SL1-SE16

ENERGY MONITORING FOR SUSTAINABILITY

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WPI

Abstract

This project developed recommendations to the WPI Facilities department on the implementation of building submetering in the context of sustainability. The project analyzed other universities' submetering strategies through three case studies, WPI's current infrastructure via collaboration with Facilities, and the WPI community's desire for the implementation of such a system through a survey of students and staff. An energy monitoring system would enable savings through other projects that would be difficult or impossible without the data provided by an energy monitoring system.

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1 Introduction

The WPI Sustainability Advisory Committee defines sustainability as an "approach for achieving the goals of environmental preservation, social justice, and economic prosperity for all members of society"[41]. In the context of this project, sustainability is defined as energy usage reduction across campus and the environmental and economic benefits thereof.

Overview

A 2008 study by Universidad de Sevilla, Spain and the Building Research Establishment in the UK found that buildings (residential, commercial and industrial) consumed 40% of all the energy generated in the United States that year, and that number was continuing to increase with the overall energy usage of the country, by more than 150% between 1973 and 2004[31]. In addition, the U.S. Department of Energy found in 2012 that nonresidential building energy usage had more than doubled, despite only a 30% increase in the number of buildings between 1979 and 2012[37][38]. This increase is caused by the growing number of electrical systems in modern buildings and serves as key motivation for building operators to seek methods to reduce their energy usage[37].

Worcester Polytechnic Institute (WPI) has a distributed campus with 60 total buildings, all of which use electricity[30]. Over the past year, the university's electricity consumption decreased from an all-time high of about 32 gigawatt-hours (GWh) in 2014 to about 30 GWh in 2015[39]. However, previous WPI Sustainability Reports have shown that the WPI campus drew only 24 GWh in 2009, indicating that even with the past year's reductions there is still a net increase in power usage of nearly 25% over the last six years[39]. With this massive electricity consumption comes several issues, including a significant financial risk due to potential billing errors, responsibility for an increased stress on environmental resources, and the overall high cost of energy use. The environmental and social determinants of these problems mean that WPI has much to gain from continuing to develop its sustainability initiatives.

WPI has been unable to implement significant energy saving measures because Facilities personnel need the appropriate tools, instruments, and monitoring equipment to be able to intelligently limit energy use in the places it is being wasted in order to reduce consumption without impacting university functionality. The university has previously installed 17 smart electricity meters on campus and connected them to the network to solve the energy monitoring problem, but there are still issues in the way the data from the electricity meters are collected.

By using the data from the electricity meters, the active systems in a building can be intelligently adjusted in an effort to decrease energy usage, thereby decreasing the total energy draw of the campus. There is no way to measure the success of these sustainability efforts without being able to measure their effects on energy usage. Unfortunately, the energy monitoring data is not available outside of the facilities department, and even then remains

disorganized and difficult to manage. This makes the data difficult to use for reducing energy consumption. It is important to note that energy monitoring does not directly save money, but as Gerry Hamilton, Director of Energy Facilities Management at Stanford University, put it, "metering is the first step towards dramatic savings"[18].

Project Statement

The purpose of this project was to perform an analysis of the benefit of energy monitoring to the WPI community and the potential costs of implementing a system that would provide energy usage data to the community. This project addressed the following problems within the context of this goal:

- How to provide better access to energy use data.
- How to present and organize energy data from building submeters.
- How to better engage the WPI community with energy conservation.
- How to integrate intelligent building control systems and energy monitoring to improve energy efficiency.

A series of recommendations for changes to university social and technical policies was presented in order to optimize the university's benefit from the proposed system.

This project attempted to solve a very specific problem that WPI has with energy data monitoring. This problem is not unique to WPI, or even other universities. Energy consumption in the twenty first century is rising and there are increasing financial and environmental incentives for individual people, academic institutions, and companies to monitor their energy consumption in order to save money and reduce pollution.

2 Background

This section provides background information on concepts that will be discussed at length in subsequent sections. First it will briefly discuss the need for sustainable energy initiatives and the context in which this need exists. It then explains why WPI would benefit from energy monitoring and how such a step would be undertaken. It also looks at the benefits derived from similar practices at similar schools.

2.1 Existing Sustainability Information for WPI

Nearly all of the current data that is publicly available on WPI's energy usage and general sustainability comes from an annual report published by the Association for the Advancement of Sustainability in Higher Education (AASHE) called the STARS (Sustainability Tracking, Assessment, and Rating System) Report[40]. This report examines all areas of sustainability at a university, including energy usage, recycling programs, composting initiatives, and sustainability-centric curriculum programs. In 2015 WPI attained only 56.1 of the 204.0 possible points on the STARS report. This score was sufficient to award WPI a Silver rating on the STARS assessment, but it placed the university in the bottom 30th percentile of the 277 schools that were assessed. While the university excelled in the Academics and Innovation categories, the largest point deficits appeared in the categories of Operations and Administration[40][39].

2014 STARS Annual Review[40]

2015 WPI Sustainability Report[39]

Figure 1

Unfortunately the data in the STARS report is not independently investigated by the AASHE, but rather it is fully self reported by the WPI Department of Facilities. Further, the report contains only the total statistics for each category and omits details such as month-by-month trends or resource usage breakdowns. Fortunately, the STARS report excels at making the data presentable and easy to reference. In addition, the only cost to the university is the twelve-hundred dollar annual subscription fee, which is nominal when compared to the institution's utility costs, which totaled over $7.5 million in Fiscal Year 2014[40][12][13].

When the WPI Sustainability Advisory Committee was established in 2007, one of its first orders of business was to mandate that all new buildings constructed at WPI must have a level of LEED certification[41]. The Leadership in Energy and Environmental Design (LEED) rating system is an initiative promoted by the United States Green Building Council to improve the sustainability of buildings and reduce their environmental impact[17]. While the WPI initiative to construct all future buildings to LEED specifications serves to promote a sustainable campus in the future, it has only affected the four buildings that were built since 2007[41]. This represents 7% of all the buildings on WPI's campus, and does not affect the more than half of WPI's campus buildings that are over fifty years old. The four LEED certified WPI buildings are tabulated below:

LEED Certified Score:40-49	LEED Silver Score:50-59	LEED Gold Score:60-79	LEED Platinum Score:80+
Bartlett Center	Faraday Hall	East Hall Sports & Rec Center	

[1]

Figure 2: Overview of LEED Certifications[39][17]

2.2 Real-Time Energy Monitoring

Real-time energy monitoring involves the collection of live data from energy monitoring tools in the field. A common system layout utilizes metering devices which measure the voltage and current of the main electrical feed to a building, or energy used by other systems such as heating and cooling. These devices then relay the energy usage data to a central computer or collaboration point where it is organized and stored for later reference. A basic layout of this system is shown in Figure 3 on the following page.

[1]The Sports & Recreation Center is WPI's only LEED certified building with smart electricity metering at time of writing.

In the context of this report, "real-time," and, "live," are used as relative terms referring to low-latency data point collection at regular intervals throughout the day. The smart electric meter and smart thermometer are used here as example devices. There are also smart gas, water, and steam meters available on the market. Gas meters simply measure pressure or flow rate, while chilled water meters may measure ambient temperature as well. Steam meters range from devices like those used to measure water and gas to noninvasive ultrasonic devices that reside completely outside the steam pipes. The majority of energy monitoring systems on the commercial market can take measurements in intervals ranging between five and thirty minutes[20]; and while it is neither constant nor instantaneous, it is sufficiently detailed to be useful[26].

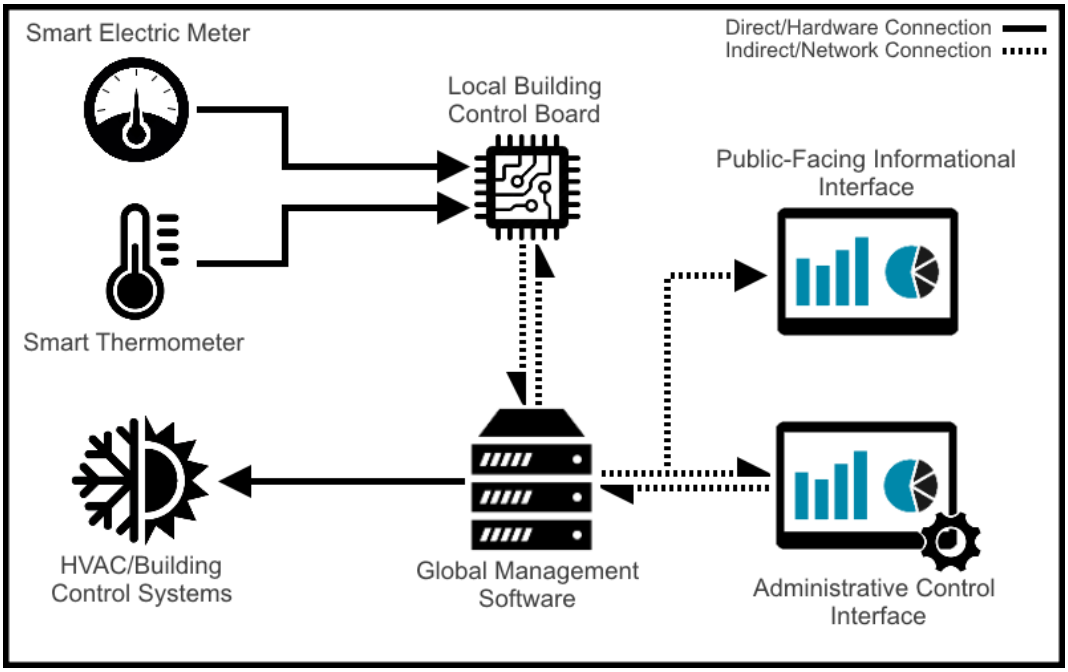

Figure 3: Basic energy monitoring system layout.

Real-time energy monitoring provides data that can be used to reduce energy usage across many different types of systems[10, pg. 51]. Facilities personnel can use the system to track energy consumption trends in order to take steps to reduce overall power usage. For professors and students, it provides data that could be used for research and a means of remaining informed on the state of the campus energy usage. Storing and organizing data in a readable format is very important to gleaning a tangible benefit from an energy monitoring system[10, pg. 50-51]. An IQP previously completed in 2010, "WPI Utilities Usage", suggested that WPI's energy monitoring system would be improved by integrating the proposed electric meter monitors into the HVAC (Heating, Ventilation, and Air Conditioning) monitoring system[10, pg. 50-51]. By doing so, facilities personnel could conveniently monitor campus energy usage via one unified platform, thereby increasing the organization of the data and thus its usefulness.

Modular systems to monitor energy usage data are available from multiple companies and allow for easy integration with other utility monitoring systems, such as HVAC monitoring and control systems[9]. These modular platforms, such as the ones provided by Schneider Electric and E-Mon Energy Monitoring Products, have advantages over in-house solutions, as they are refined by the manufacturer based their field experience to be more reliable and feature rich. They often provide better user interfaces and include enterprise support for the product for both failures and routine maintenance. Unfortunately, modular systems are often designed for industrial or corporate applications where public data availability isn't a concern. Thus, they often lack the toolsets to create a user-friendly experience and are prohibitively expensive for a non-profit institution like WPI.

2.3 WPI's Energy Monitoring System

The goals stated in WPI's Sustainability Plan are centered around academic programs, day-to-day campus operations, research promotion, and social integration with the community[41]. There is no way to measure the success of these sustainability efforts without being able to measure their effects on energy usage.

Figure 4: E-Mon D-Mon Smart Energy Meter[33]

Over the last ten years, seventeen campus buildings have been outfitted with a variety of models of the E-Mon D-Mon smart meter product line (EDSM), an example of which is shown in Figure 4[27][6]. A full list of WPI buildings equipped with EDSMs is presented in Table 1 on the following page. The data from these meters assist WPI Facilities and the Sustainability Advisory Committee in assessing where improvements can be made to reduce energy usage: "The EDSMs send their load data to the data aggregation software every 15 minutes, seven days a week. This software records instantaneous voltage, current and kilowatts for all EDSMs then stores the data on a private WPI network that is isolated for

security reasons."[7, pg. 31]. A diagram of this system architecture is presented in Figure 5. Unfortunately, the data aggregation software is antiquated, cumbersome to use, and lacking in features[11][25]. In addition, the data aggregation software is not compatible with other meters such as gas, water, steam, etc, and can not be easily integrated with other campus systems such as the HVAC controls[20].

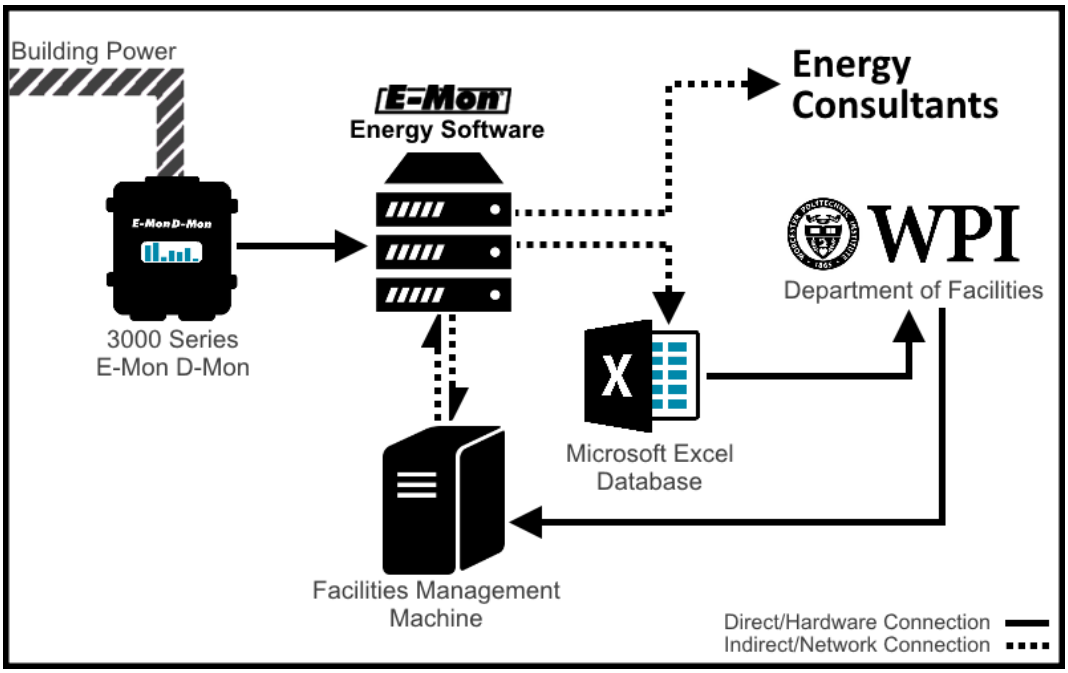

Figure 5: Current electrical monitoring system architecture.

Table 1: List of WPI Buildings Equipped with EDSMs[7].

- Alden Hall
- Atwater Kent Laboratories
- Boynton Hall
- Rubin Campus Center
- Daniels Hall
- Gateway[2]
- Goddard Hall
- Gordon Library
- Harrington Auditorium
- Higgins Laboratories
- Morgan Hall
- Olin Hall
- Sports and Recreation Center
- Sanford Riley Hall
- Salisbury Laboratories
- Stratton Hall
- Washburn Laboratories
- Power House, Main Campus Meter

[2]The MQP source for this data did not specify which of the four Gateway Park buildings the EDSM is installed in. Further research indicates that it is most likely located in 60 Prescott, though no official record could be found.

2.4 Case Study

There are many instances of real-time energy monitoring systems implemented on a campus-wide scale in the United States. Corporations, institutions, and hospitals collect this type of live data so that they can intelligently make up-to-the minute changes to their operations in order to conserve energy.

In order to maximize the relevance to WPI in studying institutional implementations of energy monitoring systems, we restricted our studies of other institutes to those that had been recognized in the past decade for sustainability programs that focused on building energy usage reduction and social awareness campaigns. The final list of campuses that fit the criteria was just five: Stanford University in Palo Alto California, Cornell University in Ithaca New York, Clark University in Worcester Massachusetts, the University of Massachusetts at Lowell in Lowell Massachusetts, and Bucknell University in Lewisburg Pennsylvania[5][28]. These campuses were also selected based on the availability of their data and dedication to sustainability objectives that were similar in intent to WPI's own.

Clark University is similar in size and location to WPI and has a well-established relationship with WPI via the Worcester consortium. While Clark does not make energy usage data publicly available, they do have energy monitoring and have data available internally. Clark university uses energy monitoring in conjunction with their cogeneration plant to save energy and money[34].

Cornell University is larger than WPI but similar in climate and makes energy monitoring data available via two separate web portals. Cornell's energy monitoring systems are very extensive and can provide a picture of an institution with more complete energy monitoring. Cornell uses energy monitoring to support projects like lake source cooling that uses the nearby lake instead of electrical chillers to cool water[5].

Stanford University is much larger than WPI and differs greatly in climate, but has a large engineering school and has a number of innovative administrative and facilities projects that rely on energy monitoring. Stanford makes energy monitoring data available via a public web interface, but that interface covers a smaller percentage of their campus than Clark's does. Stanford has numerous sustainability programs, such as back-charging departments for electricity use and recycling waste heat from cooled buildings to heat others and vice versa[35].

The University of Massachusetts at Lowell is larger than WPI but is geographically close to Worcester, and thereby has a nearly identical climate to WPI's own. UMass Lowell focuses primarily on waste reduction initiatives, such as their pioneering recycling program and the ongoing efforts to switch entirely to renewables. The source of the university's success with their sustainability program comes from the participation of their student body in waste reduction efforts across campus[36].

Bucknell University is comparable in size to WPI and is located slightly farther south, giving it a milder climate compared to WPI. Bucknell's Department for Sustainability and the Environment focuses on procuring funding for student projects and research into sustainable technologies and policies; the university campus itself is often used as a laboratory for testing these projects[3].

A complete presentation of the results of the energy monitoring studies of these universities is provided in Section 4 on page 15.

2.5 Summary of Background

Despite the recent design and implementation of WPI's sustainability initiatives, concrete data about the university's utilities usage and conservation efforts is unorganized and decentralized across multiple resources and departments. Most of the current sustainability initiatives at WPI are focused on sustainably implementing future programs, rather than improving existing buildings or programs. WPI already collects a limited amount of real-time energy use data but fails to make the data available in an easily useable or accessible manner. As such, the data cannot be used as a tool to optimize building energy usage or engage community members in day-to-day programs. Other universities have implemented energy monitoring systems in different ways. WPI can analyze these methods in order to design the best possible system for itself. This project attempted to propose ways to use components of the already existing energy monitoring system at WPI to increase the university's transparency on its sustainability and promote a culture of conservation throughout the community.

3 Methodology

This Interactive Qualifying Project explored energy monitoring at WPI and how it could be improved in order to facilitate the presentation of energy usage data to the WPI community. This project was based on a four step approach:

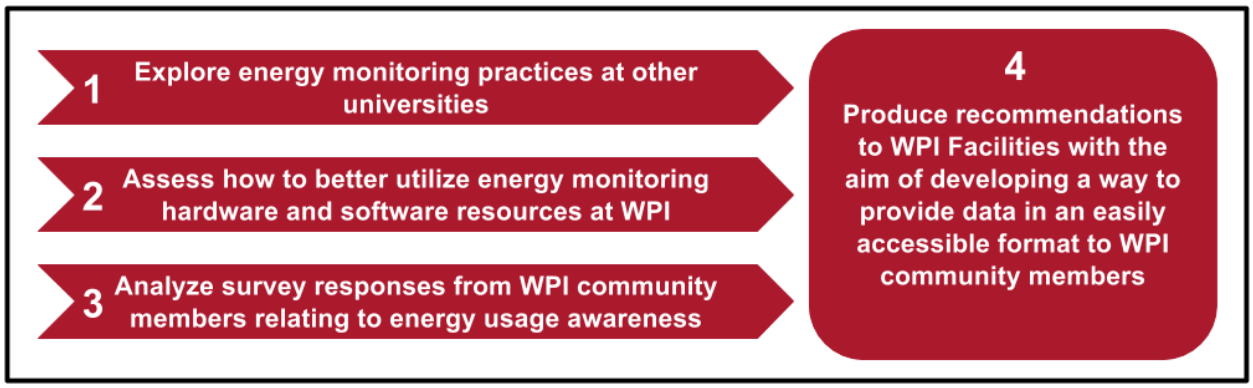

Figure 6: Fourfold approach for presenting energy usage data to the WPI Community.

3.1 Case Study Analysis

In order to ensure the viability and comprehensiveness of the project recommendations, an analysis of systems and procedures on other college campuses was performed. The list of campuses that have sustainability programs similar to WPI's is surprisingly easy to find; the STARS (Sustainability Tracking, Assessment, and Rating System) Report and similar programs already collect and organize that data in an easy to reference format that makes comparison simple[40]. The extensive list of possible candidates in the STARS Report database was narrowed down to only five campuses that met both of the following criteria: firstly that they had successfully implemented programs in line with WPI's own stated sustainability goals, and secondly had an amount of additional data available beyond just the STARS Report.

Further research into data organization techniques used on these campuses was also critical to performing a complete analysis of these case studies. One of the key problems faced by WPI at the moment is disorganization of the collected energy usage data, and therefore the inaccessibility of said data to anyone attempting to make use of it[26]. The fact that there are case studies with successful programs shows that other institutions have found ways to collect and store the many gigabytes of data while maintaining its readability and usability. By working with campus staff and speaking to students and faculty, this project analyzed the data organization and presentation methods used on the case study university campuses so that they can be adapted to WPI.

3.2 WPI's Current System and Infrastructure

The team examined WPI's current energy monitoring and data collection tools. Specifically this entailed examining what hardware was in place and what data was collected from the hardware and how. In addition, the team spoke with staff members in order to determine what was done with the data after it was collected and who was responsible for each part of the monitoring system.

Many WPI buildings are equipped with EDSM (E-Mon D-Mon Smart Meter) and digital HVAC (Heating, Ventilation, and Air Conditioning) control infrastructure devices. The team worked with one of WPI's HVAC Mechanics, Kevin McLellan, to gain more insight on the capabilities of the hardware deployed around campus[26]. The team worked with WPI's Chief Engineer, Bill Grudzinski Sr, to learn more about the other software solutions that are implemented or are planned to be implemented. By gaining a better understanding of the tools that WPI has at its disposal and the current usage of those tools, the team incorporated into its recommendations changes that maximize the benefit of WPI's current systems and infrastructure.

3.3 Qualtrics Survey

The project polled WPI students, faculty, and staff in order to better determine WPI's specific requirements and goals for the energy usage data. The team began devising questions for the poll on February 22, 2016; see Appendix A. The survey questions were split into two groups, one for students and one for faculty and staff members, with some of the questions appearing in both if applicable.

Survey Question Objectives

WPI's energy monitoring system collects a large amount of data, some of which is relevant to the needs of the university and some of which is not. Different campus groups may have different needs for the collected data. The survey questions focused on determining how the community thinks that energy monitoring can benefit them and what they would like to see developed to bring that data to them. Questions (see Appendix A) for faculty and staff targeted possible research and maintenance projects, while questions for students targeted residence hall energy usage reductions and community interaction with sustainability programs.

In addition, both groups were asked their opinions of other universities' energy data presentation systems and to rank features based on preference and functionality. User interfaces are critical to usability and convenience for data presentation systems, especially if the university wants to see the system widely used. Visual appeal is important to administrators and trustees presenting WPI's work to the rest of the world, but functionality is important to WPI Facilities staff and faculty using the system for research. In order to get accurate feed-

back the team used images to refer to other university's systems in order to avoid confusion and frustration from other references that could lead to users leaving the survey incomplete. Finally, the survey asked about the relevance of built-in statistical tools and their use to the campus community.

The purpose of the survey was to tap into the creativity and experience of the WPI community in order to get another perspective on how to design the new program. These ideas can directly influence the type of data and presentation method chosen in the recommendations and provide a background for people's expectations. The survey also provided some open-ended questions so that people with strong feelings or unique ideas could share them and have the chance to inspire inquiries or mention problems that may have otherwise gone unnoticed.

Survey Logistics

During the beginning of the IQP period the team prepared and submitted questionnaires for students and staff to the WPI Institutional Review Board (IRB) to review the survey prior to distribution to the WPI community during the remainder of the project. All community interaction involved in the project, including surveys and interviews, must be vetted by the institutional review board for potential risks to the subjects.

In order to have enough time for campus community members to complete the survey in time for the results to factor into the project, the survey was distributed in the beginning of D-Term 2016. Once the survey was approved by the IRB, the survey was distributed via WPI's Qualtrics Survey Software. There was a one-week period in D-Term 2016 for people to fill out the survey so that in week four of D-Term the analysis process began.

Survey Data Analysis

Survey data was consolidated from the two surveys by normalizing the data so that the two halves were comparable. This was done in several different ways, according to whether the question needed to be analyzed for faculty and students separately or not. In most cases, statistically analyzed questions were present in both surveys, so in order to present the data properly the results of each question had to be combined manually. Some questions, however, needed to be combined differently from others. If a question was polling what percentage of respondents knew about something, the data could just be added. If, however, there was a reason to weight student responses and faculty responses as two halves of a whole, then due to our shortage of student responses the data had to be normalized to percentages before the student and faculty data sets were combined. In other cases, instead of combining faculty and student responses, the group needed to combine question responses, but the same techniques were used. Once the data was appropriately combined, the team made graphs for easy analysis.

3.4 Economic Analysis

The team combined findings from the case studies and from interviews with Facilities, and information publicly available on energy monitoring systems to figure out an approximate dollar cost and non-monetary benefit to WPI from energy monitoring. This information is presented in financial terms in order to provide economic background to support the conclusions of the report.

The economic analysis includes the positive and negative externalities imposed on the university by energy monitoring. These were chosen by cross-referencing the effects of and uses for energy monitoring at other universities with the system the team favors for implementation at WPI. One of the most difficult parts of microeconomics is putting dollar values to externalities, so where possible, estimates were made, but in several cases the team could not find enough data to draw conclusions accurate enough for this report.

The economic analysis section also includes a breakdown of the accounting costs of the recommended system, and the explicit returns on investment that WPI could expect in dollar form. This section is primarily drawn from interviews with facilities and information that companies make available to the public about the cost of implementing their systems. This section also includes comparisons between the system the team favors and some of the other options available.

3.5 Analysis and Formation of Proposal

This report, concluded at the end of D-Term 2016, presents the data collected from case studies, WPI's current monitoring systems, and the survey of the WPI community in order to provide justification for the project's cumulative recommendations. These recommendations are based on the presented data to determine the most effective means of implementation for an energy monitoring system at WPI. In order to guarantee that the recommendations of this project address WPI's needs while remaining viable for implementation, this section covers the analysis procedure for all of the project's data with respect to relevance and usefulness.

The energy monitoring data WPI collects was compared to the information displayed on other university's public energy monitoring portals. Next, the data that WPI gathers was compared to the data that the WPI community expressed an interest in being able to see via the surveys. Using this information, the best features from each competing system at other universities were determined in order to implement a system that meets the needs and wants of the WPI community.

Once a data management and presentation software package was chosen, recommendations for general policy changes and specific technological changes to improve campus sustainability were formulated. These changes included new initiatives that can be advocated by the WPI Sustainability Advisory Committee and changes to the day-to-day operational strategies

of on-campus departments and aspects of a new campus energy monitoring system. By establishing reliable and consistent data collection methods at WPI, the groundwork has been laid out for a large host of changes that will improve WPI's sustainability, even beyond the scope and timeframe of this project.

The final step of this project was the gathering of the results of these analyses in order to form a clear and concise series of recommendations to submit to the administration on the benefits and costs of publicly available energy monitoring data.

3.6 Summary of Methods

The group performed case studies of other universities to understand how and why their sustainability initiatives work, and how they can work for WPI. Additionally, the team investigated WPI's existing smart electric meters and meter management software. The team surveyed the WPI community to learn about the community's preferences and also to provide a platform for any interested parties around campus to provide their own input and feedback to the project. Finally, the team consolidated all of the data collected by these various means and analyzed it to form a series of recommendations. Those recommendations covered suggestions for new ways to present energy usage data to the community, any improvements that could be made to the existing systems, and policy changes that use these new systems to promote a sustainable campus.

4 Results and Analysis

This section provides the results of the case studies, research on WPI's systems, results from the survey, and an overview of the economic implications of the team's favored solution. All of these results are analyzed together in order to present a clear and concise set of evidence on which to base the recommendations.

4.1 Case Study Results and Analysis

The case studies had the following objectives:

- Investigate smart energy metering strategies and history
- Investigate campus engagement strategies relating to smart energy metering
- Investigate sustainability initiatives requiring or relying upon smart energy metering
- Investigate the economic impact of smart metering and related initiatives

The case studies for this project were determined based on public reputation and recommendations from WPI staff and faculty. Universities were investigated based on information provided by Professor John Orr and Professor Fred Looft, and were selected based the public recognition or promotion of their sustainability programs. This led to the selection of five institutions to be contacted and analyzed, of which only three responded to our communication.

The three universities that were selected to be case studies and replied to our inquiries were Clark University in Worcester Massachusetts, Cornell University in Ithaca New York, and Stanford University in Palo Alto California. We were unable to get in contact with the University of Massachusetts at Lowell, from Lowell Massachusetts, or Bucknell University, from Lewisburg Pennsylvania.

Clark University

This study was conducted at Clark University in Worcester Massachusetts, through interviews with Chief Plant Operator Mark Leahy and Sustainable Clark Graduate Assistant Elizabeth Kubacki, the Clark University website, and a tour of Clark University's Cogen Plant.

Clark University has smart energy metering that they use on a regular basis to benefit facilities and regular campus operations. Clark University uses Schneider Electric's Struxureware Ion software platform to manage their smart electricity, gas, and steam meters in order to modulate the amount of power generated by the cogeneration plant[23]. Clark has been metering energy usage on its campus since the early 1990s, with 2006 seeing their installation of the first iteration of the Schneider Electric smart monitoring system. According to

Mark Leahy, the Chief Plant Operator for Clark University, the primary use of the energy monitoring system is to verify energy bills against the output of the cogeneration system; he went on to say that without the careful metering of all of the inputs and outputs of the cogeneration plant it would be impossible to operate the plant without significant financial loss[23].

Clark University derives most of its environmental and monetary savings from an eighteen-cylinder natural gas generator in their power plant, located beneath Jonas Clark Hall; seen in Figure 7. Clark has had a cogeneration power plant for thirty-four years, ever since they installed their first gas-oil hybrid generator in 1982. In 2012 the original engine was reaching end of life, and the university decided to upgrade to a two megawatt natural-gas burning generator. The newer, more modern generator sheds load dynamically (either powering excess demand from the grid or shutting it off altogether) in order to maximize the lifetime and efficiency of the engine by running at a constant rate, however this does require active monitoring of the power demand on campus. Additionally, the generator's hot-water output, gas input, and waste heat vent are carefully metered in order to comply with environmental credit requirements from the Environmental Protection Agency.

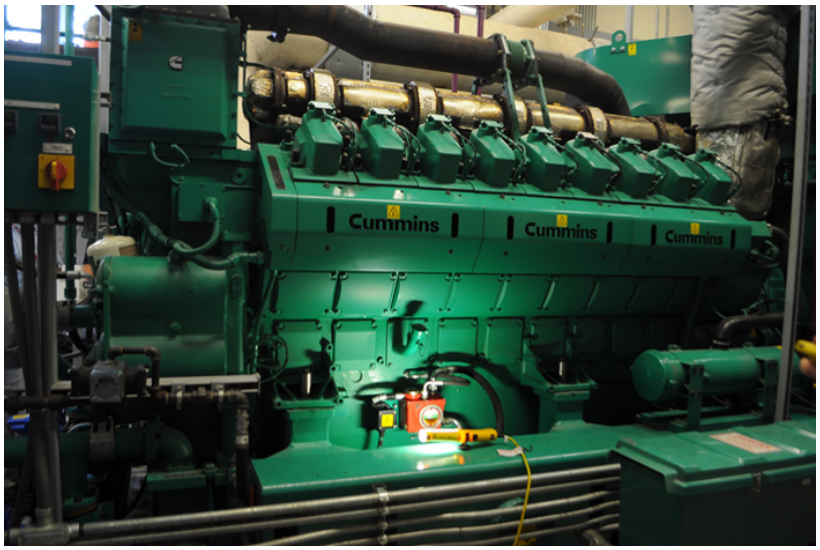

Figure 7: Clark University's cogen engine, installed in 2012 [7].

Clark makes back between 10,000 and 60,000 dollars annually by selling these credits back to the government, and more savings come from purchasing a natural gas contract as opposed to electricity by the Kilowatt-Hour (kWh); it is estimated that this saves the university an additional 400,000 to 600,000 dollars each year[23]. These savings are accomplished by pre-paying for natural gas at a negotiated rate in order to run the cogen engine at a constant rate, while letting the electric company, National Grid, supply any needed extra power to deal with peaks and selling any surplus power back National Grid when demand is low[23]. This is more optimal than running the generator at maximum all the time, as National Grid does not pay full retail prices for electricity; this results in the economic benefit of the system decreasing when the excess is being returned to the grid[23]. However the financial loss from

the cogen engine temporarily producing a small surplus is less than the loss from buying all of the university's electricity from the grid. Mark Leahy estimates that the cogen plant alone has saved Clark University between 25 and 40 million dollars since the first generator was installed in 1982.

Clark also sends out regular email updates to inform students on the energy usage of individual buildings to promote energy reduction competitions between student residence halls[22]. In the past, the university had a public web portal as part of their monitoring software to relay energy usage data to students in real time. This allowed Sustainable Clark and other organizations to run programs such as sustainability competitions and keep the general student body aware of sustainability[22]. Mark Leahy lamented that unfortunately a relatively recent update to the Schneider Electric software removed the public portal utility[23]. Since the loss of the web portal functionality, the real-time energy usage data is only available through the Power Plant Office computers because they are directly connected to the system.

Cornell University

This case study was performed on Cornell University in Ithaca, New York via a phone interview with Campus Energy Manager Mark Howe and Cornell's website. The team was unable to go to Cornell for a site visit.

Cornell University has a larger campus and therefore a need for centralized monitoring of all HVAC, water, and electrical systems in order to efficiently manage maintenance across campus. In addition, they also have meters on all of their approximately 100 steam transmission lines. They meter chilled water from the HVAC system in order to understand where their energy spent on cooling is going and this actually led them to implement a sustainable chilling system discussed later. Additionally, Cornell measures condensate production from their steam system, so as to find out how much of the energy spent on heating actually reaches its destination. This allowed them to find leaks in their steam lines that would be undetectable via other means and to dispatch repair crews before any issues get too severe[21].

Cornell uses a variety of different software and hardware solutions all of which feed data into their own custom Energy Monitoring Control System (EMCS) which is used to dispatch maintenance crews to resolve issues proactively and to make repairs. The EMCS was developed by Cornell to provide live data and trend graphs and is tailored specifically to the needs and layout of the university[21]. In addition to the EMCS providing tools for university personnel, the smart energy meters are able to directly control the HVAC system via Automated Logic software infrastructure that the university deployed[21]. Cornell has over 100 smart electrical meters and between 100 and 150 steam monitors that allowed for building-level submetering and real-time monitoring of all chilled water lines[5].

According to Cornell's Campus Energy Manager, Mark Howe, the EMCS is an outdated approach to centralized monitoring due to its utilization of older computer hardware and

deprecated software tools[21]. Rather than attempt to retrofit a public display interface into the EMCS, Cornell presents energy data to the public via the Lucid Design Group's software package, BuildingDashboard[5]. BuildingDashboard provides a user friendly and dynamic way for students and faculty to view energy usage data without having access to the control system itself.

Mark Howe said, "Having building-by-building metering is incredibly important," to advancing the sustainability of a university, though he does concede that the metering itself doesn't lead to direct monetary or environmental savings. Instead he advocated that submetering allowed for energy reduction studies that would otherwise not be possible, which in turn pave the way for projects that lead to energy reductions and the sought after savings. For example, Cornell boasts that even with a 20% growth in square footage space across their campus, their overall energy use has remained constant over the past fifteen years. This is owed in part to Cornell's Lake Source Cooling project, which operates at ten times the efficiency, and with higher uptimes, compared to traditional heat exchangers[21]. A diagram of the Lake Source Cooling project is shown in Figure 8. Such a project would not have been possible without energy monitoring infrastructure already in place.

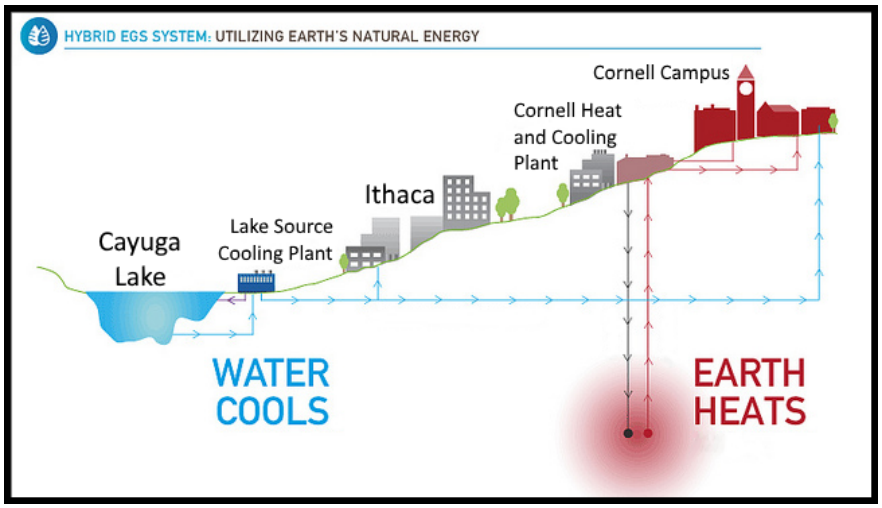

Figure 8: Diagram of Cornell University's Lake Source Cooling heat exchange project [8].

Cornell makes billing data available to the university community online through their facilities website. In order to access the data a login ID for the Cornell network is required, which can be acquired by anyone through the Cornell helpdesk; this is designed to help students do research on Cornell's sustainability and energy use[21]. With this data available, student projects can focus on advancing Cornell's sustainable practices rather than determining whether or not there is a need for them in the first place.

Stanford University

This case study was performed on Stanford University in Palo Alto, California via a phone interview with Director of Energy Facilities Management Gerry Hamilton and Stanford's website. The team was unable to go to Stanford for a site visit.

Stanford began aggressively deploying building submetering in the 1990's in order to accurately track and charge-back research overhead to the government[18]; 90% of Stanford's energy usage data comes from metering at the building level. The smart meters for water and electricity communicate with a database that Stanford uses to bill internal departments for their energy use. The database software, called eDNA, was owned by a development firm called Instep Software when Stanford implemented it, but was acquired by Schneider Electric in 2014[32]. Stanford also utilizes the Lucid Design BuildingDashboard software for its public facing real-time display. Stanford's Director of Energy Facilities Management, Gerry Hamilton, remarked that by design, the BuildingDashboard software does not perform any calculations on the data that is transmitted to it, rather it only displays data from the central database in order to ensure the data's accuracy[18]. This online interface helps students and faculty stay involved with sustainability and provides departments with an approximation of their energy use, as Stanford bills energy use internally to promote sustainability. They established a baseline use case for each department, and if the department uses more in a year, they have to pay for the extra. Conversely, if they use less than their baseline the university pays the department[35]. This internal billing leads to a high level of community involvement because individual departments are on the hook for their own energy use and they promote energy-saving practices at a more personal level than the administration of such a large institution can. In addition, Stanford runs a program called Cardinal Green, whereby students, faculty and staff can get involved with community projects and events relating to sustainability[35]. This program ties in the data from energy monitoring and human volunteers in order to run sustainable events and promote green practices around campus.

Mr. Hamilton went on to explain that Stanford's maintenance staff have integrated the submetering data into their day-to-day activities over the past ten years and have implemented over twenty million dollars of energy-focused capital upgrades. He said that these projects, which averaged a 30% energy savings and paid for themselves within four years, would have been significantly harder or impossible without the submetering on each building; he went on to reiterate that "metering is the first step towards dramatic savings"[18]. Intelligent submetering saves time when performing maintenance while also improving the effectiveness of upgrade projects. Efficiency problems that would otherwise go unnoticed are recognized and resolved which saves energy and money[18].

Stanford recently decommissioned their 42 megawatt cogeneration plant to make way for a new initiative dubbed the SESI (Stanford Energy System Innovations) project[18]. This project was designed based on data from the building submetering that showed a 70% overlap between the energy used by campus heating and cooling demands. The SESI project aims to use heat recovery chillers to recycle the waste heat from cooled buildings to heat others, and

vice versa. An additional goal of the SESI project is to reduce the line loss of the campus heating system to less than 4%; an improvement over the old steam system which experienced just over 10% losses in transmission[18]. The mild California winters did not warrant the steam output of the entire cogen plant, and so it was determined to be unnecessarily high power. As the power of the old medium-pressure steam heating system sourced from the cogeneration plant was determined to be unnecessary, the steam system has been removed and is currently being repurposed to carry hot water[18].

Case Study Analysis

All of the case studies revealed some level of distributed energy monitoring. There seemed to be some correlation between larger university size and more extensive energy monitoring, though that trend was not perfect. Even universities that do not place a large emphasis on sustainability have distributed energy monitoring for financial purposes.

Campus engagement methods were less uniform, with larger universities preferring to pay Lucid Design Group for a public portal interface, while Clark opts to send email updates to their staff, faculty, and students. This is partly because Clark already has a student body that is very active in sustainability and partly because the Lucid Design Group's software platform has been found prohibitively expensive in the past[10].

All of the case study contacts were happy to talk at length about their various sustainability initiatives made possible by distributed energy monitoring. Stanford's SESI was completely dependent on energy monitoring, while Clark's Cogen plant was less dependent on monitoring, and Cornell's Lake Source Cooling project was least dependent on energy monitoring. Despite their willingness to discuss sustainability initiatives, Cornell and Stanford were less willing to discuss financial details, though all were able to provide estimates. Clark was very forthcoming with financial information, though again they provided approximate figures more for the purpose of understanding orders of magnitude than for detailed analysis. All agreed, however, that while energy monitoring does not save the institution any money, it opens the door to significant energy savings. These savings come by way of intelligently targeted sustainability initiatives, ranging from social policies to the installation of a cogeneration engine. With distributed energy monitoring in place, sustainable solutions can be tailor made to the university's particular needs and priorities.

Case Study Best Practices

- Implement submetering of electrical, gas, water
- Implement submetering of steam generation and distribution
- Implement community engagement measures like web portals or email updates beginitemize
- Promote student involvement in engagement processes enditemize
- Promote infrastructure improvement projects by students, faculty and staff
- Achieve administrative support for sustainable practices and policies

4.2 WPI Facilities Next Generation Management Backend

WPI has a variety of data management software solutions already in place for different monitoring systems. The digital HVAC control infrastructure is managed by a central software system which monitors temperature data from sensor-equipped rooms in a building, but it was previously used only as a feedback system for the HVAC controls. Data integration between the HVAC control system and building electricity usage metering is key to creating a centralized dissemination solution for staff and students[11].

According to the WPI Chief Engineer, William "Bill" Grudzinski Senior, until late 2015 no plans were in place for developing a means by which to share energy usage data with WPI community members. Additionally, there was no user-friendly way to view the electricity usage data[11]. In January, 2016, WPI Facilities, with assistance from members of WPI's Information Technology Services Department, began making upgrades to the outdated electricity usage data collection system. Work has been progressing on integrating the data from the E-Mon D-Mon Smart electric Meters (EDSMs) into the Heating, Ventilation, and Air Conditioning (HVAC) control and monitoring system. The HVAC control and monitoring system uses hardware produced by Automated Logic. Facilities interfaces with the hardware through "WebCtrl", a web-based front-end user interface, also created by Automated Logic, to compliment their hardware. WebCtrl is built using HTML5, leading to faster responses and page load times, at the expense of more development time compared to Adobe Flash. WebCtrl is also a back-end control interface, not a public-access-grade portal. Figure 9 on the next page shows an example of data from an EDSM accessed through the WebCtrl interface.

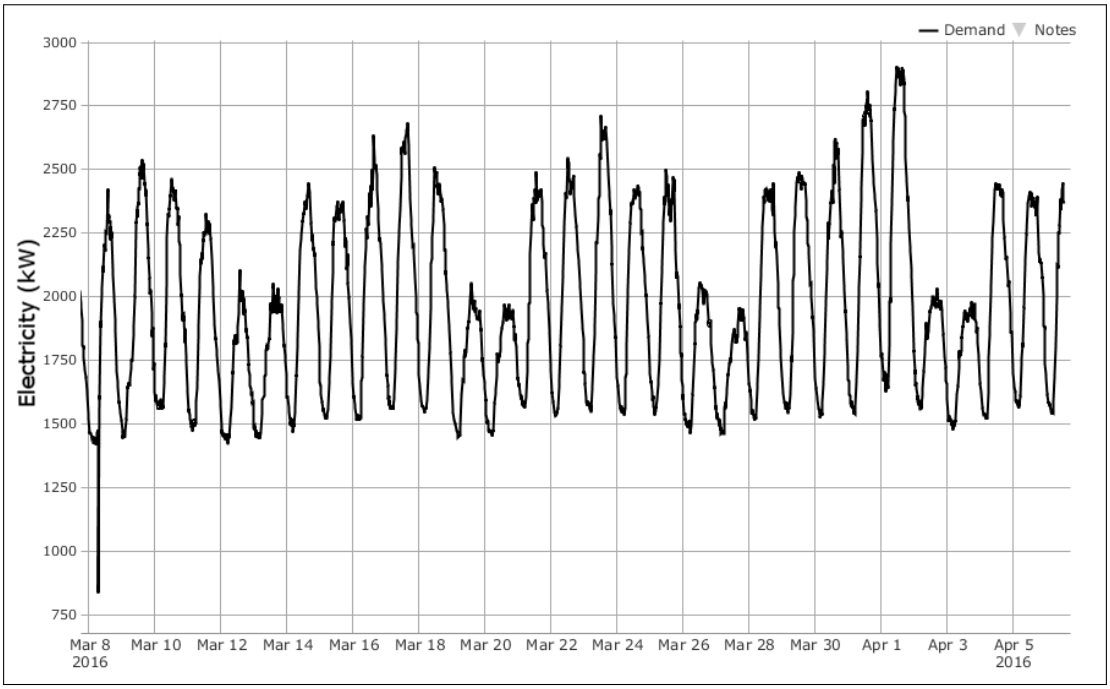

Figure 9: Example of a Building's Power Consumption Over Time, from EDSM Data Accessed Through WebCtrl.

Automated Logic

The Automated Logic management infrastructure runs on its own intranet using standard TCP/IP protocols. There is a BACnet (Building Automation Control network) Router in each building that acts as an interface between the global management software and the HVAC equipment, and EDSMs where applicable; these controllers are already installed in every building that uses Automated Logic HVAC controls[14]. The older 3000 series EDSM's are not able to interface with the system, while the newer 3400 series EDSM's are able to communicate with the controllers with the help of an adapter board[25]. 5000 series EDSM's can interface directly with the BACnet infrastructures and provide additional data, such as individual phase load and voltage values[14].

Automated Logic also has a built-in XML-based API which allows for the possibility of custom user interfaces being developed, either in-house by Automated Logic or by third parties. While they have their own public portal solution, Eco-Screen, it is programmed in Flash and because of that has prohibitively long page load times, between 1 to 5 minutes. Additionally, Automated Logic is compatible with Lenel Inc. hardware, which is used by WPI Information Technology Services for campus access control; both Lenel and Automated Logic are owned by the United Technologies Corporation (UTC) which allows them to easily share data[14].

Smart Energy Meters

Since the facilities metering upgrade project began in early 2016, eleven EDSMs have been integrated into the Automated Logic system[25]. A full list of buildings with online EDSMs is available in Table 2. The activation of EDSMs has not been immediate due to the fact that the EDSMs in many buildings are not equipped with the necessary hardware for integration with the Automated Logic system, and funding has not yet become available for a campus-wide EDSM upgrade[11].

Table 2: **WPI Campus Locations with Integrated EDSMs**[7]

- Atwater Kent
- Boynton Hall
- Daniels Hall
- Goddard Hall
- Harrington Auditorium
- Morgan Hall Main Feed
- Morgan Hall Panel DP-1
- Morgan Hall 4th Floor Panel
- Stratton Hall Panel SHP-1
- Stratton Hall Room 306
- WPI Main Electric Meter

The WPI Department of Facilities is seeking administrative funding in order to proceed with a campus-wide upgrade that would also allow for the installation of additional EDSMs in buildings not currently equipped with them. This involves replacing all of the outdated 3000 series meters with newer meters that are capable of interfacing with the Automated Logic system. The new electricity meters must be at least a 3400 model or newer, in order to relay the data properly[14]. The newer meters operate by sending a pulse output over an RS-485 connection to an Automated Logic BACnet Router, which manages all Automated Logic devices in the building.

The Facilities Department also intends to request funding for the installation of public user interfaces in residence halls and academic buildings in order to provide in-context live data on a building's energy consumption. These public user interfaces could be touchscreens which display electricity usage data in a user-friendly format so as to raise awareness of energy consumption on campus by providing an easily accessible way to view and interact with the data[11][25]. A diagram of the new proposed system architecture is presented in Figure 10 on the next page.

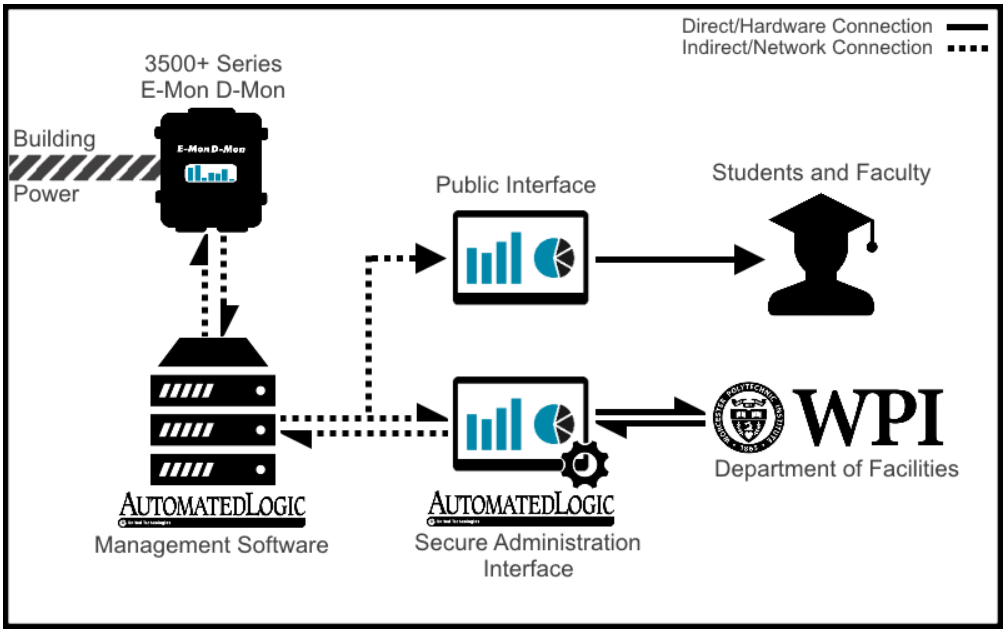

Figure 10: Proposed electrical monitoring system architecture.

Schnieder Electric Legacy System

Prior to the installation of the Automated Logic system, WPI also used a Schneider Electric system to manage HVAC systems in certain buildings. This Schneider system is still in use in some buildings[14]. Unfortunately, the newer version of the Schneider Electric management software is not backwards-compatible with the existing hardware from the old system; this makes incremental upgrades to the older Schneider Electric system much less practical, and thus they have been discouraged[14][25]. In light of this incompatibility, the Facilities Department has opted to gradually phase out the Schneider Electric system and move entirely to Automated Logic through a series of gradual upgrades whenever a need for maintenance or replacement arises[14].

4.3 Survey Data Analysis

This subsection discusses the results of a survey distributed to the WPI community in March of 2016 with a total of 114 respondents. Results from the survey suggest that the majority of the interest in energy monitoring, and the data it generates, comes from faculty with 79 respondents and staff rather than students with 35 respondents.

Community Engagement

In general, faculty thought WPI ranked slightly below average with sustainability efforts while students thought WPI was slightly above average. It is worth noting, however, that over 20% of respondents were unsure as to how to rate WPI relative to other universities (see Figure 11 on the following page). Students indicated a lack of knowledge and involvement

with sustainability by answering "No Idea," despite an interest in the subject (a fairly safe assumption is that is a slight selection bias for people interested in sustainability due to the opt in nature of the survey). Additionally, over half of respondents indicated that WPI was either on par with or worse than other universities in each of the categories the survey asked about. 41% of faculty respondents indicated some level of interest in data from energy meters around WPI's campus. That said, according to Figure 12 on the next page, the majority of survey respondents were unaware that WPI already has electricity meters in many campus buildings, again indicating both a lack of community engagement and a need for energy data presentation to the community.

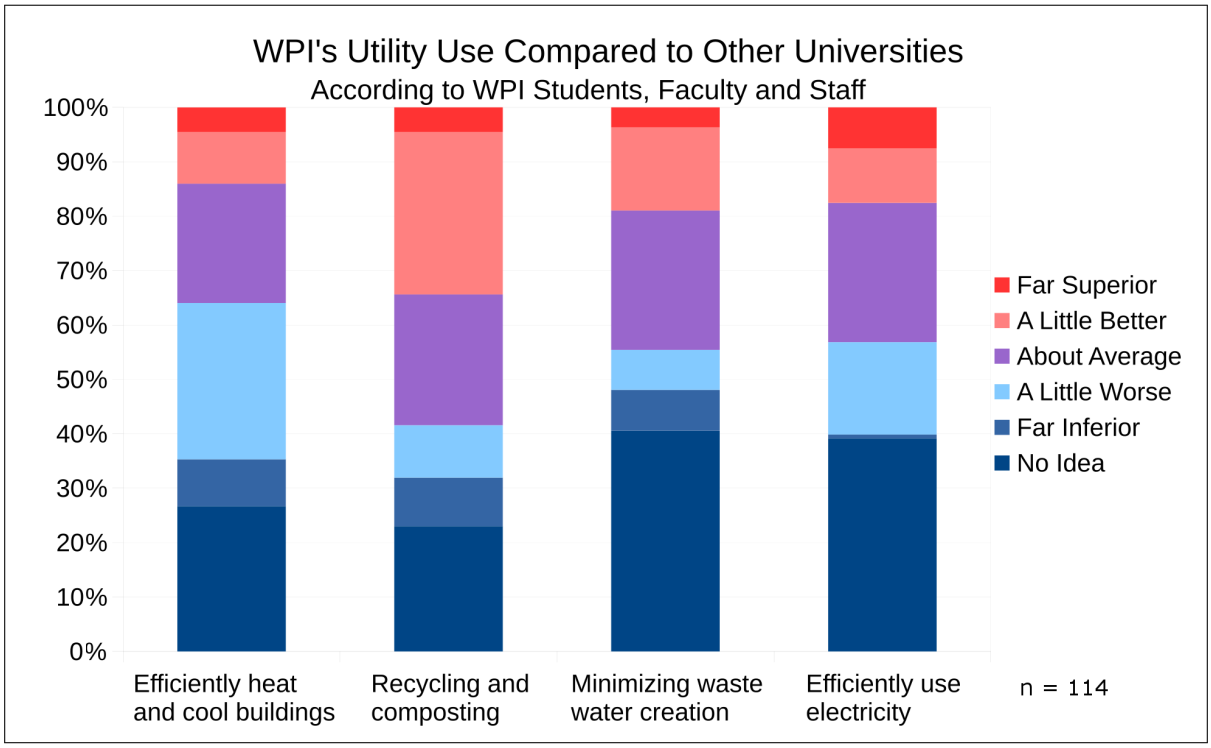

Figure 11: Opinion of WPI's Sustainability Compared to Other Universities

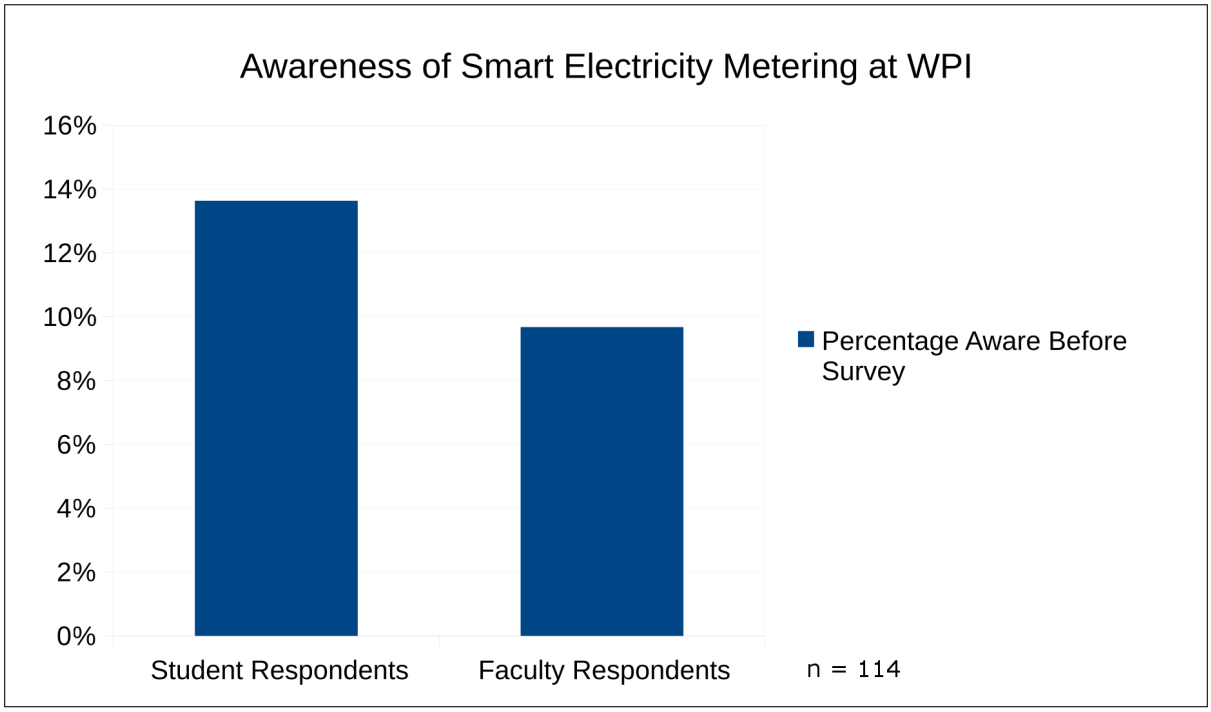

Figure 12: Survey Respondents' Awareness of EDSMs Prior to the Survey

Energy Data Web Portal

Most of the survey respondents preferred the look, layout, and data presentation of the BuildingDashboard system, but there was some support for Automated Logic's public portal. According to Figure 15 on page 28, people prioritized page load time slightly higher than portal features while fancy graphics were rated significantly lower in priority. For reference, both BuildingDashboard and Eco-Screen (Automated Logic's public portal) are flash-based, and as such have long page-load times.

As far as data presentation is concerned, students tended to prefer a web-based interface while faculty and staff preferred having monitors in the lobbies of buildings, as seen in Figure 16 on page 28. Both of these scored far higher than the rest of the options, and one anonymous respondent left the comment, "I think that a website for the WPI community that gives us data on energy usage at WPI would be a very useful resource for staff who work on sustainability issues and for students working on sustainability projects."

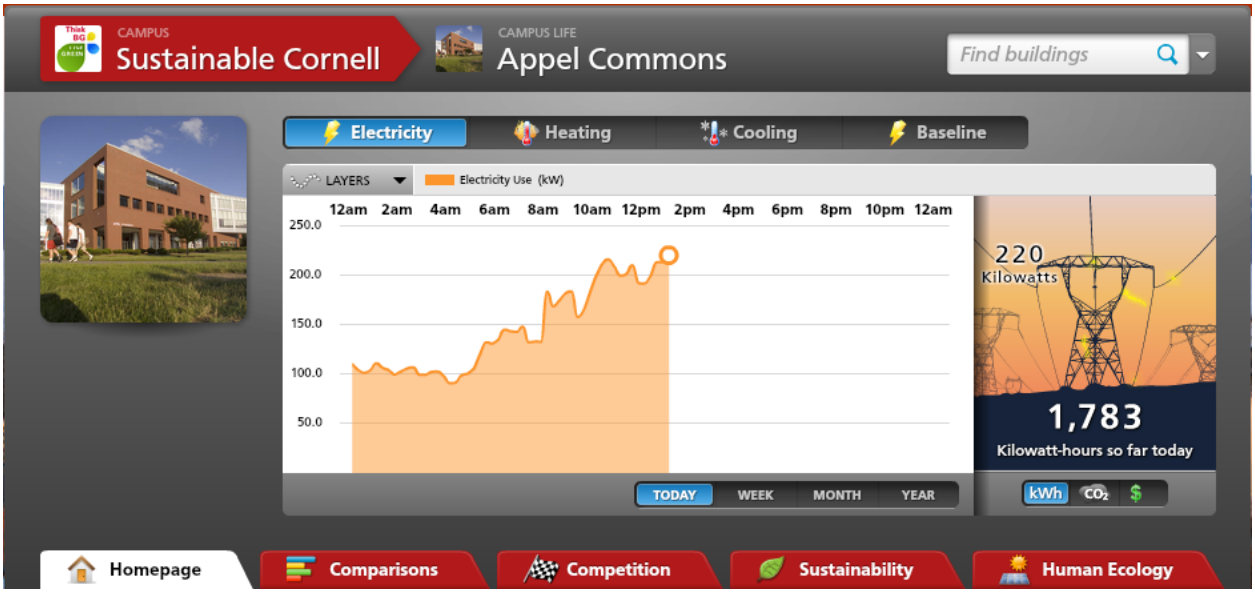

Figure 13: Example of BuildingDashboard Public Portal[5].

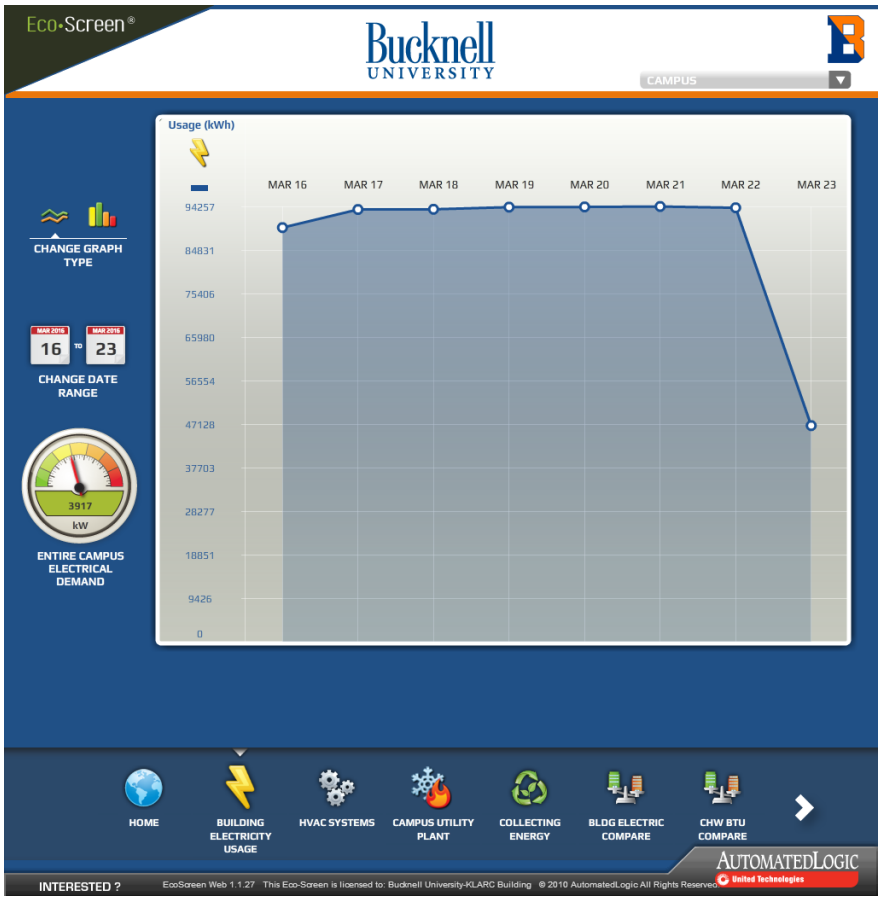

Figure 14: Example of Automated Logic EcoScreen Public Portal[3].

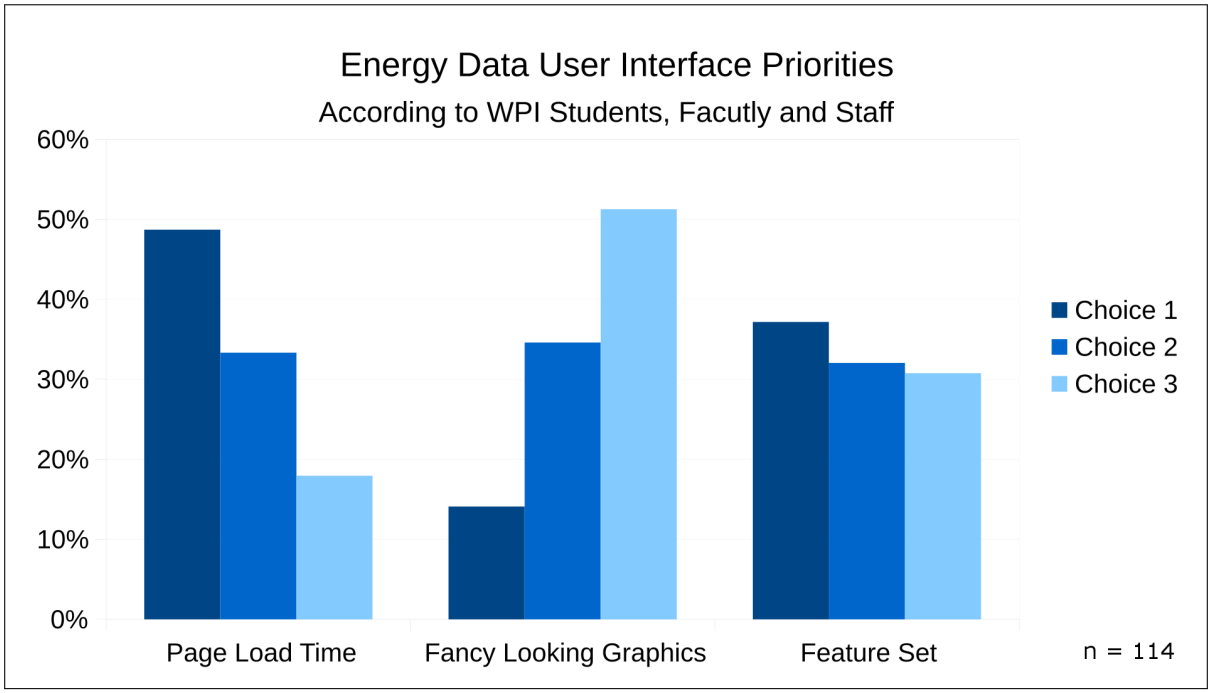

Figure 15: Survey Respondents' Preferences on Online Data Presentation

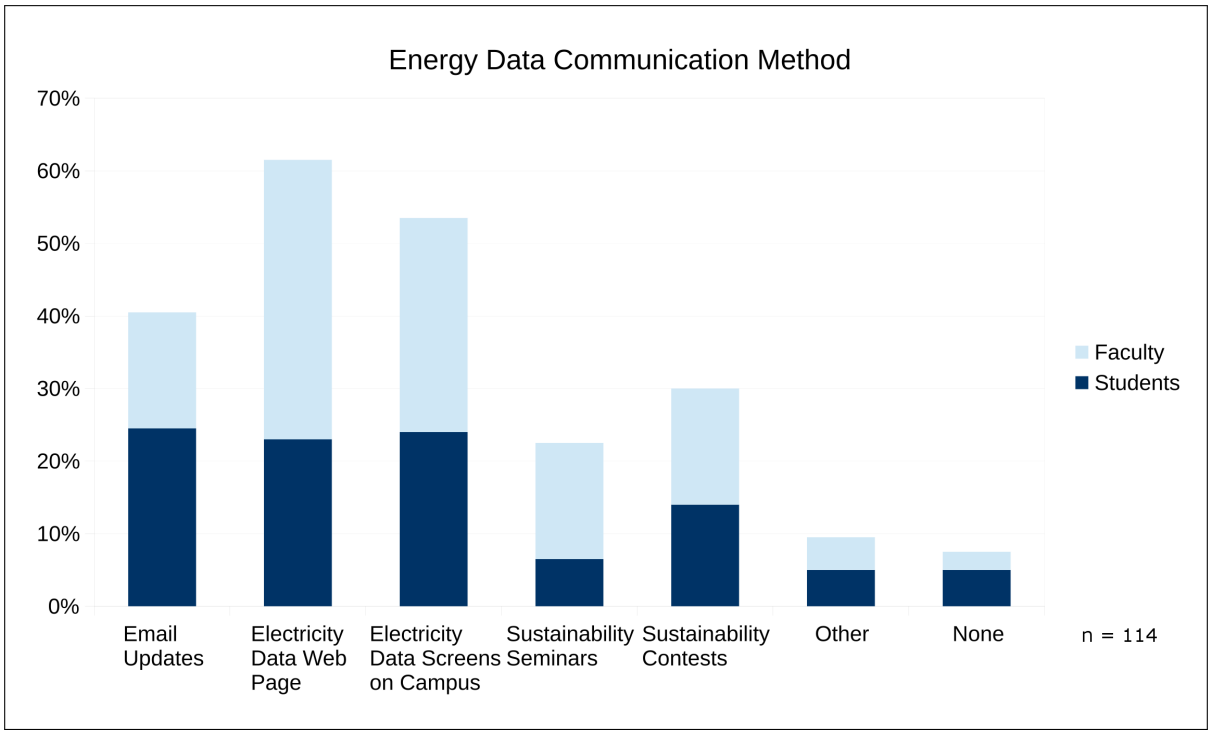

Figure 16: Survey Respondents' Preferences on Data Presentation Methods

4.4 Economic Viability

The purpose of energy metering, from an economic standpoint, is to turn money into information which can lead to savings. In WPI's case, the advent of energy monitoring is combined with consolidation of the HVAC controls all onto one platform, which also happens to support the energy monitors. This means that the HVAC technicians and electricians no longer have to fight for time on the computers hosting the Schneider system, and can save the university time and money by working more efficiently and fixing problems faster. Additionally, the integration of both of these systems into one removes the current structure where there are two control systems running on separate hardware in the same building and consolidates it all into one system, significantly reducing maintenance costs. This system also has the future potential to be integrated with lighting and access control systems that WPI already uses, in order to further reduce maintenance costs of integrated systems and increase those systems' efficiency. Energy monitoring also provides the data needed to renovate old buildings to be certified by LEED or other standards organizations or implement other energy and money saving measures like cogeneration.

Beyond the benefit to Facilities, energy monitoring provides a level of community engagement in sustainability that WPI has never seen before. More people will be aware of sustainability issues and their own impact and making a small effort to conserve a minimal amount of energy can still, on the scale of a university, translate into major energy and monetary savings. The direct availability of data on the status of energy use on WPI's campus turns the entire campus into a laboratory space for students and faculty.

Unfortunately, the team was unable to obtain data on the implementation costs of a full energy monitoring system due to time constraints. Given enough time and a proper set of data, a future economic analysis would take into account the accounting costs of the system and all of its parts, the accounting cost of installation and contracting, the benefits derived directly from the system and the recurring operating cost of the system. A thorough analysis would also include a reflection on possible savings from future projects enabled by energy monitoring, though these would be in comparison to, not added to the cost of implementation. With the rough data the group gathered, the Automated Logic monitoring system seemed about one order of magnitude less expensive than its Schneider Electric counterpart. The smart meters themselves are more expensive, but generally known to be low-maintenance and long-lasting, justifying their start-up cost. A rough estimate of the cost of all of the hardware required to bring building-level electrical submetering to a building with no existing infrastructure is about 7,500 dollars. Many of WPI's buildings have some sort of existing infrastructure, which could bring that price down to some degree.

4.5 Analysis of Results

According to the data presented thus far, energy monitoring is essential to a sustainable campus and one of the major foundational pieces of engaging the community in sustainability efforts. Cornell university started its energy monitoring program in the 1980's while Clark University started in 2001. By comparison, WPI has yet to start a full campus monitoring system and thus is by comparison 15-25 years behind peer institutions in advanced energy monitoring systems installation. Other universities take their energy monitoring systems for granted, using them for the verification of energy bills, finding problems with utilities and making repairs before critical failures occur, research projects for faculty and students, community outreach projects like residence hall competitions, and for energy and money saving upgrades to campus infrastructure.

Unfortunately, energy monitoring provides no direct financial incentive for its implementation. As discussed before, energy monitoring can allow for many opportunities to save money and energy, but the system itself has an estimated fixed cost of $7,000 per building. This includes equipment and installation costs for a building that has no existing smart infrastructure; a building with existing smart infrastructure would cost less to upgrade[16].

Something that energy monitoring does provide directly is community engagement. As indicated by the survey, WPI has historically had trouble involving students and faculty in sustainability efforts, due to busy schedules and a lack of information. With energy monitoring data available, people across campus become more motivated to optimize sustainability. Additionally, this data can be used for projects by students and faculty and the availability means lower barriers of entry into larger projects that further benefit the university. The availability of energy monitoring data turns the entire WPI campus into a lab space for students and faculty.

4.6 Summary of Results

The data in this chapter covers three prominent universities' experiences with energy monitoring, WPI's status in regards to implementing sustainable practices, the WPI community's thoughts on the relevance of energy monitoring and sustainability, and the costs associated with bringing energy monitoring to campus. The data provides perspective on what works elsewhere, the most efficient ways to monitor smart meters, and the major barriers to WPI's implementation of a full building-level smart metering system. All of this data will be used in the next chapter as a basis for the recommendations on the extent of smart metering that WPI would benefit most from.

5 Recommendations

This section will state a series of recommendations to the WPI Community to advocate for a unified energy submetering system on the WPI campus. These recommendations were formed based on the data presented in the Results Section. The recommendations describe the tools involved in, and layout of, a system that will provide a comprehensive metering solution for all attributes of WPI's energy usage. By implementing this system, the data necessary to develop further sustainability goals and initiatives can be gathered in order to track WPI's transition to a more sustainable future.

5.1 Infrastructure Development

Electrical Metering

Electricity use should be metered on a per-building basis through the installation of smart electricity meters in all campus buildings.

In order to develop a unified and easily integrated system throughout the campus it is recommended that E-Mon D-Mon Smart Electric Meters are installed in every building on WPI's campus. The 3000 Series E-Mon D-Mon product line is already in use on WPI's campus, and by continuing to utilize the newer 3400 or 5000 series product lines the deployment process will be streamlined[26]. The data from these meters can be used to pinpoint inefficiencies within WPI's electric grid, billing verification, planning for sustainability initiatives, and research projects[14][11][25].

Natural Gas Metering

Natural gas smart meters should be installed buildings that comprise the majority of the utility usage on campus.

Natural gas is used for building heating and for hot water. Monitoring of gas usage allows for better utilization of this resource in a cost effective way while maintaining acceptable levels of comfort on the campus. While it would be ideal to implement distributed natural gas metering at the building level, it is likely that the availability of funding would not permit for such an undertaking in the near future. In order to maximize the usefulness of the gathered data, the installation of smart gas meters should be focused around the buildings which are known to use the most natural gas. These buildings are listed in Table 3 on the following page, in order from lowest to highest natural gas usage, based on WPI's Fiscal Year 2015 billing data.

Table 3: **Highest Natural Gas Consuming Buildings, Ordered High to Low**[13].

1. Power House
2. 60 Prescott (Gateway Phase 1)
3. Farday Hall
4. Founders Hall
5. East Hall
6. Morgan Hall
7. Higgins House
8. Sports and Recreation Center
9. Rubin Campus Center
10. Goddard Hall
11. Institute Hall
12. 85 Prescott

Water Metering

Distributed smart metering of potable water should be implemented at the building level, with the implementation of distributed metering of chilled and hot water as a secondary goal.

Similar to natural gas metering, while it would be ideal to implement distributed water metering at the building level, it is likely that the availability of funding would not permit for such an undertaking in the near future. In addition to assisting with billing verification, the implementation of distributed water metering allows Facilities to focus building efficiency upgrades on the buildings most in need of upgrades or repairs[14][15]. However the additional data from such meters allows for tracking the progress of building efficiency upgrades, such as the installation of variable-flow lavatory fixtures.

Steam Metering

The central steam distribution system should be metered at both the distribution source and destination to better determine line losses and system efficiency.

Lack of funding would likely not permit for a full deployment of steam meters throughout the campus. The addition of steam meters, as funding becomes available, would further benefit the campus by providing additional data on campus energy usage as well as providing WPI Facilities with a means by which to easily detect leaks as well as line-loss due to deteriorated insulation, as both problems could otherwise go easily unnoticed[14][18].

System Integration

The current HVAC control software should be expanded to control data flow and organization for the smart utility meters and control systems.

WPI currently uses an energy monitoring platform with an appropriately powerful and simple user interface. This software is called WebCtrl, from a company called Automated Logic, and is used to control many of the HVAC systems on campus[26]. This system has already demonstrated its superiority over its main competitor on campus, Schneider Electric's Continuum[15]. For a publicly accessible user interface, Automated Logic's XML-based API

provides a potential opportunity for a computer science MQP to design a feature rich and profesional interface to meet WPI's requirements. The leading industry solutions, such as the Lucid Design Group's BuildingDashboard or Automated Logic's EcoScreen, are implemented using Adobe FlashPlayer[5][35], which has higher than average response and loading times; this is in direct conflict with the survey data which suggested that fast loading times was the most important attribute of a monitoring website to the WPI community.

5.2 Social and Fiscal Policy

Community Engagement

To engage the WPI community in the university's ongoing sustainability efforts, a web application should be implemented that allows for real time observation of utility and energy usage on campus.

The best way to engage any community in sustainability is to provide easily accessible, persistent reminders of its impact on the environment[22]. In WPI's specific case, making data on the energy use of individual campus buildings readily available to the public accomplishes this goal. This dashboard could be made available either on the WPI website, on touchscreens in the lobbies of campus buildings, or both. It should also be noted that students were partial to receiving automated email updates about campus sustainability, though faculty and staff were disinclined to receive such emails.

Social Policy

Using data from the energy submetering system, incentive programs can be created for WPI departments, groups, clubs, and organizations in order to promote energy conservation across campus.

The university can organize competitions between residence halls to reduce electricity use and other emissions. In addition to simply raising awareness among students, friendly competition in such an application has been proven to encourage collaborative conservation among peers[22]. Further, the university can use an energy metering system to establish a baseline of energy consumption for each academic department and then work to develop a financial incentives system to promote conservation among staff and faculty. A similar system has been active at Stanford University for some time, with noticeable and dramatic results[18].

Economic Development

By implementing an energy metering system WPI opens the doors to develop new environmental and financial conservation initiatives.

Cogeneration is one of the most established means of saving money on energy. Instead of paying full retail price for electricity the university would generate the majority of its electricity from an on-campus generator[23][21]. The generator's waste heat can also be used to preheat water for steam boilers, increasing efficiency for the HVAC system as well[23]. When proper exhaust treatment is employed the emissions from such a system are comparatively less harmful than those from a large coal-fired power plant that is often used to power the primary power grid[37].

Other institutions have utilized the data from their energy monitoring equipment to determine how to recycle waste heat and develop innovative methods of providing chilled water to campus. Stanford University recycles enough waste heat to account for approximately 70% of its energy needs[18], while Cornell University uses Cayuga Lake as a heat exchanger to provide chilled water instead of energy intensive electric chillers[21]. Similar programs and cost saving measures have the potential to benefit WPI, but without building-level energy monitoring the university is unable to plan improvements or determine the potential benefits from them[14][23][21][18].

5.3 Summary of Recommendations

Implementing building submetering at WPI is the foundational step to developing sustainable practices. In the interest of maximizing the usefulness of the submetering system, it is recommended that WPI upgrade its energy metering system to one with complete electrical submetering of all buildings. Monitoring electricity usage is most important as it allows for the planning and implementation of many other sustainable initiatives, such as solar energy and cogeneration. Natural gas, water, and steam metering allows the school to identify wasteful inefficiencies in the existing system and track the utility usage. Chilled water, steam and natural gas meters also serve to advance sustainability in the same manner that electrical metering does.

By metering utility usage the data becomes available to assess inefficiencies of campus buildings and provides the needed information for corrective action. The suggested meters allow for the creation of a publicly accessible web portal which will promote sustainable living and improve community engagement with sustainability in the WPI community. Implementing an intelligent utility metering system on WPI's campus would allow for the improved development of sustainability initiatives and efficiency improvements. Without the data provided by such a system, tangible improvements from sustainability programs cannot be determined, and thus their success is impossible to calculate.

6 Conclusion

At the end of any research project there is always opportunity for further development and expansion upon the topic. This section outlines some opportunities and suggestions for future work on this project's recommendations and process, as well as attributes of this project that could be expanded upon in greater detail. Finally, this section offers concluding remarks about this report and the state of energy monitoring on WPI's campus.

6.1 Future Development

This project explored the core principles of energy metering and the various systems in place at WPI and other universities. The information contained in this report provides a thorough overview of energy metering systems and their applications, though it does not contain a comprehensive analysis of every detail relating to these systems.

Below are portions of this project that were not explored in depth in this report due to limitations of time and scale. Expanding upon these subject areas is necessary to create a complete and comprehensive analysis of energy metering systems and their potential to improve university sustainability.

Economic Analysis

This project originally intended to include a detailed economic analysis of the cost of energy meters and their associated installation and operational costs, but the economic components were dropped from the report due to a lack of verifiable data and adequate time to acquire it. The pricing sheets from the WPI Department of Facilities were not available for reference in order to collect pricing information, and a limited time frame prevented a detailed analysis of the economic effects of installation and maintenance from being performed.

However in order to fully analyze the viability of deploying a smart electric, gas, steam, or water metering system on WPI's campus, a detailed and thorough cost analysis must be performed. The amount of research and analysis work involved in performing this analysis is comparable to an Interactive Qualifying Project.

User Interface Development

This report's recommendations call for the development and installation of a community accessible interface in order to track energy usage at WPI. The team investigated several industry solutions for an energy monitoring portal, but the software platforms were found lacking in the areas that the survey indicated were most important to the WPI community. Such platform solutions could be potentially sufficient for installed monitoring panels in campus buildings, but would not provide the WPI community with an ideal feature set in a web-based portal.

A more detailed analysis of the needed features and functionality in such an interface is necessary prior to any solution being chosen and developed. The research of these features and basic layout of a custom interface for the WPI community could be comparable to an Interactive Qualifying Project, while the actual development and implementation of the web application may constitute a Major Qualifying Project in the area of Computer Science.

Efficiency Audit

Some of the most common uses for energy metering systems is identifying building malfunctions, tracking transmission systems degradation, and locating previously invisible inefficiencies within buildings. By analyzing the data made available by a metering system, calculating the expected energy usage of the building, and contrasting the two numbers, potential problems and severe energy wastes can be identified and their solutions developed.

A student project that sought to perform energy usage audits using the energy metering system could focus on a single building or examine the entire WPI campus as a whole. Depending on the scope of the buildings to be analyzed and the solutions to be developed, energy usage efficiency auditing could serve either as an Interactive Qualifying Project or a Major Qualifying Project in one of several major fields.

6.2 Concluding Remarks

The purpose of this project was to perform an analysis of the benefit of energy monitoring to the WPI community and the potential costs of implementing a system that would provide energy usage data to the community. A series of recommendations for changes to university social and technical policies was presented in order to optimize the university's benefit from the proposed system, as outlined in Figure 17 on the next page.

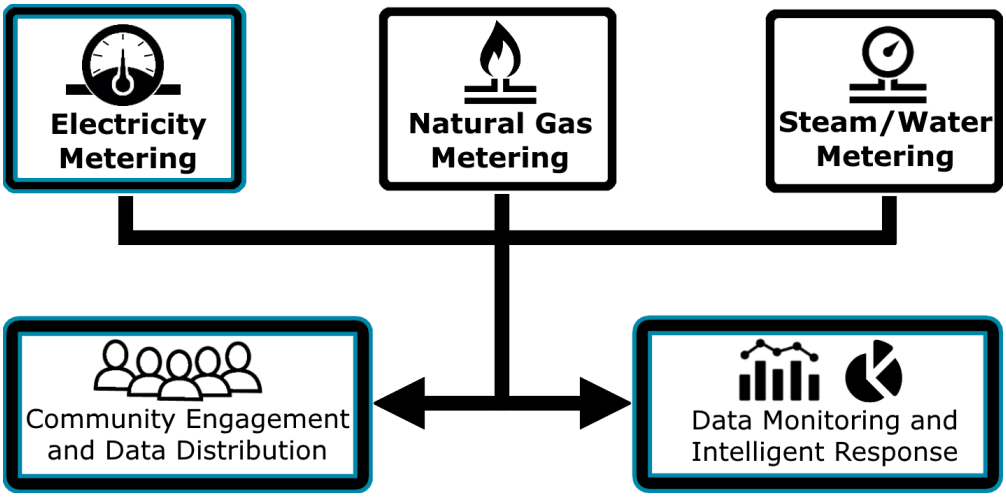

Figure 17: Flow diagram of technical and policy recommendations.

Through energy metering, data becomes available to assess inefficiencies of campus buildings and provides the needed information for corrective action. Implementing an intelligent utility metering system on WPI's campus would allow for the improved development of sustainability initiatives and efficiency improvements. Without the data provided by such a system, tangible improvements from sustainability programs cannot be determined, and thus their success is impossible to calculate. Through these programs, WPI can become a pillar of sustainable practices and an example to other schools facing the same problems, all the while promoting sustainable practices for a greener future.

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A Qualtrics Survey Questions

Block 1

Please select whichever best represents your affiliation with WPI:

- ○ Student
- ○ Faculty/Staff

Faculty/Staff Questions Block

This is a survey pertaining to the topics of sustainability and campus energy use.

Disclaimer: Your response to this survey is anonymous. We do not intentionally collect any identifying data. You will be asked if you wish to allow us to quote your answers to short-answer questions in our project report.

This survey takes approximately 5 minutes to complete.

Based on your experience, does WPI do better or worse than other Universities in the following areas:

	No Idea	Far Inferior	A Little Worse	About Average	A Little Better	Far Superior
Efficiently use electricity	○	○	○	○	○	○
Efficiently heat and cool buildings	○	○	○	○	○	○
Recycling and composting	○	○	○	○	○	○
Minimizing waste water creation	○	○	○	○	○	○

Do you feel like you are a part of the efforts to make WPI more sustainable?

- ○ Yes
- ○ No

How satisfied are you with WPI's current efforts to reduce it's...

	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied
Water Use	○	○	○	○	○
Electricity Use	○	○	○	○	○
Heating and cooling related energy use	○	○	○	○	○

How can WPI help you be more aware of campus sustainability issues? (Check all that apply)

- ☐ Periodic email Updates
- ☐ Real-time electricity usage on a university web page
- ☐ Location based electricity use trends on screens around campus
- ☐ Campus sustainability seminars
- ☐ Sustainability contests between different on-campus residences
- ☐ Other (please specify on next page)
- ☐ None of the above

You selected "Other" for one of the ways that WPI can help you be more aware of campus sustainability issues. Please explain in 280 characters or fewer:

The following are areas of sustainability related to WPI. To help us understand interest in future projects, please rank how important each area is to you.

	Slightly	Moderately	Very

	Unimportant	Important	Important	Important	Important
Reducing Energy Use	○	○	○	○	○
Economic Sustainability	○	○	○	○	○
Community Interaction	○	○	○	○	○
Water Use	○	○	○	○	○
Heating and Cooling Efficiency	○	○	○	○	○
Green / Alternative Energy Generation	○	○	○	○	○
Human Impact on Natural Environment	○	○	○	○	○

WPI has smart electricity meters in 17 of it's 60 campus buildings. Prior to taking this survey, did you know that WPI uses smart electricity meters?

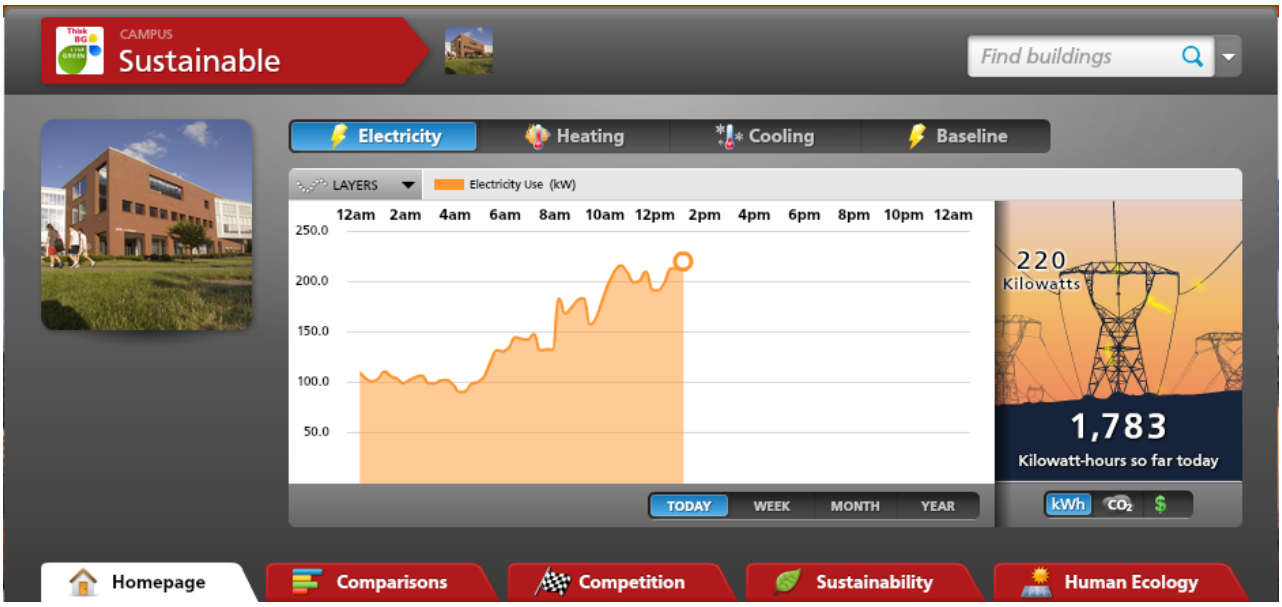
- ○ Yes
- ○ No

How did you hear about WPI's smart electric meters?

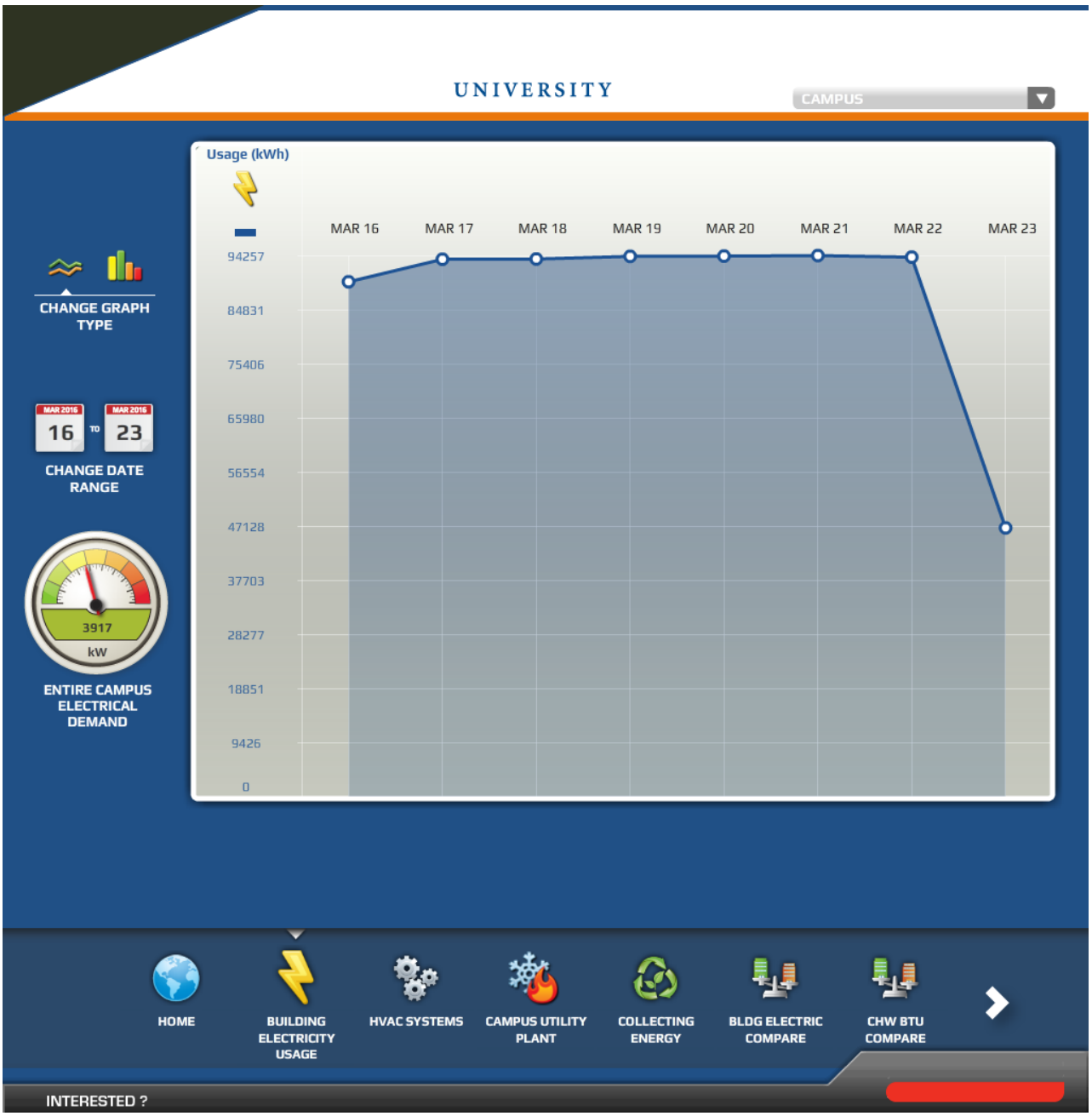
Below are three images of energy monitoring tools used at other universities. After looking at the images, please select which one visually appeals to you the most.

Option A

Option B



Option C



Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on layout and appearance?

- ○ A
- ○ B
- ○ C

Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on data presented?

- ○ A
- ○ B
- ○ C

Please rank the following common web page characteristics by how important they would be to you in a web interface like one of the three shown above.

(NOTE: If you agree with the order as-is, you must click on one of the items in order for your response to be recorded.)

Page Load Time

Fancy Looking Graphics

Feature Set (embedded analysis tools, etc.)

Are you interested in being able to access utilities data about WPI's electricity use, Heating, Ventilation, and Air Conditioning systems, natural gas use, or steam and water use?

- ○ Yes
- ○ No

Have you ever used or needed to use WPI utilities data for academic or professional purposes?

- ○ Yes
- ○ No

Choose which of the following best describes your interest in WPI utilities data:

- [ ] Job-Related (facilities technician, etc.)
- [ ] Research/Project/Other Academic
- [ ] Personal

Please select the type of utilities data from WPI you are interested in:

- [ ] Electricity
- [ ] Heating, Ventilation, and Air Conditioning
- [ ] Natural Gas
- [ ] Water
- [ ] Campus Steam Generation
- [ ] Other (Please specify on next page)

Please specify the type of WPI utilities data you are interested in (280 characters or fewer):

When you needed to use WPI utilities data for academic or professional purposes, were you able to get the data you needed?

- ○ Yes
- ○ Yes, but not in a timely manner
- ○ No

(Optional) How would you like to see the presentation of energy usage data to the WPI community improved? Please answer in 280 characters or fewer:

May we use anonymous quotes from your survey responses in our project report?

- ○ Yes
- ○ No

Student Questions Block

This is a survey pertaining to the topics of sustainability and campus energy use.

Disclaimer: Your response to this survey is anonymous. We do not intentionally collect any identifying data. You will be asked if you wish to allow us to quote your answers to short-answer questions in our project report.

This survey takes approximately 5 minutes to complete.

Based on your experience, does WPI do better or worse than other Universities in the following areas:

	No Idea	Far Inferior	A Little Worse	About Average	A Little Better	Far Superior
Efficiently use electricity	○	○	○	○	○	○
Efficiently heat and cool buildings	○	○	○	○	○	○
Recycling and composting	○	○	○	○	○	○
Minimizing waste water creation	○	○	○	○	○	○

Before taking this survey, were you aware that WPI publishes an annual sustainability report?

- ○ Yes
- ○ No

Do you feel like you are a part of the efforts to make WPI more sustainable?

- ○ Yes
- ○ No

Do you want to learn more about sustainability?

- ○ Yes
- ○ No

How satisfied are you with current efforts to reduce WPI's:

	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied
Water Use	○	○	○	○	○
Electricity Use	○	○	○	○	○
Heating and cooling related energy use	○	○	○	○	○

How can WPI help you be more aware of campus sustainability issues? (Check all that apply)

- ☐ Periodic Email Updates
- ☐ Real-Time Electricity Usage on a university web page
- ☐ Real-Time Electricity Usage on screens around campus
- ☐ Campus Sustainability seminars
- ☐ Sustainability contests in on-campus housing
- ☐ Other (Please specify on next page)
- ☐ None of the above

You selected "Other" for ways that WPI can help you be more aware of campus sustainability issues. Please specify: (280 characters or fewer)

The following are related areas of sustainability concerning WPI. To help us understand interest in future projects, please rank how important each of the following is to you:

	Neither Important

	Unimportant	Slightly Unimportant	nor Unimportant	Slightly Important	Important
Reducing Energy Usage	○	○	○	○	○
Economic Sustainability	○	○	○	○	○
Community Interaction	○	○	○	○	○
Water Usage	○	○	○	○	○
Heating and Cooling Efficiency	○	○	○	○	○
Green / Alternative Energy Generation	○	○	○	○	○
Human Impact on Natural Environment	○	○	○	○	○

WPI has smart electricity meters in 17 of it's 60 campus buildings. Prior to taking this survey, did you know that WPI uses smart electricity meters?

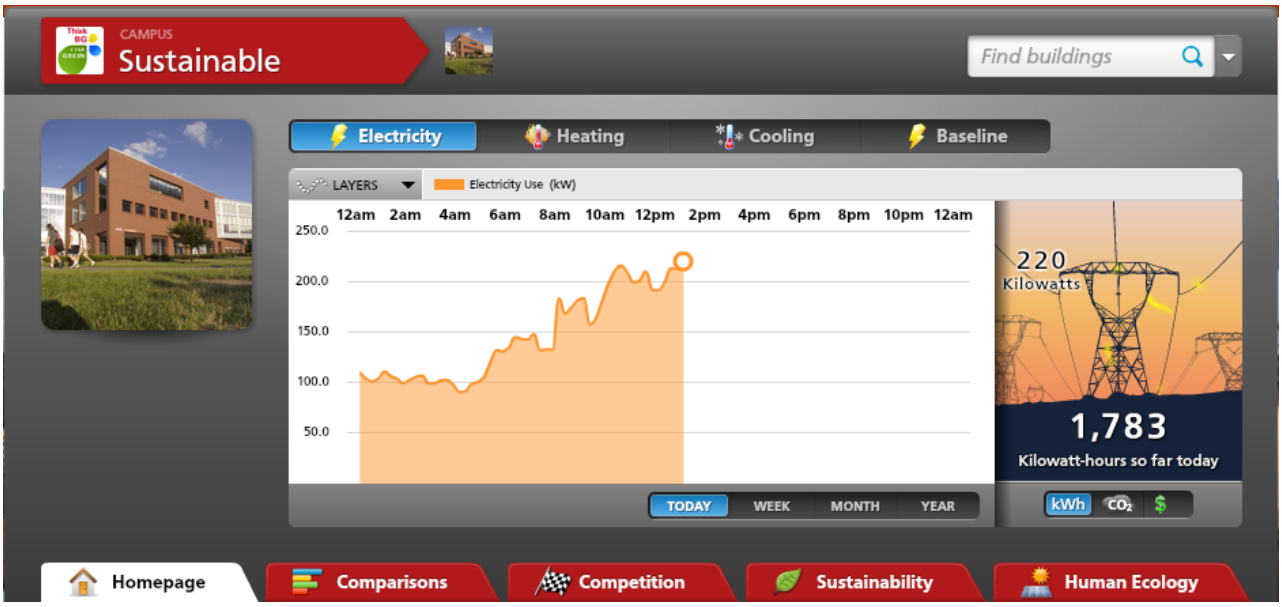
- ○ Yes
- ○ No

How did you hear about WPI's smart electric meters?

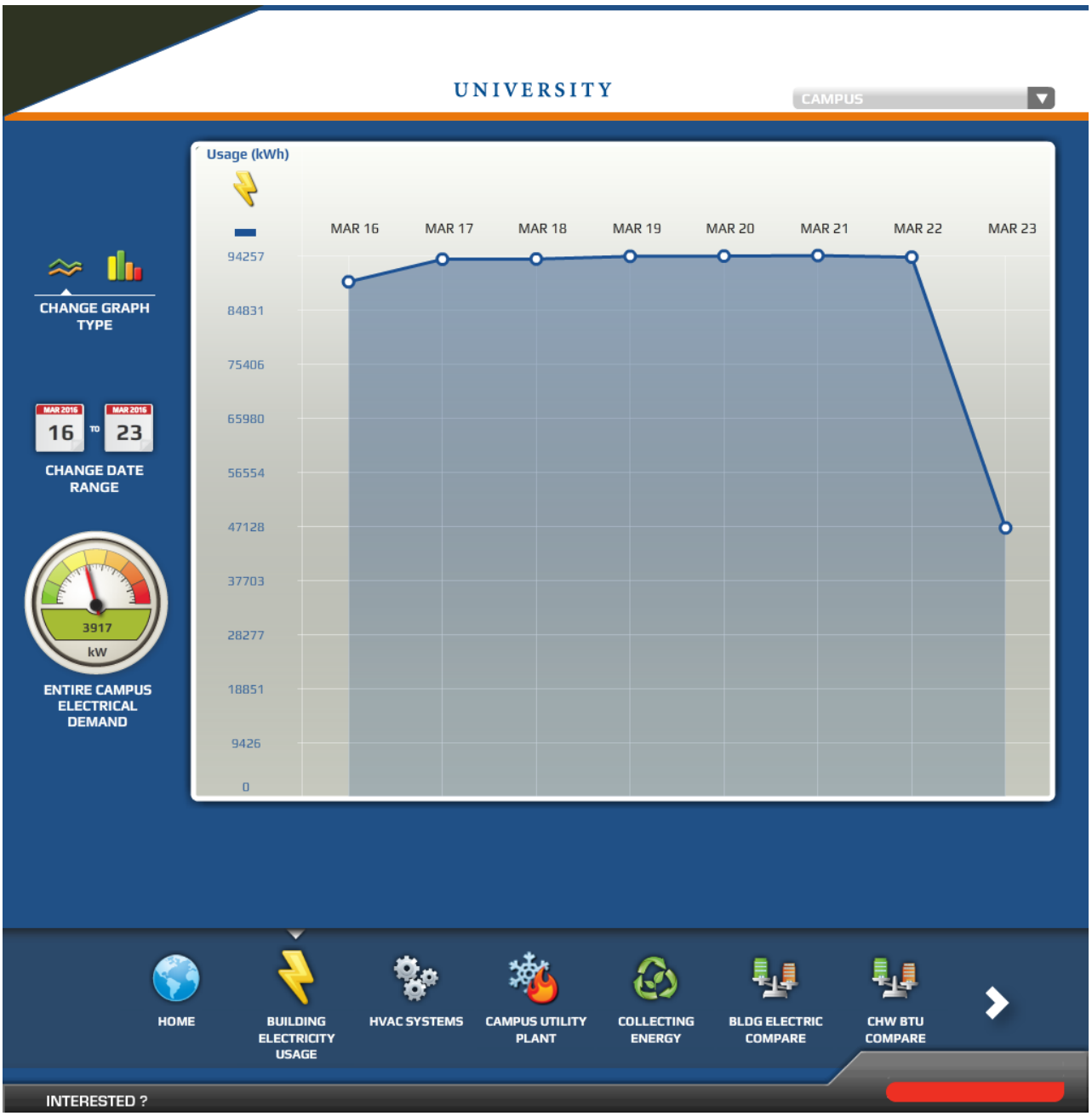
The following three images are on-line building energy and resource monitoring tools available at other universities. After looking at the images, you will be asked to select which on-line interface you prefer based on layout / appearance.

Option A

Option B



Option C



Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on layout / appearance?

- ○ A
- ○ B
- ○ C

Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on data presented?

- ○ A
- ○ B
- ○ C

How would you prioritize the following in a public facing user interface such as the three seen above?

(NOTE: If you agree with the order as-is, you must click on one of the items and drag it in order for your response to be recorded.)

Page Load Time

Fancy Looking Graphics

Feature Set (embedded analysis tools, etc.)

Do you agree to release your survey responses for anonymous quotations?

- ○ Yes
- ○ No

B Qualtrics Survey Results

Full Energy Sustainability Survey Results
Last Modified: 04/11/2016

Faculty Results

1. Please select whichever best represents your affiliation with WPI:

#	Answer	Bar	Response	%
1	Student	0.3070175	35	31%
2	Faculty/Staff	0.6929825	79	69%
	Total		114	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.69
Variance	0.21
Standard Deviation	0.46
Total Response	114

2. Based on your experience, does WPI do better or worse than other Universities in the following areas:

#	Question	No Idea	Far Inferior	A Little Worse	About Average	A Little Better	Far Superior	Total Response	Mean
2	Efficiently heat and cool buildings	25	9	15	15	7	0	71	2.58
3	Recycling and composting	23	3	4	18	23	0	71	3.21
4	Minimizing waste water creation	35	1	4	17	12	2	71	2.66
7	Efficiently use electricity	33	1	8	17	11	1	71	2.65

Statistic	Efficiently heat and cool buildings	Recycling and composting	Minimizing waste water creation	Efficiently use electricity
Min Value	1	1	1	1
Max Value	5	5	6	6
Mean	2.58	3.21	2.66	2.65
Variance	1.99	2.88	3.08	2.77
Standard Deviation	1.41	1.7	1.76	1.67
Total Response	71	71	71	71

3. Do you feel like you are a part of the efforts to make WPI more sustainable?

#	Answer	Bar	Response	%
1	Yes	0.7887324	56	79%
2	No	0.2112676	15	21%
	Total		71	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.21
Variance	0.17
Standard Deviation	0.41
Total Response	71

4. How satisfied are you with WPI's current efforts to reduce it's...

#	Question	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied	Total Response	Mean
1	Water Use	0	8	41	17	1	67	3.16
2	Electricity Use	1	18	30	16	2	67	3
3	Heating and cooling related energy use	11	24	19	13	0	67	2.51

Statistic	Water Use	Electricity Use	Heating and cooling related energy use
Min Value	2	1	1
Max Value	5	5	4
Mean	3.16	3	2.51
Variance	0.41	0.7	0.98
Standard Deviation	0.64	0.83	0.99
Total Response	67	67	67

5. How can WPI help you be more aware of campus sustainability issues? (Check all that apply)

#	Answer	Bar	Response	%
1	Periodic email Updates	0.4925373	33	49%
2	Real-Time Electricity Usage on a university web page	0.4626866	31	46%
3	Location based electricity use trends on screens around campus	0.4776119	32	48%
4	Campus sustainability seminars	0.1343284	9	13%
5	Sustainability contests between different on-campus residences	0.2835821	19	28%
6	Other (please specify on next page)	0.1044776	7	10%
7	None of the above	0.1044776	7	10%

Statistic	Value
Min Value	1
Max Value	7
Total Response	67

6. You selected "Other" for one of the ways that WPI can help you be more aware of campus sustainability issues. Please explain in 280 characters or fewer:

Text Response
<Text Responses Redacted to Protect Respondent Anonymity>

Statistic	Value
Total Response	7

7. The following are areas of sustainability related to WPI. To help us understand interest in future projects, please rank how important each area is to you.

#	Question	Unimportant	Slightly Important	Moderately Important	Important	Very Important	Total Response	Mean
1	Reducing Energy Use	0	6	10	28	18	62	16.94
2	Economic Sustainability	0	2	9	36	15	62	17.03
3	Community Interaction	2	5	17	22	16	62	16.73
4	Water Use	1	5	16	23	17	62	16.81
5	Heating and Cooling Efficiency	0	3	6	27	26	62	17.23
6	Green / Alternative Energy Generation	1	4	14	25	18	62	16.89
7	Human Impact on Natural Environment	1	3	7	27	24	62	17.13

Statistic	Reducing Energy Use	Economic Sustainability	Community Interaction	Water Use	Heating and Cooling Efficiency	Green / Alternative Energy Generation	Human Impact on Natural Environment
Min Value	15	15	14	14	15	14	14
Max Value	18	18	18	18	18	18	18
Mean	16.94	17.03	16.73	16.81	17.23	16.89	17.13
Variance	0.85	0.52	1.09	0.98	0.67	0.92	0.84
Standard Deviation	0.92	0.72	1.04	0.99	0.82	0.96	0.91
Total Response	62	62	62	62	62	62	62

8. WPI has smart electricity meters in 17 of it's 60 campus buildings. Prior to taking this survey, did you know that WPI uses smart electricity meters?

#	Answer	Bar	Response	%
1	Yes	0.0967742	6	10%
2	No	0.9032258	56	90%
	Total		62	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.9
Variance	0.09
Standard Deviation	0.3
Total Response	62

9. How did you hear about WPI's smart electricity meters?

Text Response
<Text Responses Redacted to Protect Respondent Anonymity>

Statistic	Value
Total Response	6

10. Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on layout and appearance?

#	Answer	Bar	Response	%
1	A	0.1785714	10	18%
2	B	0.7142857	40	71%
3	C	0.1071429	6	11%
	Total		56	100%

Statistic	Value
Min Value	1
Max Value	3
Mean	1.93
Variance	0.29
Standard Deviation	0.53
Total Response	56

11. Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on data presented?

#	Answer	Bar	Response	%
1	A	0.2857143	16	29%
2	B	0.5714286	32	57%
3	C	0.1428571	8	14%
	Total		56	100%

Statistic	Value
Min Value	1
Max Value	3
Mean	1.86
Variance	0.42
Standard Deviation	0.64
Total Response	56

12. Please rank the following common web page characteristics by how important they would be to you in a web interface like one of the three shown above.(NOTE: If you agree with the order as-is, you must click on one of the items in order for your response to be recorded.)

#	Answer				Total Response
1	Page Load Time	30	16	10	56
2	Fancy Looking Graphics	7	22	27	56
3	Feature Set (embedded analysis tools, etc.)	19	18	19	56
	Total	56	56	56	'-

Statistic	Page Load Time	Fancy Looking Graphics	Feature Set (embedded analysis tools, etc.)
Min Value	1	1	1
Max Value	3	3	3
Mean	1.64	2.36	2
Variance	0.6	0.49	0.69
Standard Deviation	0.77	0.7	0.83
Total Response	56	56	56

13. Are you interested in being able to access utilities data about WPI's electricity use, Heating, Ventilation, and Air Conditioning systems, natural gas use, or steam and water use?

#	Answer	Bar	Response	%
1	Yes	0.4107143	23	41%
2	No	0.5892857	33	59%
	Total		56	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.59
Variance	0.25
Standard Deviation	0.5
Total Response	56

14. Have you ever used or needed to use WPI utilities data for academic or professional purposes?

#	Answer	Bar	Response	%
23	Yes	0.1428571	8	14%
24	No	0.8571429	48	86%
	Total		56	100%

Statistic	Value
Min Value	23
Max Value	24
Mean	23.86
Variance	0.12
Standard Deviation	0.35
Total Response	56

15. Choose which of the following best describes your interest in WPI utilities data:

#	Answer	Bar	Response	%
1	Research/Project/Other Academic	0.2727273	6	27%
2	Job-Related (facilities technician, etc.)	0.2272727	5	23%
3	Personal	0.6363636	14	64%

Statistic	Value
Min Value	1
Max Value	3
Total Response	22

16. Please select the type of utilities data from WPI you are interested in:

#	Answer	Bar	Response	%
1	Electricity	0.9545455	21	95%
2	Heating, Ventilation, and Air Conditioning	0.9090909	20	91%
3	Natural Gas	0.4545455	10	45%
4	Water	0.8181818	18	82%
5	Campus Steam Generation	0.4090909	9	41%
13	Other (Please specify on next page)	0.0909091	2	9%

Statistic	Value
Min Value	1
Max Value	13
Total Response	22

17. Please specify the type of WPI utilities data you are interested in (280 characters or fewer): type of WPI utilities data you are interested in (280 characters or fewer):

Text Response
<Text Responses Redacted to Protect Respondent Anonymity>

Statistic	Value
Total Response	2

18. When you needed to use WPI utilities data for academic or professional purposes, were you able to get the data you needed?

#	Answer	Bar	Response	%
4	Yes	0.4285714	3	43%
5	Yes, but not in a timely manner	0.2857143	2	29%
6	No	0.2857143	2	29%
	Total		7	100%

Statistic	Value
Min Value	4
Max Value	6
Mean	4.86
Variance	0.81
Standard Deviation	0.9
Total Response	7

19. (Optional) How would you like to see the presentation of energy usage data to the WPI community improved? Please answer in 280 characters or fewer:

Text Response
<Text Responses Redacted to Protect Respondent Anonymity>

Statistic	Value
Total Response	8

20. May we use anonymous quotes from your survey responses in our project report?

#	Answer	Bar	Response	%
5	Yes	0.5636364	31	56%
6	No	0.4363636	24	44%
	Total		55	100%

Statistic	Value
Min Value	5
Max Value	6
Mean	5.44
Variance	0.25
Standard Deviation	0.5
Total Response	55

Student Results

21. Based on your experience, does WPI do better or worse than other Universities in the following areas:

#	Question	No Idea	Far Inferior	A Little Worse	About Average	A Little Better	Far Superior	Total Response	Mean
2	Efficiently heat and cool buildings	4	1	8	5	2	2	22	3.27
3	Recycling and composting	3	3	3	5	6	2	22	3.64
4	Minimizing waste water creation	7	3	2	6	3	1	22	2.91
7	Efficiently use electricity	7	0	5	6	1	3	22	3.14

Statistic	Efficiently heat and cool buildings	Recycling and composting	Minimizing waste water creation	Efficiently use electricity
Min Value	1	1	1	1
Max Value	6	6	6	6
Mean	3.27	3.64	2.91	3.14
Variance	2.21	2.53	2.75	3.08
Standard Deviation	1.49	1.59	1.66	1.75
Total Response	22	22	22	22

22. Before taking this survey, were you aware that WPI publishes an annual sustainability report?

#	Answer	Bar	Response	%
1	Yes	0.6666667	16	67%
2	No	0.3333333	8	33%
	Total		24	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.33
Variance	0.23
Standard Deviation	0.48
Total Response	24

23. Do you feel like you are a part of the efforts to make WPI more sustainable?

#	Answer	Bar	Response	%
1	Yes	0.5652174	13	57%
2	No	0.4347826	10	43%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.43
Variance	0.26
Standard Deviation	0.51
Total Response	23

24. Do you want to learn more about sustainability?

#	Answer	Bar	Response	%
1	Yes	0.5217391	12	52%
2	No	0.4782609	11	48%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.48
Variance	0.26
Standard Deviation	0.51
Total Response	23

25. How satisfied are you with current efforts to reduce WPI's:

#	Question	Extremely dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Somewhat satisfied	Extremely satisfied	Total Response	Mean
1	Water Use	0	5	10	4	2	21	3.14
2	Electricity Use	1	5	8	5	2	21	3.1
3	Heating and cooling related energy use	5	8	3	4	1	21	2.43

Statistic	Water Use	Electricity Use	Heating and cooling related energy use
Min Value	2	1	1
Max Value	5	5	5
Mean	3.14	3.1	2.43
Variance	0.83	1.09	1.46
Standard Deviation	0.91	1.04	1.21
Total Response	21	21	21

26. How can WPI help you be more aware of campus sustainability issues? (Check all that apply)

#	Answer	Bar	Response	%
1	Periodic Email Updates	0.3181818	7	32%
2	Real-Time Electricity Usage on a university web page	0.7727273	17	77%
3	Real-Time Electricity Usage on screens around campus	0.5909091	13	59%
4	Campus Sustainability seminars	0.3181818	7	32%
5	Sustainability contests in on-campus housing	0.3181818	7	32%
6	Other (Please specify on next page)	0.0909091	2	9%
7	None of the above	0.0454545	1	5%

Statistic	Value
Min Value	1
Max Value	7
Total Response	22

27. You selected "Other" for ways that WPI can help you be more aware of campus sustainability issues. Please specify: (280 characters or fewer)

Text Response
<Text Responses Redacted to Protect Respondent Anonymity>

Statistic	Value
Total Response	2

28. The following are related areas of sustainability concerning WPI. To help us understand interest in future projects, please rank how important each of the following is to you:

#	Question	Unimportant	Slightly Unimportant	Neither Important nor Unimportant	Slightly Important	Important	Total Response	Mean
1	Reducing Energy Usage	1	0	1	9	10	21	17.29
2	Economic Sustainability	0	1	2	7	11	21	17.33
3	Community Interaction	1	0	4	7	9	21	17.1
4	Water Usage	1	4	2	7	7	21	16.71
5	Heating and Cooling Efficiency	0	1	0	7	13	21	17.52
6	Green / Alternative Energy Generation	1	2	1	8	9	21	17.05
7	Human Impact on Natural Environment	1	0	1	6	13	21	17.43

Statistic	Reducing Energy Usage	Economic Sustainability	Community Interaction	Water Usage	Heating and Cooling Efficiency	Green / Alternative Energy Generation	Human Impact on Natural Environment
Min Value	14	15	14	14	15	14	14
Max Value	18	18	18	18	18	18	18
Mean	17.29	17.33	17.1	16.71	17.52	17.05	17.43
Variance	0.91	0.73	1.09	1.61	0.56	1.35	0.96
Standard Deviation	0.96	0.86	1.04	1.27	0.75	1.16	0.98
Total Response	21	21	21	21	21	21	21

29. WPI has smart electricity meters in 17 of it's 60 campus buildings. Prior to taking this survey, did you know that WPI uses smart electricity meters?

#	Answer	Bar	Response	%
1	Yes	0.173913	4	17%
2	No	0.826087	19	83%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.83
Variance	0.15
Standard Deviation	0.39
Total Response	23

30. How did you hear about WPI's smart electric meters?

Text Response
<Text Responses Redacted to Protect Respondent Anonymity>

Statistic	Value
Total Response	3

31. Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on layout / appearance?

#	Answer	Bar	Response	%
1	A	0.1818182	4	18%
2	B	0.6363636	14	64%
3	C	0.1818182	4	18%
	Total		22	100%

Statistic	Value
Min Value	1
Max Value	3
Mean	2
Variance	0.38
Standard Deviation	0.62
Total Response	22

32. Which of the three on-line interfaces for displaying building energy and resource use above do you prefer based on data presented?

#	Answer	Bar	Response	%
1	A	0.4285714	9	43%
2	B	0.3809524	8	38%
3	C	0.1904762	4	19%
	Total		21	100%

Statistic	Value
Min Value	1
Max Value	3
Mean	1.76
Variance	0.59
Standard Deviation	0.77
Total Response	21

33. How would you prioritize the following in a public facing user interface such as the three seen above? (NOTE: If you agree with the order as-is, you must click on one of the items and drag it in order for your response to be recorded.)

#	Answer				Total Response
1	Page Load Time	8	10	4	22
2	Fancy Looking Graphics	4	5	13	22
3	Feature Set (embedded analysis tools, etc.)	10	7	5	22
	Total	22	22	22	'-

Statistic	Page Load Time	Fancy Looking Graphics	Feature Set (embedded analysis tools, etc.)
Min Value	1	1	1
Max Value	3	3	3
Mean	1.82	2.41	1.77
Variance	0.54	0.63	0.66
Standard Deviation	0.73	0.8	0.81
Total Response	22	22	22

34. Do you agree to release your survey responses for anonymous quotations?

#	Answer	Bar	Response	%
5	Yes	1	4	100%
6	No	0	0	0%
	Total		4	100%

Statistic	Value
Min Value	5
Max Value	5
Mean	5
Variance	0
Standard Deviation	0
Total Response	4

C Interview Summaries and Notes

Appendix Contents

A Brief Overview of the WPI Electricity Metering System[7]

An informal interview with Thomas Buonomano on January twentieth 2016, conducted by Andrew Flynn in the WPI Campus Center over the course of approximately twenty minutes.

Andrew Flynn met informally with Tom Buonomano, a senior at WPI working with an MQP group developing a map of the WPI campus electrical infrastructure. The goal of the meeting was to gain a basic understanding of already extant electricity metering in place at WPI currently, and to identify staff members who could serve as resources to contact for further information.

This interview provided the group with information on both the technical state of WPI's electrical monitoring infrastructure, and the political landscape surrounding the individuals responsible for managing it. Mr. Buonomano was able to provide the group with information concerning the National Grid metering of WPI's campus, the capabilities of the software that monitors WPI's electrical systems, and the attempts to integrate the E-Mon D-Mon Smart Meters with the HVAC (Heating, Ventilation, and Air Conditioning) control software, Automated Logic. He also commented on the difficulties his MQP group had in acquiring this information due to the disorganization of both the technical systems, but also the systems' administrative oversight. Mr. Buonomano concluded the interview by recommending the group reach out to the WPI Chief Engineer, William Grudzinski Sr, for more information.

- Current electrical monitoring system is disorganized:
  - Antiquated, and non-intuitive software interface.
  - Hosting hardware for the software platform is insufficient for the load.
  - Direct interface and logging is done through Windows Task Scheduler, a notoriously unreliable software package.
- As of Mr. Buonomano's MQP, less than twenty of the campus buildings were equipped with E-Mon D-Mon Smart Meters.
- As of Mr. Buonomano's MQP, WPI Facilities was exploring the viability of a system overhaul:
  - Replace/upgrade/install new EDSMs that are compatible with new software.
  - Integrate EDSMs with Automated Logic HVAC control infrastructure.

A Discussion of Electrical Monitoring Equipment Around the WPI Campus[24]

An interview with Ted McCarty and Carl Johnson on January twenty-sixth 2016, conducted by Andrew Flynn at the WPI Campus Center over the course of approximately fifteen minutes.

Andrew Flynn met with Ted McCarty and Carl Johnson, Master and Journeyman Electricians, respectively, under the WPI Department of Facilities. The goal of the meeting was to obtain information about the technical implementation of the hardware used for electrical metering on WPI's campus and the E-Mon D-Mon Smart Meters specifically.

This meeting resulted in a greater understanding of how the hierarchical structure of the WPI Facilities Department upper management functions, and who is responsible for different systems. Unfortunately neither Mr. McCarty or Mr. Johnson were directly involved with the installation of the EDSMs, nor are they involved with the operation of the system that utilizes them. They relayed what information they had on the placement and operation of the EDSMs and closed the interview recommending that the group contact David Norberg, a contractor frequently consulted by the WPI Facilities Department.

- Most main campus buildings are equipped with EDSMs:
  - Very few EDSMs are on internal sub-panels; most are building main lines.
  - There is an EDSM in the Power House for the main line to campus.
- Very little, if anything, is done with the data collected from the EDSMs.
- Recommended contacting Roger Griffin or William Grudzinski Senior to learn about what the collected data is used for.
- Recommended contacting David Norberg, an electrician for Mercier Electric Company Inc and a frequent consultant for WPI, as he installed most of the EDSMs and can more satisfactorily explain how they operate.

A Discussion of Electrical Inefficiencies Around the WPI Campus[27]

An interview with David Norberg on January twenty-ninth 2016, conducted by Andrew Flynn in the Harrington Auditorium Main Electric Room over the course of approximately half an hour.

Andrew Flynn met with David Norberg, an Electrical Contractor for Mercier Electric Co. Inc who is often hired by the WPI Department of Facilities. The goal of the interview was to learn more about the technical operation and capabilities of the E-Mon D-Mon Smart meters deployed on WPI's campus.

Mr. Norberg oversaw the installation of most of the EDSMs on campus and could explain a little more how they work. The informal interview was primarily focused on electrical efficiency improvements that may be able to be integrated into a student project. He was also able to provide information on the history of the EDSM system at WPI.

- Dave has overseen the installation of many EDSMs at WPI, though he did not recall the exact number.
- E-Mon D-Mon Smart Meters utilize passive clamp-on electrical probes to measure current.
- Some models of EDSMs measure voltage for use in mathematical accuracy validation checks to ensure the data is correct.

Introduction to WPI's New Electricity Usage Data Collection Solution[11]

A meeting with William Grudzinski Senior on March fourteenth 2016, conducted by Andrew Flynn at the WPI Department of Facilities Office at Thirty-Seven Lee Street over the course of approximately one hour.

Andrew Flynn met with William "Bill" Grudzinski Senior, the Chief Engineer of WPI under the WPI Department of Facilities. The goal of the meeting was to learn more about the current electricity metering system in place on campus and to to learn about any plans for upgrades or improvements to that system.

This interview provided a large number of details to the group on the current state of WPI's electrical metering infrastructure, as well as the introduction to a plan to overhaul the system in order to improve its functionality and extensibility. Mr. Grudzinski commented on the extreme age of the hardware and software being used to monitor the few smart meters on the campus and demonstrated the cumbersome nature of its user interface. Beyond the usability problems this presents, including the inability to directly retrieve data due to the software's' complexity, Mr. Grudzinski was recently informed that the 3000 Series E-Mon D-Mon Smart Meters currently deployed on WPI's campus are marked for end of life service only.

Mr. Grudzinski went on to elaborate on a plan to integrate newer series EDSMs with the HVAC control software infrastructure, called Automated Logic. The new Automated Logic tool is deployed at `http://webctrl.wpi.edu`, and a brief demonstration of its capabilities was given. Mr. Grudzinski recommend contacting Kevin McLellan to learn more about the technical aspects of the Automated Logic integration. It was also mentioned that currently very few of the 3400 Series EDSMs, the minimum series required to integrate with the Automated Logic platform, were deployed on campus but he was putting together a proposal for the administration to secure funding to expand the project. The meeting was ended with a request for a second meeting, with all the members of the project group, as well as Kevin McLellan and William Grudzinski Junior of WPI ITS.

- Current software/hardware solution is out of date and unsupported:

  - Software, not service, based management tools, which makes collaboration and failover redundancy impossible.
  - Poor user interface makes data extraction impossible.
- Design and incremental implementation of new metering system is already underway:
  - Kevin McLellan and William Grudzinski Junior from ITS are working to integrate E-Mon D-Mon Smart Meters into the Automated Logic software platform.
  - Only EDSM 3400s or newer are compatible, of which few are currently deployed.
- Cross-departmental collaboration team to present project proposal and funding request to President Leshin.
- Team consists of William Grudzinski Senior, William Grudzinski Junior, Kevin McLellan, and Professor John Orr.

How Many Buildings are on Campus and do They All Use Electricity[30]

An interview with Ethan Paul on March fifteenth 2016, conducted by Johnathan Adams in the basement hallway level of Atwater Kent Laboratories, room 00F, over the course of approximately two minutes.

Johnathan Adams met with Ethan Paul, a Junior WPI student and Network Assistant at WPI Network Operations. The goal of this interview was to tie background information into the context of WPI by gathering information on the number and electrical capabilities of WPI's campus buildings.

The interview concluded that there are sixty buildings on WPI's campus, all of which use electricity. Mr. Paul referenced the WPI Network Operations Campus Building Documentation project database in order to relay this information.

- There are sixty buildings currently on WPI's campus, including garages and Gateway Park.
- All sixty of those buildings use electricity in some capacity.

A Brief Overview of Automated Logic's WebCTRL System[25]

An interview with Kevin McLellan on March sixteenth 2016, conducted by Andrew Flynn at the HVAC Maintenance Office in Atwater Kent Laboratories over the course of approximately twenty minutes.

Andrew Flynn met with Kevin McLellan, an HVAC Technician for the WPI Department of Facilities. The goal of the meeting was to learn more about the plans to implement a new electricity metering system on WPI's campus.

This meeting was technical centric with a focus on the actual implementation and operation of the electrical monitoring system. It was learned that the 3400 Series E-Mon D-Mon Smart Meters use RS-484 pulse protocol to communicate with control boards in each building which allows them to relay kilowatt demand in real-time. Mr. McLellan is personally responsible for managing the new EDSMs being installed, and is responsible for the majority of the programming that has integrated the smart meters into the Automated Logic software platform. He went on to explain that newer EDSMs, such as the 5000 Series, were capable of interfacing directly with the network, required no additional support infrastructure, and relayed much more data such as phase currents, voltages, and apparent power. Mr. McLellan mentioned also that there was no official funding for the installation of this system, but that instead he had been slipping the EDSMs onto the budget for other projects as the opportunities presented themselves. The meeting concluded with the intention of scheduling a second meeting with the full group present.

- Data from 3400 Series EDSMs is transmitted to Automated Logic hardware via RS-484 pulse protocol:
  - The pulse rate corresponds to the real-time demand in kilowatt-hours.
  - Conversion programs in Automated Logic's WebCTRL software gives campus load in kilowatts.
- Newer 5000 Series EDSMs can be directly interfaced with the network:
  - These provide additional data including phase-phase voltages, phase-Neutral voltages, phase currents, real power, reactive power, apparent power, and power factor.
  - Only one 5000 Series EDSM is currently installed on WPI's campus, in Daniels Hall.
- Additional EDSMs are being installed and brought online as projects arise and money becomes available.

A Discussion of WPI's Current Metering Strategies[26]

A meeting with Kevin McLellan on March seventeenth 2016, conducted by Ethan Paul and Johnathan Adams in the Power House Conference Room over the course of approximately one hour.

Ethan Paul and Johnathan Adams met with Kevin McLellan, an HVAC Technician for the WPI Department of Facilities. The goal of the meeting was to learn more about the technical implementation of the electrical system on WPI's campus.

This meeting involved a tour of Automated Logic's functionality and focused on familiarizing the team members with the software platform. User accounts with read-only access were created for Johnathan Adams, Andrew Flynn, Ethan Paul, and Sultan Jilani. Mr. McLellan provided a brief tour of the Power House Main Electric Room and a detailed demonstration of both the Automated Logic metering system and the Automated Logic HVAC Control and Response system.

- Group members were granted access to the Automated Logic WebCTRL system:
  - Permissions to view meter data on all online EDSMs, including primary meter.
- Only analog metering device in the system is the campus main electrical connection, which uses a straight pulse meter from National Grid.
- Introduction to, and demonstration of, demand-level logical operation within the Automated Logic control system.

Benefits of Cogeneration and Technical Sustainability at Clark University[23]

An interview with Mark Leahy on March thirtieth 2016, conducted by Johnathan Adams, Andrew Flynn, and Ethan Paul in the Plant Operations Office of Jonas Clark Hall at Clark University over the course of approximately an hour and a half.

Johnathan Adams, Andrew Flynn, and Ethan Paul met with Mark Leahy, the Director of Plant Operations for Clark University. The goal of the meeting was to learn about the technical attributes of Clark's energy monitoring system and other sustainable programs at the university.

Mark Leahy was contacted at the recommendation of William Grudzinski Senior and independent research into the operation of Clark University's Plant Operations department. The project team traveled to his office and spoke with him about sustainability at Clark prior to him giving the team a tour of Clark University's Cogeneration Plant and boiler room. He was able to describe in detail the current energy monitoring system at Clark and the history of past systems on the campus. A demonstration was provided of the Schnieder Electric management system they employ for both steam and electrical monitoring. Mr. Leahy spoke energetically and in great length about Clark's Cogeneration Plant which first opened in 1982 after WPI turned down an engine from the US Department of Energy. Mr. Leahy

then showed the project team the boiler room which uses excess heat from the cogen engine to preheat the boilers. Beyond that was the engine room itself, dominated, physically and auditorily, by an eighteen cylinder natural gas burning engine that drives a two megawatt generator. The tour concluded in the control room which has live outputs of all data feeds from the engine and the engine control station itself.

After the tour of the engine room, generator control room, and boiler room, he strongly reiterated that the cogeneration implementation was only possible due to their energy monitoring system. Mr. Leahy also noted that he has spoken in great length with several other project teams from WPI about the energy monitoring and cogeneration system at Clark over the past several years. He also noted his surprise that WPI does not have a current metering system in place. The meeting closed with his recommendation that the team contact Jenny Isler for more information on the social attributes of Clark's sustainability programs.

- The primary use of submetering is billing verification due to the demand/return fluctuation from the cogeneration engine:
  - Approximate power demand for the day is determined and the engine is locked in at that value.
  - Any gap in production and demand is compensated for by National Grid.
  - Any excess electricity is resold to National Grid at fraction of wholesale price.
- Clark uses the Struxureware Ion software package from Schneider Electric to monitor usage internally, but the trend graphs are not publicly available:
  - Primarily serves as a way to monitor the output of the cogen engine to track efficiency and qualify for energy credits.
  - The Plant Operations office provides email summaries to students on energy usage, but the data is not directly available through a public portal since a software update removed the tool.
- Clark's cogen plant saves them between four hundred thousand and six hundred thousand dollars every year on electricity, plus an additional fifty thousand dollars per quarter gained in clean energy credits.
- Clark's Plant Operations had a contract with GreenerU but terminated it some years ago. GreenerU is still employed by other Clark departments.
- Clark estimates savings from cogeneration plant since 1982 to be between twenty-five and forty million dollars total.

Future Development of WPI's Energy Monitoring System[14]

An interview with William Grudzinski Senior, William Grudzinski Junior, and Kevin McLellan on March twenty-third 2016, conducted by Johnathan Adams, Andrew Flynn, and Ethan Paul in the main conference room of the WPI Power House over the course of approximately one hour.

Johnathan Adams, Andrew Flynn, and Ethan Paul met with William "Bill" Grudzinski Senior, William Grudzinski Junior, and Kevin McLellan, all of whom are integral members of the WPI staff and are pioneering the energy monitoring system overhaul at WPI. The goal of this interview was to assess the current state of the planned upgrades, and to determine how the project team could be of most help to the Facilities Department.

This meeting was a planning and coordination meeting in order to maximize the helpfulness of the project team to the Facilities Department. It began with outline of the current implementation of energy monitoring at WPI, and the failings inherent in that system. Bill Grudzinski also provided some historical context on submetering at WPI and how previous incarnations of the system worked. The Facilities Department team also outlined the technical layout and capabilities of the new Automated Logic system, which also gave insight into why Automated Logic was chosen to be the software platform. All three men agreed that having student support for their project would be greatly advantageous to them, and that they'd like to see some data on what other schools are doing for their energy metering initiatives. The meeting closed with a request for a one or two page summary of the team's project thus far.

- Main campus electric meter feeds twenty-nine buildings, with no submetering or delineation lower than that.
- Automated Logic uses a fully HTML based interface with an XML based API that provides integration with third party systems.
  - Automated Logic has the capability to make a custom front-end user interface, such as the Bucknell College Eco Screen.
- Current E-Mon D-Mons use the 3000 model, which is marked for end of life and is not compatible with Automated Logic.
  - Newer 3400 and 5000 series use pulse communication, RS-485, or standard TCP-IP connections.
- Mention of a long-term interest in also submetering steam and gas consumption.

Energy Conservation Initiatives and Sustainability at Cornell University[21]

A phone interview with Mark Howe on April first 2016, conducted by Ethan Paul and Johnathan Adams in WPI's Gordon Library over the course of approximately one hour.

Ethan Paul spoke over the phone with Mark Howe, the Campus Energy Manager at Cornell University. The goal of the meeting was to learn about the technical attributes of Cornell's energy monitoring system and other sustainability programs at the university.

The project team decided to reach out to Mark Howe after visiting the Cornell sustainability website and identifying him as a primary contributor to the Department of Campus Energy. Mr. Howe spoke about the energy management system at Cornell and how every building on their campus is intelligently metered for gas, steam heat, chilled water, and electricity. This data is collected and monitored by the Energy Monitoring Control System (EMCS), a software platform developed in-house in the early 1970s and specifically tailored to Cornell University. The publicly accessible data from the EMCS is located at `http://portal.emcs.cornell.edu`, as well as through the Lucid Design Group's Building Dashboard software at `http://buildingdashboard.net/cornell`. The capabilities of the EMCS go beyond simple monitoring, as it can trigger alerts and manage campus systems intelligently with little or no human interaction.

When asked about energy monitoring specifically, Mr. Howe stated that Cornell has metered all utilities for the past three decades or more, with over three hundred smart meters for various utilities on campus. He went on to say that neither the EMCS nor the Lake Source Cooling Project would be possible without the energy meters, as it would be impossible to track trends in energy expenditure or savings. As a closing interesting fact, Mr. Howe mentioned that despite increasing the square-footage of Cornell's campus by 20% in the last fifteen years, the university's average energy consumption has remained constant.

- The Energy Monitoring Control System provides live monitoring tools, as well as intelligent responses and alerts to problems:
  - The platform was custom developed for Cornell by students and faculty.
  - They are seeking a replacement for it due to the systems age.
- Cornell uses two public portals:
  - Building Dashboard provides a user friendly public portal frequented by students.
  - The EMCS provides a more technical and in-depth data monitoring tool frequented by staff members and administrators.
- Cornell has a dedicated department for energy management that monitors energy demand, utility draw, maintenance alarms, and dispatches service personnel.
- The details of Cornell's software, hardware, and financial data for their energy usage are published online at `http://www.fs.cornell.edu/fs/fs_facilfind.cfm`.
- Programs like Cornell's cogeneration power station and Lake Source Cooling Project would be impossible without energy metering.

Energy Monitoring and Sustainability Efforts at Stanford University[18]

A phone interview with Gerry Hamilton on April first 2016, conducted by Ethan Paul and Johnathan Adams in WPI's Gordon Library over the course of approximately forty-five minutes.

Ethan Paul spoke over the phone with Gerry Hamilton, the Director of Facilities Energy Management at Stanford University. The goal of the meeting was to learn about the technical attributes of Stanford's energy monitoring system and other sustainability programs at the university.

This interview concentrated primarily on Stanford University's energy conservation projects and initiatives since they were first conceived in the early 1980s. Stanford uses Schneider Electric energy meters to monitor 90% of their energy consumption on individual buildings; the remaining 10% of their energy usage data comes from meters that monitor multiple buildings.This data is collected in a database software called eDNA which integrates with the Struxureware Ion software management platform since both are owned by Schneider Electric. Stanford recently decommissioned their cogeneration plant, which was used to produce steam heat as it was determined to be unnecessary due to the mild California winters, and the steam pipes are currently being retrofitted to carry hot water.

Mr. Hamilton commented on the necessity of the energy monitoring system at Stanford and how it has provided the capability to implement twenty million dollars of upgrades to campus infrastructure in the past ten years. He went on to estimate that Stanford has reduced their electricity expenditure by 30% over that time, with these upgrades returning the value of their cost within four years. He closed by mentioning the Stanford Energy System Innovations (SESI) project that continues to develop Stanford's sustainability program, and the development currently progressing on a software framework that would allow for individual departments to be back-charged for their electrical usage.

- Usage of Schneider Electric Square-D 7000 and 6000 series smart meters for monitoring, as well as hot water metering on the internal hot water plant.
- Schneider Electric Struxureware Ion software platform provides the backend monitoring tools and management interface:
  - Delta-V software tool provides active management and alert notifications based on data from the eDNA database.
  - Lucid Design Group's Building Dashboard software is used for the public interfaceand is located at `http://buildingdashboard.net/stanford/`.
- Savings have been accrued over the past fifteen years as twenty million dollars worth of upgrades have been implemented:
  - Aggressive installation of sub-metering in the 1990s allowed for the development of many sustainability programs in the early 2000s.
  - Payback on upgrade projects usually occurs within four years and has saved Stanford 30% on their energy bill since 2005.

Sustainable Clark's Social Engagement Strategies[22]

An interview with Elizabeth Kubacki on April first 2016, conducted by Ethan Paul, Sultan Jilani, and Johnathan Adams at the Sustainable Clark Office in the Gates House at Clark University over the course of approximately one hour.

Ethan Paul, Johnathan Adams, and Sultan Jilani met with Elizabeth Kubacki, the Graduate Assistant to Jenny Isler for Sustainable Clark at Clark University. The goal of the meeting was to learn about the social initiatives of Clark's sustainability programs at the university.

Jenny Isler was on a personal vacation at the time, but she was able to forward our email to her graduate assistant, Elizabeth Kubacki, who was more than happy to meet with the project group. Ms. Kubacki is involved in the design and execution of events on Clark's campus to promote sustainable ideas. One of the problems she often encounters is lack of student interest or engagement due to lack of time or interest. She highlighted several different programs on Clark's campus that she and Ms. Isler pioneered in order to address this problem and integrate sustainable practices into everyday student life. She made it clear that the administration on Clark's campus responded best to pressure from the academic departments and student base to implement policy changes, and suggested that the same might be true at WPI. The interview closed with her description of the Sustainable Clark office as a group dedicated to connecting parties interested in sustainability with the resources to implement the changes.

- Sustainable Clark involves students and faculty in social events and sustainability campaigns that promote awareness of sustainable living.
  - Social events aren't necessarily sustainability related, but promote waste reduction and conservation subtly.
  - Primary goal of Sustainable Clark is to connect different groups with each other in order to promote collaboration on sustainable initiatives.
- Communicates with on-campus academic departments in order to promote sustainable goals to drive improvements through the administration.

Discussion of the Helpfulness of Energy Usage Data for Student Projects[2]

An interview with Benjamin Beauregard on April thirteenth 2016, conducted by Johnathan Adams in the basement hallway level of Atwater Kent Laboratories, room 00F, over the course of approximately three minutes.

Johnathan Adams met with Benjamin Beauregard, a Junior WPI student and member of the Sustaining WPI 2016 IQP project center. The goal of this interview was to establish an immediate need for the proposal of this project in a practical context.

This interview concluded that the energy usage of individual campus buildings has practical applications to student projects at WPI. Mr. Beauregard commented that his project, which analyzed the energy inefficiencies in WPI's Kaven Hall, would have benefited greatly from having a history of the energy usage of the building.

A Discussion of the Financial Considerations Surrounding Energy Metering[15]

An interview with William Grudzinski Junior and Kevin McLellan on April fourteenth 2016, conducted by Johnathan Adams, Andrew Flynn, Sultan Jilani, and Ethan Paul in the main conference room of the WPI Power House over the course of approximately one hour.

Ethan Paul, Johnathan Adams, Andrew Flynn, and Sultan Jilani met with William Grudzinski Junior and Kevin McLellan, both of whom are pioneering the energy monitoring system overhaul at WPI. The goal of the meeting was to assess the financial consideration for the the energy metering system.

This meeting partially served to update the development team and the student project team on each other's progressing activities. Mr. Grudzinski said that the development team was intending to present to the administration on this topic shortly after the 2016 Commencement Ceremony, thus allowing plenty of time for the student project team to complete their work. Both men then relayed details on the ongoing development of the project including the addition of several more buildings to the immediate roadmap. The advantages of the Automated Logic management system and its advantages over competitor systems, such as Schneider Electric's Struxureware Ion, were also highlighted. The meeting closed with a request for more specific information on the itemized prices implementing this system.

- Automated Logic (ALC) was chosen over Schneider Electric's Struxureware Ion due to its significantly lower cost:
  - ALC can use older and third-party hardware, Struxureware Ion cannot.
  - Schneider Electric hardware costs between two and ten times as much as compatible hardware for ALC.
- The installed EDSMs have already detected mistaken National Grid overcharges.

Sustainability Programs at the Sustainable Communities Conference[1]

An interview with Lawrence Archey and Timothy McNamara on April fifteenth 2016, conducted by Andrew Flynn, Sultan Jilani, and Ethan Paul outside of Franklin Patterson Hall at Hampshire College over the course of approximately fifteen minutes.

Ethan Paul, Andrew Flynn, and Sultan Jilani met with Lawrence Archey and Timothy McNamara, patrons and coordinators of the 2016 Massachusetts Sustainable Communities Conference. Mr. Archey is the Director of Facilities and Grounds at Hampshire College and Mr. McNamara is the Associate Director of Campus Services at Dartmouth College. The goal of the interview was to inquire about how energy monitoring assists with sustainability programs at their respective colleges.

This interview was conducted informally after the conclusion of a tour of the solar installation at Hampshire College outside of their Franklin Patterson Hall which served as the conference center. Both men were happy to speak with the project group and were excited to have the opportunity to go into more detail on the innovative programs their colleges were implementing. Mr. Archey spoke very highly of the current and planned solar installations at Hampshire College, while Mr. McNamara mentioned the HVAC and building insulation at Dartmouth College was being revitalized and had so far saved the university many thousands of dollars. When asked directly, both men agreed vehemently that none of their sustainability initiatives could have been implemented without the submetering systems deployed on their campuses.

- Hampshire College utilizes a basic energy submetering system that tracks energy usage by sub-circuit off of the main campus line.
- Generation from solar facilities are added to the campus power line behind the utility meter, which allows them to roll the meter backwards.
- Dartmouth is currently implementing upgrades to their energy systems after installing their submetering system.

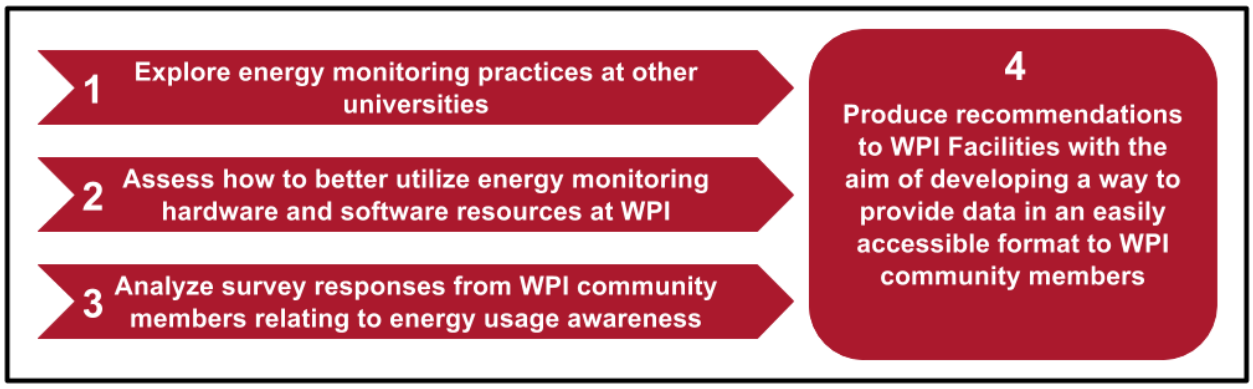
D Brief Project Proposal and Summary to WPI Facilities

The purpose of this document is to summarize the intentions and direction of this project for the WPI staff that are preparing for a proposal to the WPI administration.

To the WPI Department of Facilities,

The "Campus Energy Sustainability" group is a student project group working in the "Sustaining WPI" IQP Project Center, under the guidance of Professor Suzanne LePage (Civil and Environmental Engineering) and Professor Fred Looft (Electrical and Computer Engineering). The group's four members, Johnathan Adams, Andrew Flynn, Sultan Jilani, and Ethan Paul, are working throughout D-Term in the 2015-2016 school year to complete this project.

This Interactive Qualifying Project explores energy monitoring at WPI and how it may be improved in order to facilitate the presentation of energy usage data to the WPI community. The impetus for this project stems from the idea that providing community members with easily accessible energy usage data will not only raise awareness of energy usage on campus, but also provide students, faculty, and staff with the tools they need for future campus energy related research. This project has fourfold approach:



Through this fourfold approach, the Campus Energy Sustainability IQP group aims to provide Facilities with evidence to support an ongoing proposal to campus administrators for funding to make much needed upgrades to the energy monitoring hardware on campus.

Sincerly,
The Campus Energy Sustainability IQP Project Group

Johnathan Adams, Andrew Flynn, Sultan Jilani, and Ethan Paul

E Summary of Recommendations

These recommendations were formed based on the data presented in the Results section (Section 4 on page 15). The recommendations describe the tools involved in, and layout of, a system that will provide a comprehensive metering solution for all attributes of WPI's energy usage. This appendix is meant as a summary of the Recommendations section (Section 5 on page 31) for the WPI Department of Facilities.

Electrical Metering

Electricity use should be metered on a per-building basis through the installation of smart electricity meters in all campus buildings.

Natural Gas Metering

Natural gas smart meters should be installed buildings that comprise the majority of the utility usage on campus.

Water Metering

Distributed smart metering of potable water should be implemented at the building level, with the implementation of distributed metering of chilled and hot water as a secondary goal.

Steam Metering

The central steam distribution system should be metered at both the distribution source and destination to better determine line losses and system efficiency.

Community Engagement

To engage the WPI community in the university's ongoing sustainability efforts, a web application should be implemented that allows for real time observation of utility and energy usage on campus.

User Interface

The current HVAC control software should be expanded to control data flow and organization for the smart utility meters and control systems.