams Hall
6	Hardin Hall	26	Earle Hall
7	Martin Hall	27	Fluor Daniel
8	Long Hall	28	Lowry Hall
9	Olin Hall	29	Barre Hall
10	Kinard Lab	30	Harris A. Smith
11	Jordan Hall	31	Lee Hall
12	Vickrey Hall	32	Lee III
13	Daniel Hall/Strode Tower	33	Brooks Center
14	Edwards Hall	34	Lehotsky Hall
15	Sirrine Hall	35	Newman Hall
16	Riggs Hall	36	Biosystems Research Complex
17	Rhodes Hall	37	Poole Agricultural Center
18	Cooper Library	38	Life-Sciences Building
19	Hunter Lab	39	Godley Snell
20	Cook Lab		

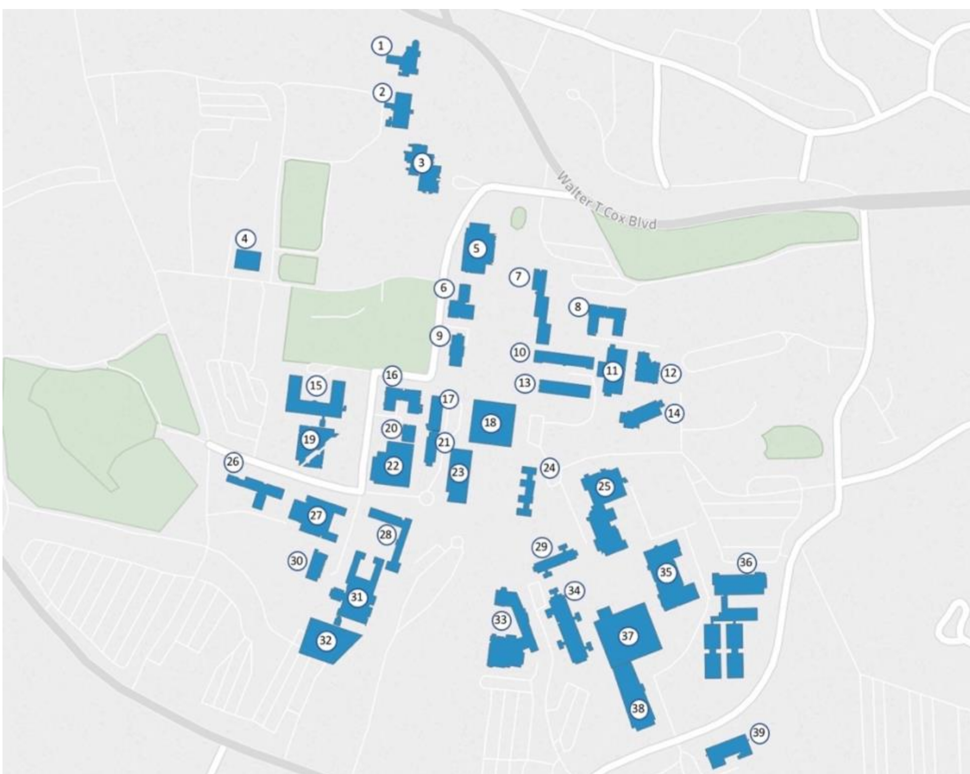

Figure 1. E&G building landscape

2.3 Environmental Impacts

Many efforts have been made by the United Nations Framework Convention on Climate Change (UNFCCC) to set energy reduction goals since the early 1990's, however have only recently gained traction with more developed countries. According to the Paris Agreement, developed nations will join forces to commit to energy reduction in an effort to fight climate change. This agreement sets a lofty but specific goal to stabilize greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system" [15]. Former President Obama signed the Paris Agreement to commit the United States towards the goal of the Agreement. However, on June 1st, 2017, President Trump withdrew the United States from this agreement, stating that it would undermine the U.S. economy. Although the government of the United States has not committed to combating climate change, many organizations and individuals are helping spearhead this topic without federal assistance.

Greenhouse gases (GHGs) are gases within Earth's atmosphere that "absorb solar energy reflected from the Earth's surface as infrared radiation" [16]. These gases trap heat inside of Earth's atmosphere, contributing to warming the atmosphere – referred to as the Greenhouse Effect. Limiting GHG emissions will limit contribution to rising global temperatures. The GHG Protocol Corporate Standard defines the following six gases as GHGs covered in the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) [17]. Methane and nitrous oxide have certain 100-year global warming potential (GWP) factors as reported by the Intergovernmental Panel on Climate Change in the Fifth Assessment Report [18], shown in Table 4. GWP is a factor that describes the volatility of the compound in the atmosphere relative to one kilogram of CO_2. CO_2-equivalent (CO_2-e) is the universal unit to indicate GWP and CO_2-e signifies the amount of CO_2 which would have the equivalent global warming impact [19]. Meaning, for each kilogram of N_2O released, it will do as much damage as 265 kilograms of CO_2 when released into the Earth's atmosphere.

Table 4. GHG gases and corresponding GWP factor [18]

Greenhouse Gas (GHG)	Global Warming Potential (GWP)
CO_2	1
CH_4	28
N_2O	265

2.4 Clemson's Resource Overview

As explained previously, buildings receive different utilities according to their function and need. Water, electricity, chilled water, steam, and in some cases, natural gas come in to the buildings and leaving the buildings are sewer water, chilled water return, steam return, and "responsible emissions". The process by which responsible emissions, or it's carbon footprint, will be calculated is explained in Chapter 3. Figure 2 provides a diagram of the mass and energy flows of Clemson University's utility operation and of a typical building, but keep in mind that each building is different and may or may not have every resource type associated with it.

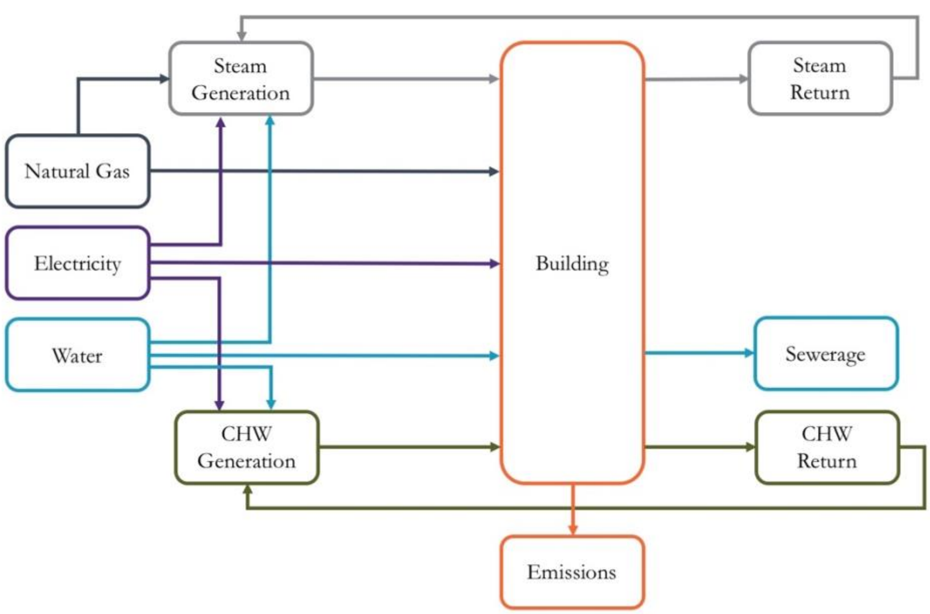

Figure 2. Mass and energy flows of Clemson University operation

2.4.1 Chilled Water and Steam

Clemson has a number of energy plants on campus that supply building's air quality needs across campus. These plants produce steam and chilled water to drive heating, ventilation, and air conditioning (HVAC) functions in all buildings across campus. An interconnected underground tunnel system transfers these resources to each building across campus. The steam plants are powered by a combination of electricity, natural gas, and a fuel-oil mix (essentially diesel fuel). Natural gas feeds into and powers the steam boilers for a majority of the operation schedule, however certain circumstances call for the fuel-oil mix to be used, but CUF claims to use the fuel-oil mix less than 5% of the operation schedule. The chilled water plants use chillers that operate using electricity, a refrigerant (R-134a), and cooling towers. Ideally, these chilled water and steam loops are close loops, however there is loss in the tunnels from leakages, and there are also evaporation losses from the cooling towers at the chilled water plants. As makeup, both plants also bring in potable water before being converted into steam or chilled water and sent through the tunnel system to the buildings. Steam and chilled water are used in HVAC systems to treat fresh and return air through dehumidification, heating, and cooling processes. Within these systems, steam is used to heat a water loop, since transferring heat from water to air is more effective than air to air while the chilled water simply runs through the system itself. Steam is also used to provide hot water for buildings. There are three typical HVAC systems within the academic buildings on campus, and the information that was available at the time of this study is shown in Table 5.

Table 5. HVAC systems within each building

HVAC System	Buildings
FCU and AHU	Brackett Hall, Cook Lab, Holtzendorff Hall, Lehotsky Hall, Lowry Hall, Sirrine Hall
VAV and AHU	Brooks Center, Cooper Library, Freeman Hall
VAV	BRC, Godfrey Hall, Hardin Hall, Harris A. Smith, Jordan Hall, McAdams Hall, Poole Agricultural Center, Rhodes Hall Annex
Multiple	Edwards Hall, Vickery Hall, Daniel Hall/Strode Tower
Reheat	Kinard
FCU and VAV	Barre Hall, Dillard, Earle Hall, Lee Hall
AHU	Newman Hall, Olin Hall
VAV and CB	Life Sciences Building
AHU, VAV, and CB	Watt Family Innovation Center
FCU	Long Hall, Martin Hall, Rhodes Hall, Riggs Hall, Tillman Hall
CAV	Fluor Daniel, Godley Snell, Hunter Hall

Figure 3 shows the simplified version of what a centralized HVAC air-handler unit (AHU) system looks like in an academic building. These AHUs are typically positioned within the basement of the typically large building (i.e. Cooper Library). There are oxygen (O_2) and carbon dioxide (CO_2) sensors within these AHUs to either let fresh air in or continue to recycle the return air. Since Clemson has a relatively humid climate, especially during the summer and fall seasons, recycling return air results in less energy and utility use because the air is already dehumidified. We then can expect to find that buildings that do not need a constant supply of outside, fresh air have a lower consumption of chilled water and steam. The conditioned air is then cycled through ducts providing heated/cooled air to the building. There are two main types of these types of systems – constant air volume (CAV) and variable air volume (VAV). CAV systems run the exhaust fan at full capacity until the designated space is heated or cooled to the desired temperature, then the fan is turned off. This constant cycling is not very efficient at keeping the space at a constant temperature. VAV systems, however, heat or cool different zones within a building more efficiently by varying the fan speed depending on the temperature in the space. The steam is used to heat the hot water coil within the AHU to provide dehumidification and heating, while the chilled water is sent through the AHU coil to also provide dehumidification and cooling.

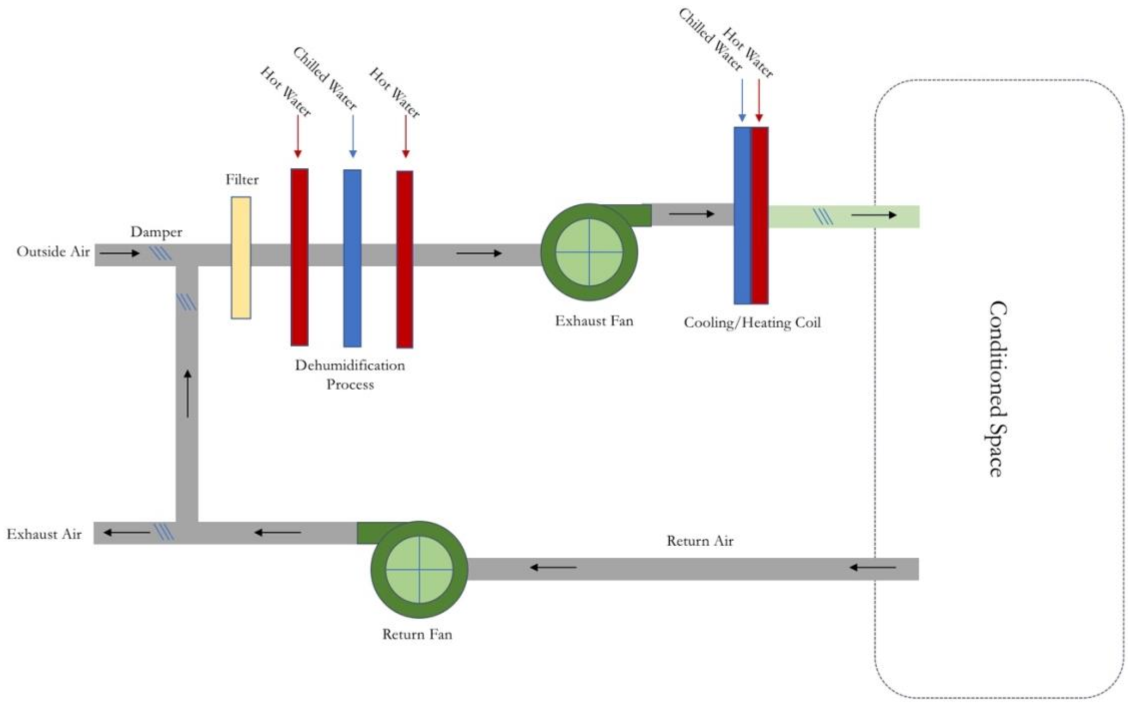

Figure 3. Diagram of a typical centralized air handler unit

Another standard HVAC system within the academic buildings on Clemson's campus are fan coil units (FCUs). These are localized air conditioning units within classrooms, offices, or other rooms. FCUs are either 2-pipe systems (Figure 4) or 4-pipe systems (Figure 5). The difference between the two systems is that 2-pipe systems only have one loop, and thus can only either have chilled water or hot water (produced from steam) running through the coils to provide the conditioned air need. The drawback of a 2-pipe system is that there is a loss of energy when changing from cooling to heating since there is only one supply and one return. Alternatively, 4-pipe systems offer a finer control of the conditioned air since there is a supply and return for both chilled and hot water. Typically, 4-pipe systems are more efficient and there is less loss of energy when switching between the two demands. However, the 4-pipe systems require more mechanical equipment, and is thus a more complicated and expensive system than a 2-pipe system. CUF is actively retrofitting the 2-pipe systems with 4-pipe systems to increase efficiency and reduce energy loss.

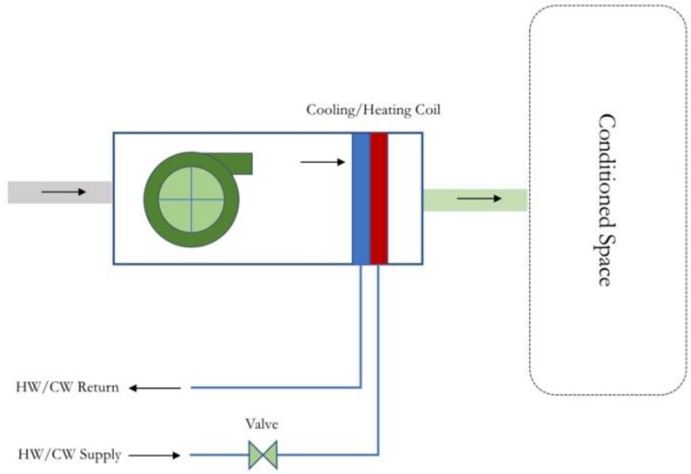

Figure 4. Diagram of 2-pipe fan coil unit system

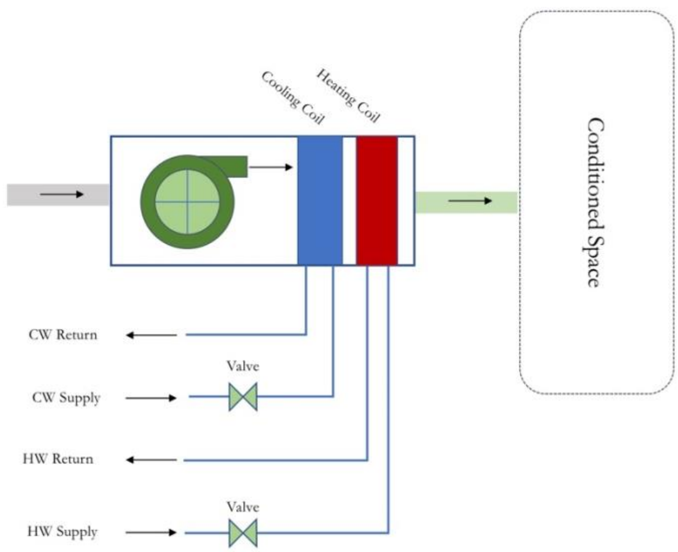

Figure 5. Diagram of 4-pipe fan coil unit

Finally, chilled beam systems could be looked at as a hybrid of the two systems. They have centralized AHUs, however these units only pretreat the air before being sent through the building. Then once in the designated space, it passes through a heat exchanger where chilled water or hot water cools or heats the air passing through. Figure 6 shows how the chilled beam system works. These systems are either hung from the ceiling or in the floors where the air is circulated.

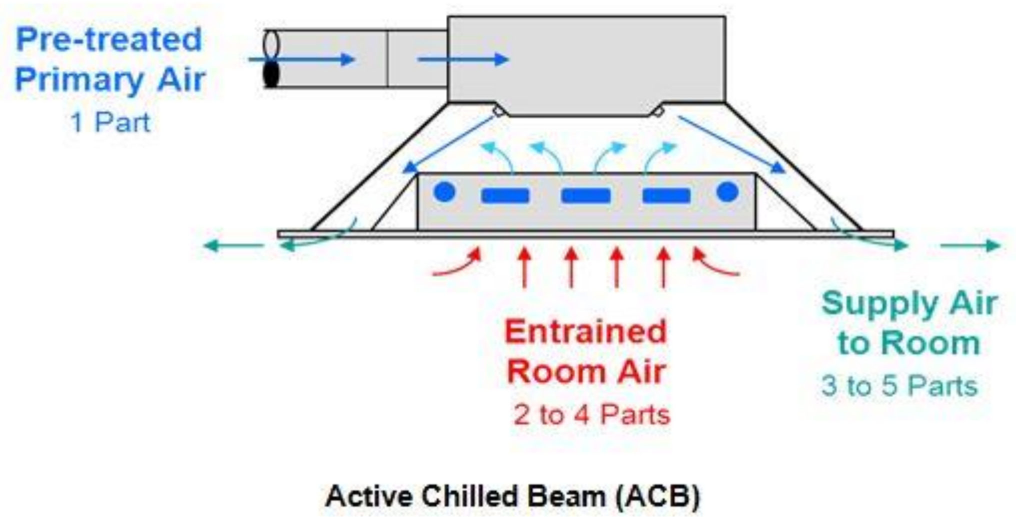

Figure 6. Diagram of chilled beam system [20]

2.4.2 Water and Sewerage

Clemson sources their potable water from Anderson Regional Joint Water System (ARJWS). ARJWS also provides clean drinking water to nearby cities Big Creek, Broadway, Anderson, Hammond, Powdersville, Sandy Springs, Central, Pendleton, and Williamston. ARJWS operates at a capacity of 45 million gallons a day, using a conventional filtration system to treat water sourced from the Lake Hartwell Reservoir [21]. There are potential plans for Clemson to construct a water treatment plant near the main campus as a replacement to sourcing from ARJWS, and depending on the capacity and water treatment process, it could change the environmental impact related to water treatment.

Water use and billing within CUF in buildings is particularly interesting because of its correlation to sewer water output. All water put into buildings is assumed to leave as sewerage, which is not metered directly – a potential source of inaccuracy. Basic water activities that occur in each building include toilet use, handwashing, water fountains, water bottle refill stations, laboratories, and in special cases, cooling for equipment in labs. One could argue that students or faculty that use refillable water bottles are taking water from one building that may or may not necessarily go back down the sewer drain in that same building. However, the opposite could be argued for building that

see high bathroom traffic but not as much drinking water use. All in all, this difference in water input and output is minimal therefore the assumption of all the water that goes in, goes out will be carried out through this report.

Clemson also runs its own wastewater treatment plant (WWTP) on the main campus and treats the wastewater from the academic buildings through a method similar to an activated sludge process. This plant treats in between 0.5-1.0 million gallons of wastewater per day.

2.4.3 Electricity

Clemson purchases their electricity from Duke Energy Carolinas, LLC and receives a competitive rate, which makes renewable energy less economically viable. The electricity demand for each building provides power for the plug load (wall outlets to power monitors, screens, laptop chargers, etc.), lighting load, and mechanical load (HVAC systems, pumps, etc.). The electricity that Clemson purchases from Duke Energy Carolinas, LLC is generated from a mix of fuels and is generated within the SRVC region shown in Figure 7.

The Emissions & Generation Resource Integrated Database (eGRID) is "a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States" [22]. The data include net generation, emission rates, GHG emission volumes and rates, and resource mix. These attributes are extremely helpful when creating GHG inventories, calculating carbon footprints, and collecting general emission information from power plants operating within the U.S. [22]. The Sightlines Sustainability Report uses the fuel mix average within the SRVC region (Figure 7), however this research uses a more refined approach. Duke Energy Carolinas, LLC operates within South Carolina and North Carolina, and the data in the eGRID database were filtered to only include Duke Energy Carolinas, LLC as the power plant operator. Table 6 and Figure 8 show the distribution of fuel mix used to generate electricity and will be used to determine greenhouse gas emissions for each building. This research analyzes the 2017 calendar year, however the data from the eGRID database is

from 2016 as this was the most updated database at the time. This is a potential source of inaccuracy, however is still a clearer depiction than taking the average of a larger region as Sightlines does.

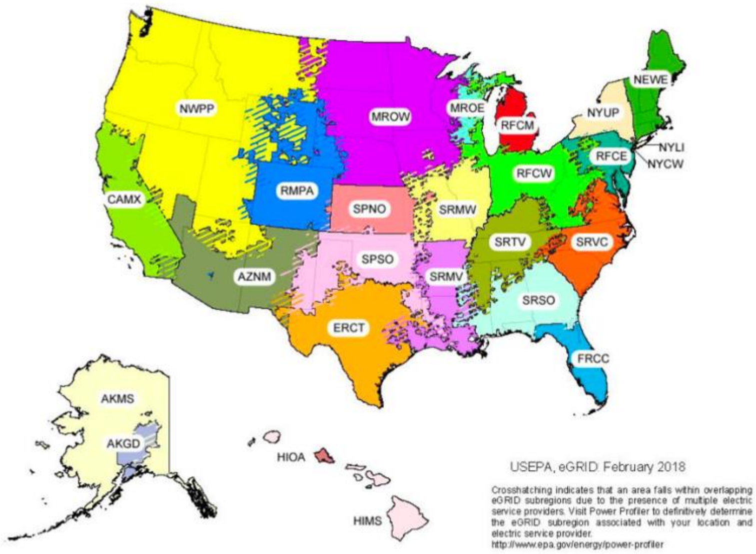

Figure 7. EPA eGRID subregion map [22]

Table 6. Duke Energy Carolinas, LLC net generation by fuel type [22]

Fuel Type	**Annual Net Generation (MWh)**	**Annual Net Generation (%)**
Nuclear	60,619,656	52.38%
Coal	25,498,872	22.03%
Gas	24,889,726	21.50%
Hydro	2,766,260	2.39%
Solar	1,093,084	0.94%
Biomass	713,082	0.62%
Oil	152,621	0.13%
Wind	6,233	0.01%
Total	**115,739,534**	**100%**

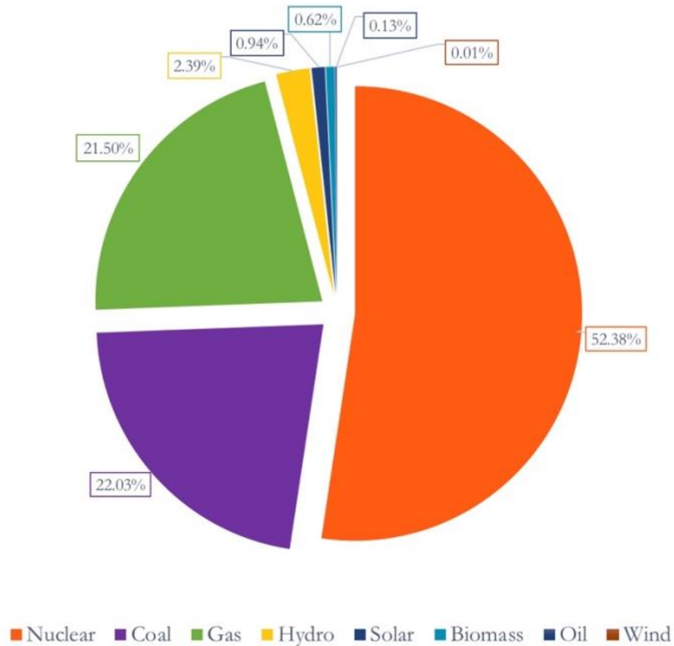

Figure 8. Annual net generation based on fuel type for Duke Energy Carolinas, LLC [22]

The eGRID database also collects and reports power plant annual emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which are greenhouse gases (GHGs). Filtering for the Duke Energy Carolinas, LLC operated power plants, the results of the emissions are shown in Table 7. Using the global warming potential factors in Table 4, the carbon dioxide equivalent (CO_2-e) emissions are calculated. The total CO_2-e emissions for all Duke Energy Carolinas, LLC operated power plants is 37,580,122 metric tons of CO_2-e. This value will aid in carbon footprint calculations outlined in Section 3.4.3.

Table 7. Plant emissions for Duke Energy Carolinas, LLC

Element	Emissions [metric tons]	CO_2-e [metric tons]
CO_2	37,365,155	37,365,155
CH_4	3,277	91,755
N_2O	465	123,212
	Total	**37,580,122**

2.4.4 Natural Gas

Natural gas is primarily used within the steam generation plants to power the boilers, however there are two academic buildings on campus that require a direct natural gas line: Bio-Systems Research Complex and the Life Sciences Building. The Life Sciences Building has an onsite boiler to produce its own steam and both require natural gas for laboratory functions. The natural gas Clemson purchases comes by way of the Transco Transmission pipeline that runs from New York, through the southeast, and into south Texas. Natural gas is a blend of a number of hydrocarbons; primarily methane, propane, and ethane as well as trace amounts of butane, hexane, and pentane. Hexane is used as a "worst-case" scenario for the trace amounts of heavier hydrocarbons. Table 8 shows the percent composition used by Clabeaux (2017) from Transco Transmission, and will be used in this study to estimate GHG emissions through combustion of natural gas [14].

Table 8. Composition of natural gas purchased by Clemson [14]

Number (i)	Element	Chemical Formula	Molecular Weight (g/mol)	Composition (%)
1	Methane	CH_4	16.04	94.60
2	Ethane	C_2H_6	30.07	3.43
3	Propane	C_3H_8	44.10	0.20
4	Hexane	C_6H_{14}	86.18	1.77

When hydrocarbons are used as a fuel source, they combust and react with oxygen, producing CO_2 and water vapor (H_2O). The elemental composition of the natural gas will react differently, producing different amounts of CO_2 and H_2O, shown in Equations (1)-(4). The stoichiometric coefficients for each component of natural gas and CO_2 will be used in the analysis later to determine the CO_2-e emissions of natural gas.

$$CH_4(g) + 2O_2 \rightarrow CO_2(g) + 2H_2O(g) \quad (1)$$

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g) \quad (2)$$

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \quad (3)$$

$$2C_6H_{14}(g) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(g) \quad (4)$$

When natural gas is combusted, nearly 99.9% of it is exhausts as CO_2, where there are trace amounts of carbon monoxide and other compounds compromising the other 0.1%. For this study, it will be assumed that all of the natural gas that is burned in the steam generating boilers is converted into CO_2, or a 100% combustion rate. The stoichiometric relationships (Table 9) of methane, ethane, propane, and hexane to CO_2 will be used in calculations later in the report.

Table 9. Stoichiometric relationships for natural gas composition

Number (i)	Molecule	Mole Molecule	Mole CO_2
1	CH_4	1	1
2	C_2H_6	2	4
3	C_3H_8	1	3
4	C_6H_{14}	2	12

2.4.5 Utility Rates

All utilities have a rate associated with them, since this report analyzes the 2017 calendar year, there are two different rates due to the fiscal year calendar (July-June), shown in Table 10. CUF tracks and monitors all utilities and bills departments for their use, acting as the utility company. Prices for each utility are determined by the company that produces, generates, or treats the resource. It's clear that the rates are consistent for electric, natural gas, and steam, however small changes for chilled water, water, sewer, and irrigation occurred between fiscal years. These are the rates that CUF charges other departments (Athletics, Housing, Dining, etc.), however does not actually pay this much themselves. These rates were used because CUF is not billed for chilled water or steam because they generate that utility themselves.

Table 10. Utility rates for Clemson University

Utility	Rate for FY 2016-2017	Rate for FY 2017-2018	Units
Chilled Water	0.00926	0.00934	\$/kBTU
Electric	0.081	0.081	\$/kWh
Natural Gas	0.9618	0.9618	\$/ft^3
Steam	0.01472	0.01472	\$/lbs
Water	0.0029	0.00292	\$/gal
Sewer	0.00615	0.00617	\$/gal
Irrigation	0.0029	0.00292	\$/gal

2.5 Life Cycle Assessment

2.5.1 LCA Overview

With energy use comes associated environmental impact with varying severity depending on the energy resource. Calculating a carbon footprint (CF) for a building can be completed through either a process-based or hybrid life cycle assessment (LCA) [23]. LCA is a tool used to analyze the interaction of the environment and the economy. It is a collection of material and energy flows through different phases of a product or processes life cycle and quantifies environmental impacts through a number of impact categories (i.e. global warming, ozone layer depletion, eutrophication, ecotoxicity). The phases studied in LCA's are shown in Figure 9. Some phases may be omitted in studies if their impact is negligible or not within the system boundary or goal and scope of the study, this process creates a streamlined LCA [24]–[27]. Streamlining an LCA will demand less time, data, energy, and generally cost by omitting phases of a product's life cycle. This also reduces the complexity of the study by selecting only the impact categories to analyze that are most impactful, however are not compliant within the 14040 standards set by the International Organization for Standardization (ISO) [24].

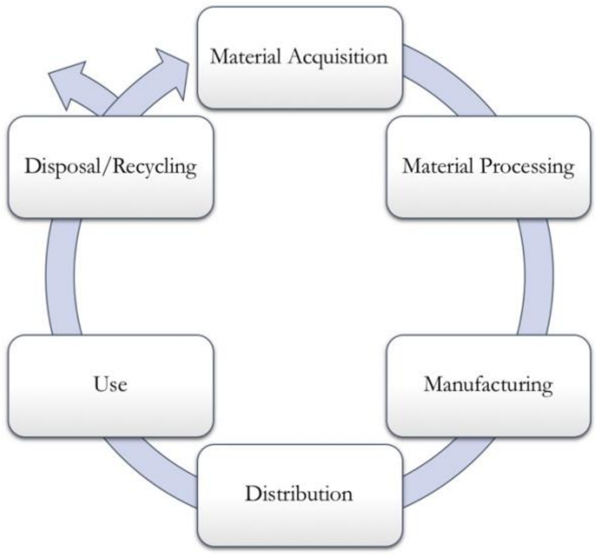

Figure 9. Life cycle phases

Figure 10 shows the four life cycle stages. The goal of a study will "unambiguously state the intended application, the reason for carrying out the study and the intended audience" [24]. The scope will define where the system boundaries lie (geographic and systemic), expected product, assumptions and justifications, as well as the functional unit. The life cycle inventory (LCI) creates an inventory of input and output flows involved with a product system, including water, energy, raw materials, and emissions or releases to air, soil, and water. Life cycle impact assessment (LCIA) evaluates the potential environmental impacts given the flows within the LCI and is the last stage within an LCA study in order to become ISO compliant. Midpoint impact categories that can be assessed, depending on the study, include global warming potential (GWP), abiotic resource depletion, ozone depletion potential, human toxicity, ecotoxicity, acidification, eutrophication, and more. The flows of mass and energy are carried through impact assessment methods so that they can be compared through a similar metric. The fourth stage of an LCA study is the interpretation, which evaluates the results from the LCI and LCIA. This interpretation cross checks the results to ensure that the end of the study still lays within the system boundaries, focuses on the goal, and is accurate and complete. Conclusions and

recommendations are made for future studies in the interpretation stage as well [24]. As shown in Figure 10, these stages happen iteratively to ensure a complete and focused study.

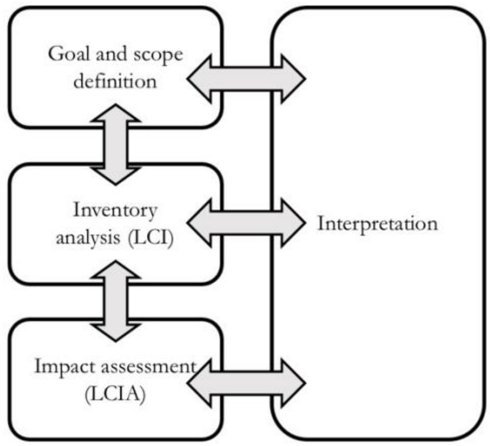

Figure 10. LCA stages

2.5.2 LCA Approach

There are many different frameworks for LCA studies, including process analysis (consumption based) or economic input-output (EIO) analysis (monetary based). Process analysis LCAs are typically more detailed studies and investigate products and processes to find areas of improvement [28], [29]. Process-based LCA uses mass and energy units and can be difficult if that data is not available or in those units. Oftentimes, institutions record consumption on monetary value or non-physical flows which is where EIO LCA comes into play. Both studies have drawbacks and deficiencies that make one study preferably over another. For many carbon footprint studies, a hybrid LCA approach is taken, where both process-based and input-output methodologies are used based on the data being analyzed [10], [29]. This is primarily due to data collection needs and data quality, using both physical and non-physical units to describe flows. There are numerous case studies of higher education institutions and large organizations that use either a process based, input-output method, or hybrid LCA to quantify the carbon footprint in an effort to reduce their environmental impact ([10],

[14], [23], [30]–[32]). However, there are no current case studies of an individual building's operation phase carbon footprint.

Although there are a number of upstream and downstream impacts (electricity, water treatment, wastewater treatment) in this study, all of the flows and inputs of the system are physical measures (kWh, kBTU, cu. ft., lbs, and gal) and therefore will be assessed through a process-based LCA framework. Additionally, the scope of the study calls for a streamlined LCA, as is fairly consistent with most carbon footprinting studies. Where most studies analyze on a holistic approach, either entire institutions or a single building's entire life cycle, this study will focus on the use phase and relative consumption of the entire academic building landscape, but on an individual building level. The use phase often accounts for over 90% a building's environmental impact [10] Each building will have a calculated carbon footprint based on the operation phase of the building. Taking into account the upstream (for electricity, water, and steam) and downstream (wastewater treatment) emissions, the carbon footprint will be measured and reported in terms of kg CO_2-e.

2.6 Carbon Footprint

There are many different definitions of what a carbon footprint is, as explored by Wiedmann & Minx, 2007 [33], and there are some commonalities as well as differences between all of these definitions. The main differences fall into whether or not to include the emissions of non-carbon dioxide (i.e. methane, nitrous oxide) emissions. The term carbon footprint is rooted in the language of an "ecological footprint" – or "an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area" [34]. However, a carbon footprint (CF) is a mechanism to account for the total quantity of greenhouse gas emissions over the whole life cycle of a product or process and GHG emissions are often quantified and normalized into a mass of CO_2-e [28], [35]–[37]. There is significant difficulty in capturing the carbon footprint of an entire lifecycle, due to data limitations and time, money, and resource intensity.

There are three scopes analyzed in carbon footprinting and are outlined in Table 11 [35]. Scope 1 is related to direct emissions within the organization, Scope 2 is indirect emissions (purchased electricity), and Scope 3 includes any other indirect emissions from sources outside of the organizations control (production of purchased materials, transportation, waste disposal, etc.). Typical carbon footprinting studies take into account all of these flows for an organization, however this study will only look at the flows that are relevant to academic building operation (i.e. commuting, waste disposal will be excluded). The flows of interest for this study and their corresponding scope is outlined in the Section 3.4.

Table 11. Scopes 1, 2, and 3 of carbon footprinting [35]

Scope 1	Scope 2	Scope 3
Fuel combustion	Purchased electricity	Transport – business, commuting, product
Company vehicles		Waste disposal
Process emissions		Leased assets, outsourcing
Fugitive emissions		Production of purchased materials
		Use of products

3. METHODOLOGY

3.1 Foundational Meter Data Collection

A foundational database was constructed to organize the front end of the meter billing process. There are over 1,000 physical meters across campus, and each meter has attributes that are distinctive to itself. These attributes include rollover count, multiplier, partitions, and calculated meters. All of these attributes are documented and taken into account in the database. There are only a handful of meters that need special attention, but it is imperative that these issues are addressed in the foundational database, otherwise errors can stem from this during data analysis.

Rollover is a term used regarding the number of digits on the meter display, and if the meter reading rolls past the magnitude specific to itself, it will reset to all zeros. Meaning the current month's reading will be multiple magnitudes lower than the previous month's reading, which is used to calculate the current month's consumption.

Multipliers are attributes linked to meters whose readout needs to be multiplied by a factor to get the true reading. For example, chilled water is measured in kBTU, however some of the meters display a value with units of 10kBTU or 100kBTU. There are some electric and natural gas meters that have arbitrary multipliers, but CUF has all of these documented and will be accounted for in this database. The past month's reading is subtracted from the current month's reading, and then that value is multiplied by the multiplier.

A partition is a term used to divide the reading by the number of buildings sharing a single meter. There are no partitioned meters for academic buildings, but many residence halls and some athletic venues have partitioned meters. These are primarily partitioned by CUF based on a gross square foot (GSF) basis for simplicity. GSF is a property of each building that is recorded by CUF as well as Clemson's Planning and Development office and is a sum of square footage of air conditioned space. So outside space of a building (i.e. patios, covered walkways) that is not climate controlled is excluded from this calculation.

Calculated meters are meters that are part of a multi-meter system within a single building. Seen in Figure 11, the master meter has a reading for the consumption of a specific utility for the entire building, however there is a submeter (which is included in the master meter reading) to record how much a specific portion is using. We see this when two departments share a building but need to be billed separately, according to what they use. The calculated meter accounts for the space outside of where the submeter accounts for. There are only a handful of these meters across all departments, and only a few within the E&G department. This concept complicates the billing process and will be challenging to overcome when tracking happens more often than the current monthly schedule.

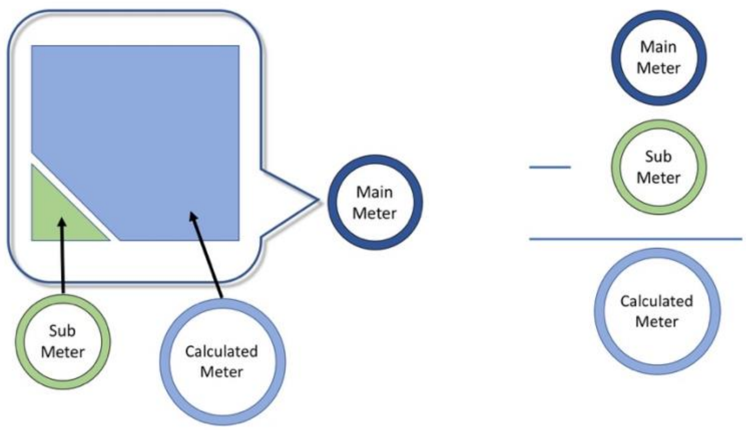

Figure 11. Virtual meter concept

It is important that these attributes are carefully tracked and updated as needed because reducing energy use is impossible without good data on which to make management and investment decisions [38], [39]. With a finalized, but fluid, foundational database, the data visualization software, Tableau, is used to analyze campus utility use in a variety of ways. Similar to the Sightlines Sustainability Report that CUF commissions, an analysis based on gross square footage (GSF) will comparably reveal how consumption is spread across campus, this will be referred to as utility "intensity". Further, the use will be distributed among the colleges that each building is occupied by to investigate which College is contributing most to the campus energy use. Tableau's software is capable of building workbooks and dashboards that can be publicized online, allowing the findings of the E&G department to be

accessible by the public. This workbook will give users a quick, yet detailed overview of Clemson's consumption.

For E&G buildings on Clemson's main campus in 2017, there were over 300 physical meters. Since water meters act as a "two-in-one" meter, i.e. water use = sewerage use, this leads to about 391 individual calculated readings that occur each month. These readings are calculated within the foundational database and take into account submeters, partitions, multipliers, and rollover. Annually, nearly 5,000 readings and calculations are carried out for the E&G buildings, granted some meters are removed and some are added based on construction activities on Clemson's campus.

3.2 Energy Use

Each month, CUF calculates the total energy use of each building in kBTUs. Steam, chilled water, natural gas, and electricity can all be taken from the units that they were measured in and converted to kBTU to capture total energy use. These conversion rates can be seen in Table 12. For electricity, steam, and chilled water, the conversion is direct. However, for natural gas the conversion is dependent on the BTU factor that CUF received from the natural gas utility company. Essentially, the composition of the natural gas varies from month to month, therefore the energy content also varies.

Table 12. kBTU conversion rates for utilities

Utility	Month	Conversion Factor to kBTU	Units
Chilled Water		1	kBTU/kBTU
Electricity		3.412	kBTU/kWh
Steam		1.189	kBTU/lbs
Natural Gas	January	1.029	kBTU/cu. ft.
	February	1.029	
	March	1.027	
	April	1.029	
	May	1.04	
	June	1.038	
	July	1.032	
	August	1.03	
	September	1.028	
	October	1.032	
	November	1.028	
	December	1.024	

Water and sewer water are excluded from this analysis because there is no direct conversion from gallons of water/sewer to kBTU. Although, there is a case study of embodied energy in drinking water systems in Kalamazoo. This study found that, for the Great Lakes region of the United states, it takes about 9.2 MJ (8.7 kBTU) of energy to produce 1 m^3 of potable water [40]. CUF is not necessarily interested in the embodied energy of potable water, the difference in geographic region, and the difference in water treatment system are the reasons that this study will exclude the embodied energy of water.

3.3 GIS Data

Partnering with the Clemson Center for Geospatial Technologies, a building footprint map was acquired. This georeferenced spatial file is Tableau compatible and the attributes connected to each polygon will have a relationship with the foundational database according to the building number designated within the CUF database. Figure 12 shows this spatial file brought into the Tableau interface. This map will be used to create the heat map as utility use is recorded.

Figure 12. Tableau interface of Clemson's main campus GIS data

3.4 Life Cycle Assessment Design

3.4.1 Goal & Scope Definition

The goal of this streamlined life cycle assessment study aims to quantify and map the carbon footprints of individual academic buildings on Clemson University's main campus for the 2017 calendar year. Looking at the release of GHG emissions from both direct and indirect sources, Scope 1 and Scopes 2 & 3, the release of emissions will be characterized in terms of metric tons of CO_2-e. Using the general framework from Clabeaux (2017) [14], and adjusting for the scope of this study, Clemson University Facilities will be able to use the results from this study to focus sustainability efforts to help push Clemson towards the sustainability goals set by Clemson administration in 2007. The audience of this study first is CUF, as they are responsible for the operation of all buildings on campus. Secondly, the general population of Clemson (students, faculty, and staff) are also the intended audience to include those that use the buildings and can be motivated to try to reduce the impact in ways that they can (turning off lights, computers, and monitors when they are unused). And thirdly, Clemson University administration is included in the audience so that they may be able to work with CUF to adjust policies, funding, and resources in an effort to reach the goals that have been set.

As laid out in Figure 1, and Table 3, the building landscape is defined as the geographic system boundary of Clemson University's main campus. Further, Figure 13 shows the systemic boundary of the operations in interest. The function of the system is for each building to operate to its intended function, providing educational, research, and/or student life services that is defined by each academic department. This study will focus only on the functions that assist in building operation and have significant effects on CO_2-e emissions. Scope 1 emissions will include natural gas use, wastewater treatment, and steam generation. Scope 2 emissions will include electricity generation and use. Finally Scope 3 emissions will include water treatment, electricity life cycle emissions, and electricity transmissions and distribution losses.

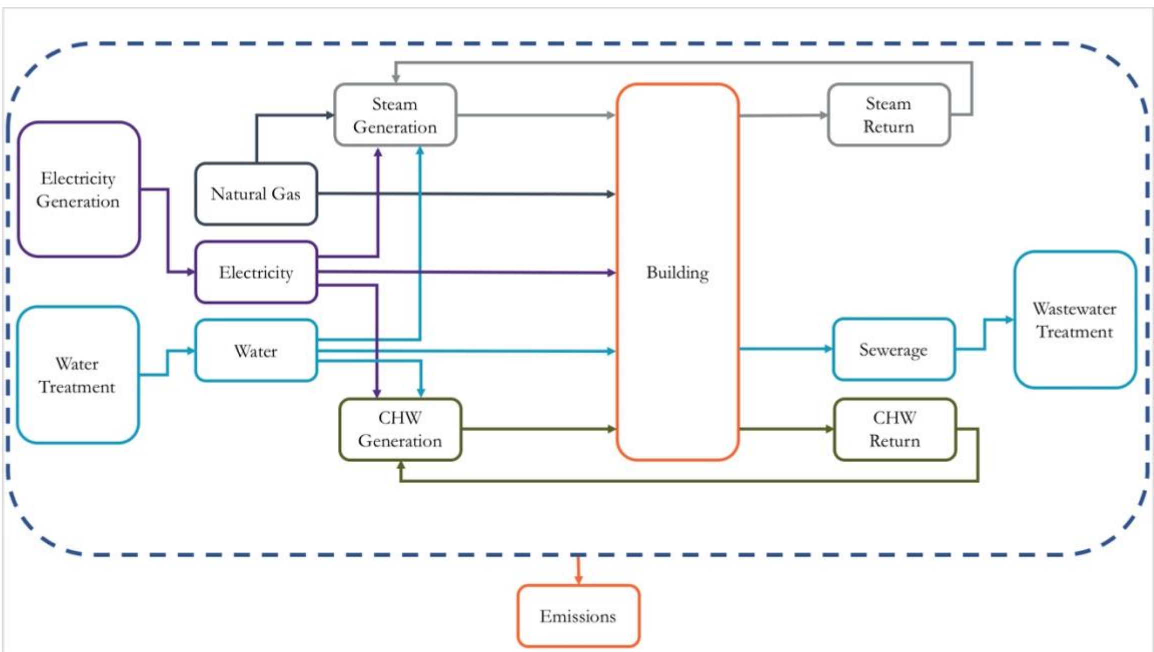

Figure 13. Inventory of flows of academic buildings

The functional unit of this study is consistent with Clabeaux (2017) [14] but with a narrower focus. For this research, the functional unit is one year's worth of educational and research services for each academic building's operation phase on Clemson University's main campus.

As stated earlier, this LCA study will be process-based and at the consumer (building) level. This varies from other carbon footprints of higher education institutions, since these studies take into

account all university related activities and services, such as commuting, waste and recycling, paper usage, air travel, fertilizer application, and more. Table 13 outlines the scopes within each utility that this study explores.

Table 13. Utilities and corresponding Scopes

Utility	Description	Scope
Natural gas	Direct line to buildings and combustion on-site	1
Steam	Natural gas combustion to produce steam	1
	Water use to account for makeup	3
	Electricity use to operate steam plants	2
Sewer	Wastewater treated at WWTP	1
Electricity	Electricity purchased from Duke Energy Carolinas, LLC	2
	Transmission and distribution losses	3
	Electricity life cycle emissions	3
Water	Water treatment in Anderson	3
Chilled Water	Electricity use to operate chiller plants	2
	Water use to account for makeup	3

3.4.2 Inventory Analysis

Figure 13 depicts the energy and mass flows within the operation phase of an academic building. Each of these flows may vary depending on the specific building. Each building has an input of the different utilities and has outputs of wastewater and emissions. The chilled water return and steam return are just functions of the chilled water and steam cycles and are not necessarily outputs in this regard. The data that was used in this study to create these flows come from a variety of sources. First, the monthly readings to calculate the monthly utility consumption was collected from all of the meters from CUF. Secondly, electricity generation data was collected from the EPA's eGRID 2016 database [22]. Thirdly, data regarding water treatment [41], wastewater treatment [42], electricity life cycle emissions [43]–[48], and electricity distribution losses [22] were taken from studies of similar systems to achieve emission factors that allow for carbon footprint calculations. Finally, data from Transco Transmission pipeline for natural gas composition and density come from 2014 [14].

3.4.3 Impact Assessment

Overview

The endpoint impact of this study is global climate change, or global warming. The midpoint impact associated with global warming that this study analyzes is the release of GHGs and their corresponding global warming potential. The 100-year time horizon GWP values characterize the impacts of the flows in interest so that they can be compared directly and will be discussed in units of CO_2-e as discussed before. The methodology of calculating the total impacts of each utility use for the academic buildings on Clemson's campus is outlined in this section, and the results are shown in Chapter 4. All emissions factors (EFs) are calculated in terms of kg CO_2-e per unit of utility (i.e. kg CO_2-e/kWh for electricity) and shown in Table 14. Transmission and distribution losses as well as electricity life cycle emissions are not recorded, because they vary depending on the building electricity use.

Table 14. Emissions factors (EF_x) for utility

Utility	Description	Scope	Emissions Factor (EF_x)
Natural gas	Direct line to buildings and combustion on-site	1	0.046 kg CO_2-e/cu. ft.
Steam	Natural gas combustion to produce steam	1	0.04 kg CO_2-e/lbs
	Water use to account for makeup	3	3.36E-05 kg CO_2-e/lbs
	Electricity use to operate steam plants	2	2.05E-05 kg CO_2-e/lbs
Sewer	Wastewater treated at WWTP	1	8.2E-04 kg CO_2-e/gal
Electricity	Electricity purchased from Duke Energy Carolinas, LLC	2	0.325 kg CO_2-e/kWh
	Transmission and distribution losses	3	0.015 kg CO_2-e/kWh
	Electricity life cycle emissions	3	Multiple
Water	Water treatment in Anderson	3	4.85E-04 kg CO_2-e/gal
Chilled Water	Electricity use to operate chiller plants	2	0.017 kg CO_2-e/kBTU
	Water use to account for makeup	3	5.91E-05 kg CO_2-e/kBTU

Electricity

Electricity generation emissions fall into the Scope 2 category and are dependent on the data recorded in the eGRID database [22]. Equation (5) shows the emissions factor (EF_E) for electricity

generation, and Equation (6) produces the carbon footprint of the building relative to Scope 2 electricity generation.

$$EF_E = \frac{P_{CO_2}}{E_{Duke}} \tag{5}$$

Where EF_E is the electricity emissions factor, P_{CO2} is total Duke Energy Carolinas, LLC emissions, and E_{Duke} is total electricity net generation from Duke Energy Carolinas, LLC, which are outlined in Section 2.4.3.

$$F_E = EF_E E_b \tag{6}$$

Where F_E is the electricity carbon footprint and E_b is the metered electricity consumption for the building each month.

Further, there are Scope 3 emissions related to electricity consumption: transmission and distribution losses and electricity life cycle emissions. The transmission and distribution losses occur when the generated electricity is transmitted over a certain distance. There are many different ways the energy can be lost, including through heat, conductors, resistors, and even length of the transmission lines. The eGRID database reports a grid loss factor (GGL) and for 2016, the GGL value for the eastern region of the United States (including where Duke Energy Carolinas, LLC operates) is 4.49% [22]. The methodology to calculate the appropriate carbon footprint due to transmission and distribution losses from the eGRID database is shown in Equation (7).

$$F_{TD} = E_b\left(\frac{1}{1 - GGL} - 1\right) \tag{7}$$

Finally, since Duke Energy Carolinas, LLC uses a myriad of fuel sources, the lifecycle emissions of these fuel sources come into play as a Scope 3 emission. The raw material extraction phase, refining and processing phase, manufacturing phase (i.e. solar panels), transportation, and end of life phase (nuclear, coal ash, etc.) all have associated emissions. The emissions factors for these values have been estimated by a number of sources and are reported in Table 15. If applicable, the median value reported for each fuel source was used, following the methodology used by Clabeaux

(2017) [14]. Since wind power contributes only 0.01% (Table 6) of the net electricity generation, the emissions related to wind would be minimal and were excluded. In an effort to not double count the emissions, the total life cycle emissions were subtracted from the electricity use emissions since these studies did not break down the emissions by phase. The product of the electricity used by each building and the emissions factors found in Table 15 give the carbon footprint for lifecycle emissions.

Table 15. Emissions factors for fuel sources of electricity generation

Fuel Source	Emissions Factor [kg CO_2-e/kWh]	Source
Biomass	0.23	[43]
Coal	0.98	[44]
Hydro	0.024	[43]
Natural Gas	0.488	[45]
Nuclear	0.012	[46]
Oil	0.778	[47]
Solar	0.207	[48]

Natural Gas

As outlined in Section 2.4.4, natural combustion produces greenhouse gases and must be quantified. Since the natural gas is combusted on campus at BRC and Life Sciences Building, it is a direct emission (Scope 1). Equation (8) shows the emissions factor (EF_G) for natural gas combustion, and Equation (9) quantifies the carbon footprint of the building relative to Scope 1 natural gas use.

$$EF_G = \sum_{i=1}^{4} P_{G,i}\rho_{NG}\frac{MW_{CO_2}n_{CO_2,i}}{MW_i n_i} \tag{8}$$

Where EF_G is the natural gas emissions factor, $P_{G,i}$ is the percent composition for i gas (Table 8) MW_{CO2} is molecular weight of CO_2, $n_{CO2,i}$ is stoichiometric coefficient of CO_2 for combustion of i gas (Table 9), MW_i and n_i are the molecular weight and stoichiometric coefficient for combustion of i gas respectively, and ρ_{NG} is the density of natural gas.

$$F_G = EF_G G_b \tag{9}$$

Where F_G is the natural gas carbon footprint and G_b is the metered gas consumption for the building each month.

Water

Using the emissions factor (EF_W) taken from a system similar to AJRWS of 0.128 kg CO_2-e/m^3 [41], converting to gallons and using Equation (10), the carbon footprint for water treatment is calculated.

$$F_W = EF_W W_b \tag{10}$$

Where F_W is the water carbon footprint and W_b is the metered water consumption for the building each month.

Sewer

Similar to the water treatment method, the emissions factor (EF_S) for a similar WWTP to Clemson's is 0.217 kg CO_2-e/m^3 [42]. This value is converted from m^3 to gallons to be used in Equation (11) for sewer use.

$$F_S = EF_S S_b \tag{11}$$

Where F_S is the sewer carbon footprint and S_b is the metered sewer consumption for the building each month.

Steam

The steam emissions factor is more involved than the other utilities. There are multiple utilities that go into steam generation, including electricity use, potable water to be converted into steam, and natural gas for the boilers. Thus, there are contributions to the carbon footprint for each of these operations, as outlined in Table 14. The Scope 1 contribution is through natural gas combustion at the central steam plant, Scope 2 is through total electricity use at the plant, and finally Scope 3 is the potable water that enters the plant to account for makeup water shown in Equations (12), (13), and (14), respectively.

$$EF_{ST_G} = \frac{1}{ST_T}(G_{STP}EF_G) \tag{12}$$

$$EF_{ST_E} = \frac{1}{ST_T}(E_{STP}EF_E) \tag{13}$$

$$EF_{ST_W} = \frac{1}{ST_T}(W_{STP}EF_W) \tag{14}$$

Where EF_{ST} is the steam emissions factor, ST_T is the total steam generated in the central steam plant, G_{STP} is the total natural gas used in the central steam plant, E_{STP} is the total electricity used to operate the central steam plant, and W_{STP} is the total makeup water from the central steam plant. These total values were received from CUF as the central plant has a gas, water, and electricity meter and the total utility use over the 2017 calendar year was gathered and used in these equations. The emissions factor for the gas, electricity, and water utilities are essentially coefficients of performance (COPs), taking the ratio of the useful heating load (steam) and input energy source (i.e. natural gas). Finally, the total carbon footprint relative to steam generation for each building is calculated using Equation (15).

$$F_{ST} = \left(EF_{ST_G} + EF_{ST_G} + EF_{ST_G}\right)ST_b \tag{15}$$

Where F_{ST} is the steam carbon footprint, and ST_b is the metered steam consumption for the building each month.

Chilled Water

Finally, the method to calculate the chilled water carbon footprint is similar to the method used for steam, except without the gas consumption. The chilled water plants (CWPs) are powered by electricity and also bring in potable water to account for makeup from leaks and evaporation in the cooling towers. Equations (16) and (**17**) show the contributions to the carbon footprint for electricity and water use.

$$EF_{CW_E} = \frac{1}{CW_T}(E_{CWP}EF_E) \quad (16)$$

$$EF_{CW_W} = \frac{1}{CW_T}(W_{CWP}EF_W) \quad (17)$$

Where EF_{CW} is the chilled water emissions factor, CW_T is the total chilled water generated in the chilled water plants, E_{CWP} is the total electricity used to operate the chilled water plants, and W_{CWP} is the total makeup water from the chilled water plants. Similar to steam, the total chilled water produced from the chiller plants was totaled from data provided by CUF. This was achieved by totaling all meter readings for chilled water across all meters on Clemson's main campus to which the chilled water plants provide the utility. The plants also have electric and water meters to account for how much electricity the chillers use and how much water is provided in makeup. These emissions factors, similar to the steam utility, are essentially COPs taking the ratio of the useful cooling load (chilled water) and input energy source (i.e. electricity). Finally, the total carbon footprint from chilled water generation for each building is calculated using Equation (18).

$$F_{CW} = \left(EF_{CW_E} + EF_{CW_W}\right)CW_b \quad (18)$$

Where F_{CW} is the chilled water carbon footprint, CW_b is the metered chilled water consumption for the building each month.

3.3.4 Interpretation

The interpretation of this streamlined LCA will occur in Chapter 5. Conclusions, recommendations, and analysis of the results from the LCIA will be discussed as well as sources of inaccuracies and uncertainties regarding the data quality.

4. RESULTS

This section describes the results of the data collection and analysis described in the previous section. First, overall annual utility usage trends for the 2017 calendar year will be presented, followed by a breakdown into individual utilities. Heat maps show the breakdown of utility intensity across Clemson University's main campus, while the graphs depict utility trends split up by the different colleges of Clemson (Table 2). Secondly, similar to individual utility use, the total energy use across campus will be presented in units of kBTU/GSF (energy intensity) through the use of heat maps and graphs. The utilities involved with total energy use are electricity, steam, chilled water, and natural gas. Finally, the Scope 1, 2, and 3 emissions for each building will be depicted in a combination of graphs, maps, and tables. All graphs and heat maps are screenshots from the Tableau software to include what the user-interface feels like and features that are included will be described to show the accessibility of the online tool. Additionally, the link to the online workbook can be found at this link.

4.1 Utility Usage

Trends for the 2017 utilities use of academic buildings are shown in Figure 14. The graphs have dual vertical axes to show the utility use (left axis) and cost (right axis) over the 2017 calendar year. Electricity use hovers around 4 million kWh per month, with a slight increase in the late summer and early fall months to accommodate the chilled water demand that peaks in July. The steam trend is almost inversely proportional to the chilled water trend, calling for more steam during the winter months, and less during the summer, to provide heating during these colder months. Both chilled water and steam trends are determined by outside air temperature. When live meters are installed, an outside air temperature reading could be recorded at the time of a meter reading to show a more direct correlation between outside air and steam and chilled water use. Meanwhile, heating degree days (HDD) and cooling degree days (CDD) were generated for Clemson, SC according to CUF climate control policies requiring buildings to provide heating or cooling to stay within 68°F and 76°F and is shown in Table 16 [49]. Water and sewer use follow a pattern we would expect, dipping in the summer

months due to low student population, and increasing during the fall months when it is warmer. Increasing drinking water use could potentially increase bathroom use, which could be another factor in the rise during these months. Natural gas use for 2017 does not necessarily tell an accurate story since there was a significant reading error in September and October. However, we would expect that value to be higher, following the same trend as the steam since that natural gas meter is used primarily for the onsite boiler.

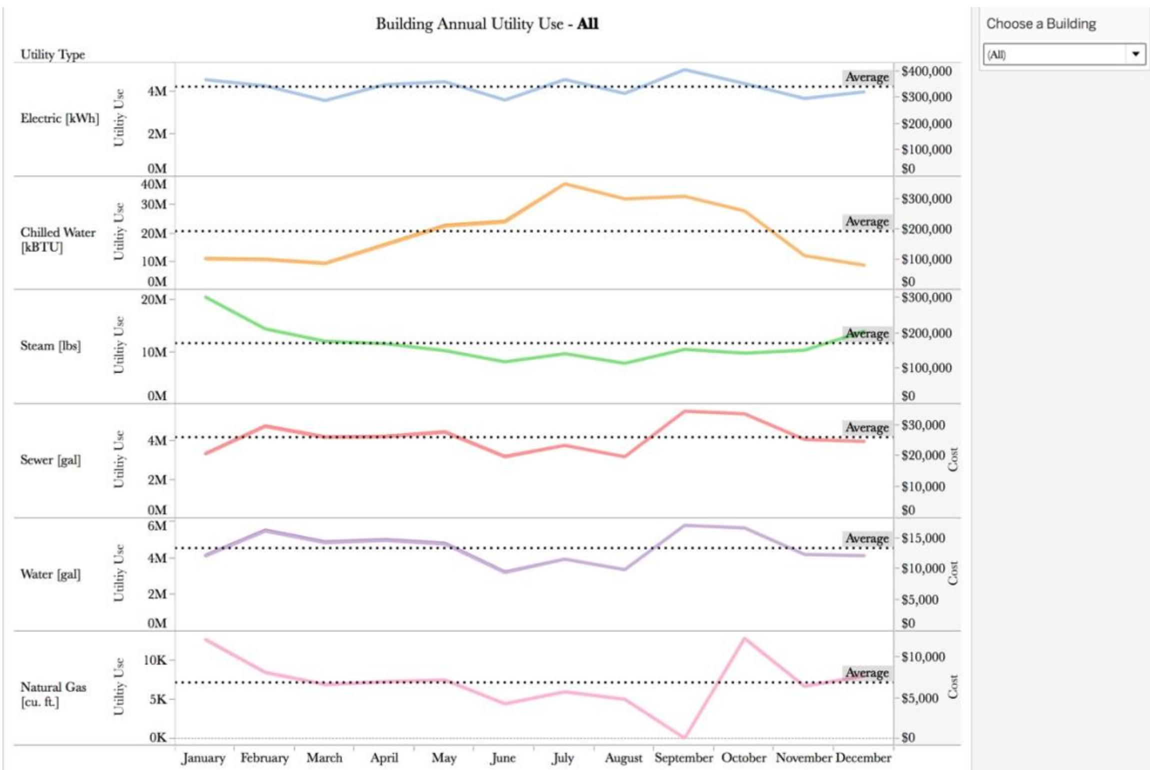

Figure 14. All E&G buildings 2017 utility use trends

Figure 15 and Figure 16 show the trends for chilled water and steam, respectively, for all E&G buildings as well as the range of HDDs and CDDs for each month (Table 16). As expected, the demand for the chilled water and steam and heating/cooling degree days follow the same trends. Additionally, Figure 17 shows the interface when you choose a specific building using the filter on the right side. Here, the 2017 utility use for Brackett Hall, where the Environmental Engineering and Earth Sciences department at Clemson's main campus operates, is shown. This filter allows the user to pick any

academic building on Clemson's main campus and see the corresponding utility use and cost. The trends of Brackett Hall roughly reflect the results shown in Figure 14.

Table 16. CDD and HDD for 2017 [49]

Month	CDD (68°F)	CDD (76°F)	HDD (68°F)	HDD (76°F)
January	10	1	565	803
February	12	0	388	600
March	30	6	403	627
April	97	28	146	317
May	156	46	77	215
June	282	98	9	65
July	421	204	1	31
August	352	148	2	46
September	199	72	38	147
October	102	25	185	356
November	12	2	415	645
December	2	0	659	904

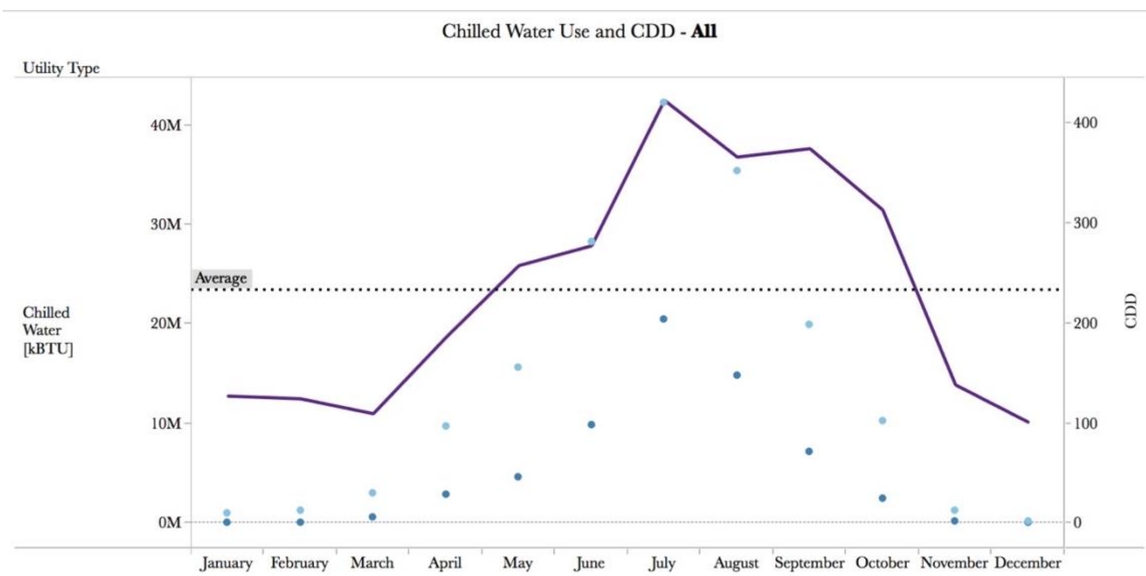

Figure 15. Chilled water use and CDDs

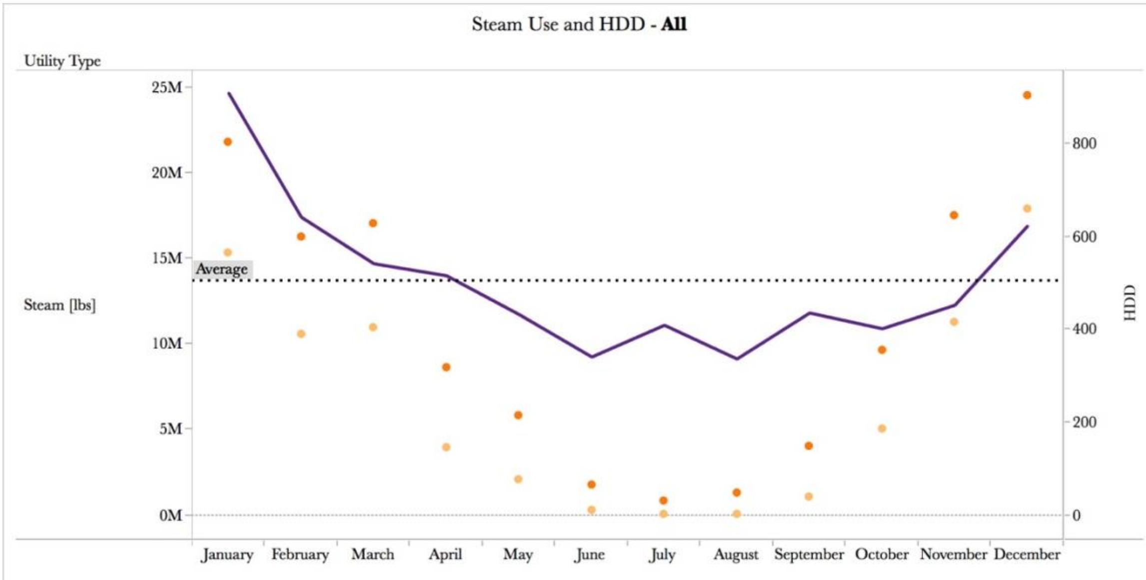

Figure 16. Steam use and HDDs

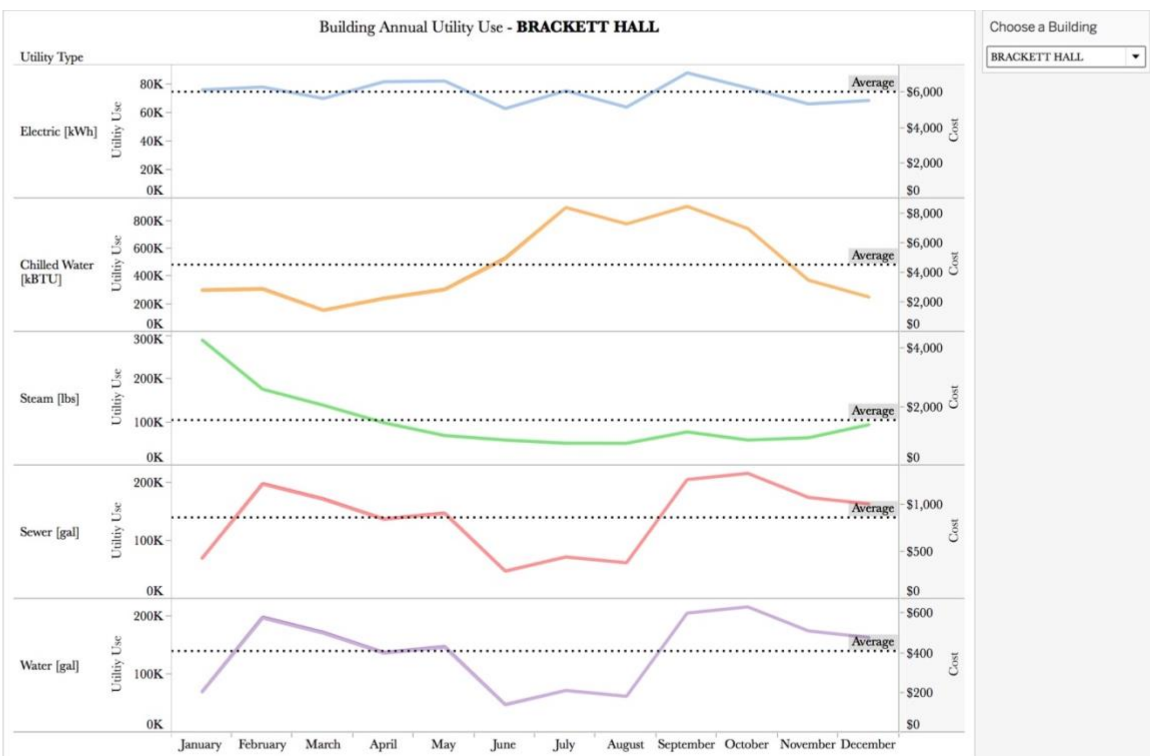

Figure 17. Annual utility use for Brackett Hall

4.1.1 Electricity Use

As stated earlier, the trend for electricity use hovers around 4 million kWh, with a peak at 5 million kWh in September, and dipping down to 3.5 million kWh in March. This demand is relatively constant throughout the year possibly due to the mechanical loads of the buildings. The pumps and fans that power the HVAC systems are constantly running to ensure the climate within the building remains within the CUF policies. Figure 18 shows the results for 2017 electricity intensity (kWh/GSF), broken down by which college operates through a specific building. Each college is a different color and each sliver within each college is an individual building. Hardin Hall, Edwards Hall, and Brackett Hall are all special cases wherein multiple colleges operate out of each building, thus they have been grouped into a "Multidisciplinary" category (teal). Additionally, buildings such as Cooper Library, Academic Success Center, Watt Family Innovation Center, and Vickrey Hall do not identify with a college, therefore they are put into a "General Academic" category (grey). This figure, as well as the ones to follow, are sorted so that the largest annual contributor is at the bottom and the smallest annual contributor is at the top. This will allow an easy glance to see which Colleges are utilizing their utilities efficiently. A large intensity typically means that the utility is being used inefficiently.

As seen from the results, the College of Agriculture, Forestry and Life Sciences (CAFLS, shown in orange), College of Engineering, Computing and Applied Sciences (CECAS, shown in black), and College of Science (CSCI, shown in brown) have the largest utility use. Godley Snell (CAFLS, seen in Figure 20 outlined in bold black) has a large electricity intensity, and a small square footage, which yields a large contribution of 58.29 kWh/GSF. This is primarily due to the onsite chiller that Godley Snell has to provide chilled water for that building only. CECAS operates in a number of buildings, but electricity use is fairly evenly distributed. Finally, CSCI occupies Hunter Hall and Biosystems Research Complex (BRC), which have a relatively large electricity intensity. BRC operates four greenhouses as part of its research activities, which are constantly using electricity to light, heat, and ventilate the greenhouse structures. Figure 19 shows the total electricity consumption for all academic

buildings, but not on a per-GSF basis. This shows primarily, that CECAS contributes less to the total kWh used, however their intensity contribution is larger. Essentially, it takes more electricity to power 1 sq. ft. in CECAS buildings than in other Colleges.

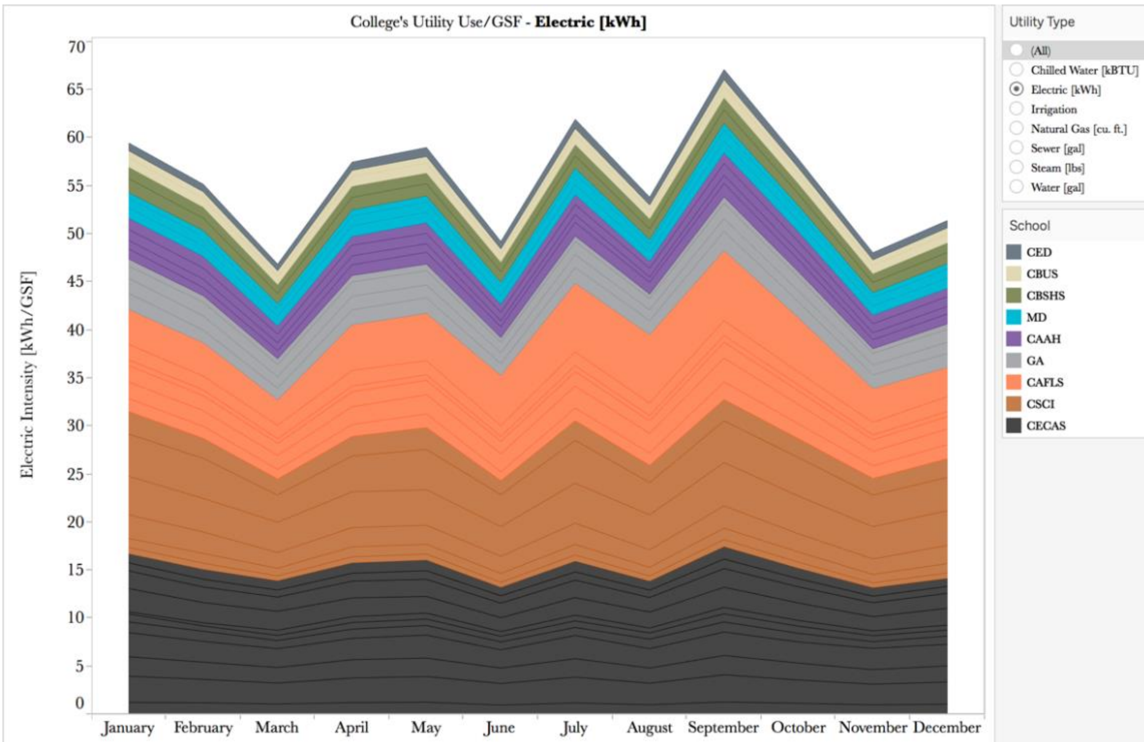

Figure 18. College electricity intensity distribution

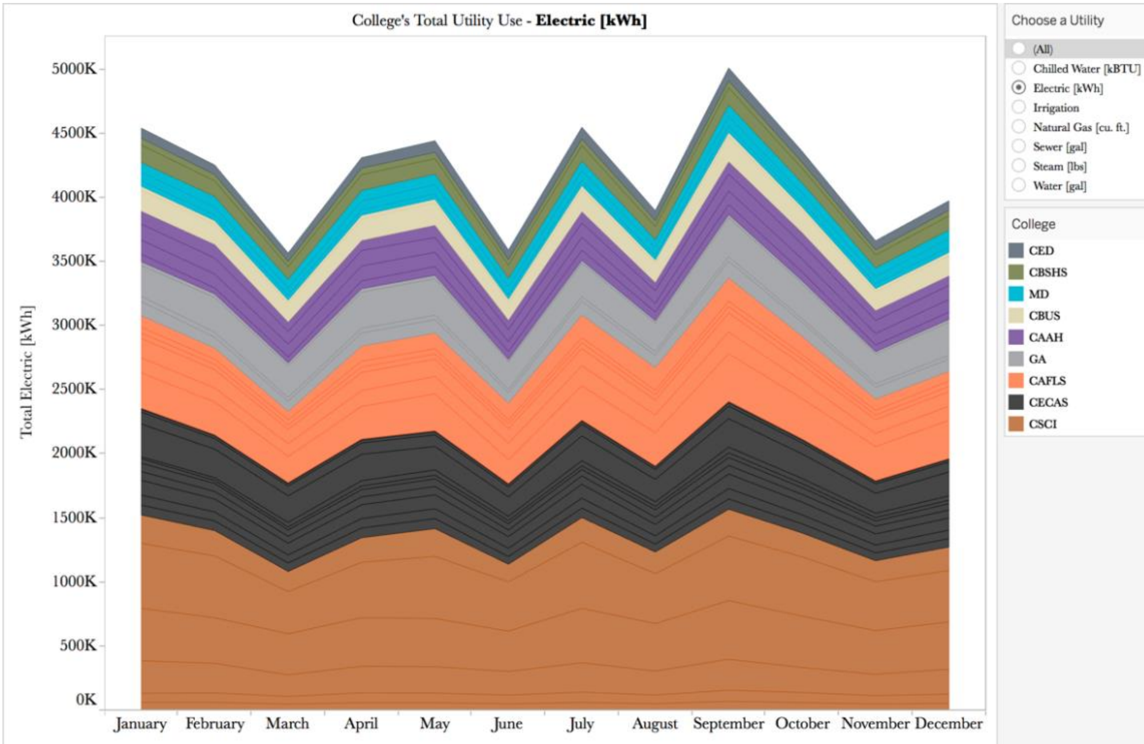

Figure 19. College total electricity use

Using GIS data from the Clemson Center for Geospatial Technologies, a heat map of electricity intensity was created and shown in Figure 20. As just discussed, Godley Snell, BRC, and Hunter Hall are the main culprits for large electricity intensity. Rhodes Engineering Annex also does not use electricity efficiently, and an energy audit should be conducted by CUF to investigate why, since the Annex is a newer building on campus (constructed in 2009). These buildings are labeled on Figure 20 as 1, 2, 3, and 4 respectively.

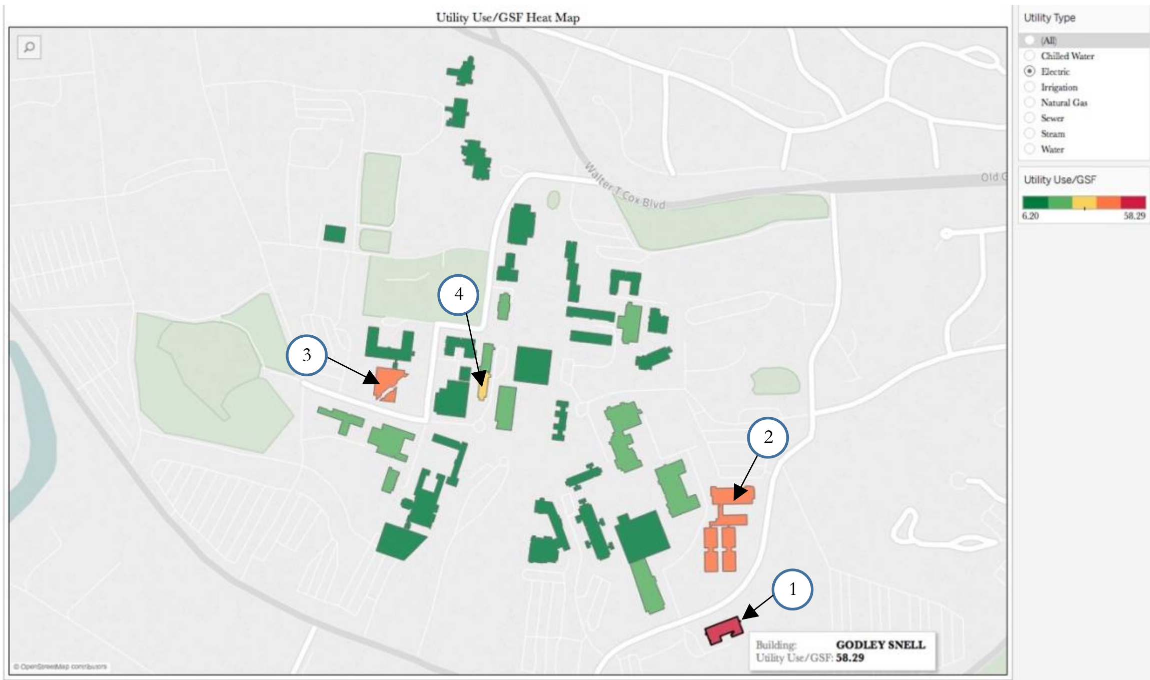

Figure 20. Electricity intensity heat map

4.1.2 Chilled Water Use

The highest demand for chilled water is during the warmer months of the year, when buildings require more space cooling. As stated in Section 2.4.1, there are different HVAC systems (chilled beam, 2-pipe and 4-pipe fan coil units, and centralized AHUs) and each provide cooling at different efficiencies. Figure 21 shows the results for 2017 chilled water intensity (kBTU/GSF), broken down by which college operates through a specific building. The largest college contributors to chilled water intensity were CSCI and CECAS, and Hunter Hall had the largest contribution across all campus with a peak value of 51 kBTU/GSF during July. The reason that Hunter Hall has such a large consumption is primarily due to the chemistry lab requirements of bringing in 100% fresh air at all times, i.e. no recirculation of inside air. The fume hoods within the labs are constantly pumping ambient air out of the building to provide a safe environment for the students, faculty, and staff within the building. Additionally, Figure 22, shows the total utility consumption of chilled water for all buildings within each college. Again, we see that CECAS adds less to the total utility use when analyzed in total

consumption but has a large contribution to the chilled water intensity. Therefore, in general, these buildings are not as resource efficient as other buildings on campus. The heat map, Figure 23, further explores the data and we can see that there are a number of buildings that have high chilled water intensity, including Hunter Hall (1), BRC (2), Fluor Daniel (3), Dillard (4), Rhodes Hall and Annex (5), Daniel Hall/Strode Tower (6), and Olin Hall (7).

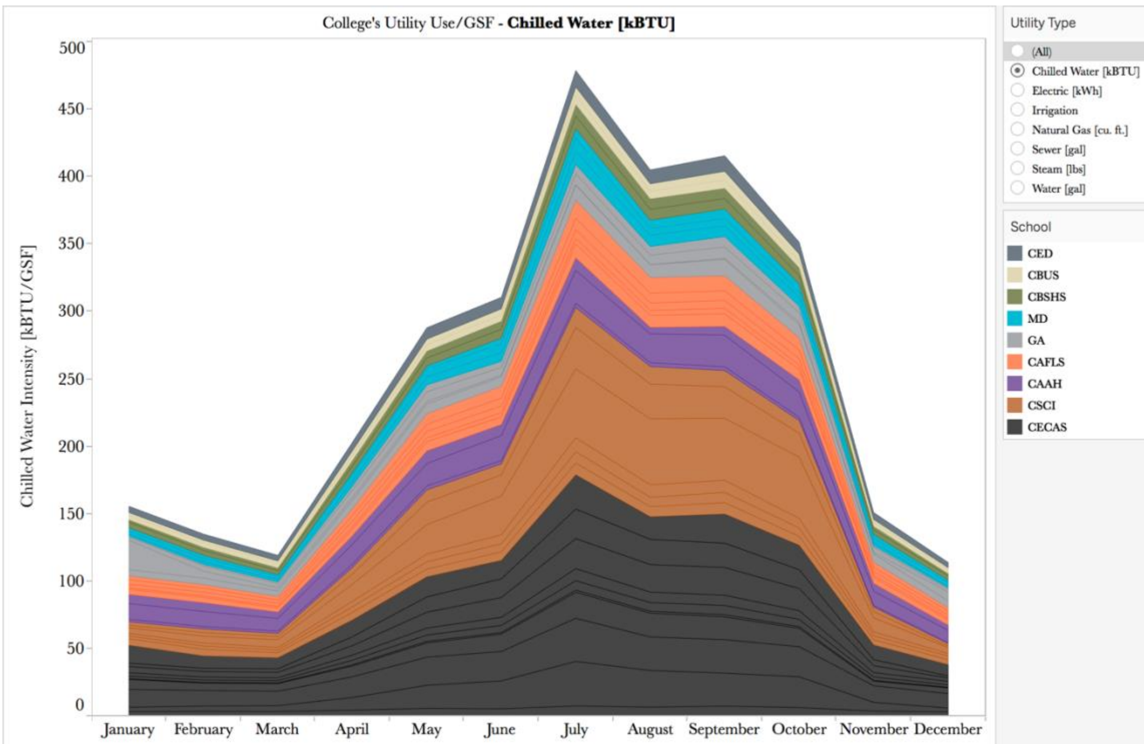

Figure 21. College chilled water intensity distribution

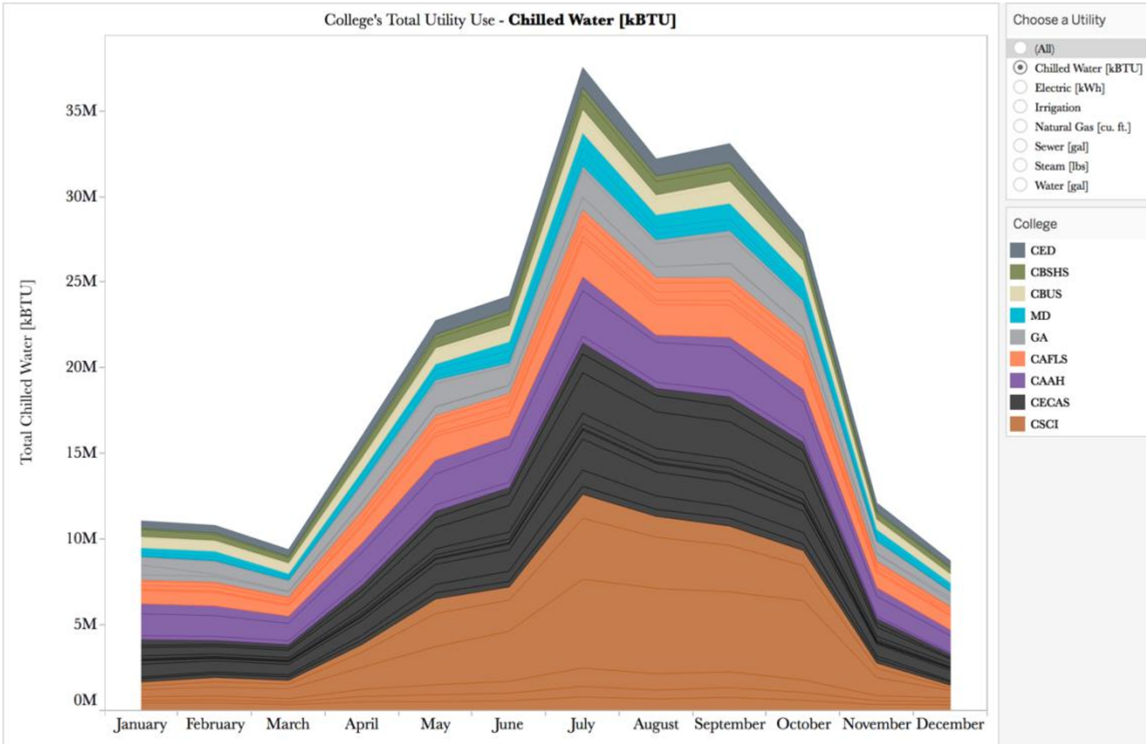

Figure 22. College total chilled water use

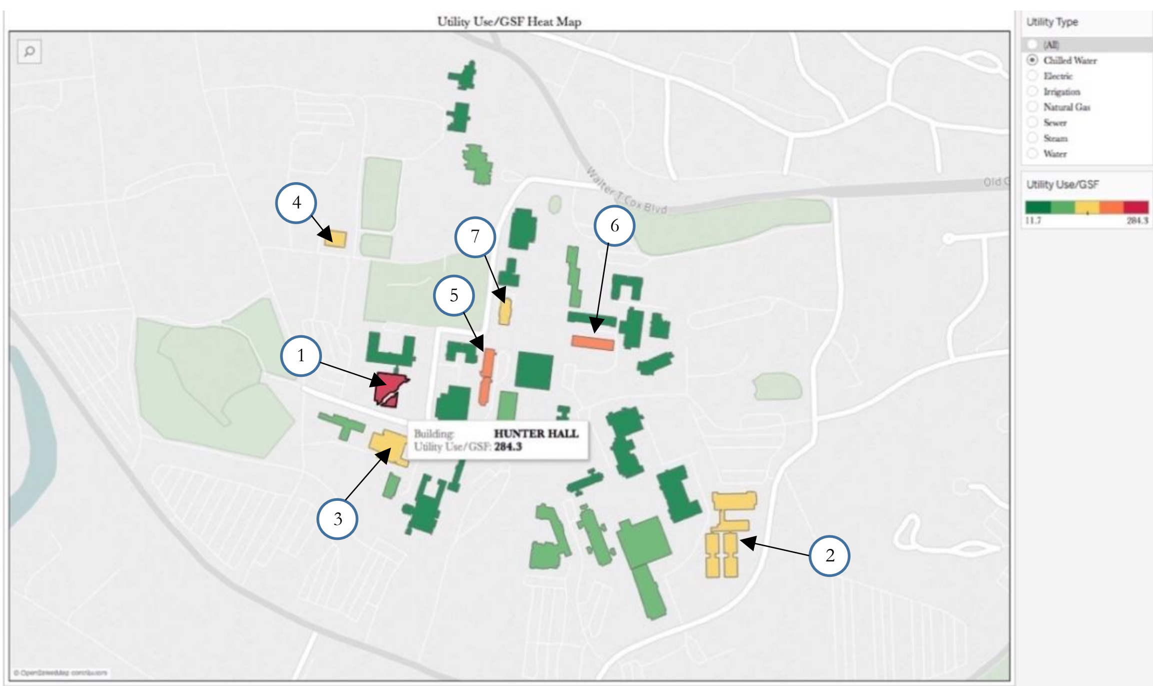

Figure 23. Chilled water intensity heat map

4.1.3 Steam Use

During the winter months, we see a large demand for steam to heat the buildings to the climate-controlled setting. Like chilled water, steam use is dependent on the type of HVAC system in place within the building. Figure 24 shows the distribution of steam intensity (lbs/GSF) for each college. Once again, the main contributors to steam intensity are CAFLS, CECAS, and CSCI. Godley Snell has the largest annual intensity contribution, and peaks in January at 33.55 lbs/GSF. Godley Snell is an Animal Sciences building with a small footprint (~22,000 GSF), and houses large and small laboratory animals including rodents, rabbits, chickens, goats, and swine. The energy-intensive ventilation cages and rooms call for the large steam demand, in similar fashion to the ventilation requirements in Hunter Hall [50]. However, this does not mean that Godley Snell uses the most steam overall, but rather has the highest steam intensity. Figure 25 shows that Godley Snell only contributes a small amount to the total steam use across all academic buildings. Figure 26 shows the heat map produced for steam intensity, where Godley Snell (1), Hunter Hall (2), Fluor Daniel (3), Earle Hall (4), and Olin Hall (5) have the highest values. Hunter Hall (2) has high values for the same reason as chilled water – constantly pumping in fresh air for the labs. Fluor Daniel (3) has a large atrium with a long wall of large windows, which allows the cold outside air to cool the windows, thus cooling the inside air and make the heating demand larger.

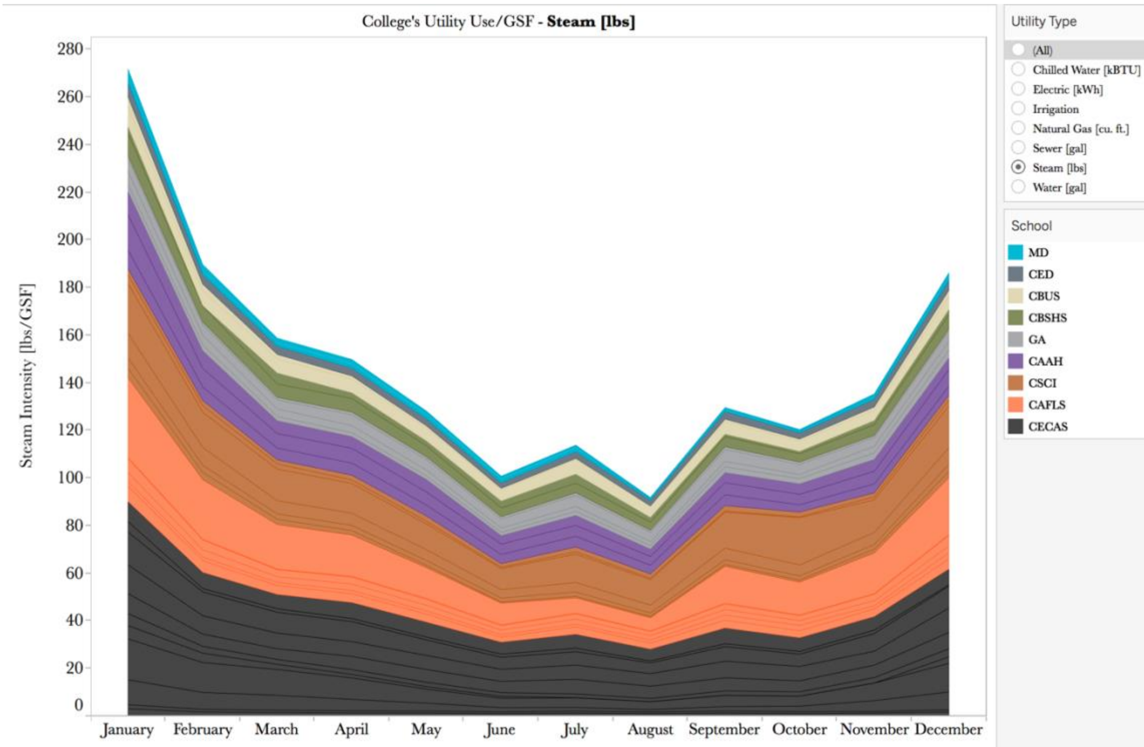

Figure 24. College steam intensity distribution

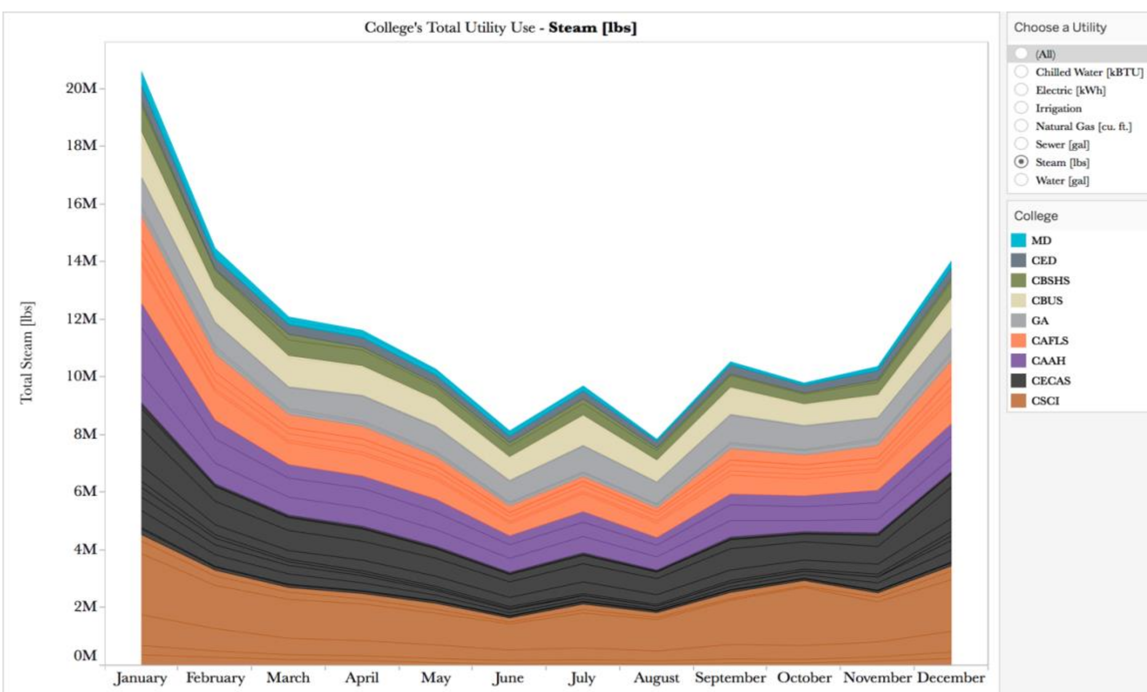

Figure 25. College total steam use

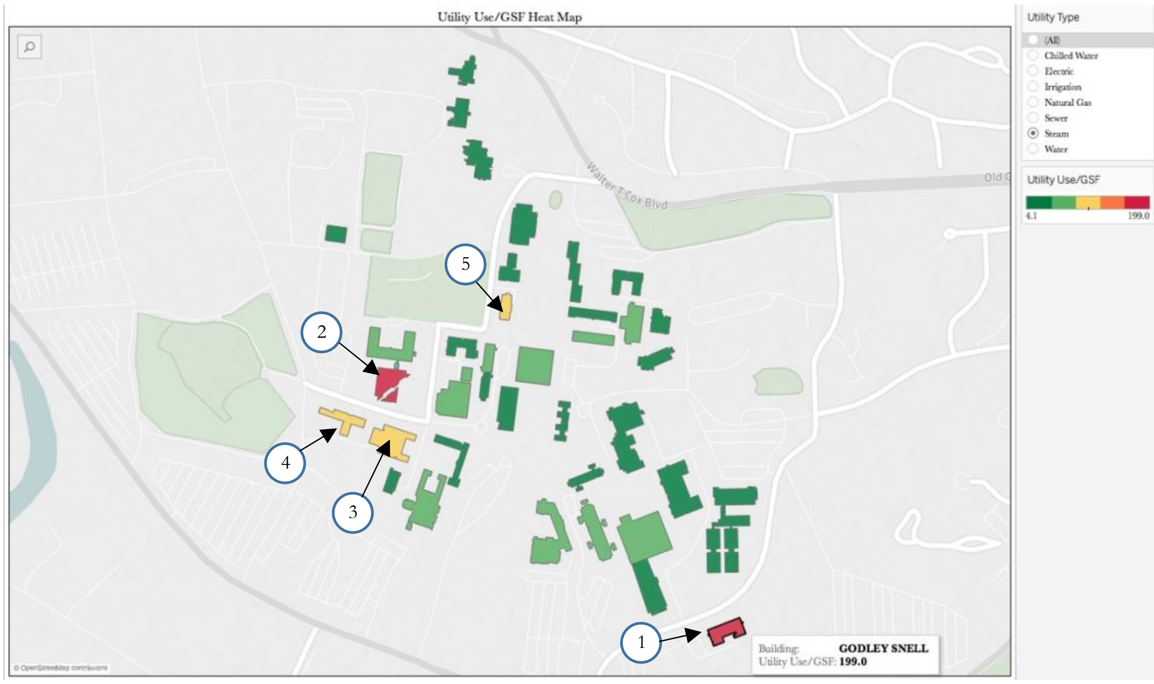

Figure 26. Steam intensity heat map

4.1.4 Water and Sewer Use

Water and sewer use trends typically line up with student population on campus. As seen in Figure 14, the water and sewer use dip in the summer months when most students are not on campus. Peak water and sewer use occurs during the fall months when the academic year starts back up in August. Main functions of water and sewer use lay within the restrooms and water fountains of the buildings, although some laboratory buildings have sinks to provide potable water for lab needs as well as cooling large equipment. There could also be additional usage during the fall months when Clemson hosts home football games, sometimes bringing in 100,000 extra people into Clemson's city limits. Although most E&G buildings are locked during the weekends, they sometimes open up the buildings for patrons to use the restrooms within the buildings. Figure 27 shows the college water and sewer use intensity (gal/GSF) and Figure 28 shows the total water and sewer use, respectively. The graphs just show water use, but sewer and water readings are from the same meter, so the consumption is the same. Finally, Figure 29 shows the heat map of water and sewer intensity across campus. Newman Hall

(1) has the largest intensity at a value of 86.11 gal/GSF and can primarily attributed to the meat processing and machine cooling that occur within the building. Additionally, Cooper Library (2) sees a large water intensity value primarily due to the volume of people that utilize the library throughout each day. Other notable buildings with large water and sewer intensity values are Godley Snell (3), Rhodes Hall (4), Hunter Hall (5), and Earle Hall (6).

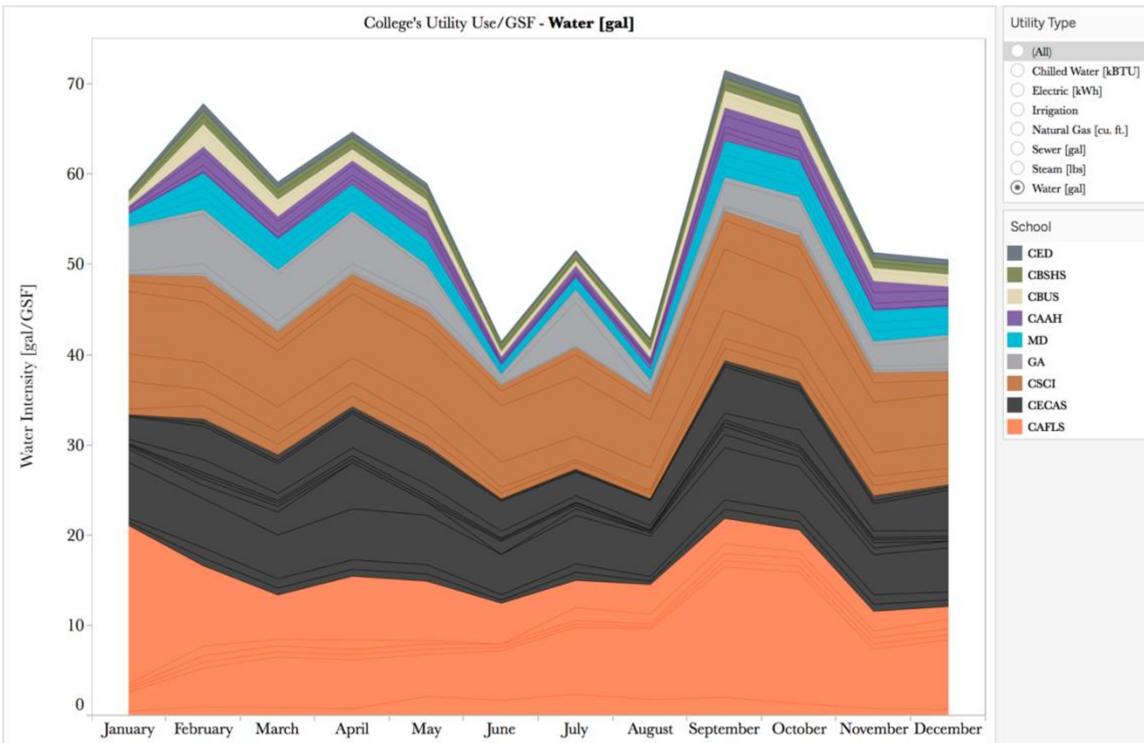

Figure 27. College water and sewer intensity distribution

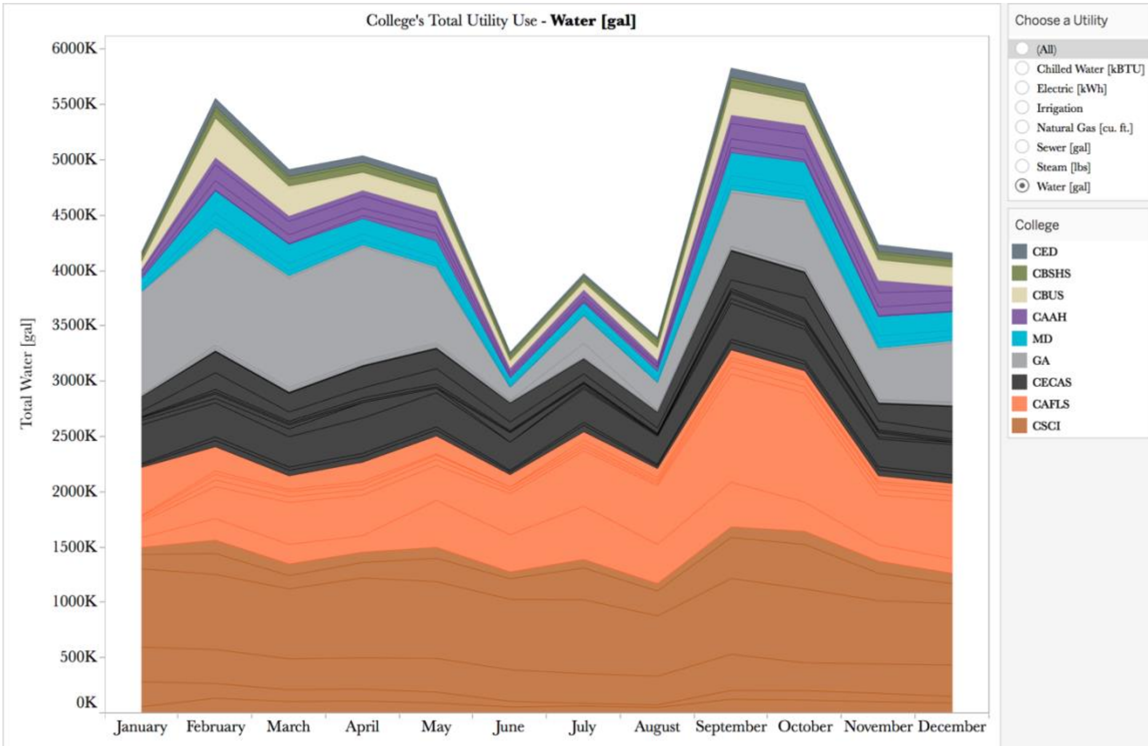

Figure 28. College total water and sewer use

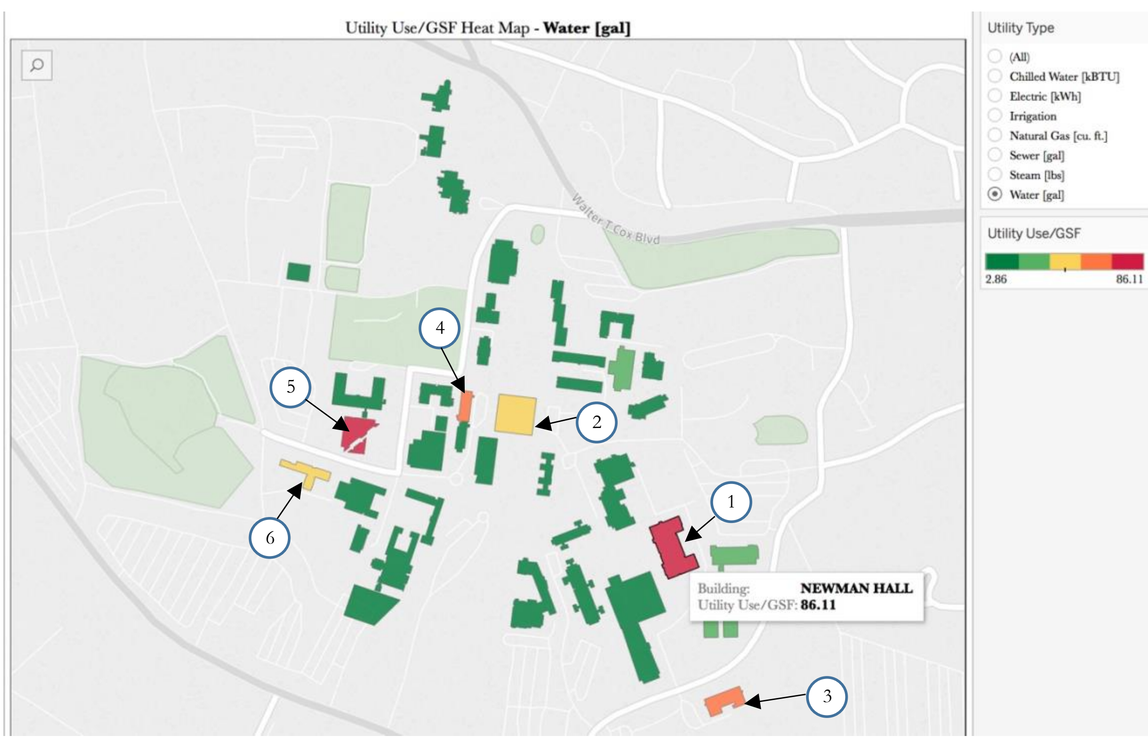

Figure 29. Water and sewer intensity heat map

4.1.5 Natural Gas Use

As previously stated, only BRC and Life Sciences Building have direct lines to natural gas and are both within the CSCI. Both buildings utilize the resource for laboratory functions, and the Life Sciences Building has an on-site boiler to produce steam for the HVAC system instead of using steam generated from the central plant for HVAC processes. The Life Sciences Building also uses steam from the central plant, but for lab equipment purposes, according to CUF. Additionally, there was a reading error in September and October 2017, so the consumption for those months are skewed. An advantage to creating this tool is that it allows the user to quickly see when there might be something wrong with the reading, and that another reading should take place as soon as possible to capture the months consumption. Figure 30 shows the use of natural gas intensity for the two buildings and Figure 31 shows the total consumption. Finally, the heat map for natural gas use is displayed in Figure 32. Although this figure is not necessarily helpful to CUF, it does show the public that only two academic buildings have a direct line to natural gas.

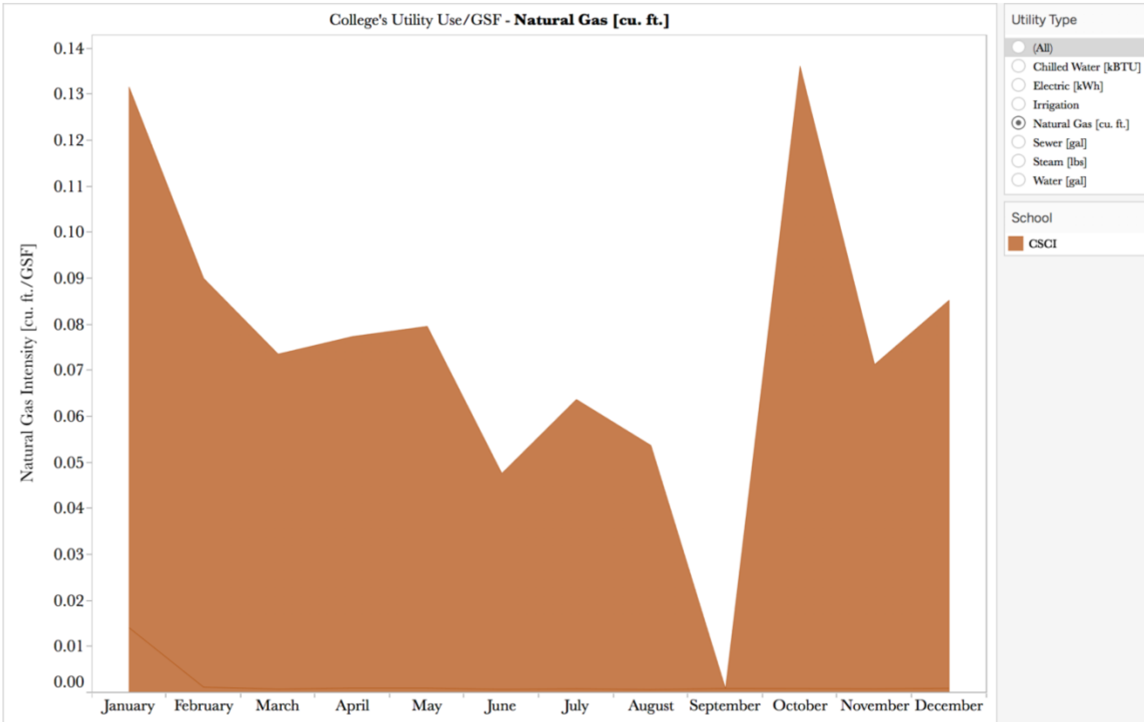

Figure 30. College natural gas intensity distribution

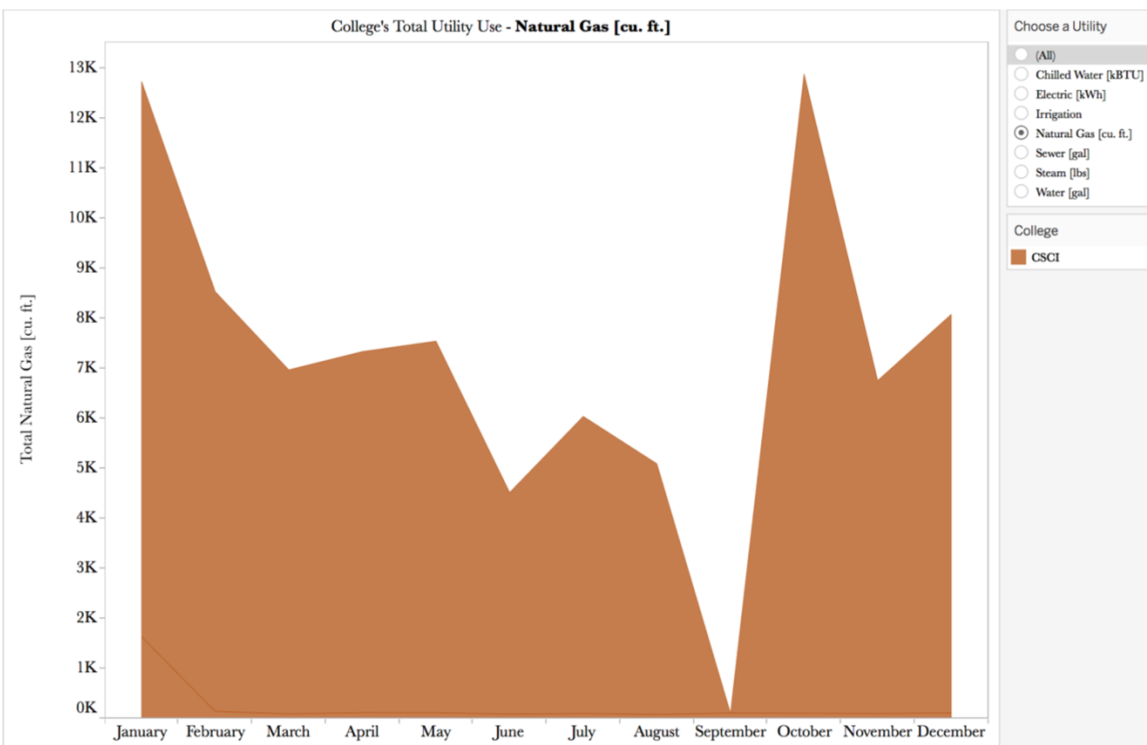

Figure 31. College total natural gas use

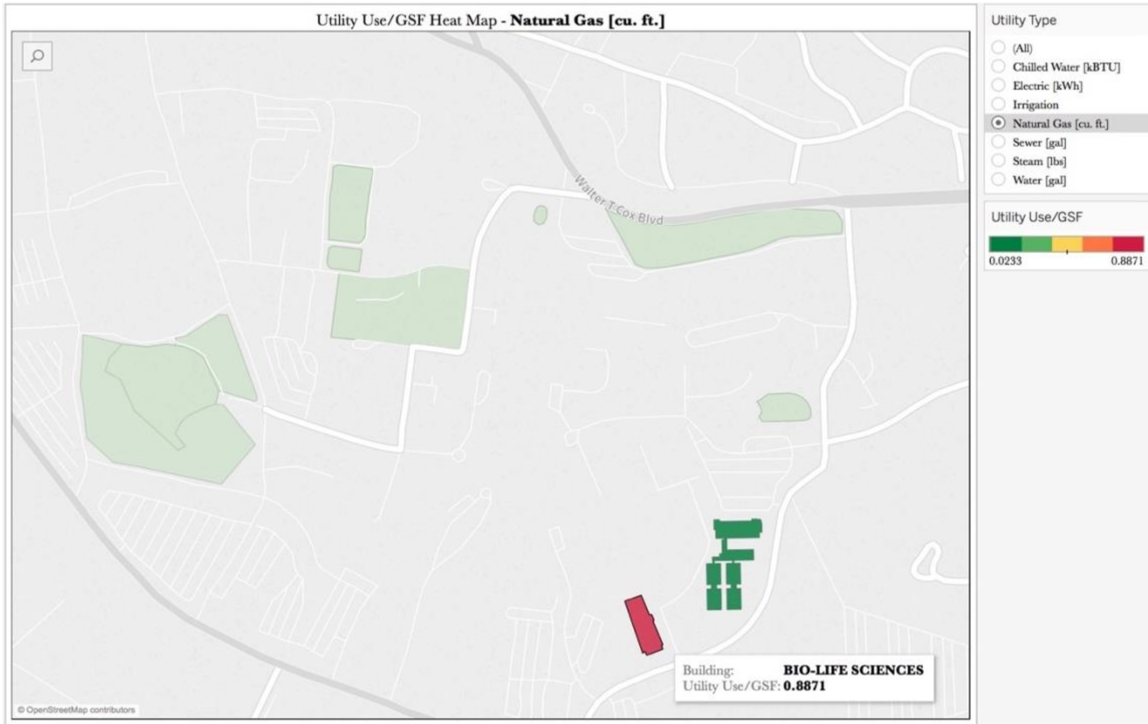

Figure 32. Natural gas intensity heat map

4.2 Total Energy Use

Figure 33 shows the heat map results after taking the conversions to kBTU from Table 12 into consideration. As one would expect, Hunter Hall (1), Godley Snell (2), and BRC (3) have high energy intensity values, with Hunter Hall being the largest at 637.8 kBTU/GSF annually.

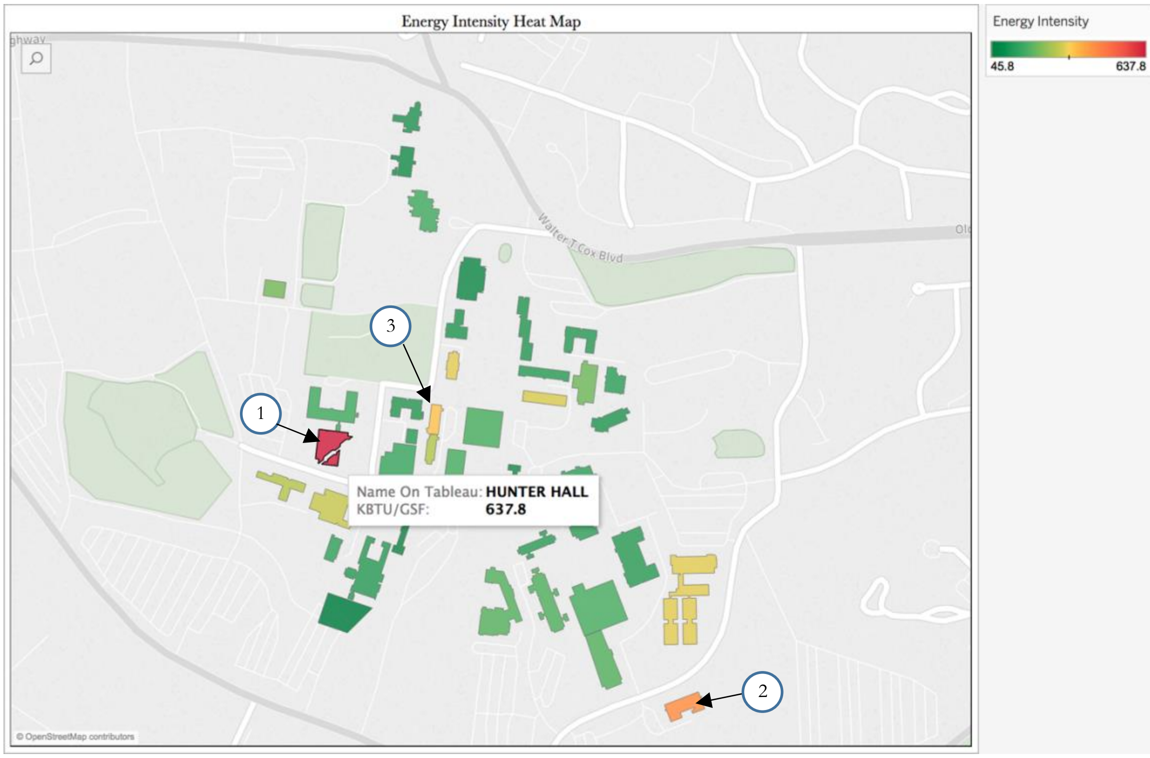

Figure 33. Annual energy intensity [kBTU/GSF] heat map

4.3 Carbon Footprint Results

Carrying out the calculations outlined in the LCIA (Section 3.4.3) Table 17 (annual) and Figure 34 (monthly) shows the contribution of each scope to the total carbon footprint of all academic buildings on campus, which is equal to 40,722 metric tons of CO_2-e for 2017. The largest contributor to the carbon footprint, as found in Clabeaux (2017), was Scope 2 through purchased electricity. A further breakdown of the scopes and flows that were assessed (Table 13) is shown in Table 18. As expected, the steam and chilled water main operation flows contribute over 16% and 11%, respectively, to the total carbon footprint.

Table 17. Results of Clemson's academic building carbon footprint

Scope	Metric tons CO_2-e	Percent of total
Scope 1	6,609	16%
Scope 2	32,104	79%
Scope 3	2,009	5%
Total Carbon Footprint	40,722	100%

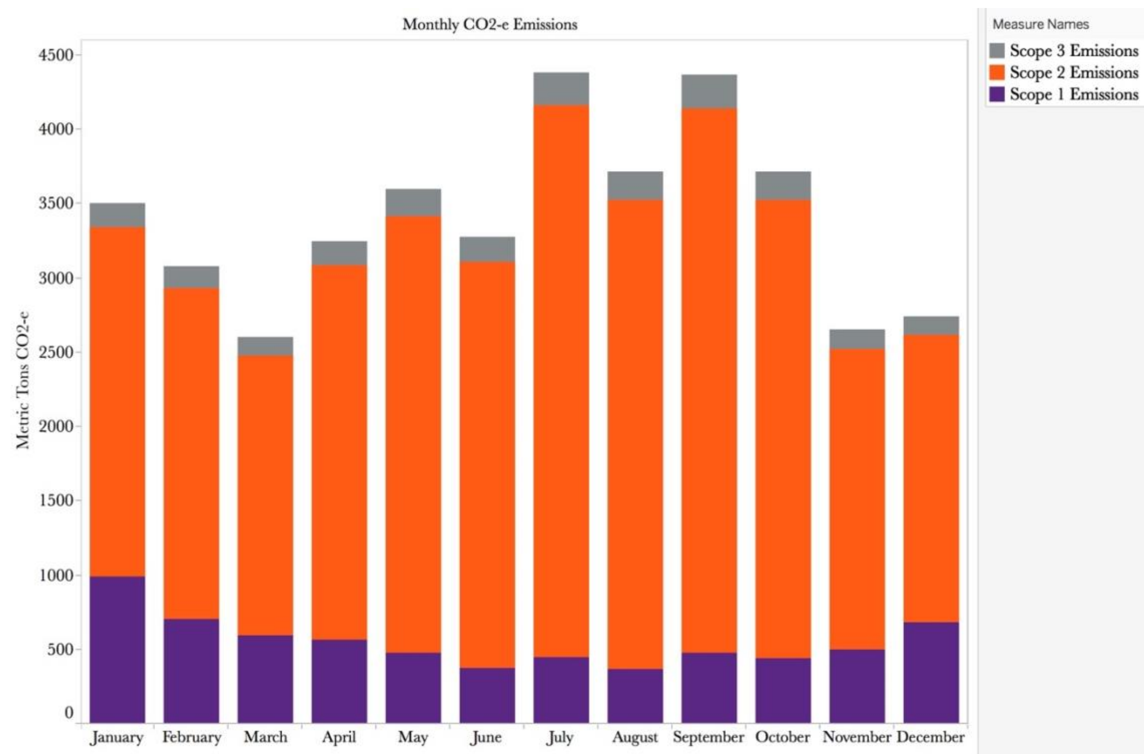

Figure 34. Monthly carbon emissions distribution of Scopes 1, 2, and 3

Table 18. Flow distribution of carbon footprint

Flow	Metric tons CO_2-e	Percent of Total	
Natural Gas Combustion	4	0.01%	**Scope 1**
Steam Generation	6,547	16.08%	
Wastewater Treatment	58	0.14%	
Purchased Electricity	27,390	67.26%	**Scope 2**
Electricity use at STP	3	0.01%	
Electricity use at CWPs	4,710	11.57%	
Water for Steam	6	0.01%	**Scope 3**
Potable Water	79	0.19%	
Water for Chilled Water	17	0.04%	
Transmission and Distribution Losses	1,287	3.16%	
Electricity Lifecycle Emissions	621	1.52%	
Total	**40,722**	**100.00%**	

Clemson's total carbon footprint in 2014 was calculated to be 95,000 metric tons [14]. And assuming that the footprint has not changed significantly since then, the academic buildings' contribution to the total carbon footprint is over 40%. Other large contributors to the total footprint would be Housing and Dining buildings, those that see a large volume of the students every day of the week, at all hours of the day and have a large GSF.

Figure 35 shows the heat map of the academic building's individual annual carbon footprint. Within Tableau, the filter on the right can be changed to view the carbon footprint heat map by month if desired. As expected, Hunter Hall (1) contributes the most to the total carbon footprint (2,754 metric tons CO_2-e) shown in Table 19. BRC (2), Poole Agricultural Center (3), and Cooper Library (4) are the next three largest contributors with 2,213, 1,723, and 1,675 metric tons of CO_2-e respectively. Likely due to the large GSF, volume, and demand of each of these buildings explored earlier. Other buildings that should be the focus of CUF to reduce environmental impact include Fluor Daniel (5), Sirrine Hall (6), and Jordan Hall (7). Figure 36 shows the carbon footprint intensity (metric tons CO_2-e/GSF) heat map for the academic buildings on campus. Godley Snell has the largest value of 0.02828 metric tons CO_2-e/GSF, followed by Hunter Hall (2), BRC (3), Olin Hall (4), and Rhodes Annex (5).

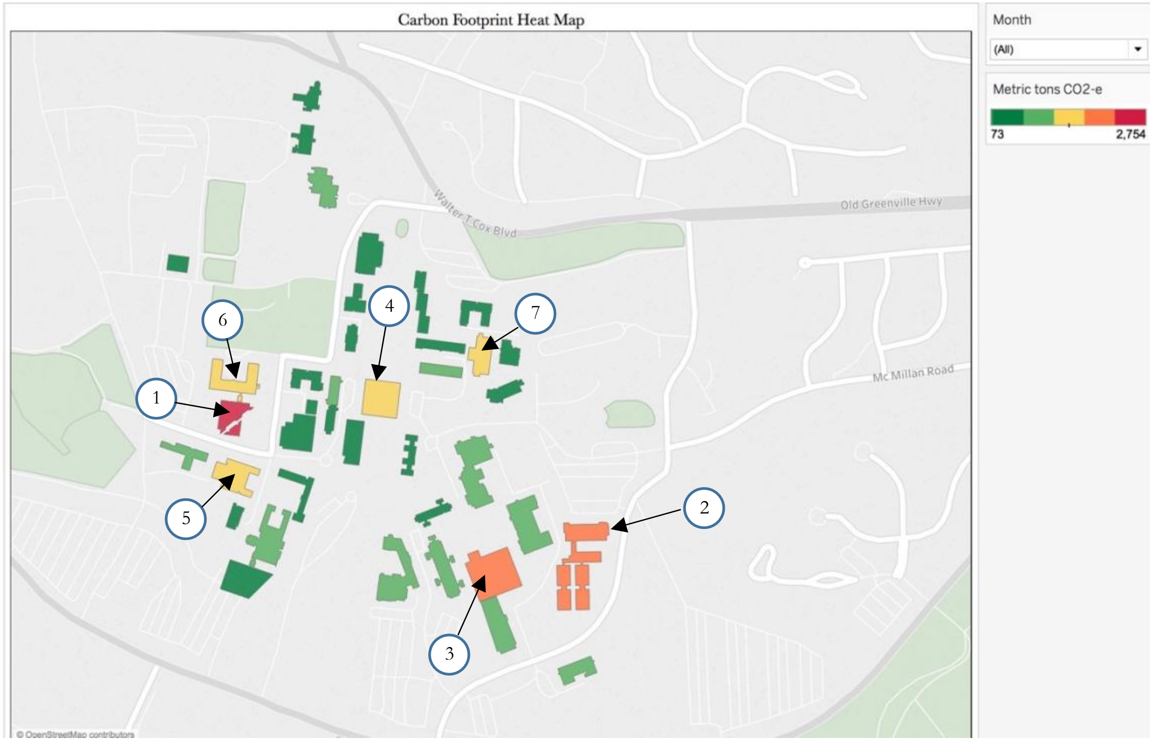

Figure 35. Carbon footprint heat map

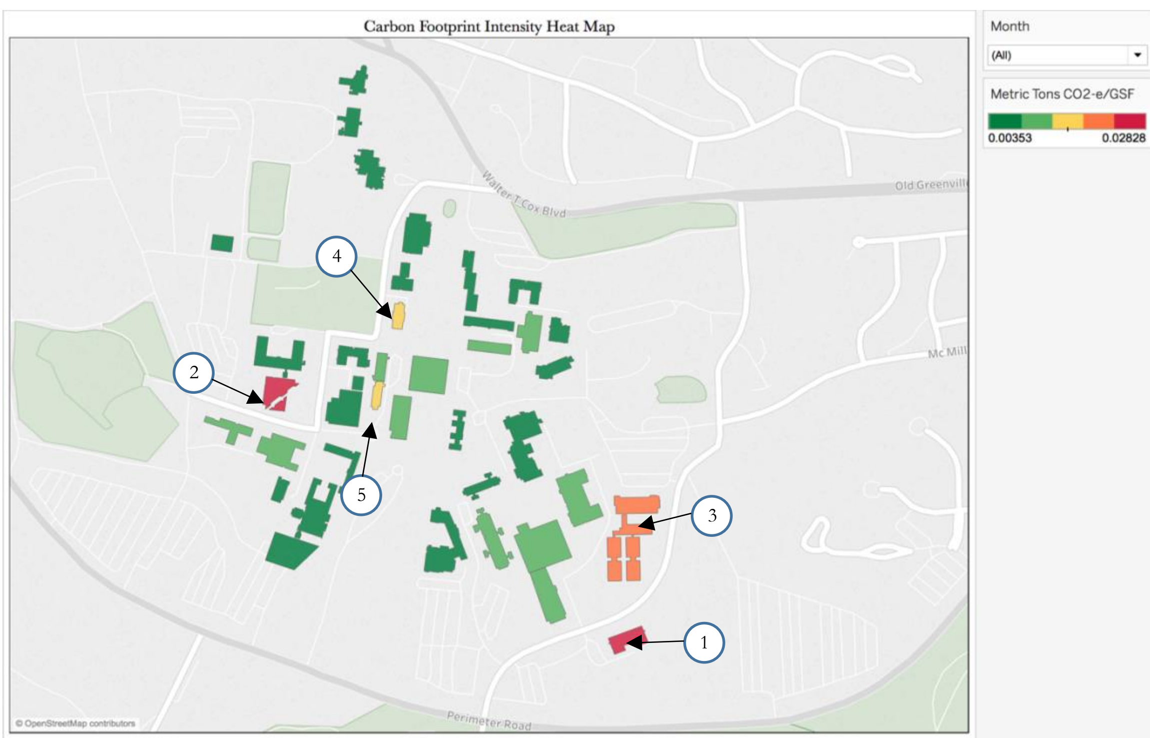

Figure 36. Carbon footprint intensity heat map

Table 19. All academic building's Scopes 1, 2, and 3 emissions for 2017 in metric tons CO_2-e

Building Name	Scope 1	Scope 2	Scope 3	Total
HUNTER HALL	696	1,951	108	2,754
BIOSYSTEMS RESEARCH COMPLEX	87	2,004	122	2,213
POOLE AGRICULTURAL CENTER	351	1,297	76	1,723
COOPER LIBRARY	395	1,206	74	1,675
FLOUR DANIEL	355	1,000	55	1,410
SIRRINE HALL	443	773	45	1,262
JORDAN HALL	272	908	58	1,238
DANIEL HALL/STRODE TOWER	325	784	33	1,142
LIFE SCIENCES BUILDING	93	854	51	999
LEHOTSKY HALL	232	555	32	819
RHODES ENGINEERING	120	600	30	751
LEE 1 & 2	276	443	28	746
MCADAMS HALL	107	574	36	717
GODLEY SNELL	198	469	34	701
BROOKS CENTER	217	453	24	694
EARLE HALL	185	428	24	637
TILLMAN HALL	155	457	23	635
NEWMAN HALL	57	530	38	624
WATT CENTER	65	485	28	577
BRACKETT HALL	51	386	21	459
KINARD LAB	81	355	21	457
OLIN HALL	104	294	17	415
MARTIN HALL	72	321	16	409
RIGGS HALL	42	336	20	397
RHODES ENGINEERING - ANNEX	13	360	20	393
FREEMAN HALL	179	199	10	388
EDWARDS HALL	41	319	19	379
LONG HALL	101	230	12	343
BARRE HALL	49	227	13	289
LOWRY HALL	42	224	15	281
LEE 3	0	239	17	256
HARDIN HALL	17	195	11	223
HARRIS A. SMITH	5	193	11	208
HOLTZENDORFF HALL	47	145	8	200
VICKERY HALL	36	148	9	194
GODFREY HALL	32	142	8	182
DILLARD	18	153	6	176
ACADEMIC SUCCESS	21	124	7	152
COOK LAB	30	40	3	73

5. DISCUSSION AND RECOMMENDATIONS

5.1 HVAC Systems

To further analyze chilled water and steam use, the HVAC systems of the academic buildings were gathered, and the annual average chilled water intensity was plotted in Figure 37. As expected the CAV system contributes to this value the most, and Hunter Hall is the building primarily responsible for the CAV impact. Buildings with only FCUs consistently contribute the second most to this total.

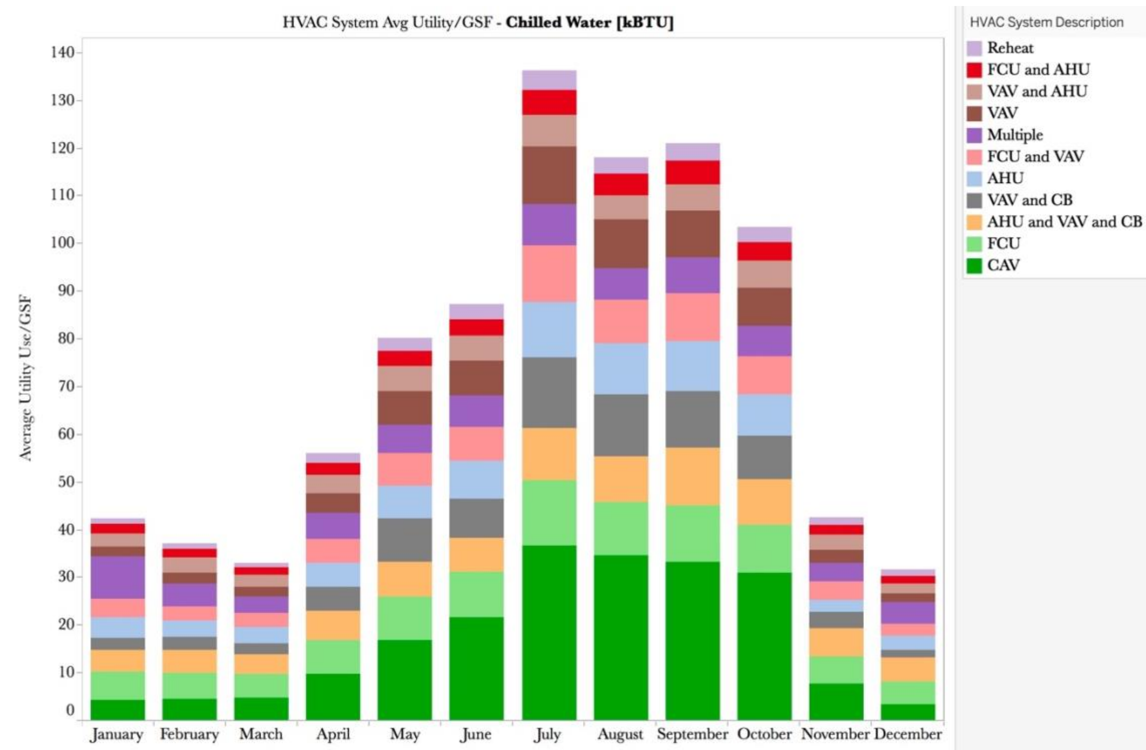

Figure 37. Average chilled water intensity distribution by HVAC system

Looking into FCUs more, Figure 38 shows the average chilled water intensity for any building that has FCUs in it, however this figure shows us that 2-pipe systems are more efficient at keeping the space cooled. Of course, each building is different in terms of conditioned space, temperature setting, other HVAC systems incorporated in the building, and air quality settings (O_2/CO_2). Therefore, this analysis just shows that on an average, buildings that have any 2-pipe FCUs operate better than any building with 4-pipe FCUs for chilled water. Table 5 details the HVAC systems in each building.

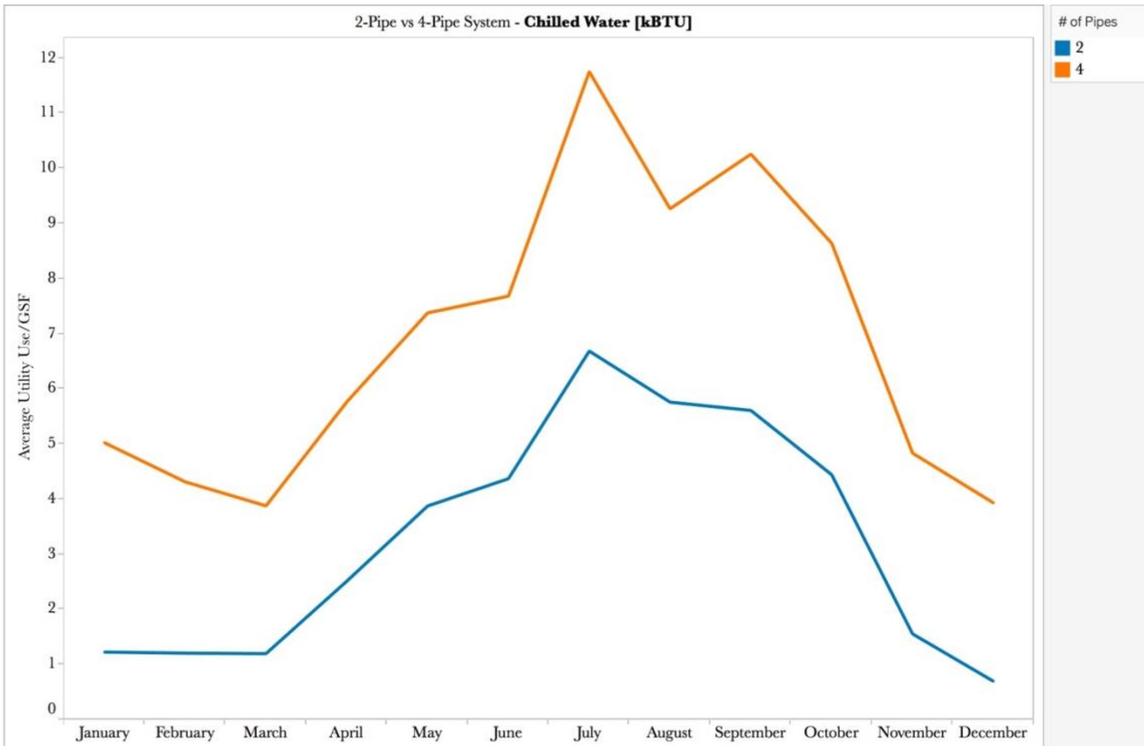

Figure 38. Fan coil units chilled water use based on number of pipes

Furthermore, the annual average steam intensity was plotted in Figure 39 distributed by HVAC system. As expected the CAV system, again, contributes the most, and Hunter Hall is the building primarily responsible for the CAV impact. Buildings with only FCUs consistently contribute the second most to this total. Looking into FCUs more, Figure 40 shows the average steam intensity for any building that has FCUs in it, however this time 4-pipe systems are more efficient at keeping the space heated. The uncertainties of conditioned space and conditioned air requirements are still at play as mentioned before.

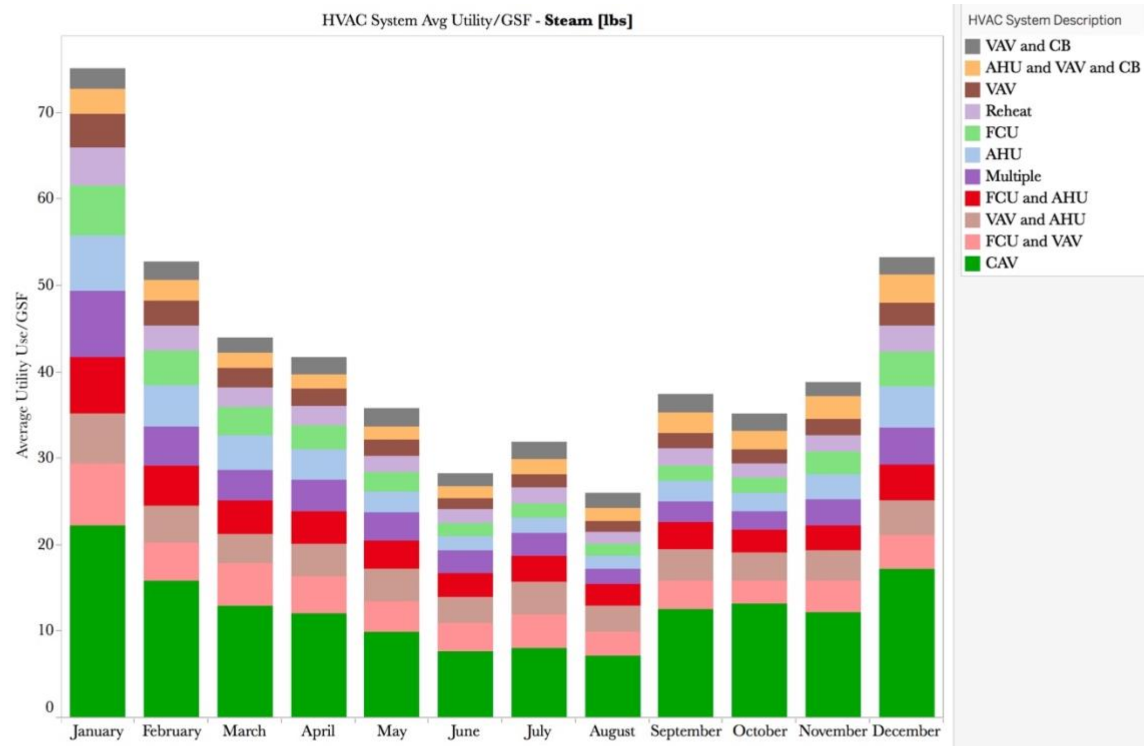

Figure 39. Average steam intensity distribution by HVAC system

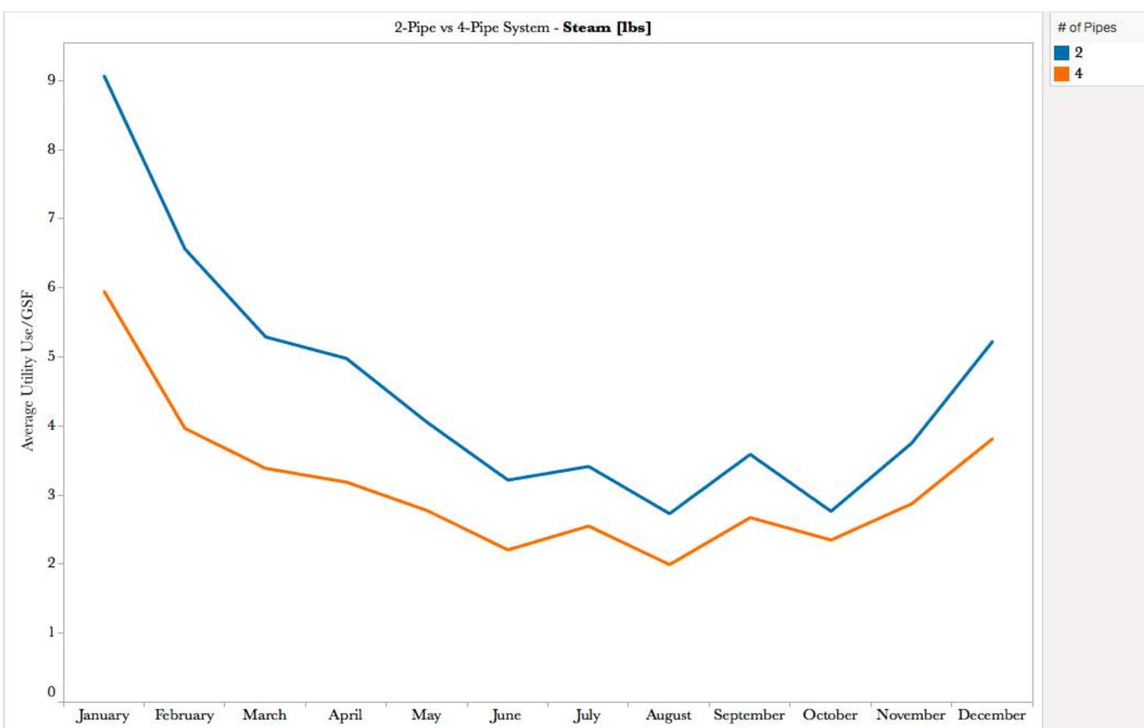

Figure 40. Fan coil units steam use based on number of pipes

Since the results vary and do not decisively tell which FCU system is best based on utility use, the system can be evaluated by monetary cost. These results are shown in Figure 41, and looks at the total cost of chilled water and steam intensity of buildings with 2-pipe and 4-pipe systems. Referring back to Table 10, the utility rates were used, and it was shown that the average cost/GSF for buildings with 4-pipe FCUs was larger than 2-pipe FCUs, $5.962/GSF and $1.934/GSF respectively. This is the average cost on a GSF basis, so the limitations of building size and demand should be considered. Also, some of these buildings have a combination of HVAC units, not just FCU units, which could be a source of discrepancy.

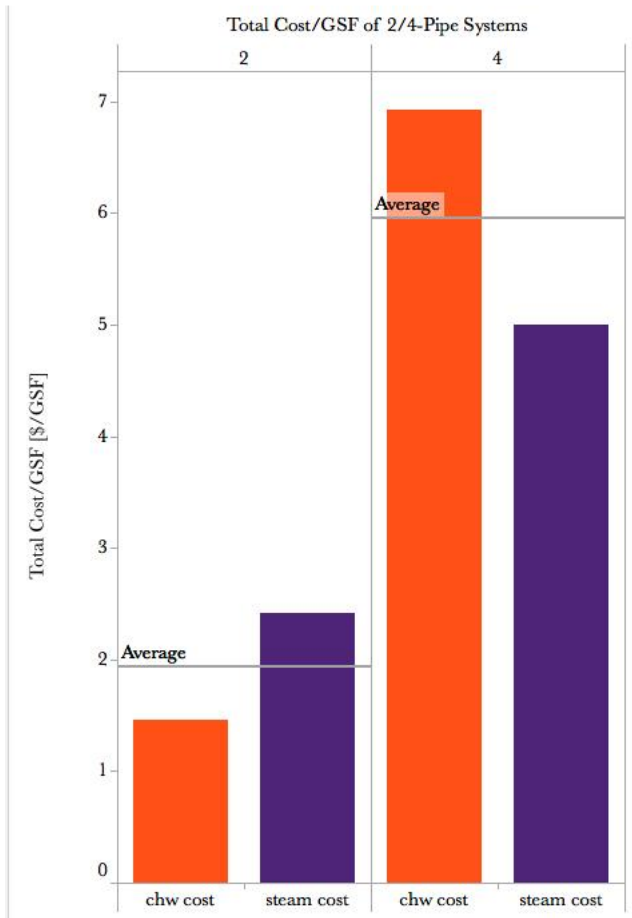

Figure 41. Total Cost/GSF of chilled water and steam for 2/4-pipe FCUs

As reported by Sightlines, the technological age of Clemson University is not where it should be, meaning the age of Clemson's mechanical systems are older than their peers. Older systems are outdated and are often energy intensive. Since there is a wide variety of systems and needs, there is no catch-all best option. But, these systems should be updated and retrofitted in an effort to reduce energy use.

5.2 Water Conservation Systems

In an effort to lower water use – thus sewer use – low flow water faucets, faucet aerators, and toilets should be installed in the most water intensive buildings (Figure 27). Low flow sinks could reduce the flowrate 1 GPM or more, which could lead to large savings, at least on an individual building basis. Some buildings have showers in them, thus there is an opportunity to install low flow shower heads and encourage shorter shower times.

Low flow toilets and urinals would also cut down water use significantly – decreasing flow from 0.5-1 gallon per flush. Toilet fixtures in the Watt Center have a dual flush option, different flows for solid and liquid waste. A standard dual flush retrofit kit can be purchased for around $50, with the rate of water at $0.0029/gal, and assuming that only 10 toilets were retrofitted, it would take around 170,000 gallons to pay back. The average academic building currently uses just under 4,000 gallons a month. If these dual flow toilets reduced the water flow by 25%, then the average building would use approximately 3,000 gallons each month, setting a payback period of less than 5 years.

Another suggestion for CUF is to implement gray water systems for irrigation. Water that is from sinks, kitchen appliances, baths, and showers are constituted as gray water and could be captured to be redistributed in an irrigation network. This would accomplish three things: reduce sewer costs, reduce impact from WWTPs, and reduce potable water use for irrigation across campus. Furthermore, condensate water that drained from all of HVAC units could easily be captured and piped into this gray water system. Every HVAC units has a drain to capture the condensate, however it all drains into the sewer. Some of the large HVAC systems have a large condensate volume, and this could be

captured year-round to be stored and used for irrigation purposes, again lowering the cost of irrigation and lowering Clemson's impact through less potable water use.

These suggestions should be considered by CUF and Clemson administration to be implemented in all new buildings, and to make plans to retrofit old buildings. These recommendations would save the university money and lower its environmental impacts.

5.3 Electricity Efficiency

An incredible example of the types of electricity efficiency projects that should take place on Clemson's campus lies with Fike Recreation Center. This building has seen dramatic electricity savings in 2017 due to an LED retrofit of over 70% of the lighting load in the building. LED light fixtures were installed and replaced the high bay metal halide lamps, fluorescent tubes in ceiling fixtures, and compact fluorescent lamps in offices and training rooms. Although Fike Recreation Center is not an academic building, it is still in the E&G department and the results can be and are shown in Figure 42. The LED retrofit took place over the summer, while a majority of the student population was not on Clemson's main campus. The clear drop in electricity use is a direct effect of the retrofit and is a great example for Clemson to pursue more LED retrofits. Not only does the lighting load drop in direct savings, but the heat given off by metal halide lamps reducing the cooling demand resulting in additional, indirect savings. As stated before, the mechanical motors within the HVAC systems are powered by electricity, so the mechanical electricity load is driven downwards as well. Currently CUF is exploring a complete LED retrofit of six-floor Cooper Library on campus, which could see tens of thousands of dollars in savings each year. An analysis of all utilities within Fike Recreation Center should be conducted by CUF using past year's data to see if chilled water and steam use decreased as an effect of the LED retrofit, justifying the assumption of indirect savings.

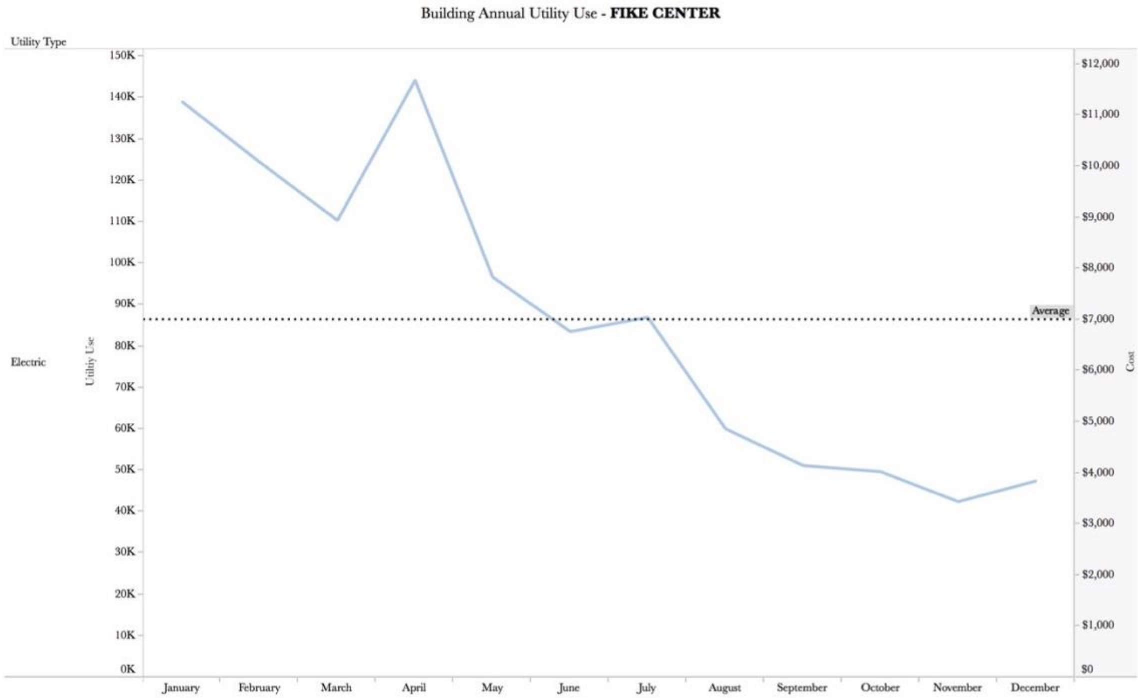

Figure 42. Fike Recreation Center electricity use

Furthermore, Clemson University recently announced a project to place a solar panel array in a parking lot on the main campus. The electricity generated from this onsite solar array should be metered, monitored, and analyzed to see the decline in electricity demand. Projects like these, that implement sustainable, responsible, and renewable energy sources on campus will lower the carbon footprint of Clemson University and show the students, faculty, and staff that Clemson is actively reducing their environmental impact. Electricity sourced from a solar array reduces the electricity sourced from fossil fuels, and as seen in this study, solar energy generation has a much lower emissions factor than coal, oil, or natural gas.

5.4 Building Age

Clemson University has multiple buildings that are over 100 years old, and multiple that were built within the last decade. Being able to look at utility consumption, energy consumption, or carbon footprint of the academic buildings and the age of the building can tell a lot. Figure 43 shows that there is a pretty wide distribution of building ages, however there is a slight trend of younger buildings being

less intensive. The points indicate the age corresponding to the axis on the right, the bars show energy intensity, and the size of the dots are corresponding to GSF of the building. The box and whisker plot on the right shows the distribution of the building ages.

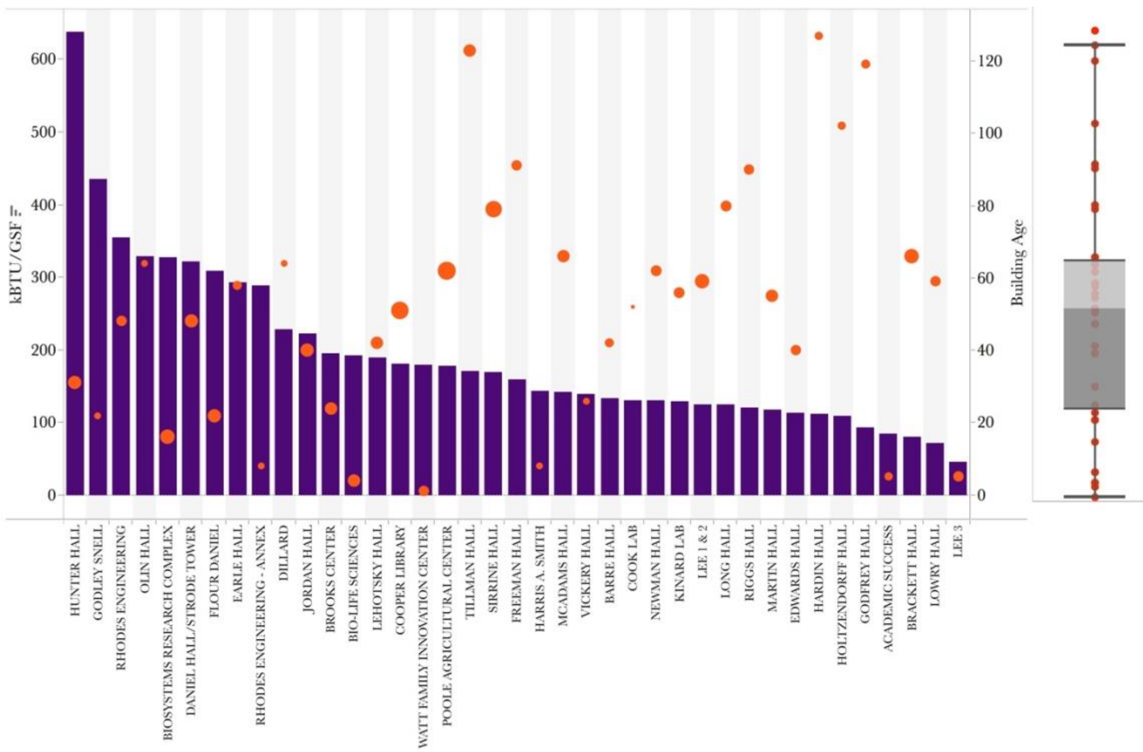

Figure 43. Energy intensity and age distribution

Exploring this topic further, Figure 44 shows the energy intensity of the buildings but displayed by increasing age of the building. The average age of the university's academic buildings is 52, and the average energy intensity is 192.6 kBTU/GSF. Building that are built less than 52 years ago have an average energy intensity of 236.6 kBTU/GSF, whereas buildings built 52 years ago and further have a value of 150.7 kBTU/GSF, a difference of 85.9 kBTU/GSF. This tells CUF that the newer buildings are not being designed in a way to save resources and money, with few exceptions including Lee III and the Academic Success Center.

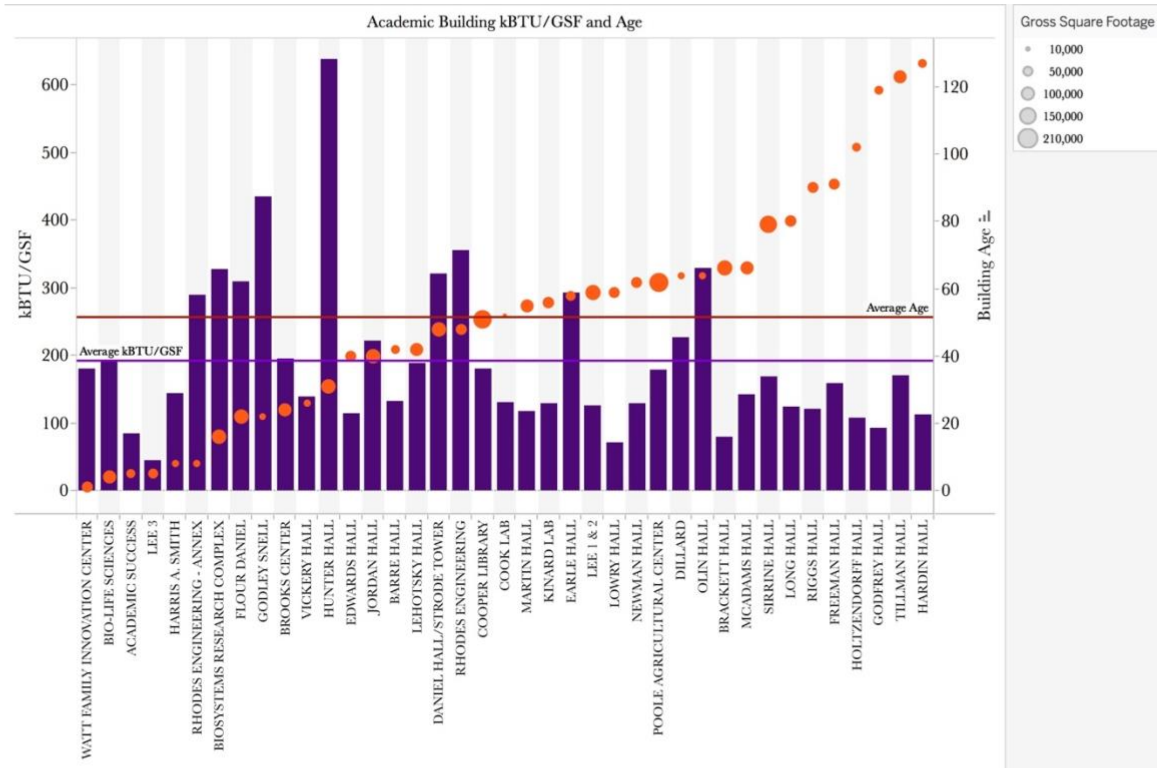

Figure 44. Energy intensity ranked by building age

The Sightlines report claims, "Older buildings = higher energy consumption", however this report claims the opposite. Table 20 shows the distribution of the ages, and their total energy intensity. The buildings that are over 50 years old have the lowest energy intensity and the buildings that are 25-50 years old are the most intensive. Hunter Hall, the most energy intensive building on Clemson University's campus, is 31 years old. If Hunter Hall is excluded from this analysis, the buildings aged 10-25 would have an average energy intensity of 210 kBTU/GSF – still larger than the oldest buildings on campus. It is encouraging to see the low value for the buildings under 10 years and this could be attributed to the policy implemented by administration to achieve LEED Silver or higher in all new buildings. Figure 45 shows the age energy intensity of the buildings binned in their age categories defined in Table 20.

Table 20. Age categories and corresponding energy intensity

Age Category	Number of Buildings	Average Energy Intensity [kBTU/GSF]
Under 10	6	156
10-25	4	317
25-50	8	264
Over 50	21	152

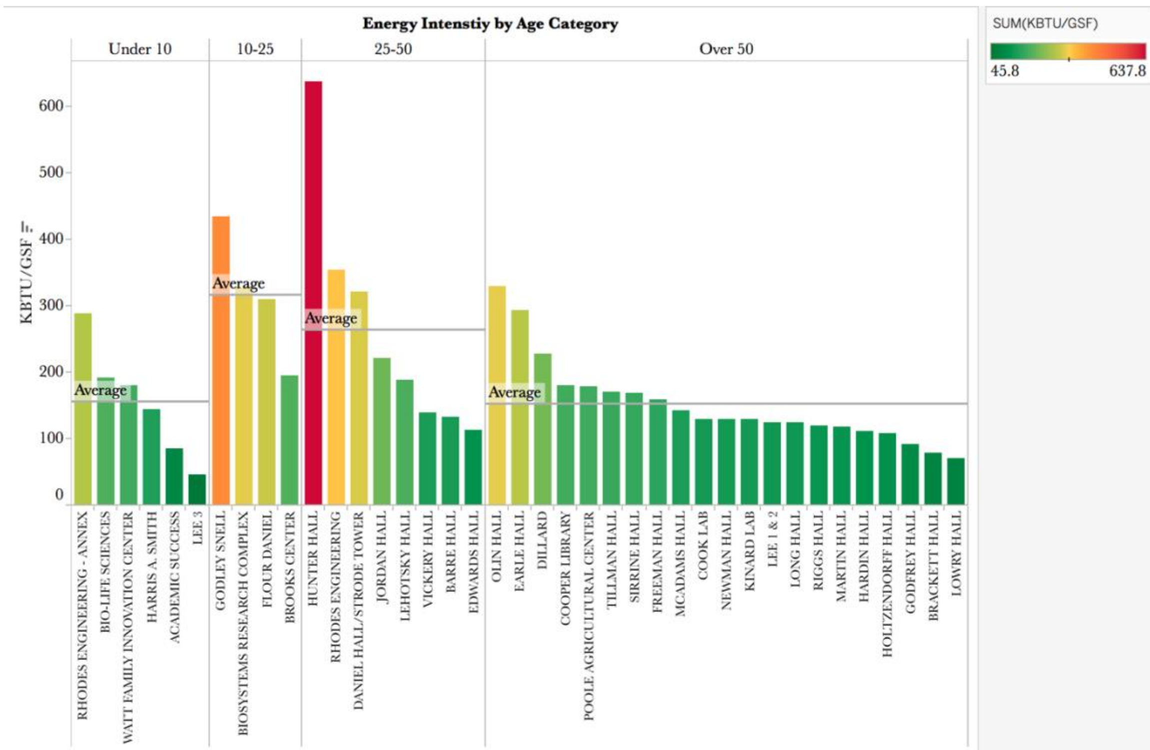

Figure 45. Energy intensity of academic buildings by age category

5.5 Carbon Footprint Interpretation

As discussed before, the results from this study are similar to what was found for Clemson's total carbon footprint [14], where Scope 2 emissions are the greatest. Scope 3 emissions for the total carbon footprint is larger, however that includes flows that are not related to academic building operation, such as commuting, waste, and fertilizer. There are sources of inaccuracies and uncertainties within this study, however a quantified method or uncertainty analysis could not be conducted. Therefore, a 10% error margin is added to Figure 46 to account for calculations and assumptions. This

gives a range of emissions for Scope 1, 2, and 3 to be 5,948-7,270, 28,894-35,314, and 1,808-2,210 metric tons of CO_2-e respectively. Often in LCA studies, data is analyzed qualitatively based on reliability, geographic and time relevance, and completeness. The input data received for this study was received from CUF and was taken as accurate and complete. However, errors within the billing process can occur, such as reading errors, data entry errors, calculation errors, and instrument error with the meters. These errors occur often, however it takes at least a week to recognize these errors with the current CUF meter billing method. With the use of this tool, the error can be recognized as soon as the raw meter reading is entered. This will mitigate billing errors and allow CUF to gain a more accurate depiction of the utility use.

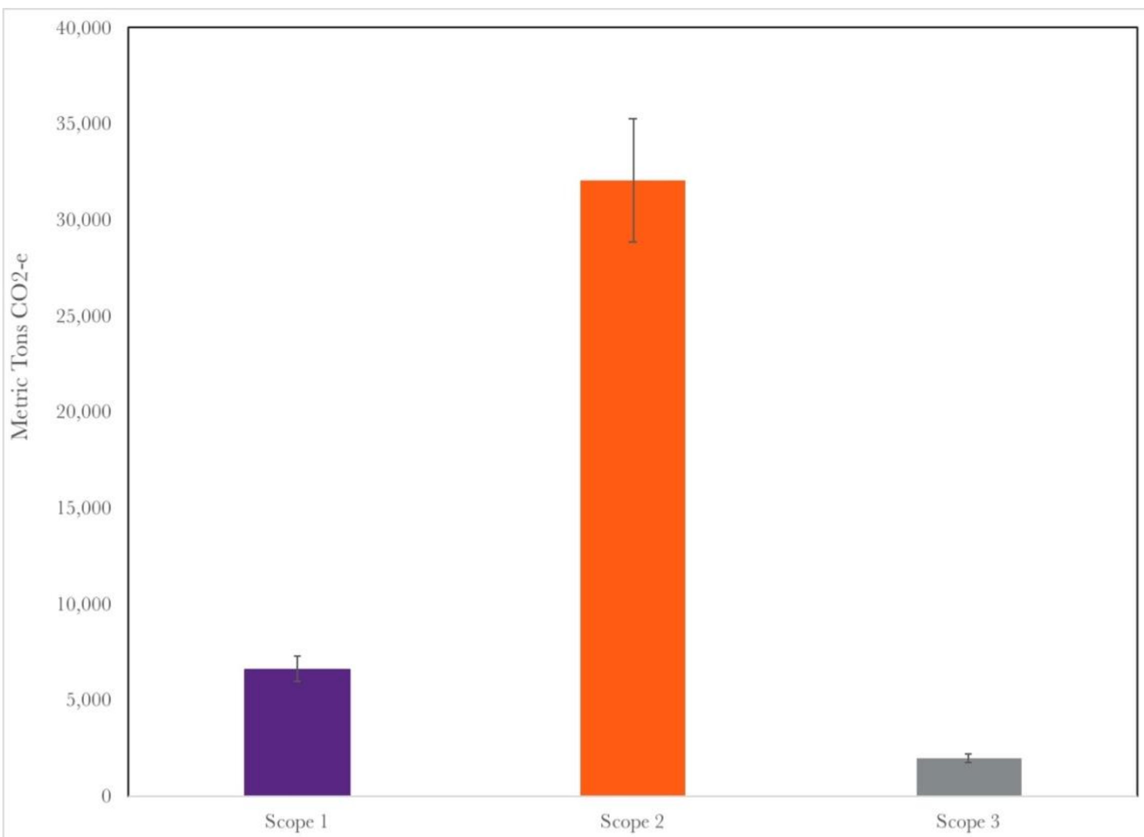

Figure 46. Carbon footprint results with 10% error margin

Further, the emissions factors taken from studies are sources of uncertainty and inaccuracy. The values found in literature were the most relevant and applicable to this study, also they are coherent

with the framework outlined in Clabeaux (2017). For the water treatment and wastewater treatment emissions factors, the uncertainties lie in the geographic relevance as well as the processes that occur within these treatment plants and how they vary from the plants associated with Clemson University. The electricity life cycle emissions factors that are taken from literature are also sources of uncertainties due to how, when, and where the results were calculated. Finally, the electricity generation emissions factor carries a source of uncertainty with it, since the net generation was attributed to a range of power plants, rather than just the plant that Clemson is associated with.

Recommendations for how to reduce the carbon footprint are directly related to reducing utility and energy consumption as discussed before. Priority should lie with the largest contributors (chilled water generation, steam generation, electricity use), and CUF should focus their efforts to reduce the overall impact. Secondly, the heat maps allow CUF to target which buildings should be a focus, and can monitor their progress as they renovate, retrofit, or change the operation. With this information, CUF and administration will be able to look at which buildings are performing well, what features are included in these buildings, and apply them to future additions on campus. This can range from HVAC systems, to water distribution systems, and more.

5.6 CUF Meter Billing

The foundational meter database is set up and ready for CUF to use immediately. This database contains all meter and building information. All of the calculations are automated and the time to bill the customers will be much shorter. Previously, calculations were done manually and were very time intensive. However, supposing the database stays up to date, all calculations can be made as soon as the reading from the meter is entered. The current billing method should be updated to live meters as soon as possible, and the framework of this database's methodology of calculating the current month consumption can be implemented into the software system that is used. Live, or smart, meters give a more accurate reading of the specific utility and can be paid for by raising the rates of the utilities slightly. Having the flexibility of smart meters will streamline the billing process for CUF, invite the

departments to view their use trends, and increase the resolution of one month to one day or even one hour. Further, if buildings are removed from buildings, they should then be removed from the database and billing sheet to reduce confusion and time. Through the use of this database and the Tableau workbook, CUF will easily be able to export monthly totals and bills. They will also be able to share the Tableau workbook online with the departments to allow them to view their utility use throughout the year.

5.7 Operation Cost

Although CUF covers the bill of the utilities for the academic buildings (i.e. no one is being billed like the Housing or Dining departments), CUF still benefits from analyzing how much a building costs to operate. Economic analyses can take place if a retrofit project is presented. Obviously, the more utility a building uses, the more expensive it will be to operate, as seen in Figure 47, Hunter Hall cost Clemson University nearly $1 million in operational costs for 2017. The main contributors, as discussed, are electricity (orange), chilled water (grey), and steam (navy).

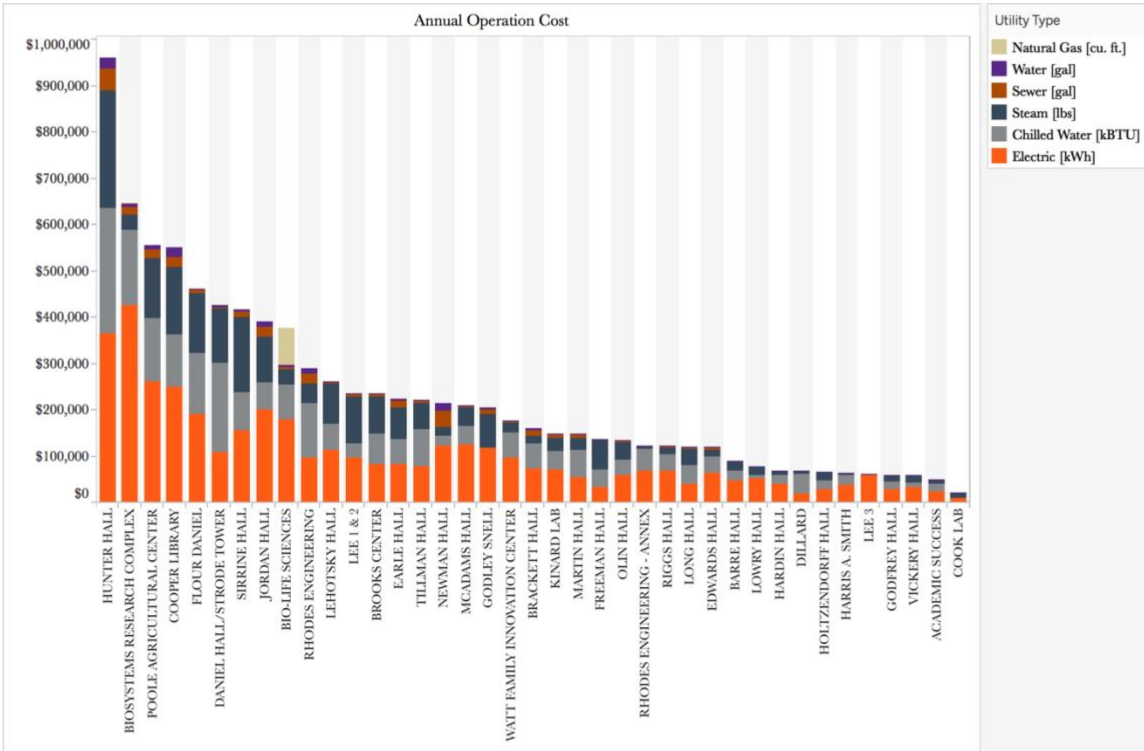

Figure 47. Annual operational cost for academic buildings in 2017

Additionally, Figure 48 shows a graph that divides the buildings into four categories where priority lies with the buildings in the "Critical" quadrant, followed by "Inefficient", then "Acceptable", and finally "Favorable". The buildings in each quadrant are defined in Table 21. This figure plots overall cost against cost intensity ($/GSF). A building with a large annual cost and cost intensity is considered critical and should be the top priority of CUF. Buildings with a low operational cost but a high cost intensity are the buildings that are inefficiently using their utilities. The buildings with large operational cost but low cost intensity are labeled as acceptable, as these buildings have a large GSF and are expected to have a large annual cost. The buildings in the final quadrant have a low annual operational cost and cost intensity. These are label as favorable as CUF does not need to prioritize these buildings since their impact will be minimal.

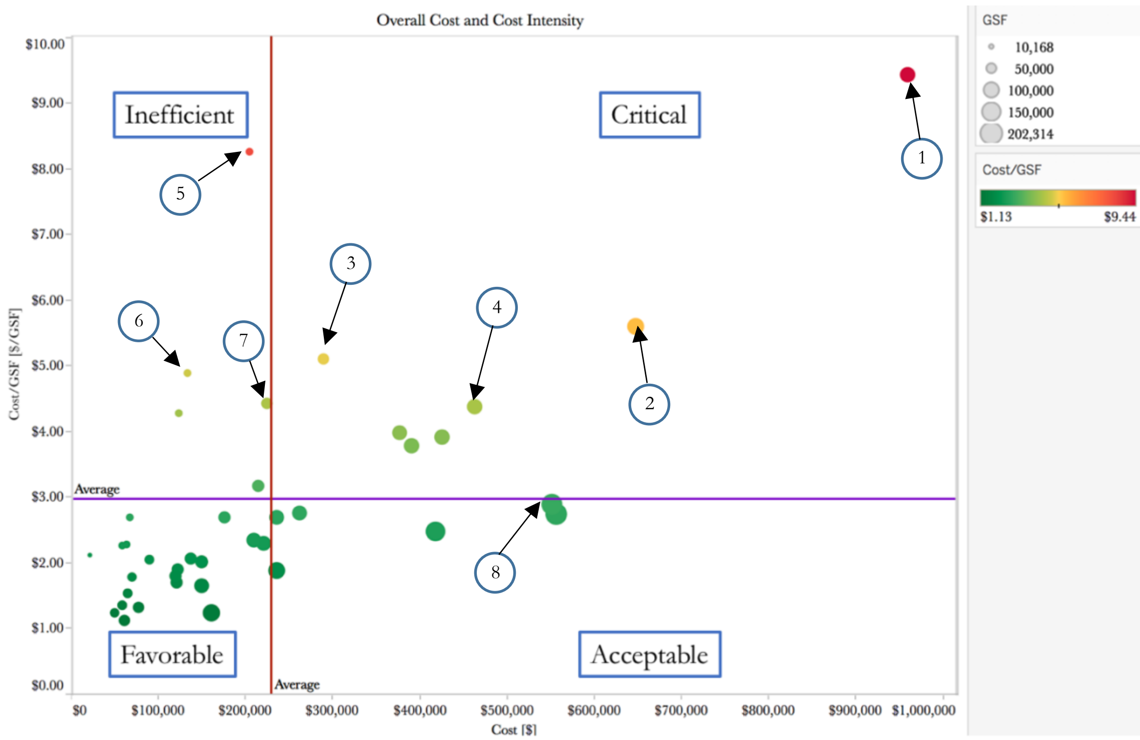

Figure 48. Annual operational cost and cost intensity

Table 21. Academic buildings in quadrants in Figure 48

Quadrant	Buildings
Critical	Hunter Hall (1), BRC (2), Rhodes Hall (3), Fluor Daniel (4), Daniel Hall/Strode Tower, Life Sciences Building, Jordan Hall
Inefficient	Godley Snell (5), Olin Hall (6), Earle Hall (7), Rhodes Annex, Newman Hall
Acceptable	Cooper Library (8), Poole Agricultural Center, Sirrine Hall, Lehotsky Hall, Lee Hall
Favorable	Watt Center, Dillard Hall, McAdams Hall, Tillman Hall, Brackett Hall, Martin Hall, Kinard Lab, Freeman Hall, Riggs Hall, Edwards Hall, Long Hall, Barre Hall, Harris A. Smith, Vickrey Hall, Cook Lab, Hardin Hall, Holtzendorff Hall, Lowry Hall, Godfrey Hall, Academic Success Center, Lee III

5.8 Lab Buildings

In an effort to further categorize buildings to the point of direct comparability, an observation of the results shows that the buildings of high utility intensity, carbon footprint, and criticality are mostly buildings that have laboratory capacity. Whether the lab is for the chemistry department, packaging science department, or another department, buildings with varying lab equipment (i.e.

Hunter Hall, BRC, Fluor Daniel) were the buildings. Fume hoods within Hunter Hall pull conditioned air out of the building and need to constantly pump in untreated air, which requires a large chilled water and steam demand to operate the dehumidification and heating/cooling processes. This lab equipment also requires a larger electricity demand to operate. Comparing buildings with labs to buildings without labs yields results that are unsurprising to CUF. Therefore, filtering buildings to be able compare utility use in buildings with labs, without labs, or both will offer CUF another way to focus their efforts. CUF is aware that Hunter Hall has large utility use, however that is to be expected. Therefore, filtering out these types of buildings, we get a new sense and of which non-lab buildings should be focused on. Figure 49 shows the heat map of energy intensity for the buildings that have labs, while Figure 50 shows the energy intensity of buildings without labs.

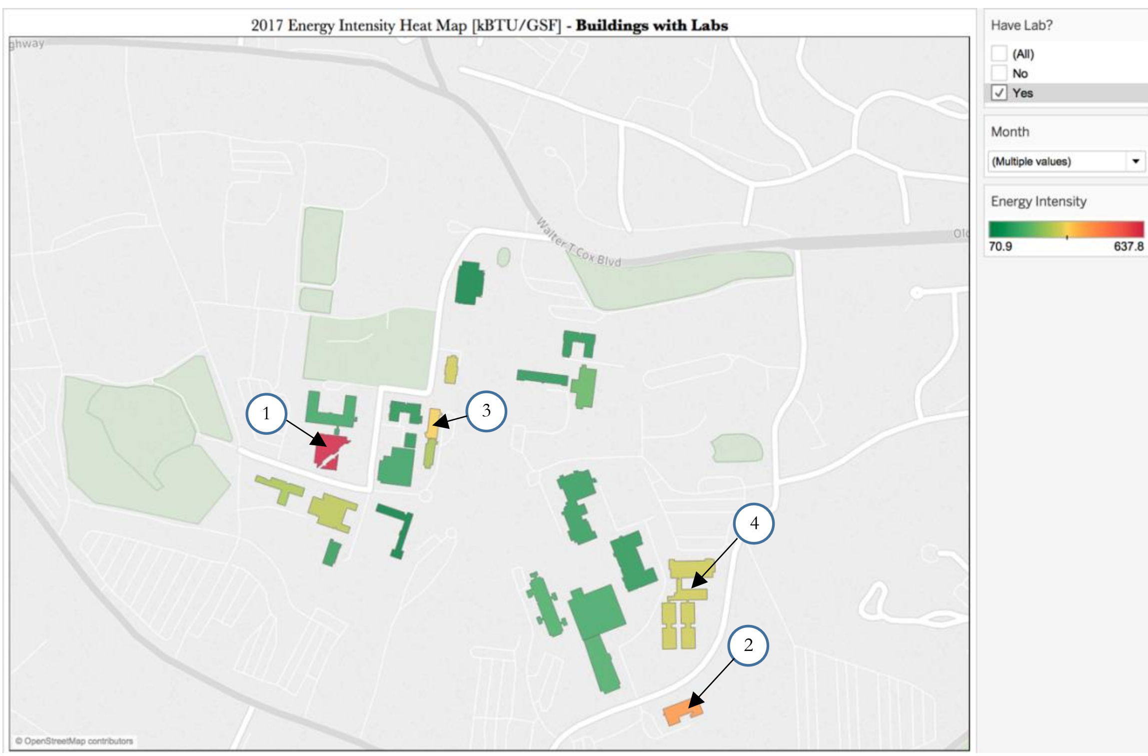

Figure 49. Energy intensity for buildings with labs

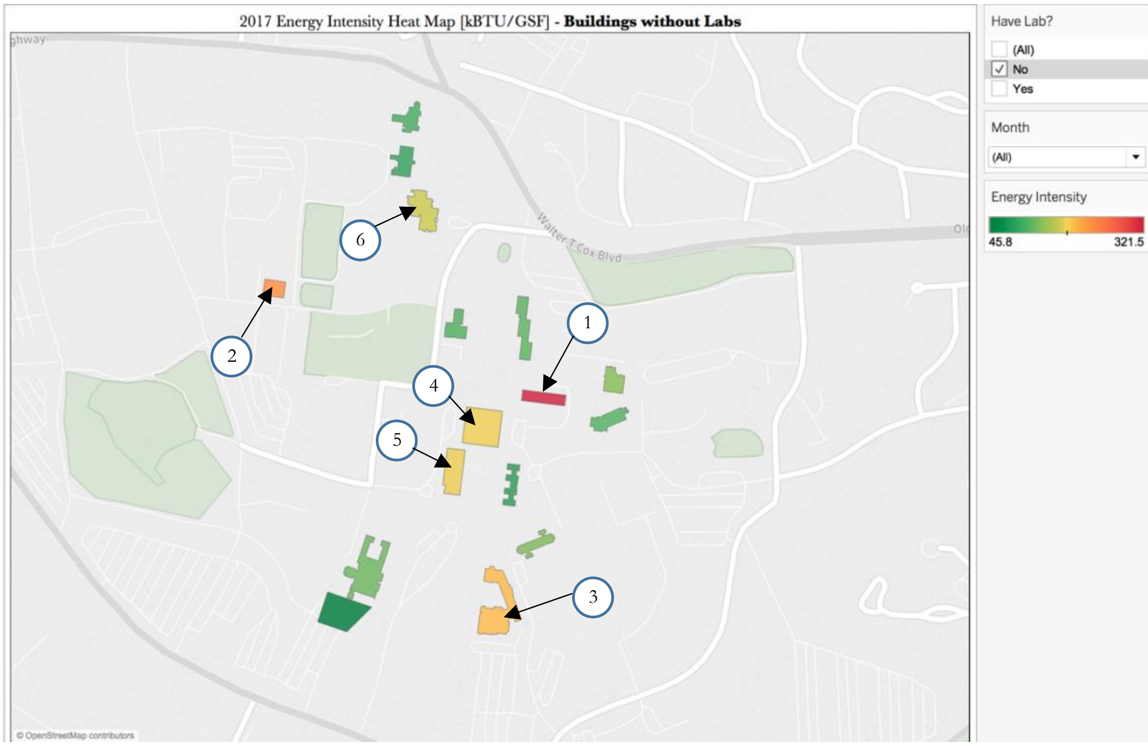

Figure 50. Energy intensity for buildings without labs

Figure 49 shows only buildings with labs in them and produces a result that looks familiar: Hunter Hall (1), Godley Snell (2), Rhodes Hall (3), and BRC (4) are the most energy intensive. The upper bound for energy intensity for buildings with labs is within Hunter Hall at 638 kBTU/GSF, whereas the upper bound in buildings without labs is almost half of that value at 322 kBTU/GSF in Daniel Hall/Strode Tower (1 in Figure 50). There is some uncertainty with this value due to the fact that CUF lumps together Daniel Hall and Strode Tower, essentially this is two buildings in one. Other energy intensive buildings without labs include Dillard Building (2), Brooks Center (3), Cooper Library (4), Watt Center (5) and Tillman Hall (6).

Thinking similarly, we can recreate Figure 48 to prioritize within lab buildings and non-lab buildings. The operational cost and cost intensity averages will change, supplying a new distribution within the four quadrants. In Figure 51, the circles represent non-lab buildings whereas the squares

represent lab buildings. Furthermore, Figure 52 and Figure 53 show the distribution with only lab buildings and only non-lab buildings, respectively.

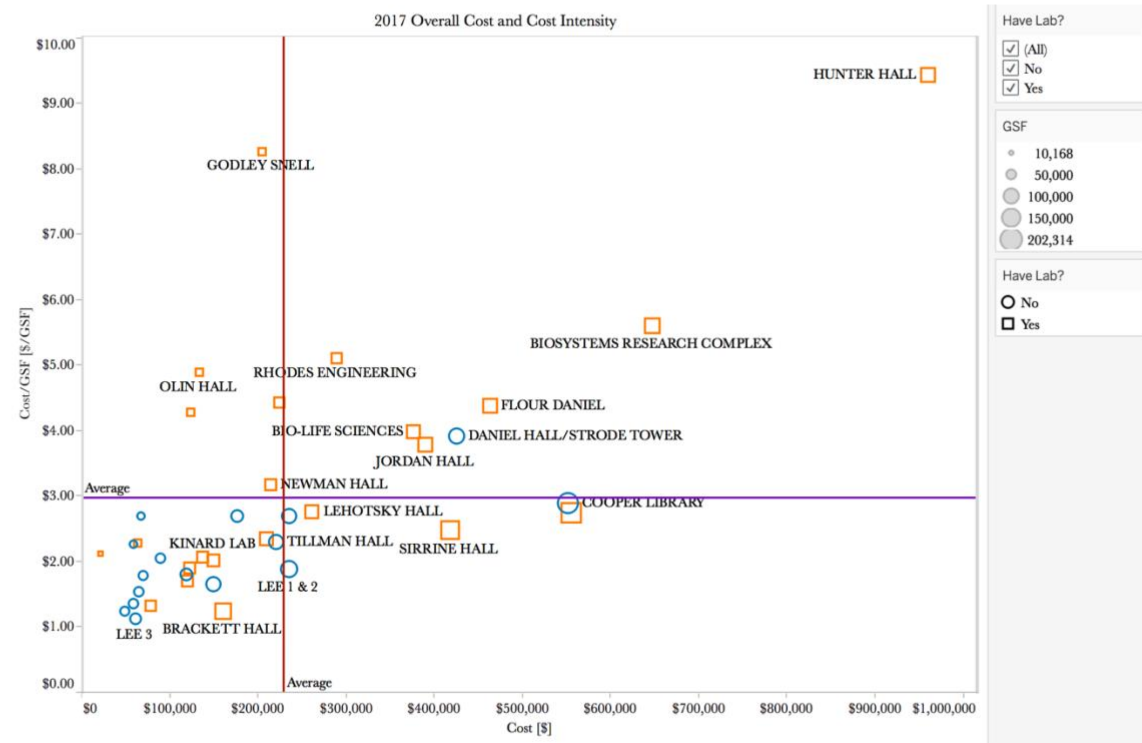

Figure 51. Overall cost and cost intensity of lab and non-lab buildings

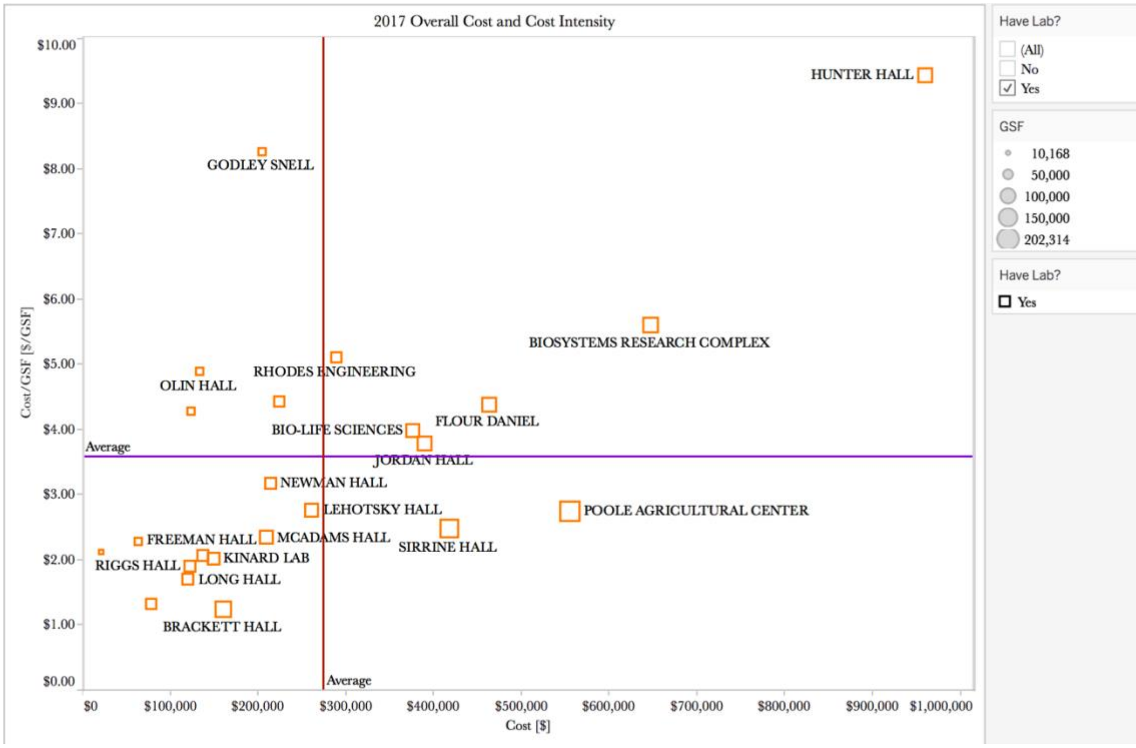

Figure 52. Overall cost and cost intensity of lab buildings

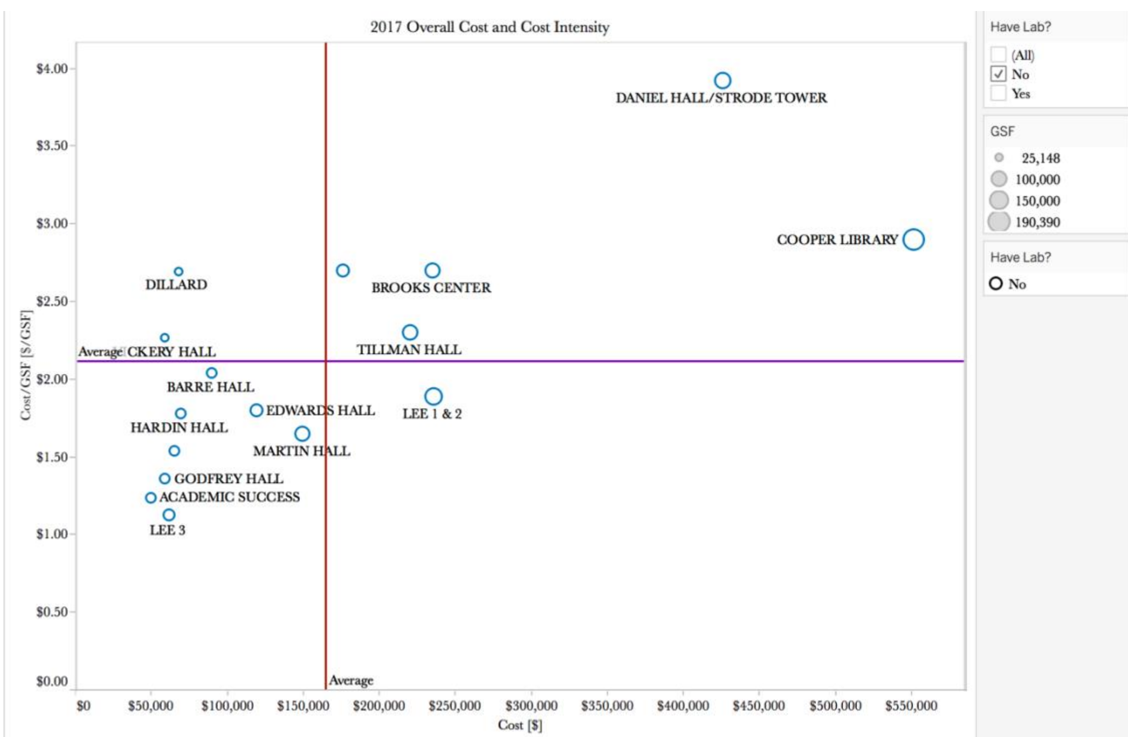

Figure 53. Overall cost and cost intensity of non-lab buildings

By analyzing the buildings based on whether or not there are lab buildings or not, this can offer a more insightful look into which buildings should be prioritized. If CUF only focused on the lab buildings, savings in the non-lab buildings will be ignored because they are inherently less intensive than lab buildings. By categorizing the buildings, CUF can now have two lists and prioritize accordingly. Furthermore, an analysis of the lab buildings should be carried out looking at fume hoods, mechanical equipment, and other lab functions that may increase the utility use. This will do a better job of comparing the buildings directly.

6. CONCLUSION

The academic buildings on campus have a wide variety of uses and equipment and vary in size and age. Partnering with CUF, this research has accomplished many goals that will assist in utility billing, track utility use, as well as focusing sustainability efforts. The buildings that should be prioritized are the ones that are consistently producing large utility intensity values, including: Hunter Hall, Godley Snell, Biosystems Research Complex, Fluor Daniel, Rhodes Engineering Hall and Annex, Earle Hall, Cooper Library, and Olin Hall. Also, discerning between lab and non-lab buildings is an important factor in determining which buildings should be prioritized based on operational function. Energy or utility audits could be performed to find potential areas to focus within the building. There is already proof of electricity reduction with an LED retrofit project in Fike Recreation Center. Observing trends between buildings with laboratory capacity and occupancy should be further investigated to maximize and optimize savings.

When energy and utility use is decreased, associated environmental impact and carbon footprints decrease as well. This research, alongside Clemson's total carbon footprint [14], will greatly help University administration and CUF monitor the university's progress towards the sustainability goals that they have set. The results from this research is published online at Tableau Public and can be viewed by the public [51]. Remembering that universities and higher education institutions are to serve as microcosms of society [7], Clemson University can help lead the charge of sustainability on campuses and develop a mindset within its student body to always strive towards reducing environmental impact.

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