An analysis of building energy submetering and its uses for colleges and universities

by

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Abstract

The intent of this report is to cover the topic of building energy submetering. Utilizing submeters to quantify building and sub-building energy usage can lead to reduced utility consumption, increased energy efficiency, lower operating costs, increased equipment longevity, improved occupant experiences, and also contribute to solving other issues. Additionally, submetering may be required to fulfill state and local building code requirements that have become more stringent over recent years, as well as to satisfy building benchmarking and energy audit requirements.

This report identifies the needs, technologies, and benefits of providing energy submetering. While it generally covers these items, it also specifically applies them for colleges and universities that are comprised of multiple buildings with varying uses and energy demands. A case study is also provided for an actual university department in an existing building, identifying practical solutions and estimated costs for implementing a submeter system.

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Acknowledgements

I would like to acknowledge my parents for instilling in me the curiosity of learning and starting me on my journey. I would also like to acknowledge my graduate advisor, Professor Ray Yunk, for helping me navigate this process in my new career. I would also like to acknowledge my graduate committee members, Associate Professor Shannon Casebeer and Professor Fred Hasler, for their assistance and support along the way. Finally, I would like to acknowledge Gary Weishaar with K-State's Division of Facilities, for taking the time to meet with me and walk me through the campus metering.

Dedication

Dedicated to my wife and children, for every day with them is a blessing to share.

Chapter 1 - Introduction

Buildings in the United States account for approximately 40% of the total energy usage (U.S. EIA, 2016). Included in that are college and university campuses that spend over two billion dollars every year on utility costs, a number that is expected to increase as utility costs could become more volatile in the future (Southface Energy Institute, n.d.). Additionally, approximately 30% of the energy consumed in buildings is wasted due to inefficient existing building systems, inadequate building operations and monitoring, and wasteful building occupant behaviors (Southface Energy Institute, n.d.). It's a staggering amount to think about as the general public's awareness and commitment to items such as reducing greenhouse gas emissions and shifting to building decarbonization has been increasing in recent years.

One of the key tools available to both new and existing buildings in order to reduce energy consumption is the application of energy submetering. Submetering can be done at many levels, whether at each building in a campus setting or sub-building. It provides the necessary information and data needed to make appropriate decisions that can improve efficiency, support building operations, and engage building occupants in energy conservation measures.

The below quote from H. James Harrington, a leader in business process improvement, effectively summarizes what is considered the building facility manager's mantra when it comes to the topic of submetering:

> "Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it." (Harrington, 1991)

While the main focus of this report is the general analysis of energy submetering and its application, the sub-focus is applying it to a college or university campus. Chapter 2 looks to introduce the basics of submetering, including what it can be used for, what the fundamentals of energy metering technology are, and how they can be implemented. Chapter 3 looks to expand on both the required uses and the major benefits that using submeters can provide. Chapter 4 looks to identify how submetering can be applied at a college or university for the purposes of teaching and marketing. Chapter 5 introduces a case study performed on an actual university building that applies and demonstrates some of the information presented throughout the report.

Chapter 2 - Submetering Basics

Meters by themselves save no energy or water, and actually add extra cost to purchase and install. Metering simply provides the data that when analyzed allows the building owner, staff, and occupants to make informed decisions. The communications equipment and software required to analyze the metered data is not a primary emphasis of this report. However, the uses and benefits that the metered data can provide after analyzing it are an emphasis and can be summarized in Figure 2.1. These uses and benefits will be further discussed in Chapter 3.

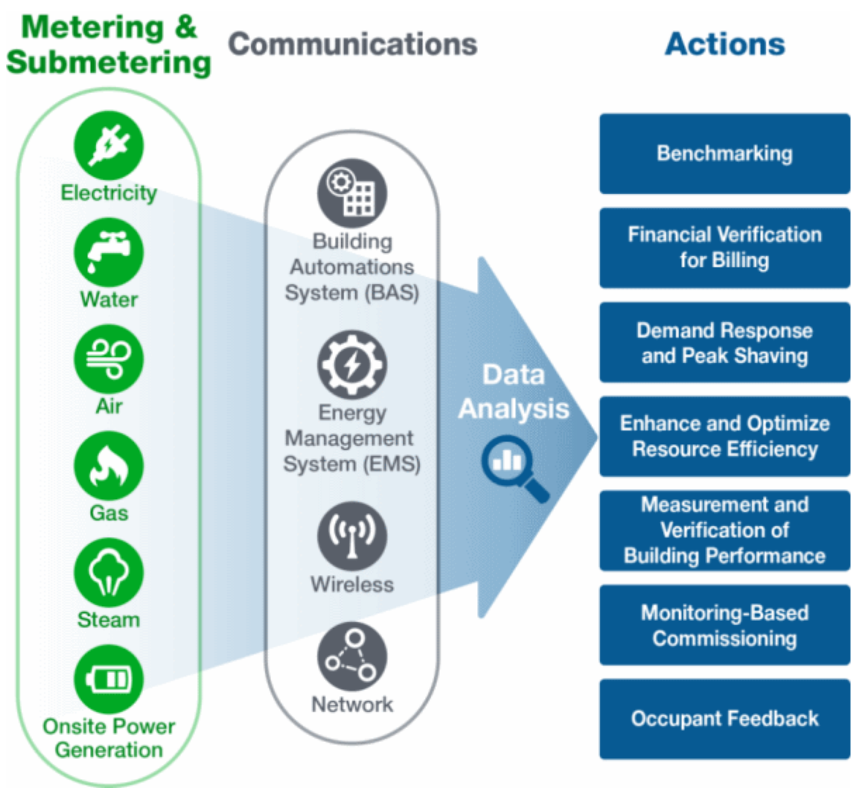

Figure 2.1 Metering and Submetering Sequence of Events
(Source: Sustainable Facilities Tool, n.d.)

2.1 Levels of Metering

A basic definition of a meter is a device that tracks and provides an output related to the resource used, whether that be water, steam, gas, electric, etc. A submeter is generally defined as a meter below the level necessary for utility billing (Sustainable Facilities Tool, n.d.). If a campus or facility has one utility meter that serves multiple buildings, then meters added to each building would be considered submeters. Submeters can exist in multiple levels, as seen in Figure 2.2 (Parker et al., 2015). The sub-system, branch-circuit, and end-use levels will all be discussed in more detail throughout this report.

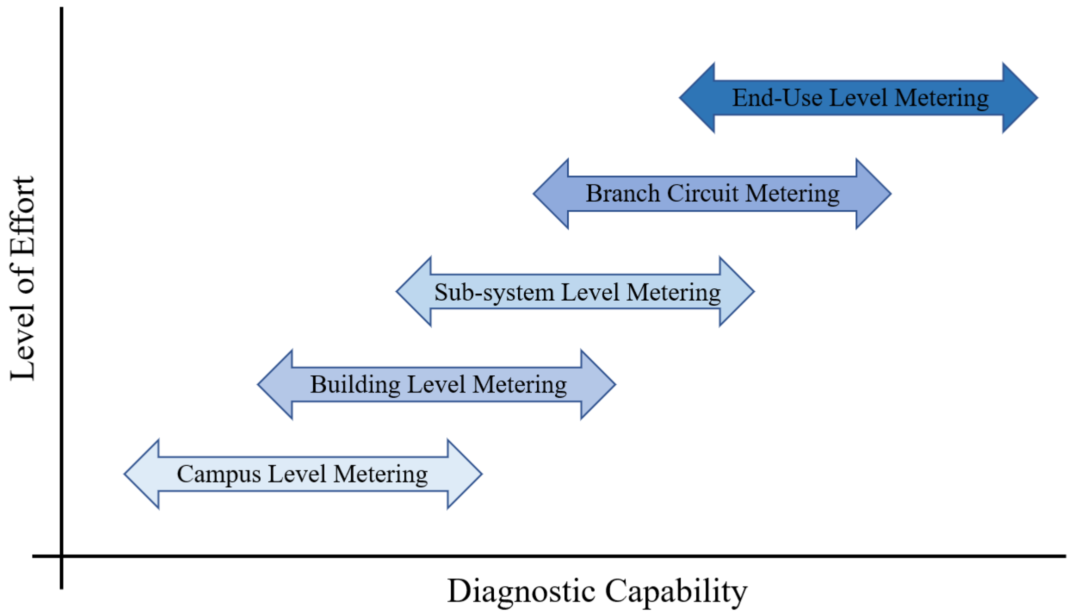

Figure 2.2 Metering Hierarchy
(Source: adapted from Parker et al., 2015)

2.2 Meter Performance

In general, all meters will operate within certain parameters and have varying levels of performance. Some of the more universal performance metrics include accuracy, precision, turndown ratio, installation, runs of straight piping, operations and maintenance, and cost (Parker et al., 2015). It is important to outline these performance metrics before looking at specific metering technologies.

Accuracy is important because it provides the difference between an actual value and the value measured. While no meter manufacturer can claim to be 100% accurate, most can get close. Depending on the standard, a requirement of +/-2% could be needed, with some even dictating a requirement of +/-0.2%. An owner can expect to pay more for a meter with a higher degree of accuracy. When it comes to utility demands and chargebacks discussed later in this report, higher accuracy is desired.

Precision involves the meter's ability to provide the same value of the same parameter, under the same conditions. Though related to accuracy, this ensures that the meter is reliable over time.

Turndown ratio typically only applies to meters flowing a liquid or gas. This ratio refers to the range of flow rates that the meter will maintain its rated accuracy and precision. For example, a water flow meter then can measure a peak of 100 gallons per minute all the way down to 5 gallons per minute of flow with the same level of accuracy would have a turndown ratio of 20:1. Larger turndown ratios will be desired when you have utilities that may experience a very versatile load profile, such as natural gas peaks between summer and winter usage.

Installation concerns may affect the type of meter selected. The size and weight of the meter and whether it is located outside or inside will have an impact on space needed and materials used. Additionally, the connection of meters to a building automation or energy management information system that requires power or communication wiring will have an impact on the overall installation.

Straight piping distances required typically only apply to meters flowing a liquid or gas. This straight pipe distance is the length needed upstream and downstream of the meter before hitting any obstructions like valves, pipe fittings, or other devices. Some meters need a stabilized, or laminar, flow pattern for accuracy and these obstructions cause turbulence in the piping which can lead to inaccurate readings. Normally the distance is expressed as a multiplier of the pipe diameter. For example, a meter needing 5x straight pipe distance on a 4” water main would require 20” of straight piping upstream and downstream. This correlates back to the installation concerns and space needed. When these straight piping distances cannot be met, especially in existing installations, then sometimes a device can be inserted to help provide the needed laminar flow, but this should be avoided where space allows.

Meter operations and maintenance factor in mainly as cost components. Smart, advanced type meters that can communicate their output directly have largely eliminated the labor needed for staff personnel to physically read meter outputs on a periodic basis. Meter calibration is another maintenance concern, as is replacing parts such as sensors, control boards, valves, etc. Controlling leaks in a fluid flow meter is another maintenance item that must be addressed over time, especially in a high pressure or high temperature application.

When looking at the total cost required for installing meters, all of the above factors can contribute and should be considered. The lowest first cost meter may not be the best choice if it has high associated maintenance costs such as calibration, sensor replacement, etc. (Parker et al., 2015). In some applications, especially in existing buildings, the cost to shut down the system and redesign the layout for proper installation might outweigh the potential savings. As discussed throughout this report, the addition of meters by themselves do not save any costs, but it is the application of operational changes implemented by an owner based on data provided by those meters that allows for cost savings. All of these things should be considered when looking at a life cycle cost and payback period, as this is the recommended approach to be taken to determine the best overall decision.

2.3 Metering Technologies – Fluids

The following section will primarily outline the technologies and types of meters used in fluid flow applications such as natural gas, steam, domestic water, and chilled/heating water systems. These meter types can be used as campus-level meters, or as building-level and sub-system level meters as well. The information presented was largely gathered from the U.S. Department of Energy's Metering Best Practices: A Guide to Achieving Utility Resource Efficiency, Release 3.0 (Parker et al., 2015) and from The California State University's Building Metering Guide (2012) that outlines typical meters produced by manufacturers. A summary of the meter types discussed is illustrated in Table 2.1, and some advantages and disadvantages for each type of meter are discussed throughout this section.

Fluid flow meters used for natural gas, steam, domestic water, or heating/chilled water typically utilize one of the following technologies: positive displacement (diaphragm, rotary or nutating disk), velocity (turbine, vortex shedding, ultrasonic, or magnetic), or differential pressure (orifice or venturi).

Positive displacement, diaphragm type meters utilize two fixed volume compartments that alternatively fill and empty with the source fluid. The number of fill/empty cycles are counted, which allows the volume to be calculated. While they don't require straight pipe distances, they do have an increased pressure drop associated with them. They are typically the most widely used on natural gas systems except for high flow/pressure applications.

Positive displacement, rotary type meters operate on the same principle as diaphragm type meters but instead have two impellers in separate fixed volume compartments. The meter counts the number of rotations, which allows the volume to be calculated.

Positive displacement, nutating disk type meters have a spherically shaped head in a measuring chamber that allows a fixed volume to pass. The number of nutations are counted, which allows the volume to be calculated. Generally, they are the most widely used meter type on domestic water systems.

Velocity, turbine type meters utilize an impeller blade device in the fluid stream. As fluid passes, the turbine rotates at a speed related to the fluid's velocity. The pulses of blade rotation allow for calculation of flow rate because of this relation to fluid velocity. Generally, they are the most widely used meter type for heating/chilled water systems. However, because of the moving parts they require routine maintenance.

Velocity, vortex shedding type meters utilize a fixed body in the middle of the fluid stream. This creates vortices that can be sensed downstream and allows velocity to be calculated. These aren't recommended for low flow applications, but are ideal for low maintenance applications due to no moving parts.

Velocity, ultrasonic type meters utilize ultrasonic signals and a series of transducers. The transducers alternatively transmit and receive the signals, comparing the time difference to calculate fluid velocity. The type of fluid can limit the application and the accuracy is typically the lowest amongst all meters discussed. However, the main advantage to these meter types is that they are non-intrusive, existing entirely outside of the pipe. This allows them to easily be placed temporarily or permanently.

Velocity, magnetic type meters operate in similar fashion to ultrasonic type meters, but instead use a magnetic field to generate flow through a pipe. When a conductive liquid flows through this magnetic field, a voltage signal is created. The faster the fluid flow, the greater the voltage signal. Small electrode sensors capture the voltage signal and a transmitter processes it to determine flow (Omega, 2018). While generally more expensive, the lack of moving parts and high level of accuracy at low flow make them ideal for applications where low pressure drop and low maintenance area required. They are typically found in heating/chilled water systems.

Differential pressure, orifice type meters utilize a circular metal disk positioned between two flanges that has a small hole in the center, the orifice. As fluid flows through the orifice, the restriction creates a pressure differential that can be measured and applied proportionately to the fluid flow rate. Orifice flow meters have traditionally been used in steam applications, but because of the large restriction, the pressure drops are generally higher.

Differential pressure, venturi type meters utilize a reduction in pipe area to a small throat opening. This takes advantage of the pressure-velocity relationship to calculate flow. The main difference between venturi and orifice type meters is that the venturi type often has lower pressure drops in the fluid.

Table 2.1 Common Fluid Flow Meter Technologies and Key Criteria

Goal	Positive Displace-ment	Orifice	Venturi	Turbine	Vortex Shedding	Ultrasonic	Magnetic
Accuracy	Good	Moderate	Good	Good	Good	Moderate	Very Good
Turndown Ratio	10:1	<5:1	<5:1	10:1	20:1	10:1/20:1	>20:1
Repeat-ability	Good	Good	Good	Low	Very Good	Good	Good
Installation Ease	Easy	Easy	Moderate	Challenging	Moderate	Very Easy	Moderate
Pressure Loss	Medium	Moderate	Low	Moderate	Low	None	Low
Re-calibration	In-frequent	Frequent	In-frequent	Frequent	In-frequent	Moderate	In-frequent
Capital Cost	Low	Low	Moderate	Moderate	Moderate	High	High
Installed Cost	Moderate	Low	Moderate	Moderate	Moderate	Low	Moderate
Mainte-nance Cost	Low	High	Moderate	Moderate	Low	Low	Low

(Source: adapted from Parker et al., 2015)

It should be noted that chilled and heating water system meters typically do not only measure flow rate by itself, but also utilize temperature sensors to create a British Thermal Unit (BTU) energy meter. This is more effective at measuring the energy usage over time. The separate supply/return temperature sensors and a flow meter can independently be connected to a building automation or energy management system. Other times the sensors, flow meter, and BTU calculator can be provided by the same manufacturer, allowing for minimized calculation error.

2.4 Metering Technologies – Electric

The following section will primarily outline the technologies and types of meters used in building electrical systems. It starts with the building-level meter technology and continues into the sub-system, branch-circuit, and end-use meter technology. The focus of this section is more in regards to energy and operational efficiency results, rather than characteristics such as power quality or harmonics.

Building-level meters have developed over the years from mechanical to electro-mechanical to solid state/digital advanced type (Parker et al., 2015). Mechanical meters are more traditional, but are limited in their data storage and digital communication capabilities. They are typically checked manually and read on regular intervals, taking the difference between current and past readings. In the current market of metering, these mechanical meters are seldom used. Electro-mechanical meters have replaced them, because, though they operate on the same principles, they also have some sort of pulse output or communication capability allowing for remote reading and storage of the data.

Solid state or digital meters, known as advanced meters, are becoming more popular and are more widely used at a sub-system, branch-circuit, or end-use level. These meters require no moving parts, but instead rely on integrated circuits, current transformers, on-board memory, and communication technology (Parker et al., 2015). These advanced meters are able to track and record data and communicate it to a remote source for analyzing, usually in low increments of 15 minutes of less. 15 minutes should be the minimum interval chosen to comply with the latest energy codes which are discussed in Chapter 3.

The availability and capability of these types of advanced meters has been increasing over the years while the costs to implement them have been dropping, thus allowing them to gain a larger market share. However, it should be noted that in today's world of data analytics and available technology, the right electrical meter is the one that does what is needed and not necessarily the more expensive type that provides more data than can be analyzed.

When it comes to applying electrical submeters at various points in the building electrical system, there are different options to consider. Figure 2.3 illustrates the potential location and types of submeters that can be used. At the building level utility entrance, a whole building meter (WBM) would be utilized, normally consisting of a socket-type meter. After that, submeters can be located in various forms. There exists a single-point submeter, which can be located externally or internally to a panelboard and used to meter the entire panelboard load. Branch circuit meters can be located internal to a panelboard and provide individual current transformers (CTs) on each panel's over-current protection device (OCPD). The branch circuit meters are more easily utilized in new construction, but are more difficult to add to an existing panelboard because of potential space limitations inside the panel. Otherwise, a multi-point meter could be added, which performs the same task of metering individual circuit loads, but is typically located in a separate housing external to the panelboard.

There are many other advantages and disadvantages to using a single point meter, branch circuit meter panelboard, or a multi-point meter. The single point meter is simple to integrate into the system, but if a panel serves multiple end-use load types such as HVAC, lighting, and receptacles, then it doesn't provide the necessary data needed to meet the energy codes discussed later in Chapter 3. The multi-point meter allows for flexibility in deciding how many circuits to meter, whether the entire panel or just a portion of it. This could allow for a panelboard serving multiple types of loads to have a single point meter installed, and then a multi-point meter to monitor a fewer number of circuits that can then be subtracted from the total panel load. The potential downside of a multi-point meter though is that there might not be physical space inside of an existing panel for all of the necessary CTs to be installed. It also requires a dedicated three-pole circuit breaker to power the meter and monitor the load across each phase, thereby reducing the number of allowable breaker poles for the building loads.

The branch circuit meter panelboard can also have additional space savings. While the panel itself might be taller or slightly wider in order to fit all the integral CTs, it avoids the wall space required for the external multi-point meter cabinet. This can reduce square footage needed for electrical room layouts.

An application of these different submeter types will be further analyzed in Chapter 5 for an existing university department. Other major factors to consider relative to all of these submeter types is the cost required to implement, and how to analyze and process all of the metered data that will be produced.

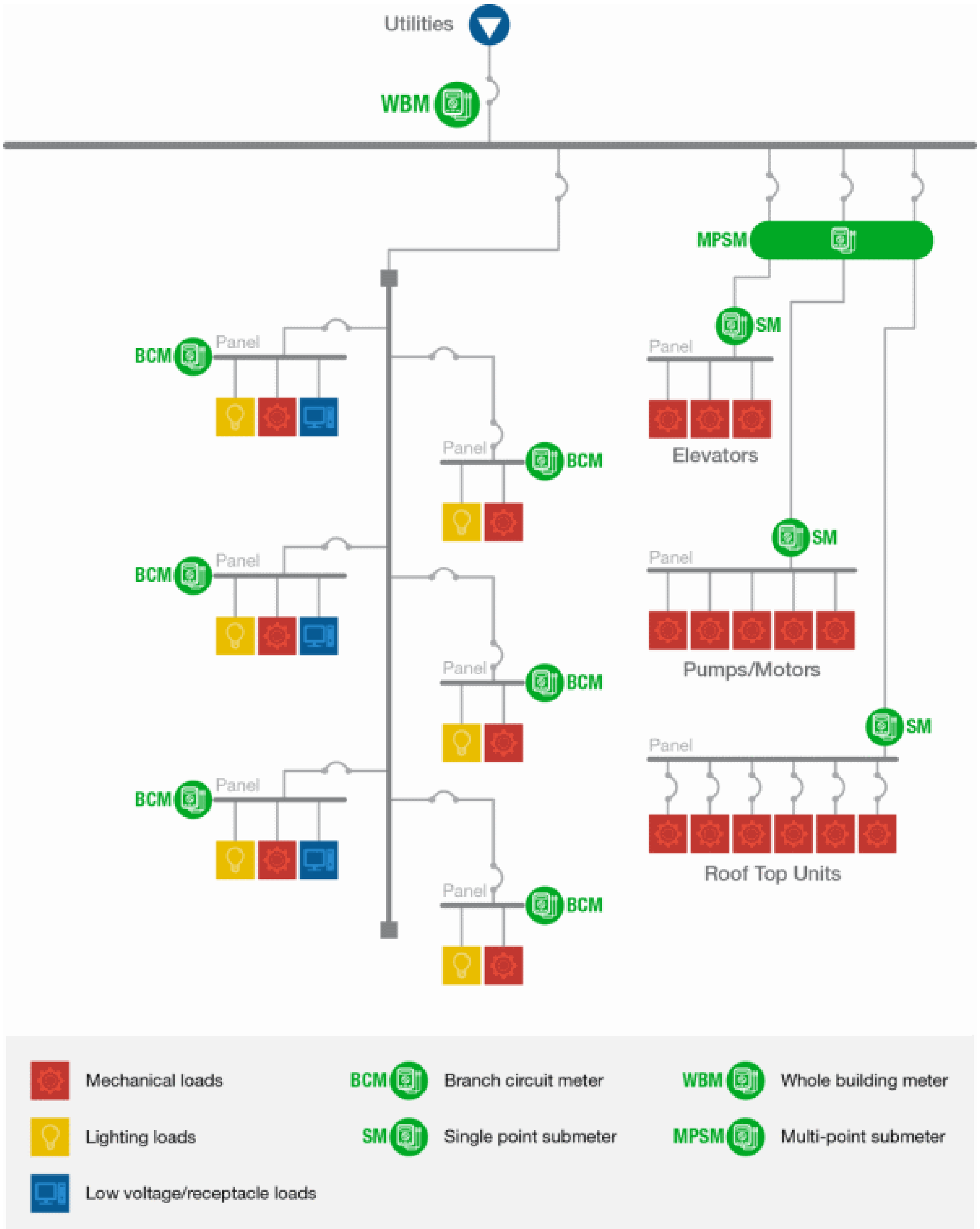

Figure 2.3 Example Diagram of Building Electrical Distribution and Meter Types/Locations

(Source: Sustainable Facilities Tools, n.d.)

2.5 Submeter Cost Feasibility

As stated before, meters by themselves save no energy or water, and in fact add extra cost to implement. Metering simply provides the data that when analyzed allows the building owner and staff to make informed decisions. Thus, the issue becomes how to address whether submeters are financially viable for a given building. However. this isn't an issue of feasibility when the submeters are required by building energy codes as discussed in Chapter 3, but instead how to provide and install them as economically as possible.

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy published a guide regarding metering specifically for federal buildings for electricity, natural gas, steam, and domestic water. Part of that guide included a summary of the potential savings for varying applications of submetering, as shown in Table 2.2. The initial 0-2% indicated for installing meters is commonly attributed to the Hawthorne Effect, which states that simply having the monitoring equipment will lead to savings (Legrand, 2013). Bill allocation, load management, and ongoing commissioning benefits and costs are all discussed further in Chapter 3.

Table 2.2 Estimated Metering Savings

Action	Observed Savings	Reasoning
Installation of Meters	0-2%	Initial impact, but savings will not persist
Bill Allocation Only	2.5-5%	Improved occupancy awareness
Building Tune-Up and Load Management	5-15%	Improved awareness, identification of simple operations and maintenance improvements, and managing demand loads per electric rate schedules
Ongoing Commissioning	15-45%	Improved awareness, ongoing identification of simple operations and maintenance improvements, and continuing management attention

(Source: adapted from U.S. DOE, 2014)

An important study that was analyzed for this report was performed by Mills and Matthew in 2009. It consisted of energy management software and energy submeters being installed in 24 buildings throughout the University of California and California State University school systems. The total cost of the project was $2.9 million, with submeter costs averaging $48,333 per building. The resulting energy savings yielded around $0.25/sf-yr, offering a median simple payback of 2.5 years. Other similar studies showed estimated simple paybacks of 1.2 to 3.4 years (Zhai & Salazar, 2020).

Since colleges and universities can expect to operate and occupy buildings for much longer periods of time, any simple paybacks of 5-7 years at a minimum can make economic sense. The larger issue then becomes how to cover the necessary first costs for installation. Generally, colleges and universities will first install submeters for the electrical loads, since electric utility makes up approximately 80% of the total energy budget on average and the meters themselves are usually more economical (Southface Energy Institute, n.d.). That number can be expected to increase over the years as trends such as building decarbonization and electrification start to impact internal and external policies. As a basis for comparison, the electric utility at Kansas State University, which is the location of the building case study done in Chapter 5, comprised approximately 65% of the total campus utility budget for the 2021 fiscal year (KSU Facilities, 2021).

2.6 Integration of Submeters

As building energy and system-level metering becomes more common, university facility groups will be faced with an increasing and potentially overwhelming amount of data (Kramer et al., 2019). This data does not typically lead to insights, corrective actions, and energy savings unless it is stored, organized, analyzed, and prioritized. While Chapter 3 gets into the potential uses of this data, this section discusses how the metered data is communicated.

When providing submeters, in addition to specifying the type of meter and the data to be collected and used, the design must also specify the analysis software and communication tools that will be necessary to manage the data and provide it to the operators or occupants to control the building's energy and water use (National Science and Technology Council, 2011). Figure 2.1 provides some of the common communication tools used. If interfacing with the building automation system (BAS), it not only integrates the control logic but also provides access to the other BAS features such as trend analysis, report generation, and user information display. A standalone energy management information system (EMIS) can also be utilized. These systems also provide several features and tools needed to analyze, assess, and report the data. Regardless of which system is used, the specific communication protocol used between the meter and BAS/EMIS should be specified, preferably a non-proprietary, open-protocol network that can interface with several meter manufacturers economically.

Chapter 3 - Uses and Benefits of Submetering

Choosing the right level of application for submeters in buildings, specifically at a college of university, is largely determined by the benefits that an owner hopes to achieve to meet the building energy performance goals (Sustainable Facilities Tool, n.d.). The two main areas of operation that can benefit the most from submeters are usually economic and environmental policy, but there are others as well. Sometimes the decision to include submeters could just be simply meeting a code or policy requirement for the building. The following chapter seeks to identify the main benefits and uses that submetering can offer a university campus.

3.1 Energy Code Compliance

It is generally accepted that increasing the energy efficiency of building systems is one of the most effective ways to reduce energy costs and greenhouse gas emissions. Energy codes support this strategy, since their primary focus is increasing energy efficiency in buildings. Additionally, voluntary rating systems also encourage and require buildings to increase energy efficiency.

Energy codes are part of the collection of building codes that all jurisdictions adopt at a state or local level to govern the design and construction of commercial and residential buildings. This section addresses the latest versions of the most widely used energy codes and what the requirements are for submetering and monitoring a building's energy use.

Energy codes have been around since the 1970s, created largely in part to offset the energy crisis during those times. They have evolved over the years, and generally fall into the categories of model codes and enforceable codes.

Model energy codes are designed to serve as a framework for states and local jurisdictions to adopt as enforceable law without having to spend large amounts of time and effort developing their own. The two most common model energy codes that exist for commercial buildings are the International Energy Conservation Code (IECC) and ANSI/ASHRAE/IES Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings, commonly referred to as ASHRAE 90.1. The IECC is developed by the International Code Council (ICC). ASHRAE 90.1 is a joint effort between the American National Standards Institute (ANSI), the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), and the Illuminating Engineering Society (IES).

Both model codes are updated on a 3-year cycle. Typically, changes made are meant to make buildings following the model codes more energy efficient than the previous edition. This is evident in Table 3.1, which shows the efficiency increases of ASHRAE 90.1 throughout its history. That figure includes the most recent ASHRAE 90.1-2019, which in July of 2021 was determined by the Department of Energy (DOE) to be approximately 4.7% more efficient in sit energy and 4.3% more efficient in source energy then the 2016 editions (U.S. DOE, 2021).

The energy codes do not make changes only for efficiency sake. They also need to be cost justifiable. In other words, the model codes won't make an owner comply with more stringent requirements unless it was shown to save money over the building's lifetime. This is reinforced in the same DOE study that concluded the ASHRAE 90.1-2019 edition had an energy cost savings of approximately 4.3 percent of commercial building energy consumption compared to the 2016 edition. It also addresses why submetering has not always been a requirement of the energy codes even though it was demonstrated that it was able to help save significant energy usage and cost. That's because until recently, the costs to provide the additional meters did not justify the energy savings they could provide.

Table 3.1 Percent Energy Efficiency Improvements of ASHRAE Standard 90.1

ASHRAE 90.1 Edition	% Change in Site Energy from Previous Edition
90.1-1989	-14.0%
90.1-1999	-4.5%
90.1-2004	-11.8%
90.1-2007	-4.5%
90.1-2010	-18.5%
90.1-2013	-7.5%
90.1-2016	-6.8%
90.1-2019	-4.7%

(Source: adapted from Overbey, 2018 and U.S. DOE, 2021)

It should also be mentioned that the IECC allows ASHRAE 90.1 to be used as an alternative compliance path to satisfy its requirements. Because of this, the IECC tracks behind ASHRAE 90.1 by two years. That is to say that the 2018 IECC allows buildings to meet ASHRAE 90.1-2016 to achieve code compliance. This has presented a situation in recent years for design engineers because the IECC has not always updated to match ASHRAE 90.1. This means that newer requirements of ASHRAE 90.1 could be overlooked by a building owner simply by designing towards the IECC instead. This is further addressed below with the submeter requirements.

Model codes have the ability to then become enforceable codes. Enforceable codes are those that are adopted at the state or local level and become law. While a majority of states will adopt one of the model energy codes (IECC or ASHRAE 90.1), they may decide to modify or amend certain portions via an ordinance. There are also some states like California that instead developed and manage their own energy code, Title 24. Regardless of which one is used, these codes set the minimum efficiency standards that the jurisdictions must meet for new construction and major renovation projects. Figure 3.1 outlines the current energy code adoptions by state. If a state had adopted the IECC, then the image lists the equivalent ASHRAE 90.1 edition. For the states shown in white, there is no state-wide energy code. Instead the code adoption process falls to the local jurisdictions to decide which to use and enforce for compliance. Relative to Manhattan, KS, which is the location of the case study building discussed in Chapter 5, the adopted energy code is the IECC 2009 edition.

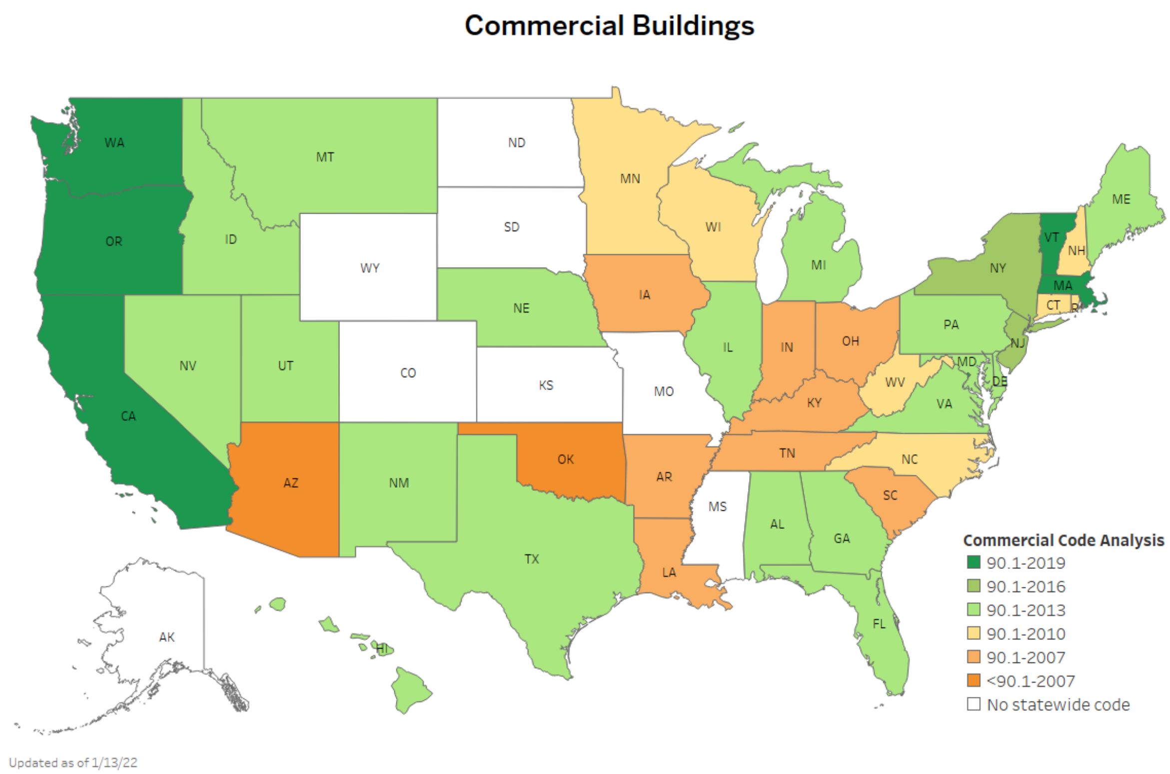

Figure 3.1 Status of State Energy Code Adoption as of 01/13/2022
(Source: U.S. DOE's Office of Energy Efficiency and Renewable Energy, 2022)

The following subsections will specifically outline and compare the submetering requirements of each model code discussed, ASHRAE 90.1-2019 and the 2021 IECC. In addition to these energy codes, there are other voluntary rating systems that a building owner can choose to meet. The one that is most widely known is LEED, or Leadership in Energy and Environmental Design, that was developed by the U.S. Green Building Council (USGBC). The requirements for submetering under the energy points that are available are similar to those of ASHRAE 90.1 and the IECC, but are not a focus of this report.

ANSI/ASHRAE/IES Standard 90.1-2019

Regarding the topic of submetering, ASHRAE 90.1 first introduced requirements in the 2013 edition of the standard. This consisted of electrical monitoring requirements that have been expanded over the years. The current 2019 edition requires electrical energy monitoring, i.e. submetering, for all buildings 25,000 sf or larger, and individual tenant spaces 10,000 sf or larger (ASHRAE, 2019). It does exclude residential dwelling units and critical power needed for healthcare facilities. Measurement devices, i.e. submeters, are needed to monitor the electrical use separately for each of the following: total electrical energy, HVAC systems, interior lighting, exterior lighting, and receptacle circuits. The energy measurements taken need to be recorded a minimum of every 15 minutes, and reported hourly, daily, monthly, and annually, storing the data a minimum of 36 months. The energy use data should be graphically displayed, and when related to a tenant area, the information should be provided to that tenant. The standard is open for interpretation for what graphical display involves. This could simply be displayed internally for only a single person such as the building facility manager, rather than externally to the building occupants. However, future discussions in this report state the case for displaying that data for the general building occupants as well.

2021 International Energy Conservation Code

The IECC has taken a slightly different approach relative to its submetering requirements. Even though both model codes are updated on a 3-year cycle, the IECC typically follows guidance from ASHRAE 90.1 and lags behind by two years. While energy monitoring was first required in ASHRAE 90.1-2013 and subsequently ASHRAE 90.1-2016, it did not end up being a requirement in the IECC's 2015 or 2018 editions. However, energy monitoring has finally been introduced in the IECC 2021 edition.

The requirements track very similarly to ASHRAE 90.1-2019. The key difference is that it also requires electrical energy monitoring for two additional categories: process loads and building operations loads (ICC, 2020). The non-receptacle process loads are only required when they exceed 5% of the building connected load, which would capture facilities such as data centers, commercial kitchens, and manufacturing buildings. The building operations loads include everything else not already monitored. The building operations loads would be easy to calculate without additional equipment, since the total building energy could have all of the other required loads removed. Other differences include only requiring data recorded a minimum of hourly, and it clarifies that the graphical display is to be accessible to the building operations and management personnel (ICC, 2020).

In addition to mandatory building energy codes, another metric of performance that is being adopted by more jurisdictions and relies on submetered data is the concept of benchmarking systems, discussed next.

3.2 Energy Benchmarking Systems

The ability to measure data provided by submetering provides owners with a method to reduce building energy consumption by identifying areas to eliminate wasted resources. It also lets a building owner see their energy usage over time, whether month-to-month, year-to-year, etc. In order to determine the improved efficiency of a building or specific subsystem, the new energy performance data needs to be compared to its past performance. In many instances, an owner also wants to compare how their building is performing relative to other buildings that have similar size or space usage, known as benchmarking.

Generally, there are two ways to assess a building's energy consumption performance: certification systems and rating systems. Certification systems are defined for this report as ones that only give a classification and can be more subjective in nature. Rating systems are ones that offer a numerical score to use for comparison to other similar type buildings, offering a more objective result. Programs outlined in this section are considered rating systems for discussion purposes, but they are also commonly referred to as benchmarking programs. Benchmarking can use a pre-determined value or score to assess whether a building is energy efficient.

Before discussing the benchmarking programs, it's important to offer some background on how the rating systems are quantified. Numerical values are commonly used for rating systems to give a score. Specific to building energy performance, the two most common values are EUI and ECI.

EUI, or energy utilization index, is the average annual energy consumption of a building per square foot of floor area, measured in kBTU/(yr*ft^2). EUI's are offered in two ways: site EUI and source EUI. Site EUI consists of the energy used within a building's property line, downstream of the utility meter. Source EUI encompasses site EUI but also includes the energy losses required by the utility company infrastructure to generate and transmit the resource to the building site. Source EUI can be calculated by taking the site EUI and multiplying it by a specific efficiency factor (Energy Star, 2021b). Both of these values will be used throughout this report.

ECI, or energy cost index, is the average annual energy cost per square foot, represented as $\$/(yr*ft^2)$. This is based on the amount of money an owner spends for its energy delivered to the site. While renewable energy is not a focus of this report, it should be noted that as on-site renewable energy continues to grow, its generation skews the ECI because it does not factor in this cost credit, thus making it a less reliable indicator than EUI.

The two benchmarking programs focused in this report are the U.S. Environmental Protection Agency (EPA)'s Energy Star Portfolio Manager and ASHRAE's Building Energy Quotient (bEQ).

Energy Star Portfolio Manager

The EPA developed the Energy Star program in 1992 to initially certify low-energy appliances used in buildings, but expanded it over the years to benchmark low-energy consuming buildings (Energy Star, n.d.). Since it is the most mature benchmarking program available, it is also the most widely used. The Portfolio Manager is the online tool used to produce ratings for existing buildings. It uses a normalized EUI that is adjusted for weather and gives a statistical average for a given building type (Energy Star, n.d.), which then allows a 1-100 percentile to be given. A higher number percentile represents a more energy efficient building. For example, an average building is assigned a value of 50 for the 50th percentile. To qualify as an Energy Star rated building, it must be assigned a value of 75 or greater (75th percentile or better).

A major component to participating in the Portfolio Manager is providing a minimum of 12 months of continuous metered energy data. This is similar to a Level 1 energy audit discussed later. When a utility meter is placed at the building level, that data would qualify for the entire building. However, in the case of a multi-tenant building or a large campus without building-level utility meters, then the data would need to come from the appropriate submeters. Since a building's energy use will change over time, and the existing building portfolio stock that is used to benchmark against typically increases in efficiency, it is recommended that a building receive a new Energy Star score every few years. This means that if a building fails to continue to improve its energy efficiency over time, it's score will likely fall over the years if the existing building stock as a whole, increases in efficiency.

ASHRAE Building Energy Quotient (bEQ)

ASHRAE, which is recognized as a professional non-profit organization, developed the Building Energy Quotient program in 2012. This program is different from Energy Star Portfolio Manager in that it offers two categories for submission, As-Designed or In-Operation (ASHRAE, n.d.). As-Designed compares the potential energy use a building may use based on the building's construction and systems simulated, and In-Operation compares actual building energy use based on metered energy information, thus making In-Operation the more direct comparison to Portfolio Manager and the focus of this report.

ASHRAE provides a bEQ rating as a numerical score, but also references those numerical scores to letter grades, similar to a school report card to indicate a commonly identifiable level of performance. The numerical scores range from 0 to 200, with a lower number being a better value. A score of 0 or less is the best possible score and is reserved for a net zero energy building, which is a building that produces as much or more energy than it consumes in an annual period. If a building produces more energy than it consumes in an annual period, it would receive a negative score, which seems counterintuitive to most rating scales. An efficient building has a score less than 100, representing low energy use. An average building will fall near the median value of 100, which serves as the baseline value of energy use intensity for similar type buildings. And finally, an inefficient building has a score greater than 100, representing above average and high energy use. The letter grades provided are an A+ (0 or less), A (1 to 25, high performance), A- (26-55, very good), B (56-85, efficient), C (86-115, average), D (116-145, inefficient), and F (146-200, unsatisfactory) (ASHRAE, n.d.).

While bEQ also factors in a normalized EUI based on the same method and data sources as Portfolio Manager, including a minimum of 12 months of metered data, it does have one main distinction from Portfolio Manager in that it rates more than just energy usage. It also factors in indoor environmental quality (IEQ), which normally consists of thermal comfort, indoor air quality, acoustics, and lighting quality. It also provides recommendations of improvements to help a building get to the next letter grade. ASHRAE recommends that a building recertify at least every 3 years to keep current with average EUI values. However, legislation and policies are trending towards requiring annual benchmarking.

Benchmarking Policies

Originally benchmarking programs were just meant to serve as a comparison tool to induce changes. Recently, however, legislation has been passed in many states and municipalities that require the reporting of this measured and benchmarked energy data by building owners. Typically, the reporting is required to be transparent, which refers to making the energy use data public so that the performance is recognized, providing an important incentive for improvements. This transparent benchmarking can create and support a range of measures that provide energy and cost savings.

As the trend in climate awareness shifts to things like decarbonization and net-zero energy buildings by 2050, it's likely that benchmarking requirements start to become required and enforced in more states and cities moving forward. With these increasing requirements, it will be more important that a building owner be able to provide reliable and regular metered energy data. A map of current states and cities with benchmarking policies in place is shown in Figure 3.2. It encompasses 4 state-wide policies and 39 cities with policies for existing buildings.

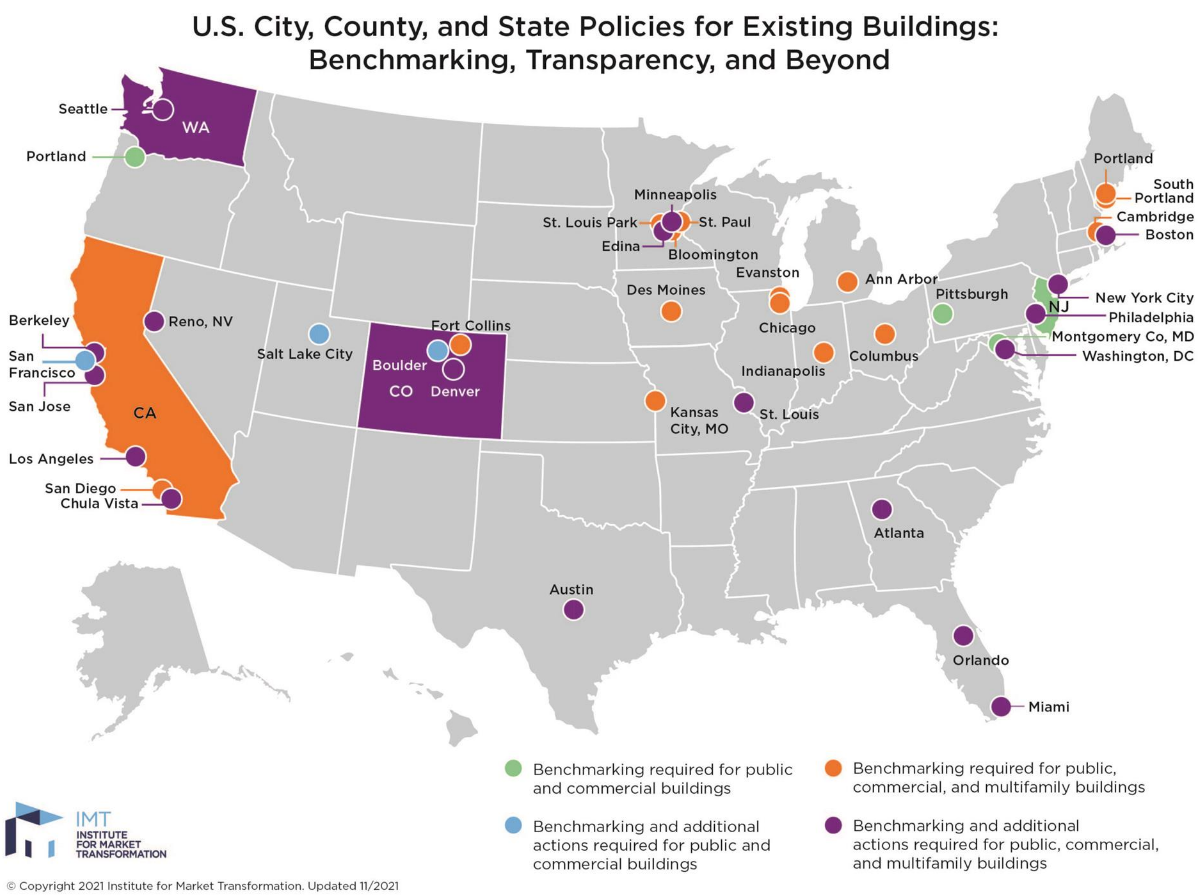

Figure 3.2 Map of Adopted Mandatory Building Benchmarking Policies
(Source: Institute for Market Transformation, 2021)

In addition to mandatory legislation, another benefit of benchmarking a building is that it makes it more enticing for buyers and renters if they know they are getting a more energy efficient building with lower operating and maintenance costs. As an example, in New York, it is sometimes a requirement with a commercial building sale that a benchmark report be provided (Meng and Han, 2017).

Typically, a building benchmark is performed before an energy audit can take place, which is the next topic of discussion.

3.3 Energy Audits

As the name implies, an energy audit is an external study or assessment of a building's energy performance. Much of what has been standardized as common practice when it comes to energy audits is based on publications by ASHRAE. Their initial publication, Procedures for Commercial Building Energy Audits (PCBEA), established the levels of audits commonly referred to today as well as the tasks that should be achieved for each level. In an effort to establish a minimum performance level for energy audits that could be adopted as a code enforceable reference, ASHRAE then expanded on PCBEA to create ANSI/ASHRAE/ACCA Standard 211-2018: Standard for Commercial Building Energy Audits. This standard helps ensure that audits are held to the same appropriate level of rigor and depth.

The purpose of an energy audit is to identify a list of energy efficiency measures (EEMs), also commonly referred to as energy conservation measures (ECMs), that can outline the savings opportunities for the building. There are three different types of EEMs according to ASHRAE 211-2018: no-cost measures (NCMs), low-cost measures (LCMs), and capital-intensive measures (CIMs). NCMs are ones that are typically identified in operations and maintenance activities and can reduce energy usage with little to no cost except for maybe some internal labor (i.e. changing a thermostat setpoint by a degree or replacing air filters regularly to reduce fan energy). LCMs are ones that can significantly reduce energy usage with relatively little capital investment (i.e. providing a variable frequency drive on a fan to limit airflows when not needed). Finally, CIMs are ones that can also significantly reduce energy usage, but incur a higher capital investment. Normally these are planned well in advance (i.e. installing a solar photovoltaic system to an existing building).

There are also different levels of audits defined by ASHRAE 211-2018: Level 1, Level 2, Level 3. Before any level energy audit can occur, the auditor must first complete a Preliminary Energy Use Analysis (PEA). This analysis is essentially the same process as benchmarking the building that was previously discussed. Once this is done the owner can work with a third-party auditor to decide what level of audit is most appropriate for the building.

A Level 1 energy audit is used to identify a basic potential for energy savings, and includes a list of EEMs. These EEMs are expressed qualitatively only, and don’t require any cost or savings information to justify them.

A Level 2 energy audit contains everything that a Level 1 audit does, but starts to quantify the potential EEMs. A Level 2 audit is what most people think of when they consider the term energy audit (Kelsey, 2021). This is where the submetering of building energy use becomes critical, as it is required to provide a summary of the building energy systems broken down by end use similar to what is required by the energy code. Additionally, the auditor performs a detailed building survey, meets with the owner or staff, and puts together a simple payback analysis on all of the proposed EEMs, including estimated implementations costs and savings potential. A summary of a Level 2 audit is shown in Figure 3.3.

A Level 3 energy audit contains everything that a Level 2 audit does, but dives deeper into the details of the EEMs that have been identified. This level typically involves more detailed life cycle cost analyses, obtaining actual quotes from manufacturers and venders for equipment needed, possible temporary monitoring and metering of specific data not already available, etc. This is typically done to ensure product feasibility and to limit potential risk. However, this level of audit is generally not performed (Kelsey, 2021).

Measure Number	Measure Description	Annual Energy & Cost Savings					Financial Metrics				
		Peak Savings (kW)	Electricity Savings (kWh/yr)	Gas Savings (therms/yr)	Total Cost Savings	CO_2 Savings (tons)	Measure Cost	Potential Incentive	Net Measure Cost	Net Present Value	Simple Payback
NCM-1	Adjust Case Lights Schedule	-	5,500	-	$ 980	1.0	$ -	$ -	$ -	$ 2,784	-
NCM-2	Enroll in CleanpowerSF	-	-	-	$ 2,627	-	$ -	$ -	$ -	$ 12,114	-
NCM-3	Schedule Air Handler Operation	-	6,500	-	$ 1,158	1.2	$ -	$ -	$ -	$ 3,290	-
NCM-4	Implement Floating Suction Control	-	19,700	-	$ 3,509	3.7	$ -	$ -	$ -	$ 9,972	-
LCM-1	Automatic Door Closures on Walk-in Coolers	-	1,400	-	$ 249	0.3	$ 600	$ 150	$ 450	$ 2,064	1.8
LCM-2	Install Occupancy Sensors on Frozen Food Case Lights	-	1,400	-	$ 249	0.3	$ 600	$ -	$ 600	$ 1,165	2.4
LCM-4	Repair Air Handler Economizer	-	1,100	-	$ 196	0.2	$ 600	$ -	$ 600	$ 304	3.1
LCM-5	Reprogram Supply Fan VFD	-	7,700	-	$ 1,371	1.4	$ 2,000	$ -	$ 2,000	$ 1,896	1.5
CIM-1	Install Solar PV System	144.3	236,900	-	$ 42,193	44.3	$496,944	$315,559	$ 181,385	$558,105	4.7
	Sub-Total	144.3	280,200	-	$ 52,532	52.4	$ 500,744	$ 315,709	$ 185,035	$ 494,098	3.5
TOTALS (All Recommended Measures)		144.3	280,200	-	$ 52,532	52.4	$ 500,744	$ 315,709	$ 185,035	$ 686,837	3.5

Figure 3.3 Sample Energy Efficiency Measure Summary
(Source: Kelsey, 2021)

In some states, performing regular building energy audits has become law. Once such state is Kansas, whereby Kansas Administrative Regulation 1-66-2 states that a building energy audit must be performed for all state-owned buildings at least every 5 years. It is understood that public universities, such as Kansas State University which is the focus of the case study in Chapter 5, fall under this requirement. There are other public universities in Kansas, such as the University of Kansas (KU), that perform energy audits for each of the buildings on their campuses. The logic behind the law could be similar to that of the energy codes requiring submetering, in that the justification to perform these building energy audits will inevitably lead to cost savings over time.

While it is apparent that building energy audits are a great tool to identify energy cost savings, they rely heavily on the use of submetered data. Yet the EEMs are implemented and then the building goes back to operating, largely going unchecked except for routine maintenance. Over time, those EEMs might need to be revisited and monitored to ensure they're still in effect, or there could be new EEMs that exist which may go undocumented until the next audit. This leads into the next benefit of submetering, which involves constantly monitoring the building for new EEMs.

3.4 Monitoring Based Commissioning (MBCx)

Effective commissioning is critical to ensuring building and energy system performance meets the original design intent. Commissioning (Cx) is the process of planning, documenting, scheduling, testing, adjusting, verifying, and training to provide a facility that operates as a fully functional system per the owner's design requirements (Complete Commissioning, Inc., 2021). While traditional Cx is considered for new construction and major renovations, there are other types of commissioning that are suitable for a university campus with multiple existing buildings that were originally built without commissioning being performed.

Retro-commissioning (RCx) is the application of the commissioning process to buildings or systems not previously commissioned. Many buildings or systems that were delivered without undergoing commissioning have deficiencies in design or construction that prevent the building and its equipment from functioning properly or in an energy efficient manner.

After the initial Cx or RCx process is complete, there is a growing trend in Monitoring Based Commissioning (MBCx). MBCx is the continuous application of the commissioning process to a building or energy system and is an effective method to keep energy costs low and minimize system problems that may be caused over time by building performance deterioration and changes to building operations (Swegon Air Academy, 2017). A key component to the implementation of MBCx is the utilization of energy submeters. They allow for enhanced building performance by utilizing metered data to recognize system inefficiencies and energy changes. These include identifying energy consuming loads that increase over time without reason, and also enabling remote monitoring of major system usage. Using submeters installed and integrated with the MBCx software can allow the building operator to develop key performance indicators to track the performance of larger pieces of equipment such as chillers, boilers, pumps, and fans, leading to optimized utilization and potentially extending the useful life of the equipment (U.S. EERE, 2021).

The image shown in Figure 3.4 was taken from a study done by the Lawrence Berkeley National Laboratory (LBNL). The green, light blue, and dark blue areas represent potential savings in energy usage from utilizing MBCx. The green area represents savings from continuous monitoring, which is afforded by the data gathered from the submeters. These savings could result from data that helps building operators identify occurrences such as equipment malfunctions or a suboptimal control sequence for the building HVAC system. The light blue area represents savings from implementing new EEM's over time. As previously discussed, submeters allow for real-time verification that EEM's are performing as expected. The dark blue area represents savings from newer technologies that potentially don't exist at the time that initial Cx or RCx is performed, and are realized in the way of newer EEM's and continuous monitoring efforts.

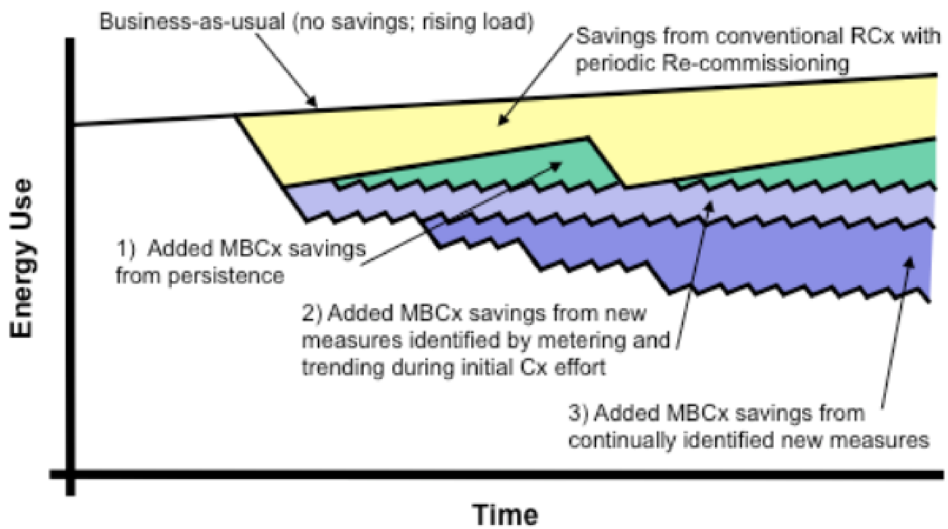

Figure 3.4 Potential Savings from Monitoring Based Commissioning
(Source: U.S. EERE, 2021)

The final discussion point regarding the use of submeters for MBCx is the life cycle cost implications and a case study of a university campus using this strategy. MBCx costs typically include the initial installation cost and labor as well as annual use of hardware, software licenses, submeters, and maintenance labor (U.S. EERE, 2021).

Several studies have generally indicated 9-15% median energy savings with simple payback periods around 3.2 years (U.S. EERE, 2021). Another study conducted by the LBNL analyzed data from 35 building portfolio owners that totaled over 400 million sf of space that use the energy management and information systems needed to conduct MBCx. The study found that users reported a median base cost to implement of $0.03/sf for installation and $0.05/sf in annual operating/labor costs. However, the reported savings had a median cost savings of $0.19/sf, resulting in 7% annual energy savings that is expected to increase over time (Kramer et al., 2019).

From a university standpoint, the Colorado School of Mines entered into an energy savings performance contract in 2018 that included the integration of an MBCx program across 32 buildings. This MBCx program, combined with an additional building occupant behavioral change program that is discussed later in this chapter, included a cost savings guarantee of $234,000 per year (U.S. EERE, 2021).

3.5 Utility Demand Reduction and Allocation

Since utility bills are calculated by both the overall use of energy and peak power demand prices, demand response helps to reduce resource consumption when electrical utility companies are nearing grid capacity and can avoid brown outs (Sustainable Facilities Tool, n.d.). Demand response can also reduce consumption during peak time of use energy rates, or for other forms of demand shedding.

Another benefit that submetering provides relative to utility usage is the ability to verify and allocate the utility costs. The University of Kansas has had success in utilizing their robust submetering system in this regard. They track utility data across their 175-building portfolio, which uses 1,100 meters and submeters, to provide 600+ monthly utility bills for electricity, natural gas, steam, chilled water, sewer, and domestic water. These bills allocate energy use to a myriad of divisions and departments; and fairly charge back each for its energy use. According to the Energy Conservation and Utility Manager at KU, Scott McVey,

> "Because annual revenue from these chargebacks totals over $2.3 million, accurately creating and managing campus chargeback transactions is a high priority business process." (EnergyCAP, 2021).

When individual departments on a college campus or tenants in a multi-tenant building are provided their utility bills and usage directly, it can inherently produce a savings, as indicated in Table 2.2. This bridges the gap into the next topic of discussion regarding building occupant decision making.

3.6 Occupant Behavioral Changes

Evermore, the increase in knowledge and public concern with regards to climate change has warranted increased attention towards energy consumption, specifically in buildings (Janda, 2011). Utilizing that increase in knowledge to enact change in behavior that can then become habit is something that colleges and universities are poised to achieve.

Yet those same people who occupy these buildings are rarely trained or provided much information about how the building systems that they use operate, or how their behaviors, both individually and collectively, affect a building's energy performance. In order to capture energy efficiency wherever possible, an important thing to consider is occupant behavioral change. Behavioral change refers to alterations in patterns of action and choices (Wolfe et al., 2014).

Another behavioral aspect to consider ties back to the topic of utility demand response control that was discussed earlier. If a building has identified that the utility loads need to be reduced, it could use load shedding to reduce the loads of the HVAC system or lighting. One study performed at Rutgers University imposed a load shedding event during a summer day. This included both a thermal comfort event by increasing the thermostat setpoint several degrees to keep the cooling cycle from running, and an illumination event by reducing the artificial lighting. The study found that in both events the load shedding was barely perceptible to the occupants, yet the building electrical use reduced almost 50% during that period (Andrews et al., 2013).

The previously discussed topic of commissioning can also be effective when paired with behavioral change because there generally is a gap between the design of a building and its ultimate construction. Additionally, it has always been difficult for designers to model and predict how a building will actually be used when occupied, as well as how effective a building owner will maintain the building. These relationships between the design, construction, and operation of a building are illustrated in Figure 3.5.

Figure 3.5 The gap between the predicted and actual use of buildings
(Source: adapted from Delzendeh et al, 2014)

This is to say that if building occupants were made aware and provided with information that let them see how their actions might affect the building's performance, this awareness could yield a more positive participation in operational change. Given that the largest energy consumers in buildings (HVAC, lighting, plug loads) are all directly utilized by the building occupants, these were the primary focus of the research that was analyzed. Figure 3.6 indicates how typical building occupants and their behavior impact a building's energy consumption.

However, as current energy codes become stricter, it might seem counterintuitive that building occupants will be left with much control over building energy usage. Lighting system efficiency is increasing while lighting controls are moving to mostly automatic occupancy controls, turning off on their own when not in use. Also, HVAC system efficiencies are also increasing, while also limiting the temperature controllability by the occupant. Yet the area of energy usage that occupants retain the greatest control of is plug loads.

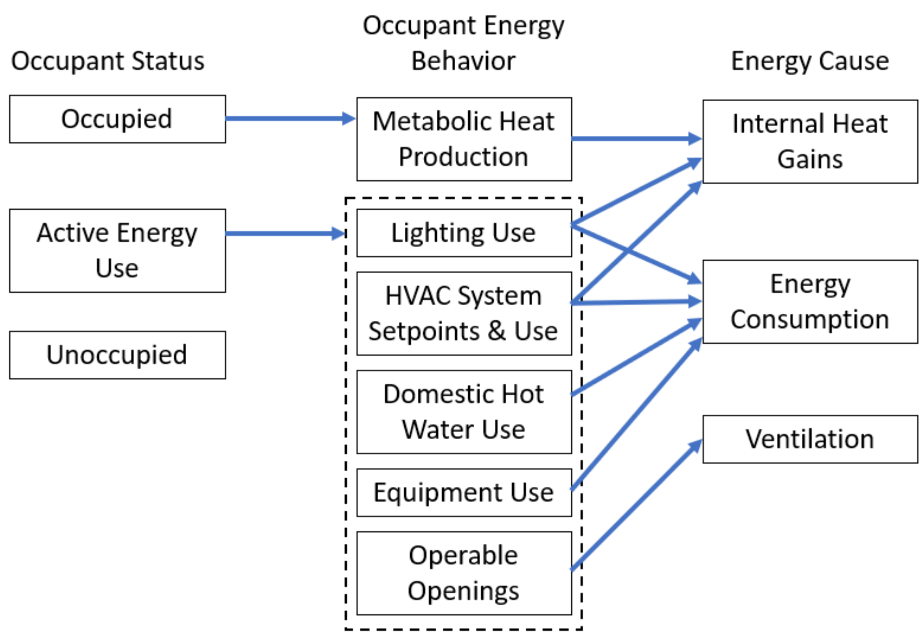

Figure 3.6 Occupants' types of activities affecting building energy consumption
(Source: adapted from Delzendeh et al, 2014)

Plug Loads

It appears the largest impact in energy use reduction that building occupants can produce is in their utilization of plug loads, which is all of the miscellaneous equipment power consumption not attributed to a traditional end use such as lighting or HVAC. While the energy used for lighting and HVAC systems is expected to decrease, the energy for these miscellaneous plug loads is expected to increase approximately 40% by 2050, as seen in the "other uses" and "computers, office equipment" categories of Figure 3.7 (U.S. EIA, 2022). This trend can likely be attributed to the growth in the market share of electronic devices combined with an increased requirement to utilize new electronic products that can aid worker productivity and student learning in university buildings (Hafer, 2016).

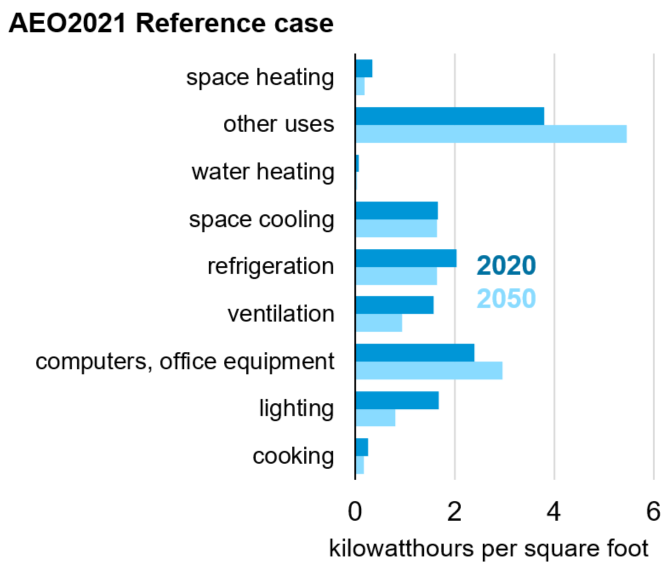

Figure 3.7 Annual Energy Outlook of Commercial Electric Intensity by End Use
(Source: U.S. Energy Information Administration, 2022)

Additionally, a study done at Stanford University looked at inventorying and assessing plug loads for 220 buildings on Stanford's campus, including lab, office, classroom, recreation, and service building types. Over 8.9 million sq. ft. in total was surveyed which showed that approximately 32% of the electricity consumed in the buildings was from plug loads (Hafer, 2016).

So, the building occupants will have more control potentially over a building's energy performance than they do now. Yet they somehow need to be made aware of the impact they can provide. This topic will be further analyzed in Chapter 4 when discussing the use of submetered data as a marketing tool for colleges and universities.

Chapter 4 - Submetering as a Tool

In addition to the uses and benefits of submetering addressed in Chapter 3, there are additional ways in which submetering can benefit colleges and universities. With a business model based around recruiting and educating people to prepare them for future work in their areas of interest, universities are capable of using submetered data both as a marketing tool and a teaching tool.

4.1 Submetering as a Teaching Tool

Since a college or university's main role is to educate and prepare its students for their future careers, it makes sense that the topic of this report be taught in a formal course if the opportunity presents itself. Most major colleges and universities have architecture and/or engineering programs that deal with some aspect of the building industry, specifically sustainability and energy efficiency. As such, there exist course offering frameworks that have been created by both the Energy Star Program as well as ASHRAE. The initial framework is offered at no cost to interested parties, and can be adapted and modified to create an official university course offering. The courses are centered around benchmarking and auditing an existing building, so the requirement for metered data that was previously discussed is required.

Part of this report is the creation of a potential future course offering for the department of Architectural Engineering and Construction Science (ARE/CNS) at Kansas State University, based off of ASHRAE's bEQ course framework. The course is titled ARE 715 – Problems in ARE: Benchmarking and Assessment of Building Energy Performance. The content developed includes a course outline, schedule, and syllabus, all of which can be found in Appendix A. This would be a full 16-week course that can be modified as a 2 or 3 credit hour offering as needed. The course is comprised of up to 10 weekly sessions of in-class instruction, followed by 5 weeks of field work in a commercial building, with a final report being submitted. While the main course focus is energy benchmarking and auditing of an existing building, the students would also be exposed to the benefits and applications of energy submetering that is required for the benchmark/audit.

One of the main reasons the course was developed around ASHRAE bEQ and not Energy Star Portfolio Manager was also the creation of a new ASHRAE Building EQ Student Design Competition in 2021. The students involved in the competition should be ASHRAE student members, with a team of 3-5 students recommended (ASHRAE, n.d.). If more students take the course, then multiple teams would be created. Since the faculty member teaching the course would be a registered Professional Engineer (PE), he/she would submit the final report for the team of students, which is a requirement. The scoring rubric used to evaluate the submissions also includes the size and complexity of the building benchmarked, the level of energy audit performed, use of ASHRAE's Building EQ online portal for submitting the report, the client's financial need, a client reference letter (bonus points), and finally, overall communication skills used (ASHRAE, n.d.)

A course such as this one would provide several student benefits. The first benefit is that it gives them practical experience. With the target audience being senior-level undergraduate and graduate students, they will have the opportunity to think through real-world energy efficiency problems and get hands-on experience prior to entering the workforce. The second benefit is that it gives them skills to benefit future clientele. By gaining skills that can be used in the workplace, students can improve their project's profitability through energy efficiency. The third benefit is that it applies community service, by using their newly acquired skills to benchmark a building for a local building owner or the university that ultimately results in lower utility bills.

Another possible teaching tool that can be implemented is one offered by Energy Star. This is in the form of a "energy treasure hunt" (Energy Star, n.d.). Instead of a formal university course with an energy audit and benchmark, this would be more of a 1- or 2-day event in which students, faculty and staff can walk around a campus building and look for quick ways to save energy. The advantage to something like this is that the time and cost commitment is low, and it allows anyone interested to participate regardless of class standing. Multiple student organizations on campus could partner together and make it an annual event. According to Energy Star, hundreds of organizations have used these treasure hunts to reduce their facilities' energy use by up to 15 percent (Energy Star, n.d.). A treasure map produced by Energy Star for K-12 Schools could be modified for higher education and there's also one for student housing buildings that could be used.

4.2 Submetering as a Marketing Tool

According to The Princeton Review's 2021 College Hopes & Worries Survey Results, 75% of the participants said a college or university's environmental commitment would affect their decision of where to attend. This was an increase compared to 66% of participants in the 2020 survey. This survey had over 14,000 participants, of which around 20% of respondents were parents and around 80% were high school students (Princeton Review, 2021).

Increased awareness of a campus' energy efficiency efforts should place more emphasis on utilizing submetered data to help promote marketing for any institution. This section identifies some possible solutions to increase marketing awareness in this area.

Energy Dashboards and User Interfaces

Having a real-time snapshot of how a building is currently performing and the ability to compare that performance to baseline and historical data can be a powerful marketing tool. This information is generally presented in an energy dashboard or a user interface. Whether it is to increase occupant awareness, allow for facility planning and decision making, or to display real-time performance, today's technology allows these dashboards to be available to the general public via a building kiosk/display, computer, or mobile device. These dashboards offer a more visually appealing presentation of information in a way that can be understood by typical building occupants such as students, faculty, staff and guests on a university campus.

These dashboards are usually available as a feature to a college or university's energy management information system. An example of an energy dashboard can be seen in Figure 4.1.

Figure 4.1 University of California Berkeley Sample Building Dashboard

(Source: UC Berkeley Energy Dashboard website, n.d.)

Additional dashboards could be centered around a university's student housing facilities. There are several universities, such as the University of Colorado-Boulder, that have an energy dashboard setup for each housing and dining building. They even hold energy competitions each semester to see which building wing can reduce its energy usage the most during a span of two weeks, with the winner getting a catered meal for everyone. It's competitions like these that can enact the behavioral changes discussed earlier which can lead to sustained energy performance improvements. Yet in order to have these types of displays and competitions, a university needs to be able to separately meter and process the data.

Peer Institution Comparisons

As discussed previously in Chapter 3, benchmarking a building to determine its performance compared to similar facilities can be of great interest. That is why in 2020, Energy Star launched a new initiative for college and universities call the Higher Education Benchmarking Initiative (HEBI). The goal was to create interest amongst institutions to see how their campus energy and water use intensities compared with similar institutions. The only caveat for participating in the initiative was that institutions had had to self-report campus energy and water data through the Portfolio Manager program. 101 institutions participated, with 79% being public institutions and 21% being private institutions (Energy Star, 2021a). Looking through the institutions that participated, the only one from the State of Kansas appeared to be the University of Kansas.

A summary of the findings is shown in Figure 4.2 and Figure 4.3. Kansas State University resides in IECC Climate Zone 4 which represented the highest percentage of participants at 36%. A point to note is that Kansas State University's Seaton Hall, the case study building discussed later in this report, had an approximate Site EUI of 84.32 kBtu/ft2*yr, Source

EUI of 133.23 kBtu/ft2*yr, and WUI of 1.74 gal/ft2*yr for the 2020 information on file from the Department of Facilities (Weishaar, 2021). An item to note for this data from 2020 is that the COVID-19 pandemic significantly altered normal operations of the building, including largely remote courses and limited building occupants from March to December of that year, likely leading to lower values than normal, especially for the WUI. Another building on campus, the Staley School of Leadership Studies that was built in 2010, had a Portfolio Manager benchmark study performed in 2017 that indicated a Source EUI of 339.5 and a Site EUI of 112.5 (Damron, 2017). A water usage index was not calculated as part of that report.

Even though the values presented for K-State aren't for the same year, if these two buildings are used as a representation of the campus as a whole, then K-State buildings would generally fall in the middle to bottom half percentile amongst other Climate Zone 4 institutions. This indicates that definitive improvements could be realized.

The EPA is considering additional rounds of participation for the HEBI, and is also exploring the possibility of developing a specific Energy Star score for higher education campuses. As campus sustainability and energy efficiency continue to become an increased focus of future potential students, participation in programs such as these will be an important factor to consider. Yet it will require reliable, annual, building-level submetered utility data for the energy audits to be performed and participation to be a possibility, as discussed previously in Chapter 3.

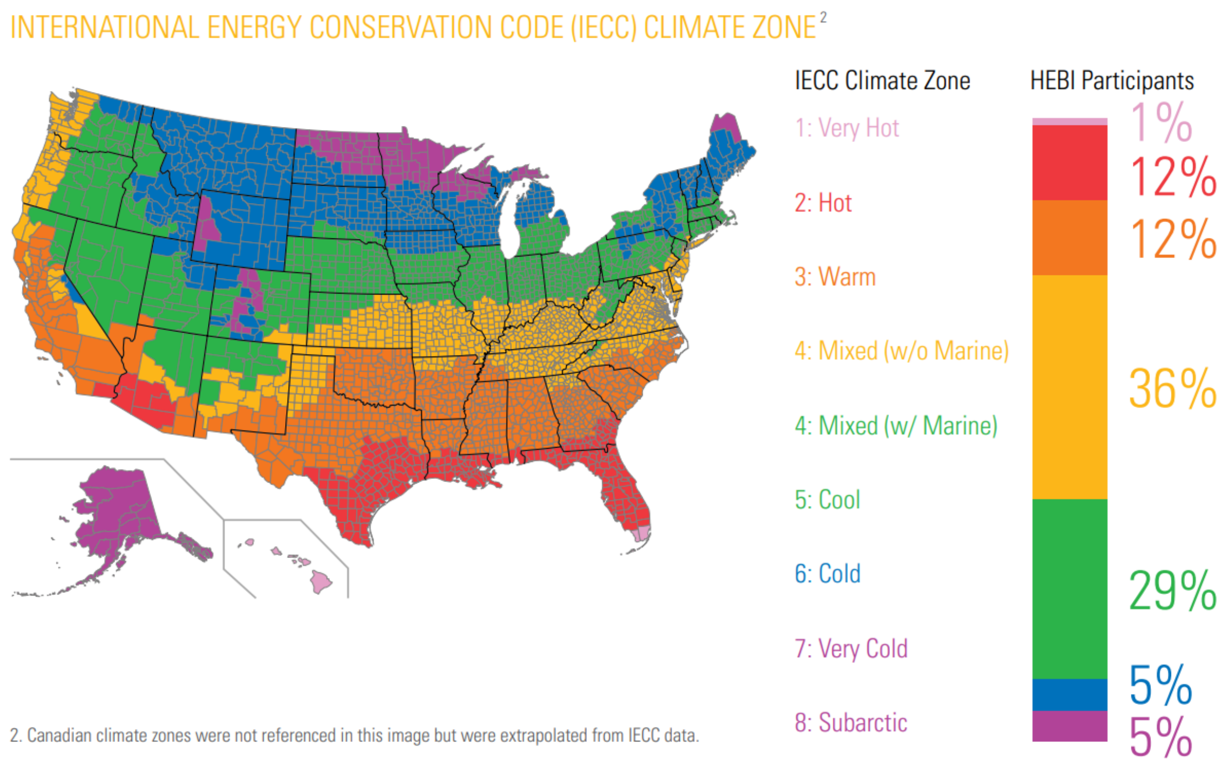

Figure 4.2 Energy Star HEBI Participation Summary by IECC Climate Zone

(Source: Energy Star, 2021a)

IECC CLIMATE ZONE

Category	Peer Group	Source EUI (kBtu/ft^2)						WUI (gal/ft^2)					
		Count (excludes outliers)	Percentile					Count (excludes outliers)	Percentile				
			10th	25th	50th (median)	75th	90th		10th	25th	50th (median)	75th	90th
IECC Climate Zone	1: Very Hot & 2: Hot	20	67.7	95.0	117.2	171.3	210.6	6	15.9	19.1	31.2	47.0	50.6
	3: Warm	20	121.6	139.8	177.4	191.4	253.8	5	8.7	13.8	32.7	34.2	46.9
	4: Mixed	60	72.4	101.6	139.3	193.6	220.0	13	16.2	17.7	23.1	29.1	31.1
	4: Mixed Marine & 5: Cool	50	132.6	144.2	182.9	231.6	266.1	27	8.4	12.6	18.4	24.1	29.9
	6: Cold	9	146.4	153.6	199.2	253.4	279.9	7	15.2	18.3	21.2	24.5	25.0
	7: Very Cold & 8: Subarctic	9	138.7	189.7	202.1	222.3	312.8	3	9.8	14.4	22.1	23.3	24.0

Figure 4.3 Energy Star HEBI Performance Results by IECC Climate Zone

(Source: Energy Star, 2021a)

Chapter 5 - Seaton Hall Case Study

Energy submetering can be a challenging task for individual departments within universities, especially when several departments occupy the same building. This chapter aims to apply submetering to an existing building at Kansas State University.

Kanas State University is a public land-grant research university that is comprised of 65 academic departments in nine colleges that occupy over 120 buildings across 3 campuses. On the main campus in Manhattan, KS, Seaton Hall was selected to identify common issues and solutions that could be applied to several other similar buildings.

5.1 Background

Seaton Hall was originally constructed in 1929, and has since gone through half a dozen additions and renovations, the last being in 2016 when the building expanded and is now formally called Seaton-Regnier Hall. Comprising approximately 380,000 square feet of floor space, it is occupied by 3 colleges and 7 departments. The entire College of Architecture, Planning and Design with its 3 departments are the main tenant, occupying approximately 63% of the building. The College of Arts and Sciences' Geography and Geospatial Sciences department is its sole tenant, occupying approximately 5.6%. The College of Engineering has three departments located there: the entire department of Architectural Engineering & Construction Science (ARE/CNS), the entire department of Biological and Agricultural Engineering (BAE), and a small portion of the Mechanical and Nuclear (MNE) department. In total, the College of Engineering occupies approximately 27.4%. The remaining 4% of the square footage is made up of general University support areas and classrooms. A summary of areas broken down by floor is shown in Table 5.1.

The building is supplied with several campus utilities including electricity, domestic water, natural gas, steam, and chilled water. Natural gas doesn't serve any of the building heating systems, but instead a single emergency generator and some small laboratories. According to the University's Campus Energy Manager, the eventual plan is that each college's utilities will be submetered such that the allocated costs can be directly billed to better reflect the latest campus budget model (Weishaar, 2022). Currently, only building-level meters exist, and each college is billed a portion of the entire building's utility usage. This portion is based on a ratio of the college's square footage compared to building as a whole. Any non-revenue generating spaces are added on based on this same ratio (Weishaar, 2022).

Table 5.1 Seaton Hall Space Summary

College/Unit	Basement	1st Floor	2nd Floor	3rd Floor/Roof	Total
Architecture	59,955	71,888	75,297	32,141	239,281
Arts & Science	2,235	12,087	673	6,245	21,240
Engineering	41,838	30,527	30,658	790	103,813
General	9,273	5,297	518	0	15,088
Totals	113,301	119,799	107,146	39,176	379,422

This seems to be the most appropriate way to divide costs, given the level of metering that exists for the building. However, for departments such as Geography and ARE/CNS that have a lower EUI profile due to not having energy intensive research laboratories like BAE, or large quantities of college-specific resources like Architecture, the utility bills could be skewed higher than their actual usage. This inequity would be solved with the plan of submetering the building at the college and/or department level.

The next issue that must then be addressed is how each college effectively divides its utility bill across its multiple departments. In the case of the College of Engineering and the new university budget model, a department that offers a higher ratio of total revenue compared to its energy use could be negatively impacted. A case could be made that submetering down to the department level could prove to be the best metric.

Since the building is occupied by three separate colleges, and given its age and complex infrastructure over the years, completing the task of submetering utilities by college is complicated. It also has implications for each college as well. For example, the College of Engineering has large areas of energy intensive research labs and support areas, which likely have a much larger EUI then other colleges like Arts and Sciences. If the utility bills start to be allocated based on actual energy use and not a ratio of square footage, then the bill amounts could change drastically from what a college may currently estimate in their annual budget.

If a college were then to apply the same square footage ratio logic to each individual department to effectively chargeback their utility bills, this could adversely affect individual departments who’s EUI is less than the remainder of the college, such as the ARE/CNS department. This scenario lends to examining the ARE/CNS department to serve as a good candidate for assessing the viability of submetering energy use at the department level.

5.2 Submetering Application

The Department of Architectural Engineering and Construction Science is located on the 2nd floor of Seaton Hall, as identified in the space allocation floor plans in Appendix B. It comprises approximately 30,660 square feet of space, made up entirely of offices, classrooms, computer labs, and storage space. The primary utilities utilized are electricity, steam heating, and domestic water. There is limited chilled and heating water serving the center drafting wing and offices. Natural gas is currently not utilized for that portion of the building, and there are no imminent plans to add it, so it was not factored into this study.

A room-level walkthrough survey was performed which identified two (2) areas of plumbing where domestic water submeters would need to be added, two (2) areas where steam submeters would need to be added, (1) area where chilled and heating water submeters would need to be added, and six (6) areas where electrical submeters would need to be added. The electrical submeters would serve a total of seven (7) panelboards and one (1) main distribution panel.

Domestic Water Submetering

There are two main areas of the department that utilize domestic water, the north and center wings. The north wing has a single user restroom, a janitor closet with mop sink and storage tank water heater, an electric water cooler, and a faculty/staff breakroom which has a kitchen sink and two single user restrooms. The center wing has a men's restroom containing three lavatories, three urinals, and one water closet, a women's restroom containing two lavatories and one water closet, as well as a dual-station electric water cooler.

Given the piping arrangement of the two areas, a total of 3 nutating-disk type water meters would be required to effectively submeter the water usage. One meter would be located on the cold-water line in room S2034 before it splits off to serve the water heater. The other two meters would be located on the hot and cold-water mains respectively that serve the center wing plumbing fixtures. Access to the piping chase in room S2056 would be needed to install these two water meters.

The estimated cost to furnish and install these meters would be $1,200. This is based on the 2020 RS Means Building Costs and adjusted to today's dollars for historical inflation rates. The metered data would then need to be communicated to the building's BAS system for totalizing.

Steam Submetering

There are two main areas of the department that utilize steam heating. The west exterior offices and classrooms utilize steam radiators, as does one air handling unit that utilizes two steam air coils to serve some center wing faculty offices.

One steam meter could be installed in the condensate return line that serves the west exterior spaces. The steam condensate return line is preferred to the supply line by the university's Facilities team for the meter location (Weishaar, 2022). This would be installed in the first-floor ceiling plenum below since that is where the piping main runs are routed. The other steam meter could be installed in the condensate return line located in room S2059 which is a mechanical/electrical room where the two steam heating coils are located for the center offices.

The estimated cost to install these two steam meters would be $5,200. This is based on the 2020 RS Means Building Costs and adjusted to today's dollars for historical inflation rates. The metered data would then need to be communicated to the building's BAS system for totalizing.

Chilled/Heating Water Submetering

There is one small area of the department that utilizes chilled and heating water systems, which is the center drafting wing containing classrooms and faculty offices. The water lines serve several floor mounted fan coil units with cooling and heating coils. Based on preliminary field inspections, the use of ultrasonic flow meters could be utilized on the existing piping. In addition to the flow meters, a BTU station as discussed in Chapter 2 could be utilized to fully capture the energy usage.

The estimated cost to furnish and install these meters would be $2,800. This is based on the 2020 RS Means Building Costs and adjusted to today's dollars for historical inflation rates and manufacturer data searches. The metered data would then need to be communicated to the building's BAS system for totalizing.

Electrical Submetering

The electrical utility presents the largest challenge to submeter due to it supplying the largest energy demand of all the utilities and also due to the complex combination of infrastructure renovations that have occurred over time. The 7 panelboards requiring submeters are identified and located as indicated below. There is also one main distribution panel, MDP-1, located in room S1026A, that also serves several HVAC rooftop units for the department that would need to be submetered. Refer to the drawings in Appendix B for more information on room names and locations.

- Panel 2H1 (277/480V, 3 phase, 4 wire, 250-amp, 30 pole) is located in room S2032 and serves lighting loads, one HVAC unit load, and Panel 2L1.
- Panel 2L1 (120/208V, 3 phase, 4 wire, 150-amp, 84 pole 2-section) is located in room S2032 and serves receptacle loads, plumbing fixtures including water heating, and very limited lighting loads.
- Panel 2L3 (120/208V, 3 phase, 4 wire, 400-amp, 42 pole) is located in room S2017A and serves lighting loads, receptacle loads, and HVAC loads.
- Panel 2L2 (120/208V, 3 phase, 4 wire, 250-amp, 42 pole) is located in room S2059 and serves lighting loads, receptacle loads, and HVAC loads.
- An unidentified panel (120/208V, 1 phase, 3 wire, 100-amp, 12 pole) is located in room S2011A and serves and serves receptacle loads and HVAC loads.

- Panel JJ (120/208V, 3 phase, 4 wire, 100-amp, 20 pole) is located in room SCR2007 and serves lighting loads, receptacle loads, and HVAC loads.
- Panel GL1 (120/208V, 3 phase, 4 wire, 225-amp, 42 pole) is located in room SCR2008 and serves lighting loads, receptacle loads, and HVAC loads.
- Distribution Panel MDP-1 (480V, 3 phase, 4 wire, 1200-amp) is located in room S1026A and serves multiple building loads, including five (5) HVAC rooftop units that condition the department and would need to be submetered.

Given the variety of end uses served by each panel, the desired end result will need to be carefully considered to determine the necessary submeter requirements. If the end goal is simply to determine the utility load used by the department, then only entire panelboard meters would need to be added to all of the above panels except Panel 2L1, since it's load would already be metered by Panel 2H1. However, if the end goal is to submeter the electrical utility by end use to the meet the requirements of ASHRAE 90.1-2019 or the 2021 IECC as discussed earlier, then the amount of submetering work needed would be substantially more. For the purposes of this study, submetering by end use per the energy code requirements has been considered. A series of meters including multi-point meters will be utilized, as outlined in the Second Floor Department Submetering Plan from Appendix B. The data can then also be used for future teaching purposes and research projects within the department.

In order to install an integral panelboard meter or external multi-point meter, there typically has to exist an open 3-pole section of the panel that represents each phase of power. The meter utilizes these three poles to install a circuit breaker that not only provides power for the meter to operate, but also lets it calibrate and sense each phase voltage properly (Clements, 2020). For this case study, a problem presents itself in that not every existing panel has 3 adjacent poles of space available. Panels 2L3, JJ, GL1, and the unidentified panel do not have the available space. It could be possible that the existing panel loads could be re-circuited to allow for 3 poles of space, and that would need to be verified by a licensed electrician. For the purposes of this report, it will be assumed that the panel loads can be recircuited as needed.

In regards to the types of loads being submetered, it would not always be necessary to meter every circuit in the panel. Good examples of this are Panel 2L1 that has very limited water heating loads, and Panel 2L3 that consists mainly of receptacle and lighting loads, with only one HVAC load on the panel. In these instances, it could be economical to meter the entire panel load, but then only provide an external multi-point meter for the non-majority types of loads. This could reduce overall cost and labor, but adversely require 6 poles of space to power multiple meters.

The ARE/CNS department has a planned major renovation to begin sometime in 2023. Part of the renovation consists of demolishing the existing spaces served by Panels JJ and the unidentified panel. Given the age of these panels, and the fact they would need to be relocated and wiring extended, it would be beneficial to the department to plan to remove these panels and provide a single new panelboard with integral branch circuit metering. In addition, Panel GL1 could also be considered for replacement due to its age, location in a public corridor, and the extensive recircuiting that will be done for the renovation. However, for the purposes of this study, the scope of work to submeter these existing panels was still included in the analysis.

The estimated cost to install all of the electric meters likely needed would be $16,750. This is based on the 2020 RSMeans Building Costs and adjusted to today's dollars for historical inflation rates and manufacturer data searches. The metered data would then need to be communicated to the building's BAS system for totalizing.

Cost Feasibility

For the purposes of analyzing cost feasibility, a simple payback period can be considered. The total cost for all of the meters discussed prior is approximately $25,950. In order to calculate a simple payback, the estimated utility cost savings from the addition of the submeters needs to be established. Table 5.2 provides a summary of the approximate utility cost data for 2020 for the entire building based on information provided by the Facilities department (KSU Facilities, 2021). The department occupies approximately 8.1% of the total building area. Using that same percentage of the total building utility cost, the annual utility bill for the department could be estimated to be $37,640.

Table 5.2 Seaton Hall Utility Cost Summary

Utility	2020 Usage Total	Units	Cost per Unit	Total Cost
Electric	2878659.2	KWh	$0.0844	$242,958.84
Steam	8548.25	MMBTU	$8.1300	$69,497.27
Chilled Water	13033.1	MMBTU	$11.3100	$147,404.36
Water	865	CCF	$2.4630	$2,131.42
Sewer	865	CCF	$4.3900	$3,798.99
Natural Gas	--	MCF	$3.9100	--

The final component needed is an approximate savings in energy usage that can be expected from installing the submeters. Based on the case studies established in Chapter 2, the department could realistically see a reduction of approximately 10% in annual energy use. This results in an annual savings of $3,764, and a simple payback period of 6.9 years. Given the long-term nature of a university's operation, coupled with the planned renovation, this appears to be a reasonable payback period.

5.3 Future Recommendations

When looking at the application of submeters, there must be a coordinated effort and timeline to guarantee results. Specific to this case study, as mentioned previously the ARE/CNS department is planning on undergoing a major renovation in the summer of 2023 that will upgrade and replace much of the building system infrastructure. This will include items such as replacing the existing HVAC systems, upgrading aging electrical systems, and replacing decades-old plumbing fixtures with modern ones that provide better water conservation.

In order to serve as an effective demonstration of potential savings and more accurately analyze life-cycle cost paybacks, it would be recommended that temporary meters be installed 12 months prior to the start of renovation, at a minimum on the electrical system. The department has several panelboard meters already in its possession that can be used for this stage in order to limit costs. This would help determine a baseline usage that can then be analyzed and compared to the future values provided by the permanent energy submetering system installed during the renovation. This comparison of data before and after can help quantify the payback period, and serve as a road map for expanded energy use reduction initiatives for future departments and projects across the university. It would also be a great asset to the department itself to use in future research projects and as a teaching tool in its courses.

Chapter 6 - Conclusions

Today there exist several benefits, uses, and requirements for building energy submetering. Regardless of the utility or method considered for metering, there are now more options and paths to compliance than when the concept was first being introduced. With additional methods and technologies continuing to be developed, it will continue to become more cost effective to implement submetering. Since electricity typically accounts for 80% of total building energy costs, and because this is the main utility expected to increase in consumption in the future, it will become imperative for building operators to seek ways to monitor and decrease their usage of electrical power. Fortunately, the decreasing costs in electrical submetering will allow more building owners to implement metering below the building level to achieve these usage reductions.

For universities, this sub-building level metering can also help campus staff allocate energy costs equitably between individual colleges and departments. Additionally, being able to compare annual building energy consumption to national and/or similar climate datasets with similar building types through benchmarking programs can help identify under-performing buildings in need of additional energy improvements. These improvements can be part of a coordinated marketing effort for the university, and can even serve as an aid in certain teaching environments.

However, as building energy and system-level monitoring becomes more common, facility teams will be faced with an overwhelming amount of data. This data does not typically lead to insights, corrective efficiency measures, and energy savings unless it is stored, organized, analyzed, and prioritized in automated ways. Additionally, being able to process and display the information to regular building occupants will provide additional behavioral changes that will lead to even more energy savings.

Implementing submetering into commercial buildings, specifically college and university campuses, is more feasible today than ever before. Yet as typically referred to by facility managers, you can't manage what you can't measure, and you can't improve what you can't manage. With that sentiment in mind, submetering will be a critical component for reaching reduced emission targets and building decarbonization goals in the coming decades. Thoughtful planning and improvement-oriented budgeting should be incorporated into every campus's energy management plans and goals so that the long-term cost saving benefits can be fully realized.

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Appendix A - Sample University Course Materials

This appendix outlines the course materials created for a potential future course offering on the topics of building energy performance, submetering, audits, and benchmarking. It contains a course outline, schedule, and syllabus. The course will comprise of up to ten weekly sessions of in-class instruction building a foundation of knowledge, followed by five weeks of field work in a real commercial building with students performing the assessment tasks discussed during the first ten weeks.

Course Outline

The following describes the first ten weeks of the course in detail. Each week contains learning objectives, delivery format, student preparation, and assignments. This outline is modified from the available framework provided by the partnering organization for this course, ASHRAE.

- Week 1 – Course Introduction
    - Learning Objectives:
        - Describe the syllabus for the course, including the course prerequisites and expectations
        - Recognize the instructional team, including instructor, professional mentors, and building client, and understand the role of the team members
        - Discuss the reason for using the Building EQ program as a course framework
        - Describe global and U.S. energy consumption characteristics and the role of commercial and residential buildings
        - Explain the building energy end use consumption characteristics

- Delivery:
    - Lecture slides for course introduction and building energy characteristics
- Student Preparation:
    - Explore websites of the U.S. Energy Information Administration
- Assignment:
    - None

- Week 2 – Review of building mechanical/electrical systems
    - Learning Objectives:
        - Describe the framework of typical HVAC systems in commercial buildings
        - Identify typical primary and secondary HVAC equipment and their role in meeting system requirements
        - Explain the basics of electrical distribution systems and their equipment in commercial buildings
        - Explain the basics of lighting systems in buildings, including performance terminology, lighting technologies, energy performance, and the role of daylighting
    - Delivery:
        - Lecture slides on building mechanical, electrical, and lighting systems
    - Student Preparation:
        - TBD
    - Assignment:

    - Homework to describe the mechanical and electrical system design of a building, possibly the semester project building

- Week 3 – Introduction to Building Energy Benchmarking and Assessment
  - Learning Objectives:
    - Discuss the differences between benchmarking, labeling programs, and energy auditing
    - Identify and understand the metrics used to benchmark building performance
    - Explain the role of building type and climate zone on energy use
    - Explain the ASHRAE Building EQ ‘As Designed’ and ‘In Operation’ ratings
  - Delivery:
    - Lecture slides on benchmarking and the Building EQ program
    - Preliminary field trip to expose students to building features
  - Student Preparation:
    - Building EQ example and case study
    - Articles about U.S. and other international programs
  - Assignment:
    - Homework to explore benchmarking tools, such as Portfolio Manager and Building Performance Database
- Week 4 – Preliminary Energy Use Analysis (PEA)
  - Learning Objectives:
    - Analyze utility rate schedules and energy billing data

        - Compare energy performance of similar buildings
        - Develop appropriate energy target requirements
    - Delivery:
        - Lecture slides on preliminary energy use analysis
        - Conduct in-class case study by applying PEA to sample building
    - Student Preparation:
        - Procedures for Commercial Building Energy Audits Part 1 and select readings
    - Assignment:
        - Perform PEA for sample building
        - Compare performance with at least two databases for benchmarking (could be in-class exercise)
- Week 5 – Measuring and Monitoring Building Performance
    - Learning Objectives:
        - Identify instrumentation for measuring indoor environmental quality and building energy
        - Perform measurements of indoor environmental quality and building energy
        - Discuss accuracy of building measurements
    - Delivery:
        - Lecture slides on building measurements and monitoring
        - In-class demonstration of instrumentation
    - Student Preparation:

        - Performance Measurement Protocols for Commercial Buildings: Best Practices Guide, Ch. 1-2
    - Assignment:
        - Hands-on exercise of building measurements, including airflow rate, environmental temperature and humidity, electrical power, and lighting levels
- Week 6 – Walk Through Analysis
    - Learning Objectives:
        - Identify the components of an ASHRAE Level 1 walk through survey and the differences between Level 1, 2, and 3 surveys
        - Conduct an interview of the building owner/operator
        - Validate a space function analysis
        - Identify low-cost/no cost opportunities for improvements to the facility or O&M procedures
        - Identify potential capital improvement projects for further study
    - Delivery:
        - Lecture slides on walk through analysis
        - Preliminary walk through of sample building site with instructor and/or building client
    - Student Preparation:
        - Case studies of audit processes
    - Assignment:
        - Develop template for interview with building client

- Week 7 – Indoor Environmental Quality (IEQ)
    - Learning Objectives:
        - Describe the role of HVAC systems in maintaining indoor environmental quality
        - Apply ASHRAE Standard 55 to evaluate thermal comfort in a commercial building
        - Apply ASHRAE Standard 62.1 to evaluate indoor air quality in a commercial building
        - Explain the role of lighting and acoustic systems in maintaining indoor environmental quality
    - Delivery:
        - Lecture slides on indoor environmental quality
        - Field measurements in sample building to evaluate indoor environmental quality
    - Student Preparation:
        - Performance Measurement Protocols for Commercial Buildings: Best Practices Guide, Ch. 1-2
        - Articles about Standards 55 and 62.1
    - Assignment:
        - Prepare checklist for site visit
- Week 8 – Engineering Efficiency Measures – Engineering Calculations
    - Learning Objectives:

        - Explain the process of identifying energy efficiency measures within the ASHRAE commercial building energy audit classification
        - Calculate power and energy consumption for simple equipment
    - Delivery:
        - Lecture slides on engineering calculations for evaluating energy efficiency measures
    - Student Preparation:
        - TBD
    - Assignment:
        - Homework problems involving energy calculations and life cycle cost calculations
- Week 9 – Engineering Efficiency Measures – Opportunities and Impacts
    - Learning Objectives:
        - Demonstrate the role of envelope characteristics, HVAC systems, and lighting systems on building energy use
        - Identify low-cost and no-cost energy efficiency measures
        - Identify common EEM opportunities for systems and explain their impacts
    - Delivery:
        - Lecture slides on the opportunities and impacts of common energy efficiency measures
    - Student Preparation:
        - Procedures for Commercial Building Energy Audits pp. 59-72
        - DOE Advanced Energy Retrofit Guides

    - Assignment:
        - Homework assignments to calculate energy savings and economic feasibility of EEM retrofits
- Week 10 – Reporting
    - Learning Objectives:
        - Prepare an energy audit report for the building client
        - Conduct a post-audit interview with building client
        - Describe concepts of branding for small building energy assessment firms
    - Delivery:
        - Lecture slides on reporting for energy analysis and benchmarking
    - Student Preparation:
        - PCBEA pp. 78-89
        - ASHRAE Building EQ website
    - Assignment:
        - Submittal of Level 1 Energy Audit
- Weeks 11-15 – Field Performance
    - These weeks are spent with hands-on training and application performing some of the tasks identified throughout Weeks 1-10. These weeks will require specific preparation each semester for the building being used working with the building owner. In general, two weeks are spent on mechanical systems, two weeks are spent on electrical systems, and the final week is spent on developing and submitting an ‘In-Operation’ building rating and semester debriefings with both the Instructor and the building owner.

Course Schedule

ARE 715 Benchmarking and Assessment of Building Energy Performance - Schedule

Semester Offering TBD

Date	Class Period	Day of Week	Topic
			Week 1 - In the Classroom
--	1	T	Course Introduction
--	2	U	Building EQ
			Week 2 - In the Classroom
--	3	T	Review of Building Mechanical Systems
--	4	U	Review of Building Electrical Systems
			Week 3 - In the Classroom
--	5	T	Energy Benchmarking
--	6	U	Energy Assessment
			Week 4 - In the Classroom
--	7	T	Preliminary Energy Use Analysis
--	8	U	Preliminary Energy Use Analysis
			Week 5 - In the Classroom
--	9	T	Measuring Building Performance
--	10	U	Monitoring Building Performance
			Week 6 - In the Classroom
--	11	T	Walk Through Analysis
--	12	U	Perform Walk Through Analysis with Building Owner
			Week 7 - In the Classroom
--	13	T	Indoor Environmental Quality (IEQ) - Thermal
--	14	U	Indoor Environmental Quality (IEQ) - Air Quality/Acoustics
			Week 8 - In the Classroom
--	NA	T	Energy Efficiency Measures (EEMs) - Calculations
--	NA	U	Financial Performance Analysis
			Week 9 - In the Classroom
--	15	T	EEMs - Opportunity and Impact (Mechanical)
--	16	U	EEMs - Opportunity and Impact (Electrical)
			Week 10 - In the Classroom
--	17	T	Reporting Energy Audits
--	18	U	Submit Energy Audit for Semester Building
			Week 11 - In the Field
--	19	T	Performing Assessment Tasks - Mechanical
--	20	U	Performing Assessment Tasks - Mechanical

	Week 12 - In the Field		
--	21	T	Performing Assessment Tasks - Mechanical
--	22	U	Performing Assessment Tasks - Mechanical
	Week 13 - In the Field		
--	23	T	Performing Assessment Tasks - Electrical
--	24	U	Performing Assessment Tasks - Electrical
	Week 14 - In the Field		
--	25	T	Performing Assessment Tasks - Electrical
--	26	U	Performing Assessment Tasks - Electrical
	Break (move up in semester for Spring Break)		
--	27	T	Holiday - Thanksgiving Break or Spring Break
--	28	U	Holiday – Thanksgiving Break or Spring Break
	Week 15 - In the Field		
--	29	T	Closeout Meeting with Building Owner
--	30	U	Closeout Meeting with Instructor
	Finals Week		
	TBD - Submit Building EQ rating for Semester Building		

Course Syllabus

ARE715 Topics in ARE –

Benchmarking and Assessment of Building Energy Performance

Semester 20xx

T/U 3:55-5:10pm Seaton ####

Instructors: Name, PE and/or BEAP

Office: Seaton ####

Office Hours: As posted, or by appointment

E-mail: ######@k-state.edu

Phone No.: (###) ###-####

Course Description

An introduction and study of building energy assessment principles and protocols for existing commercial buildings. Course topics include hands-on techniques of energy measurement and verification, IEQ identification and measurement, energy unit comparison and analysis, and energy auditing, applied in the context of a building rating program. *Prereq: ARE561, ARE562 and on sufficient demand.*

Student Learning Outcomes

Upon completion of the course, students will have the ability to assess the energy performance of an existing building, using industry-standard methods, by applying their knowledge of thermal sciences and building mechanical/electrical systems. The course will build a foundation of knowledge regarding building energy assessment and the application of building rating programs through hands-on exploration in real buildings under the guidance of practicing professionals. Outcomes of the course include:

- Conduct an ASHRAE Level 1 energy audit for the building provided in the class
- Produce an ASHRAE Building EQ 'In Operation' rating for the building provided in the class
- Produce a listing of potential Energy Efficiency Measures (EEMs) including economic feasibility analysis
- Perform measurements of indoor environmental quality and HVAC system performance

- Identify different building types and determine the impact of climate on energy use
- Analyze raw energy consumption data from measured-meter readings
- Understand energy metrics and how they are developed and applied
- Understand the process of certifying professionals in energy assessment

Required Materials

Department Provided Text ($10 semester loan fee, payable to NEGDRESFEE):

ASHRAE Procedures for Commercial Building Energy Audits, 2nd edition

All other reference materials needed will be provided via Canvas.

Because of the hands-on aspect of the course, minimum personal protective equipment (PPE) may be required. This includes department hardhat, high-visibility vest (provided), eye protection (provided), and closed-toe shoes. Additional measurement and verification tools will be provided by the Department and campus Facilities group.

Evaluation

Grade Scale:		**Evaluation Values**:	
A	900-1000 points	Homework Assignments	650 points
B	800-899 points	Building Energy Audit	100 points
C	700-799 points	Building EQ Submission	100 points
D	600-699 points	Owner Meetings	100 points
F	< 600 points	Attendance/Participation	50 points

Homework Assignments: Frequent homework and quizzes will be given over each week's covered material. All quizzes and homework assignments are due at the time and date listed for the assignment. Any assignment turned in after the due date and time will be considered late. Late assignment will be accepted up to 24 hours after its due date with a 50% reduction in grade. No assignment will be accepted after that time unless prior arrangements have been made with the instructor.

Building Energy Audit: You will have the opportunity to perform an ASHRAE Level 1 Audit on a selected building on campus that is 'in-operation'. The course setup builds towards the submission of this audit after the first 10 weeks of class.

<u>Building EQ Submission</u>: You will also have the opportunity to provide a Building EQ submittal through ASHRAE's building portal. The course setup builds towards the submission of this rating after performing 5 weeks on hands-on application in the field. This submission serves as the course capstone assignment.

<u>Owner Meetings</u>: You will have the opportunity to prepare for and execute three separate meetings with the building owner throughout the course. These meetings are professional in nature and provide you the opportunity to document your progress and understanding of knowledge.

<u>Attendance / Participation</u>: Punctuality, class attendance and participation are reflections of your professionalism. Unavoidable absences must be reported to the instructor or the department office prior to the absence. If a student has a medical or family emergency that prohibits you from attending class, you must contact the Office of Student Life and they will then notify all of your instructors.

<u>Disclaimer</u>: The instructor reserves the right to modify and/or added to this syllabus as necessary.

Appendix B - Seaton Hall Floor Plans

This appendix includes the building floor plans for Seaton Hall at Kansas State University that was the focus of the case study in Chapter 5. There are 6 plans in total:

- Basement Floor Space Allocation Plan
- First Floor Space Allocation Plan
- Second Floor Space Allocation Plan
- Third Floor Space Allocation Plan
- Roof Plan
- Second Floor Department Submetering Plan

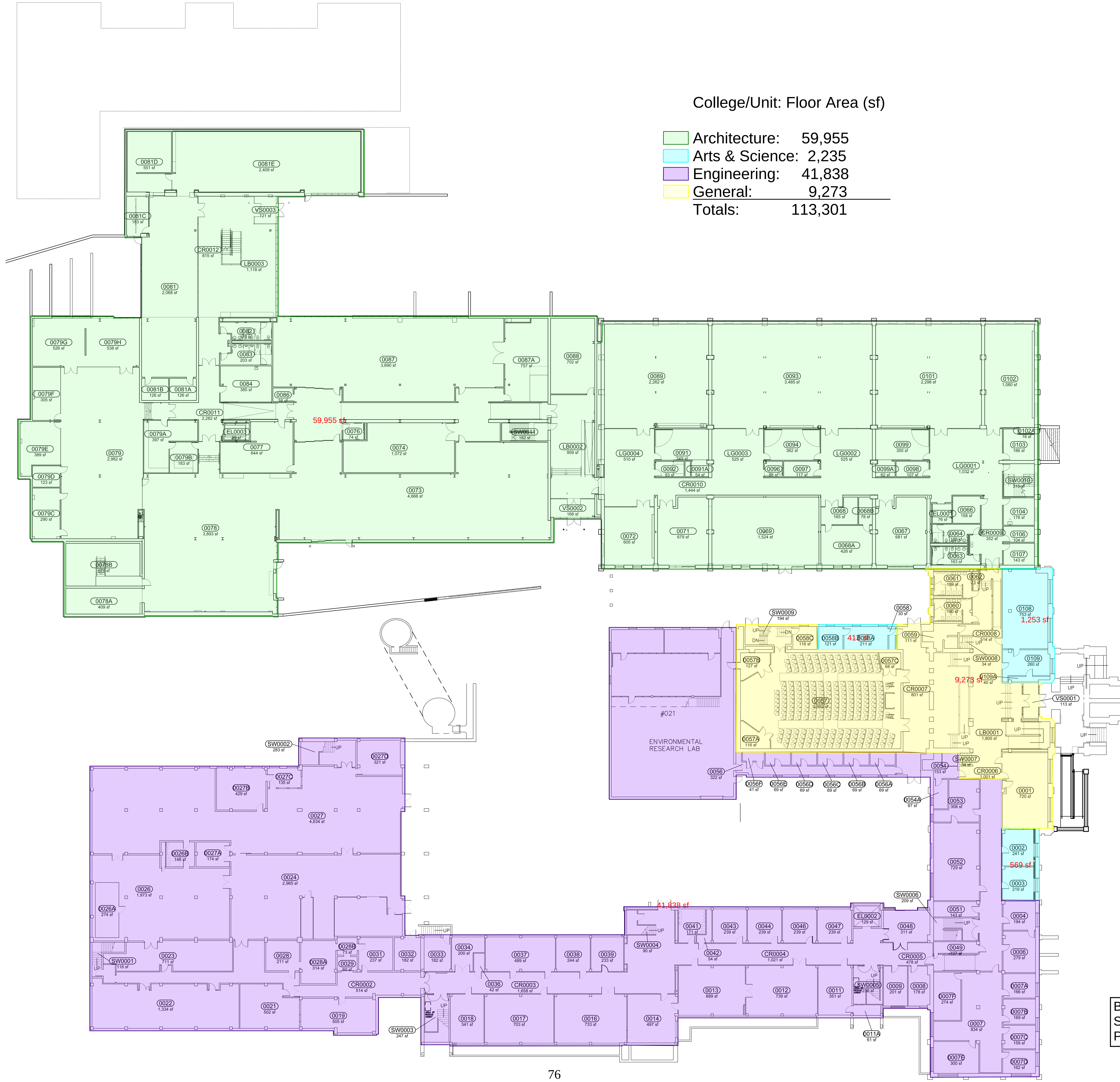
The plans have been highlighted with different shading colors to represent which College occupies the space. Color legend is as follows:

- College of Architecture – light green
- College of Arts and Sciences – light blue
- College of Engineering – light purple
- General University Support Space – light yellow

Additionally, the Department of Architectural Engineering and Construction Science, which was the focus of implementing a submetering plan, has an additional floor plan provided indicating the locations of proposed energy and water meters and their types.

College/Unit: Floor Area (sf)

Architecture:	59,955
Arts & Science:	2,235
Engineering:	41,838
General:	9,273
Totals:	113,301



BASEMENT FLOOR
SPACE ALLOCATION
PLAN - APPENDIX B

SEATON / REGNIER HALL

BASEMENT

BUILDING ABBREVIATION: S
BUILDING NUMBER: 00102
GSF: 372448
BUILT / RENOVATED: 1922, 1959, 1966, 1989, 2000, 2016
UPDATED: 2/12/2013
FILE NAME: 00102-SEATON-BASEMENT.DWG

KANSAS STATE UNIVERSITY

PLANNING & FACILITIES MANAGEMENT
DYKSTRA HALL
MANHATTAN, KS. 66506
785.532.6377

College/Unit: Floor Area (sf)

Architecture:	71,888
Arts & Science:	12,087
Engineering:	30,527
General:	5,297
Totals:	119,799

FIRST FLOOR
SPACE ALLOCATION
PLAN - APPENDIX B

SEATON / REGNIER HALL

FIRST

BUILDING ABBREVIATION: S	BUILDING NUMBER: 00102
GSF: 372448	BUILT / RENOVATED: 1922, 1959, 1966, 1989, 2000, 2016
UPDATED: 2/12/2013	FILE NAME: 00102-SEATON-1ST.DWG

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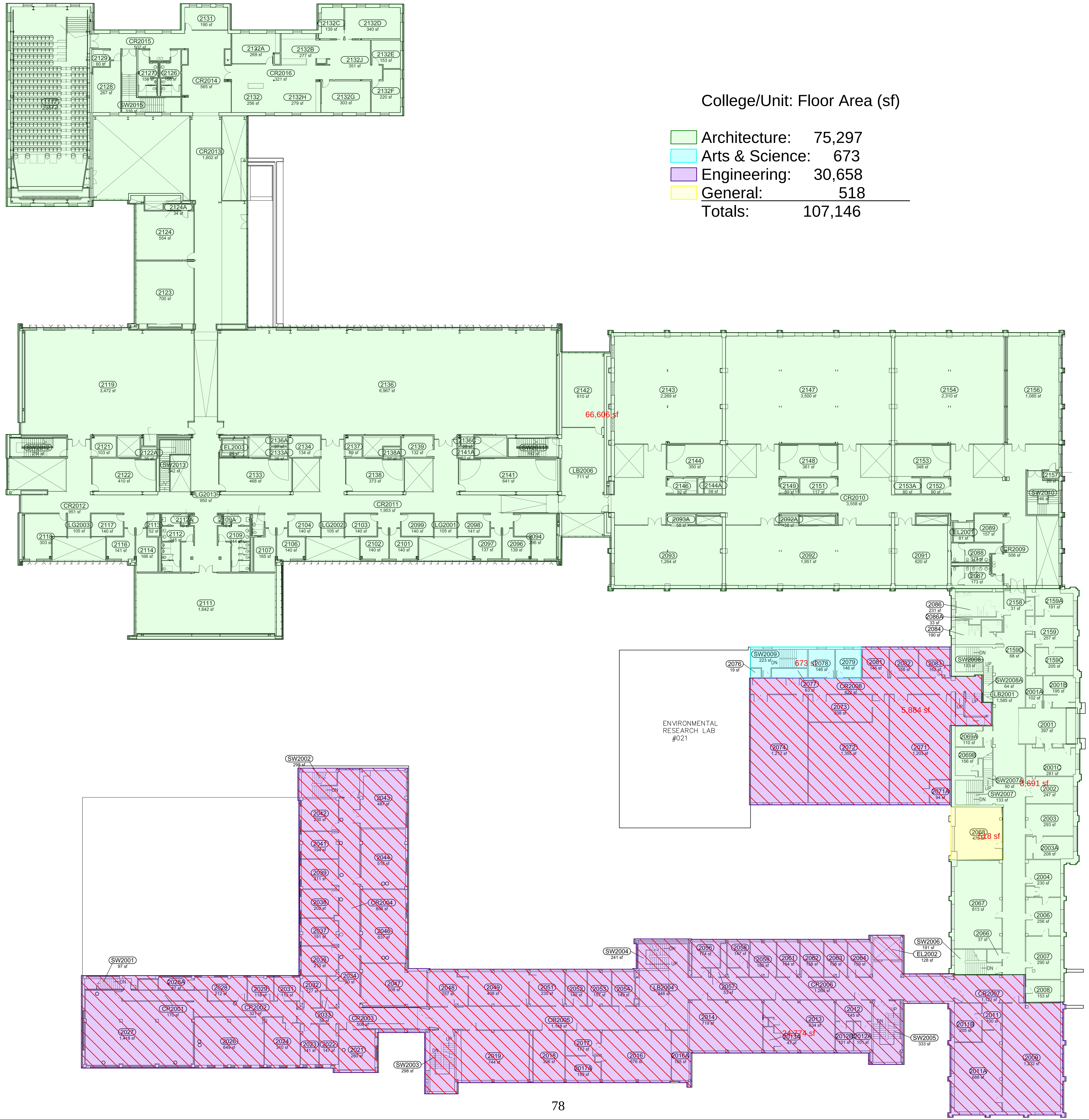
MANHATTAN, KS. 66506
785.532.6377



College/Unit: Floor Area (sf)

Architecture:	75,297
Arts & Science:	673
Engineering:	30,658
General:	518
Totals:	107,146

SECOND FLOOR SPACE ALLOCATION PLAN - APPENDIX B

3/64" = 1' -0"

SEATON / REGNIER HALL

SECOND

BUILDING ABBREVIATION: S	BUILDING NUMBER: 00102
GSF: 372448	BUILT / RENOVATED: 1922, 1959, 1966, 1989, 2000, 2016
UPDATED: 2/12/2013	FILE NAME: 00102-SEATON-2ND.DWG

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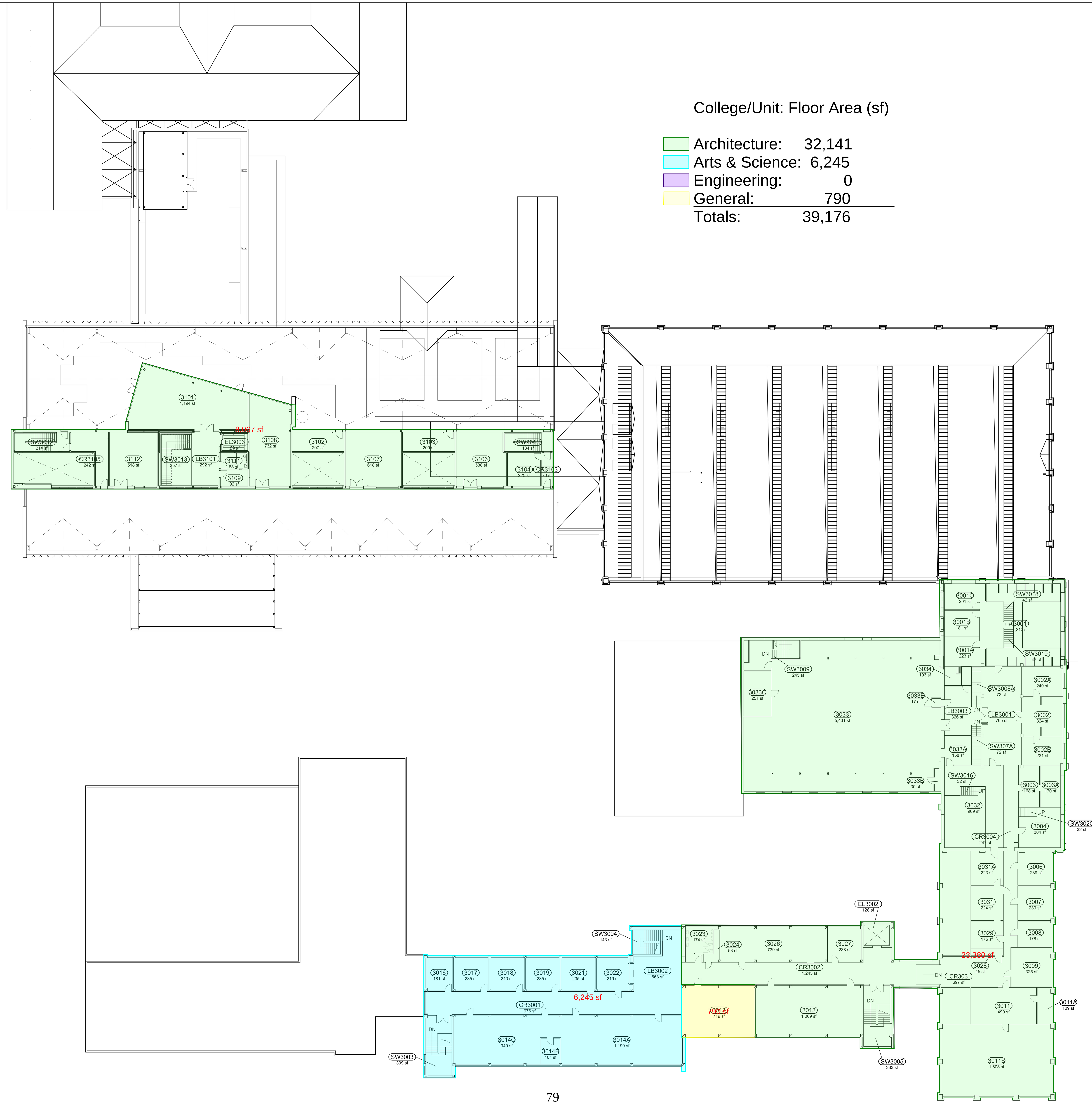
College/Unit: Floor Area (sf)

Architecture:	32,141
Arts & Science:	6,245
Engineering:	0
General:	790
Totals:	39,176



THIRD FLOOR
SPACE ALLOCATION
PLAN - APPENDIX B

SEATON / REGNIER HALL

THIRD

BUILDING ABBREVIATION: S

BUILDING NUMBER: 00102

GSF: 372448

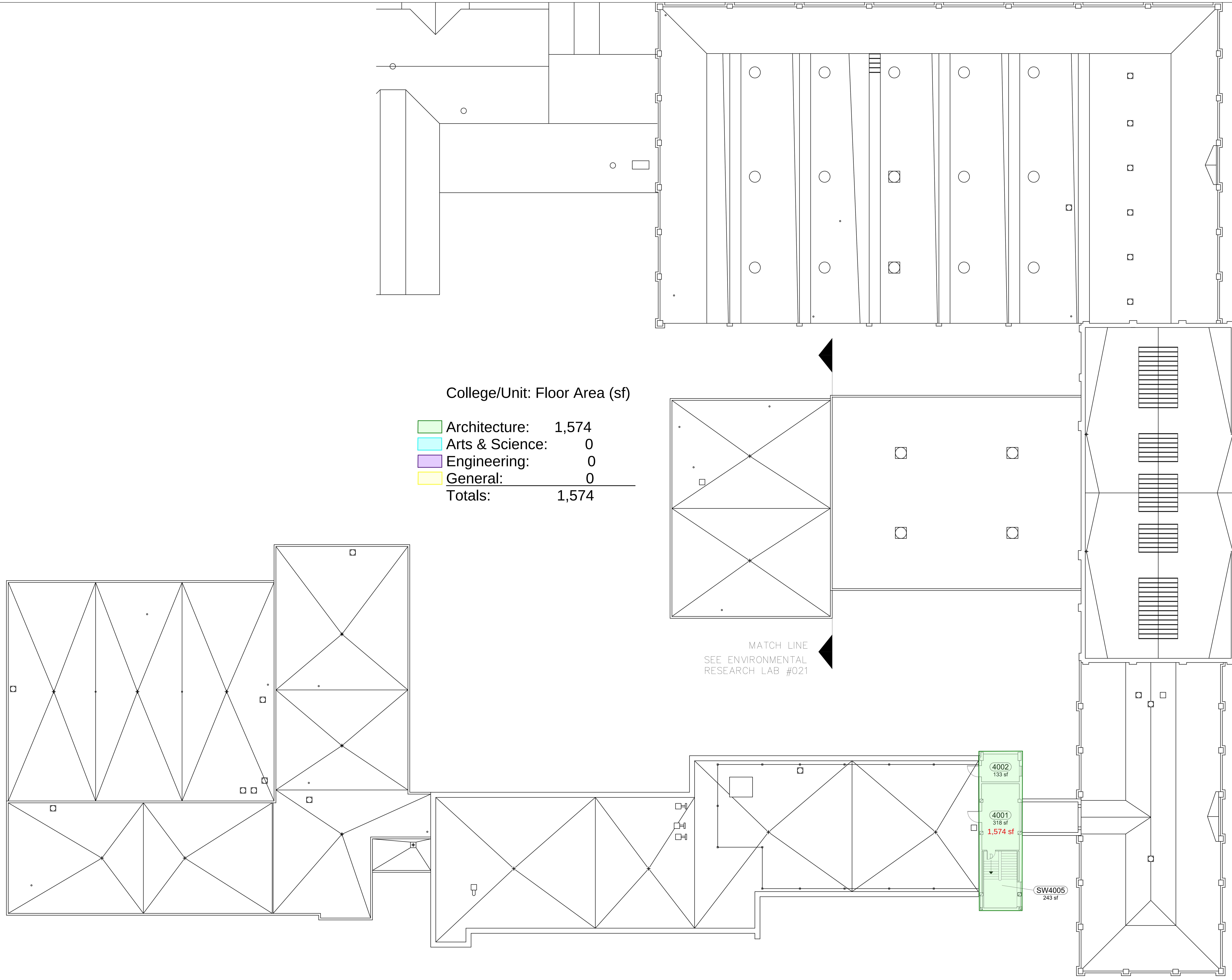
BUILT / RENOVATED: 1922, 1959, 1966, 1989, 2000, 2016

UPDATED: 2/12/2013

FILE NAME: 00102-SEATON-3RD.DWG

KANSAS STATE UNIVERSITY

PLANNING & FACILITIES MANAGEMENT
DYKSTRA HALL
MANHATTAN, KS. 66506
785.532.6377



ROOF SPACE ALLOCATION PLAN - APPENDIX B

1/16" = 1'-0"

DURLAND/RATHBONE/
FIEDLER/ENGINEERING HALL

THIRD

BUILDING ABBREVIATION: DU *	BUILDING NUMBER: 00153
GSF: 255225	BUILT / RENOVATED: 1976, 1984, 1999, 2000
UPDATED: 6/26/2012	FILE NAME: 00102-SEATON-4TH.DWG

KANSAS STATE UNIVERSITY

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785.532.6377


PROVIDE MULTI-POINT CIRCUIT METER FOR LIGHTING/ RECEPTACLE/ HVAC CIRCUITS FOR PANEL GL1 IN SCR2008
MATCH LINE SEE ERL 021
ENVIRONMENTAL RESEARCH LAB #021
5,884 sf
PROVIDE ULTRASONIC FLOW METERS FOR CHILLED AND HEATING WATER RETURN LINES SERVING FCU'S IN DRAFTING CLASSROOMS AND OFFICES
PROVIDE FLOW METER FOR STEAM CONDENSATE MAIN SERVING AHU HEATING COILS IN S2059
PROVIDE ENTIRE PANELBOARD METER AND MULTI-POINT CIRCUIT METER FOR LIGHTING/ HVAC CIRCUITS FOR PANEL 2L2 IN S2059
PROVIDE (2) NUTATING DISK FLOW METERS FOR DOMESTIC HOT AND COLD WATER LINES IN S2056
PROVIDE (1) NUTATING DISK FLOW METER FOR DOMESTIC COLD WATER LINE IN S2034
PROVIDE ENTIRE PANELBOARD METER AND CIRCUIT BREAKER METER FOR DOMESTIC WATER HEATER FOR PANEL 2L1 IN S2032
PROVIDE CIRCUIT BREAKER METERS FOR THE (5) HVAC UNITS SERVED OFF THE MDP IN S1026A LOCATED BELOW ON THE FIRST FLOOR.
PROVIDE ENTIRE PANELBOARD METER FOR PANEL 2H1 IN S2032
PROVIDE FLOW METER FOR STEAM CONDENSATE MAIN SERVING WEST PERIMETER RADIATORS, FINAL LOCATION TBD
PROVIDE MULTI-POINT CIRCUIT METER FOR ALL CIRCUITS/LOAD TYPES FOR PANEL 2L3 IN S2017A
24,774 sf
PROVIDE MULTI-POINT CIRCUIT METER FOR LIGHTING/ RECEPTACLE/ HVAC CIRCUITS FOR PANEL JJ IN SCR2007
PROVIDE MULTI-POINT CIRCUIT METER FOR LIGHTING/ RECEPTACLE/ HVAC CIRCUITS FOR UNKNOWN PANEL IN S2011A
SECOND FLOOR DEPARTMENT SUBMETERING PLAN - APPENDIX B
3/64" = 1'-0"
SEATON / REGNIER HALL
SECOND
BUILDING ABBREVIATION: S
BUILDING NUMBER: 00102
GSF: 372448
BUILT / RENOVATED: 1922, 1959, 1966, 1989, 2000, 2016
UPDATED: 2018
KANSAS STATE UNIVERSITY
PLANNING & FACILITIES MANAGEMENT
DYKSTRA HALL
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785.532.6377