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A NETWORK INFRASTRUCTURE FOR REAL-TIME MONITORING OF CAMPUS ENERGY CONSUMPTION

by

SANDEEP KUNCHUM

A THESIS

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Approved by

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ABSTRACT

Pressing environmental concerns and rising energy costs have led many organizations to carefully review their energy consumption. Conservation requires that energy use be monitored accurately and continuously, to identify areas with higher energy consumption. Lighting has repeatedly been identified as such an area. A simple, yet effective method for reducing lighting energy consumption is retrofitting existing light fixtures with modern energy-efficient versions.

The University of Missouri-Rolla is currently carrying out a lighting retrofit of all fixtures on campus. The pilot building for this project is McNutt Hall, as it has the single highest consumption of lighting energy. The results of the pilot study will be used to guide the remainder of the retrofit project.

The focus of the research described in this thesis is the development and deployment of an automated, networked system for real-time monitoring of lighting energy. The specific contributions of the research involve the design of the lighting monitoring system architecture and the communication network that links it to the campus building automation system. The system has been deployed in McNutt Hall, and will be scaled to cover the entire campus in the immediate future.

By providing real-time high-resolution data, the system enables accurate calculation of the energy savings achieved by the lighting retrofit project. Early estimates indicate that the retrofits in McNutt Hall will achieve close to 70% savings in lighting energy consumption over one year. The payback time for this building is estimated to be close to four years, for an approximate project cost of $141,000. The figures highlight the considerable savings achieved, and further underscore the necessity for lighting retrofits across campus. The monitoring system developed will facilitate accurate accounting, identification of energy sinks, and decision making regarding future investments in energy conservation.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1 INTRODUCTION

Pressing environmental concerns and rising energy costs have led many organizations to carefully review their energy consumption. Conservation requires that energy use be monitored accurately and continuously, to identify areas with higher energy consumption. Moreover, deregulatory policies of the electric industry and the peak demand charges have necessitated the collection of accurate information about usage patterns. Building automation systems with integrated facilities are the most efficient means of gathering energy data, but are prohibitively expensive, and as such, rarely used. Metering products equipped with communication protocols serve as a more cost-effective alternative for a broad range of monitoring applications.

University campuses are no exception to the ongoing energy conservation drive. One of the main sources of energy consumption on a campus is lighting. In a university environment, numerous lighting appliances and fixtures operate continually, beyond regular business hours, resulting in considerably higher energy costs as compared to commercial organizations or residences.

A simple, yet effective method for reducing lighting energy consumption is retrofitting existing light fixtures with modern energy-efficient versions. The University of Missouri-Rolla (UMR) is currently carrying out a lighting retrofit of all fixtures on campus. The pilot building for this project is McNutt Hall, as it has the single highest consumption of lighting energy. The results of the pilot study will be used to guide the remainder of the retrofit project.

The focus of the research described in this thesis is the development and deployment of an automated, networked system for real-time monitoring of lighting energy. The system provides high-resolution, continually updated information about energy usage, which is critical to post-retrofit assessment of the project. The specific contributions of the research involve the design of the lighting monitoring system architecture and the communication network that links it to the campus building automation system. The system has been deployed in McNutt Hall, and will be scaled to cover the entire campus in the immediate future.

An electric meter or energy meter is a device that measures the energy consumption of a business or residence. The most common type is the *watt-hour* meter, where a rotor element is driven to revolve at a speed proportional to the power. The total energy consumption, measured in watt-hours, is determined by counting the number of revolutions of the rotor element. Meter installations are classified into two types: *direct-metered* and *master-metered* [1]. In a master-metered installation, the utility company installs a main meter at the service entrance of the building, and measures the total energy consumed. This poses a problem for multi-tenant buildings, as accounting for the individual energy consumption of each tenant is not possible.

Direct-metered installations are more appropriate for multi-tenant buildings, or any situation where more detailed accounting of energy usage is required. In such installations, a separate meter is installed for each tenant or other entity whose energy usage is to be monitored at an individual level. The main disadvantages of this approach are the number of meters required, as well as the space needed for their installation. An additional problem is the cost and feasibility of installing home-run wiring for the meters, which necessitates the connection of every meter to a single central panel. This can be a primary concern for larger entities, such as a university campus.

Submetering is a solution that allows for monitoring individual usage, while eliminating the space and wiring concerns associated with direct metering. In contrast to direct metering, submetering takes a distributed approach, by using smaller, less expensive meters to monitor individual entities. These submeters are connected to each other, but are not required to be wired to a central panel. This is a prudent approach for monitoring lighting energy consumption, where information is required for a large number of physically distributed entities throughout a building, e.g., laboratories and classrooms.

A lighting monitoring system encompasses the tasks of collecting energy usage data at regular intervals and reporting this data to one or more repository databases. An additional task is interfacing with the main building automation system (BAS). A BAS uses autonomous monitoring to coordinate, organize, and optimize the various control subsystems of a building, including HVAC equipment, security and fire systems, and electric meters. The BAS software aggregates data from all of these systems and presents this information in a variety of formats.

Low cost, interoperability, and conformance to standards are among the main criteria for any monitoring system [2]. Advances in communication technology have facilitated automation and remote maintenance of monitoring systems [3], enabling a broad range of tasks, from a reporting of a single faulty device to managing an entire network of meters [4]. One of the major tasks facilitated by monitoring systems is lowering of demand charges [5], [6], which are levied based on rate of energy consumption, rather than the total energy consumed. Spreading out demanding tasks throughout the day lowers the peak demand rate, and as a result, the demand charges. This is referred to as demand peak shaving. The typical approach is load shifting, where non-essential device or units with high power consumption are operated in shifts rather than in tandem, and are shut off during peak times. Modern energy monitoring systems can accurately predict the demand peak and schedule the equipment or units accordingly.

As detailed in the remainder of this thesis, the proposed monitoring system fulfills all of these requirements. As an initial application, the data collected by the system was used to assess the lighting retrofit of McNutt Hall. It is estimated that this retrofit will result in a 70% reduction in lighting energy consumption over a period of one year. From the financial perspective, the payback time for the investment is just under four years. Both figures highlight the considerable savings achieved, and further underscore the necessity for lighting retrofits across campus.

The remainder of this thesis is organized as follows. Section 2 provides a background and describes related literature. Section 3 elaborates on the problem statement and requirements, and compares two approaches to the overall system design. The architecture proposed for the lighting monitoring system is discussed in Section 4. The energy and cost savings achieved by the retrofit are presented in Section 5. Section 6 concludes the thesis and describes possible extensions to the research.

2 BACKGROUND AND RELATED WORK

This section provides a background to concepts relevant to the research, and discusses related work. Submetering, which was introduced in Section 1, is elaborated upon and a number of related energy conservation projects are discussed. Finally, a number of case studies on building automation systems are presented, including applications to university campuses and industrial plants.

2.1 SUBMETERING

As described in Section 1, submetering is an effective technique for gaining detailed information about energy usage. The increased granularity offered by this type of measurement system facilitates calculation of energy expenditures and savings related to retrofit programs. In addition, submetering allows each tenant to incur a service charge corresponding to only their own energy usage. Furthermore, it can measure the energy consumption associated with a particular task, such as lighting. Normally, a main electrical meter is installed in each building to monitor the total consumption of electrical energy. This meter is typically located at the main circuit breaker panel, where the electrical mains feed into the building. If lighting energy is monitored, the corresponding submeters are located near the circuit breaker panels into which the lighting circuits are wired. A university campus is a very appropriate scenario for submetering, due to the high number of buildings that need to be monitored individually.

The drive to reduce the amount of energy consumption in UMR has been the propelling factor behind the lighting retrofit project described in Section 1. Accurate estimation of lighting energy consumption necessitates submetering of the lighting circuits. The submeters chosen, which are described in greater detail in Section

3, have networking capability. This facilitates their connection to the supervisory HVAC controllers in the building, as well as the BAS network and eventually to the campus backbone or LAN. This facilitates the acquisition of their data by the operator workstation or server. Facility managers can use the information generated by the submeters to generate trend analysis reports of lighting energy consumption patterns. The BAS software can generate reports in various user-friendly formats for specified periods of times, i.e., for a day or week.

2.2 RELATED LIGHTING RETROFIT PROGRAMS

Many organizations in the United States are undergoing lighting retrofit programs aimed at reducing energy consumption and universities are no exception. Most of the university buildings in the country are very old, and contain older, inefficient lighting fixtures that are not compatible with modern building automation technologies. Extensive lighting retrofit projects are being carried out to replace the older fixtures and lighting appliances with newer fixtures that are more energy efficient.

One such lighting retrofit project is reported in [7], where the building in question is the library of the University of Technology in Malaysia. The various lighting fixtures in the library were retrofitted with newer ones capable of providing the same amount of luminance and performance at lower wattage. These retrofits included replacing the magnetic ballasts with electronic varieties, and installing high quality reflectors and compact fluorescent lamps instead of incandescent lamps. A data acquisition and monitoring system called Enflex® was also installed, and was responsible for logging data from as many as 576 electrical data logger points. The end devices range from HVAC equipment to meters and Air-Handling Unit (AHU) coils. These devices send the data through the serial communications protocol to a data logger that monitors as many as twelve electrical points. The retrofit exercise carried out by this university library has resulted in savings of approximately 40%

of the entire building load, with more than 70% of the savings attributed to lighting retrofits [7].

In a similar project at Yale University, the physical facilities department is gathering real-time data from numerous meters installed around campus [8] [9]. The university has older buildings, as well as new construction. Similar to the situation at UMR, the metering in the old campus buildings was not compliant with modern industry standards, and did not have an integrated communications interface. Therefore, the university decided to install a Modbus interface for the older meters to communicate with each other and also to the building automation network.

The newer buildings at Yale, including the School of Medicine, and the Yale New Haven Hospital are connected to a building automation network comprised of a Johnson Controls BAS, the Ethernet backbone of the university, various servers and the operator workstations. As a result, the university has a completely networked utilities metering system and significant energy savings have been obtained by regular monitoring of energy consumption on campus. This system has helped facility managers to optimize power plant parameters and flatten the peak demand by continuous analysis of building operations.

2.3 RELATED ENERGY MANAGEMENT SYSTEMS

The BAS or Energy Information System [10] is the heart of any modern energy monitoring system. Most modern structures, especially those on the scale of a university campus, employ such systems to facilitate easier management of their energy resources. This subsection discusses a number of case studies on the deployment and use of BASs.

In [11], the SISGEN Energy Management System is used for efficient control of the energy supply and consumption in all campuses of the University of Sao Paulo, Brazil. SISGEN is based on the dual network architecture of Modbus RS-485 and

TCP/IP communication protocols. This system, which has its own autonomous supervision module software, is able to constantly trend the required data and present it in graphical form. The study documents an annual reduction of 8000 MWh in the university's energy consumption. Newbold and Agarwal present a study carried out at the University of Nebraska Lincoln, where an energy management and control system has been developed in-house [12]. The system implementation began in the 1980s, with the primary aim of adapting to newer building automation standards. The developed control system has an interactive Java user interface that is used to trend data obtained from various monitoring points around the campus, and is based on an architecture that is comprised of networked controllers and servers running the software. This system underscores the need for an effective software solution for presentation of large amounts of data in user-friendly formats.

Electrical energy monitoring in an industrial scenario is described by Dorhofer and Heffington in [13]. The essential elements of the monitoring system and the network architecture are typically the same as that of a university. The difference arises in the monitoring needs of the facility managers. An industrial plant typically includes very large equipment with high power consumption. A small defect in these machines could lead to ineffective operation, thereby raising the potential energy expenditures. The use of current transducers for monitoring equipment such as large plasma cutters, air compressors and large press brakes is described in [13]. New monitoring points have also been proposed to control the operation of the press brakes and the plasma cutters.

The development of an Internet-based electric energy monitoring system is described in [14]. The data logger used in this study is of higher intelligence, as it facilitates time synchronization through the use of GPS signals. A data logger known as the Network Computing Terminal (NCT) is used to gather both digital and analog information. The NCT then transfers data to a database server or web server through an intranet or the Internet.

Of greatest relevance to the research presented in this thesis is the study described in [15]. The architecture described, which forms the basis for the architecture of the McNutt Hall lighting control system, breaks down the BAS structure into a hierarchy. This facilitates easier understanding of the entire system by facility managers and other users. The same hierarchical architecture has been used to enable communication among circuit breaker units. Engel and Murphy, in [16], present the idea of controlling all important breaker information by networking the circuit breakers to intelligent control systems. The circuit breakers communicate via twisted pair wires through an accessory bus to a variety of slave devices. Circuit breakers are daisy chained to one another for effective control and communication among them. A similar network is described in [17], where circuit breaker trip units communicate via RS-485 protocol to a display and monitoring unit. The trip units are small auxiliary contacts mounted on top of the circuit breakers. These units are daisy chained to a power meter that is also connected to the monitoring unit for the acquisition of data to a central location.

Pitzer College, a private undergraduate institution in Claremont, California, is also undertaking load curtailment programs that make power monitoring a stringent requirement [18]. The same basic principles have been applied; modern power meters are coupled with an Ethernet Gateway that communicates the data over a LAN, as well as powerful data analysis software. RS-485 protocols are being used to connect the lighting panels to be monitored. Advised by the utilities company to reduce its peak demand, Pitzer College has entered into a tariff agreement with the utility company. The agreement stipulates that Pitzer reduce its lighting loads during emergency periods, such as outage declarations by the utility company, which occur when the peak demand increases to a state where it cannot be met by the existing reserves of generated power.

The energy management and utility monitoring system (UMS) being used by the Hyatt Hotels Corporation is described in [19]. This paper discusses the issues involved in corporate enterprise-level energy management, and the steps taken by Hyatt in order to keep a validated account of their energy consumption. The corporation maintains a utility monitoring system, with a ThinServer [19] as the central element. This ThinServer gathers data from various metering points around the hotel buildings over various communication channels. The data is then sent to workstations where it is analyzed and reports are generated with EnerTel® software. The data analysis includes continuous load profiling. Any deviation from the normal is captured and analyzed to determine the root causes of the disparity. The ThinServer also transfers the collected data to a backup database. Insight into the complexity of managing energy consumption on a very large scale is given in [19], which describes network monitoring solutions with a UMS architecture, both at the enterprise level and at the local level, within a hotel building.

The interesting case of a retail store [1] in the Northeastern United States is presented in [20]. A submetering program was carried out to identify a dramatic increase in energy bills. Lighting energy, provided by a combination of incandescent and fluorescent bulbs, was found to be responsible for the bulk of the energy consumption, and a retrofit was carried out. Enercept™ meters and their associated data acquisition server have been used as a solution. The Enercept™ meters are digital meters that are capable of communicating with each other through serial communication. The Building Manager Online (BMO)™ software by Obvius™ has been used as reporting software. Given start and end dates of the period being investigated, the software plots various power quality characteristics, such as real and reactive power, phase

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[1] Name withheld in paper.

imbalances, and harmonic distortions for each day during the specified period. The configuration and data patterns of the control panels for which the data acquisition server collects the data can be viewed in the BMO window.

In conclusion, any modern monitoring application requires standard monitoring devices conforming to industry standards, appropriate monitoring software, and network connectivity among the monitoring devices. The reporting software of the BAS should be configurable, and capable of presenting data in a variety of user-friendly formats, as well as generating alerts in case of emergency situations such as the power demand exceeding the peak level. The data can be used by facility managers to assess and validate retrofit projects. Continuous commissioning is vital to energy conservation, and requires periodic refinement of building operations with the help of specialized energy analysis software.

3 REQUIREMENTS AND DESIGN CONSIDERATIONS

This section provides a more detailed description of the problem statement, and articulates short- and long-term solutions to the monitoring of lighting energy. The section concludes with a comparison of the two approaches.

3.1 PROBLEM STATEMENT

The objective of the UMR lighting retrofit program is replacement of old and inefficient lighting fixtures with their modern energy-efficient counterparts, with the ultimate goal of reducing lighting energy consumption. Assessing the success of the program necessitates accurate measurement of energy consumption. To this end, the autonomous monitoring system described in this thesis was designed and deployed.

As described in Section 1, McNutt Hall is the pilot building for the study. This building originally had three independent metering substations with GE 700X66G1™ meters. Throughout this thesis, the term substation is used to refer to a hub that connects two or more meters. The substations are not connected and cannot directly communicate with each other. Autonomous monitoring necessitated that these meters be connected to each other, and to the campus LAN. Similar connectivity was previously added to the CM 3350 Power Logic® meters at the campus power plant. These meters communicate with a server, but are running outdated trending software.

In contrast, the modern Enercept™ meters installed in the Havener Center building across from McNutt Hall and the power plant, have Ethernet connectivity, but are incompatible with the outdated software. The solution desired for McNutt Hall was a networked monitoring system linked to real-time data analysis software. Furthermore, the meters comprising the system were required to be compatible with industry automation protocols and device driver standards.

One of the initial designs conceived for monitoring the lighting energy in McNutt Hall involved the replacement of existing meters with Enercept™ meters, which offer the advantages enumerated below.

- *Ease of installation*, because of their split core current transformer [21] technology, which eliminates the need for the conductors to be removed before installation.
- *Choice of two forms*, the first of which is the 8035/8036 [21] with a Modbus communication interface. The second form is the H8025/8026 [21] series, which communicates on a Metasys N2® [22] bus.

Devices connected to the BAS are often associated with proprietary protocols, and hence, it is critical to select metering products that facilitate the use of open protocols and standards. Another important factor is ease of integration and forward compatibility with the changing building automation technologies. This again underscores the importance of support for open building automation standards, the most common of which are BACnet and LONWorks. The Enercept™ meters, depicted in Figure 3.1 are compatible with these protocols. This support for the major open communication protocols, and the reasonable costs of Enercept™ meters made them the products of choice for the McNutt Hall monitoring system. What makes them unique is their serial communication capability through the Modbus RS-485 protocol. The higher version of the Enercept™ meters, known as the Enhanced Enercept™ meters, is being used for the project at UMR. These meters can gather information about a range of parameters such as power factor, reactive power, apparent power and real power, and are comprised of a microprocessor-based electric meter and split core transducers. Each meter can monitor up to 63 electrical loads on a single RS-485 drop. The problem of incorrect CT load orientation during the meter installation is also rectified, as the meters can automatically detect and compensate for phase reversals [21].

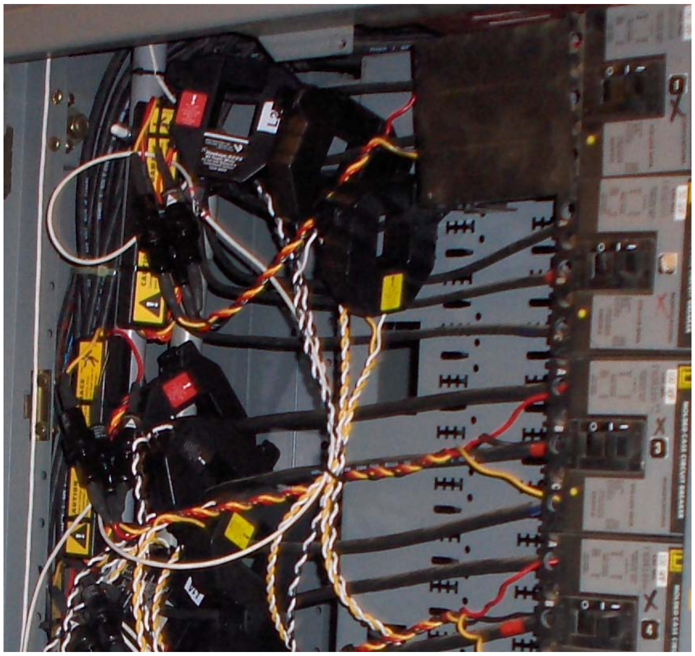


Figure 3.1. The Enercept™ meters.

3.2 SHORT-TERM SOLUTION: INDEPENDENT ARCHITECTURE

One of the short-term monitoring solutions identified was the deployment of a lighting monitoring infrastructure as an independent entity, with no connection to the BAS. This solution was rejected in favor of the networked architecture described in the next subsection and subsequent sections of the thesis. The description provided here is for reference only.

The main task associated with the implementation of an independent metering architecture is installation of the H8035/8036 meters, which should be daisy-chained and connected to the serial port of a server or data acquisition device. The Enercept™

meters were Ethernet-ready, but were not connected to the LAN, as they were incompatible with the outdated software running on the server that would be the final recipient of their data.

One solution to this problem was to connect a new data acquisition server (DAS) to the Enercept™ meters in different buildings, and tie them into the campus LAN. This approach required the procurement of two different servers, one for the UMR power plant and another for the Havener Center and McNutt Hall. In some cases, the DAS is accompanied with a trending software. This software can be used on any web-enabled server for analysis of the collected data. The DAS also includes a modem.

The other solution to the software incompatibility issue was upgrade of the existing software running on the server used for processing of the power plant data. This would provide a single point of access to the data from all three buildings, the power Plant, the Havener Center and McNutt Hall. Such an upgrade is costly, and would require an investment of approximately $20,000 towards purchasing packages such as Power Logic™'s System Management Software®, which is interoperable with the CM3350® meters situated at the power plant.

Implementation of an independent lighting monitoring system requires the following tasks:

- Laying down Ethernet cabling in McNutt Hall to connect the DAS to the server.
- Laying down RS-485 cabling to connect the daisy chained meters to the data acquisition device.
- Replacing the existing GE™ meters in the building with the new Enercept™ meters.
- Connecting these meters via RS-485 cable to a DAS compatible with the Enercept™ meters to gather and record the data from all meters.

- Connecting the DAS to the campus LAN. The data from the DAS is transported via Ethernet to the server hosting the trending software.
- Accessing the data from this server using any web browser.

3.3 LONG-TERM SOLUTION: NETWORKED ARCHITECTURE

The short-term approach of deploying an independent lighting monitoring system provides a temporary solution, but falls short of providing connectivity to the BAS, which provides a central point of control for the power, fire and security, and HVAC systems, regardless of their respective vendors. Any long-term solution to the monitoring of lighting energy requires incorporation of the monitoring system into the BAS architecture. The solution proposed in this thesis and implemented at UMR facilitates this integration by supporting the major open communication protocols, such as BacNet and LONWorks.

Among these protocols, as of the date of publication of this thesis, BACnet [23] was gaining wide popularity. Its main advantage is that it supports five different LAN technologies [24]. It is compatible with high-speed Ethernet, as well as low speed LAN technologies such as the ARCnet. It is also compatible with the proprietary LONTalk protocol, which enables BACnet and LONWorks controller products to share the LONTalk LAN. Nonetheless, these devices cannot interoperate, as this would necessitate the conformance of all the controller products to the standard LONMark agreement. This could be a factor of hindrance to an open architecture and the easy integration that is desired from a building control system. Typically, under these circumstances, the use of a gateway is required to facilitate interfacing of the two communication protocols.

BAS controllers can be connected to the Ethernet through their built-in-serial-to-Ethernet interface. The BAS-compatible software would be running on all servers to analyze the data received from various controllers across the campus. This would include all the lighting system controllers, the HVAC controllers and the controllers associated with building security.

The H8035/8036 meters proposed above require a gateway device for connection to the BAS. Other options include H8025/8026 Enercept™ meters, which can be directly connected to a Johnson Controls (JCI) Metasys® N2 bus, the proprietary cabling standard for connecting JCI controllers. Another option is to use BACnet® -compatible Enercept™ meters. This option was chosen for the UMR lighting monitoring project.

The following tasks were associated with deployment of the networked monitoring system at UMR. These tasks were carried out between July and October 2007 per the guidelines determined by the research described in this thesis.

The steps discussed below have been implemented for the UMR lighting monitoring system installation.

- Laying down Ethernet cabling in McNutt Hall to connect the DAS to the server.
- Laying down RS-485 cabling to connect the daisy chained meters to the data acquisition device.
- Installation of suitable gateways (if necessary) to integrate the power meters into the BAS network.
- Initial installation of building automation system controllers at different points in the building.
- Laying down either proprietary LAN or Ethernet cabling for the building automation system to connect the controllers.

- Connecting all application-specific controllers, supervisory controllers and servers to the BAS network. The next step would be to interconnect the BAS servers using the campus network.
- Replacing the existing old GE meters in the building with the new Enercept™ meters.
- Connecting these meters to the building automation system.

3.4 SUMMARY

McNutt Hall occupies an area of 145,000 square feet. A typical BAS costs between \$100,000 and \$130,000 for an area of approximately 200,000 square feet [10]. Considering energy rebates, and the annual savings offered by BAS providers, the payback period tends to be between five and seven years. A pared-down BAS, which could be procured at lower cost, would suffice for UMR's needs, as the main requirements are networking capability and the availability of a suitable software interface.

The most significant costs associated with a campus BAS are installation, operation, and maintenance costs. Such systems are usually procured with a 5-10 year maintenance contract. Contract costs are weighed against resulting energy savings to select the provider and solution with the greatest return on investment. A bidding process is required, with preference given to vendors with a long-standing relationship with the university. Typical unit pricing must be included in the bid, which includes the costs of the initial installation, maintenance and operation. The bid must also specify unit prices for future expansion. Table 3.1 summarizes the discussion and provides a comparison between the short- and long-term solutions described in this section.

Table 3.1. Comparison of available solutions.

	SHORT-TERM (NO BAS)	LONG-TERM
Meters	Enercept™	Enercept™
Installation Costs	Low (only meters)	Low (existing JCI BAS)
Cabling	RS-485 and Ethernet	N2 and Ethernet
Software costs	Procurement of DAS	Commissioning for JCI
Interoperability	Low	High

4 PROPOSED MONITORING ARCHITECTURE

The focus of this section is the architecture proposed for the lighting monitoring system. Details are given about the BAS already deployed on the UMR campus, components of the proposed architecture are described, and the integration of these components into a unified system is discussed.

4.1 EXISTING JOHNSON CONTROLS INFRASTRUCTURE

The BAS currently deployed on the UMR campus is the Johnson Controls™ Infrastructure (JCI), specifically, the Metasys® architecture. This simple, hierarchical architecture integrates numerous controllers manufactured by Johnson Controls, including air volume controllers, air handling units, and zone temperature controllers in the form of HVAC equipment.

The integral element of a Metasys® architecture is the network automation engine (NAE). These application engines are the intermediate supervisory controllers that control all of the field equipment devices installed at various points on campus. The NAE is able to provide the integration required between the Metasys® Architecture and the BACnet, LONworks and N2 devices. For example, if the Metasys® features field equipment controllers that use BACnet as their data communications protocol, then these controllers can be connected to web servers or user interfaces through the NAE. In brief, outstanding features of the Metasys® system include the following.

- High scalability
- Ease of integration of devices from various third party vendors
- Suitability for the size and layout of university campuses

- Inclusion of intelligent stand alone-controllers
- Compatibility with BACnet, LONWorks and Modbus protocols
- Ease of configuration

The automation engines from Johnson Controls come in various configurations, such as NAE-35 and NAE-55. The NAE-35 currently installed in McNutt Hall is shown in Figure 4.1.

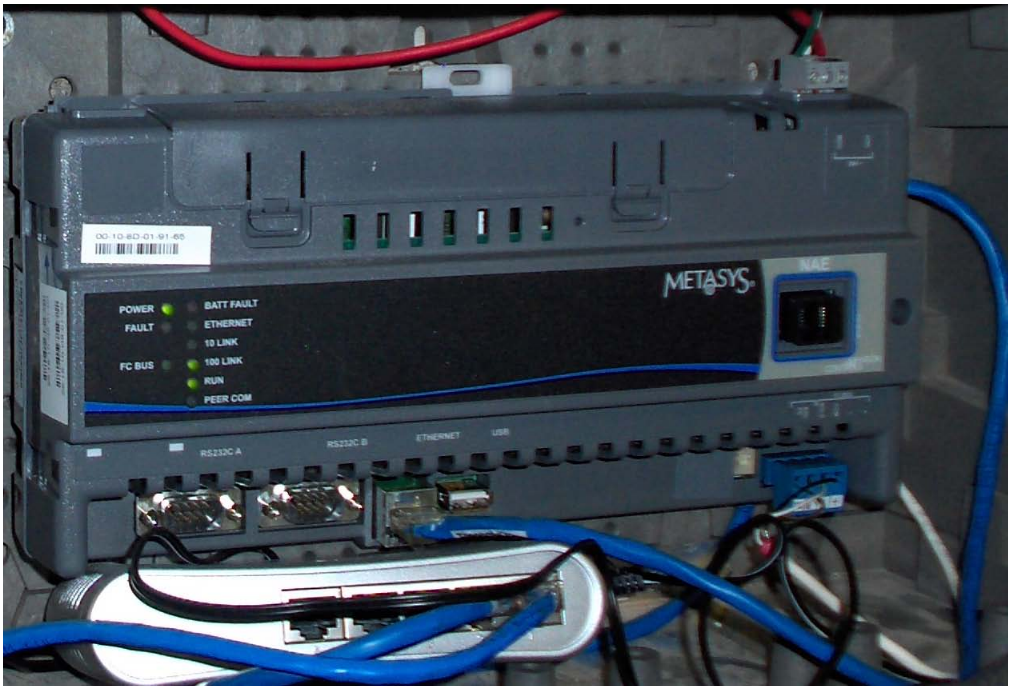


Figure 4.1. The NAE-35 Network Automation Engine.

For the UMR campus, selection of Johnson Controls products would facilitate a clean architecture that uses N2 cabling to directly interconnect the Enercept™ meters with its NAE-35, without requiring an intermediate gateway device. The NAE is similar in function to any DAS, as an authorized user is able to access the collected data through an interactive and user-friendly GUI. The GUI can be reached and executed from Java-enabled web browser on any computer.

4.2 SYSTEM COMPONENTS AND COST STRUCTURE

Table 4.1 depicts the initial cost estimate provided to the university by Johnson Controls. The lighting panels in McNutt Hall house circuits for the lighting fixtures in various offices, classrooms, laboratories and corridors of the building. The maximum switch breaker current rating associated with the lighting panels is 225 A, and the minimum rating is 100 A.

The AH08 coils are needed at each substation to step up the current transducers to the level of the primary current being carried on the conductors. For instance, the primary current rating on substation three in McNutt Hall is of the order of 2000-3000 A, and using a 2000:5 current transducer would necessitate a step-up coil to accommodate current ratings of more than 2000 A.

Commissioning and software support are very important to ensure that the system operates continuously and according to specifications. The associated fees charged by the vendor include annual maintenance visits.

Table 4.1. Initial cost estimate.

QUANTITY	DESCRIPTION	UNIT PRICE	TOTAL
8	100 A Enercept™ meters	$759	$6072
2	225 A Enercept™ meters	$781	$1562
3	Shunting terminal blocks	$55	$165
3	AH08 Step-up coils	$123	$369
1	NAE-35	$2742	$2742
12	Commissioning/software support	$93.50	$1122
GRAND TOTAL	-	-	$12,032

However, Johnson Controls has a long-standing business relationship with UMR, and the majority of the controllers on campus have been manufactured and are maintained by them. In light of this positive association, and the high levels of scalability and interoperability provided by the NAE-35, this server was selected as the computational core of the system.

Table 4.2 shows the final cost structure, which differs from the original quote only in the price of the NAE-35, which was reduced from \$2742 to \$1895. The relationship with Johnson Controls was leveraged to negotiate a substantial discount on this cost, bringing it closer to the price of other comparable data acquisition devices. The final cost of the complete system was \$11,185.

Table 4.2. Final cost structure.

QUANTITY	DESCRIPTION	UNIT PRICE	TOTAL
8	100 A Enercept™ meters	\$759	\$6072
2	225 A Enercept™ meters	\$781	\$1562
3	Shunting terminal blocks	\$55	\$165
3	AH08 Step-up coils	\$123	\$369
1	**NAE-35**	**\$1895**	**\$1895**
12	Commissioning/software support	\$93.50	\$1122
GRAND TOTAL	-	-	**\$11,185**

4.3 THREE-TIER ARCHITECTURAL DESIGN

The three-tier architecture depicted in Figure 4.2 is proposed for the lighting monitoring system in McNutt Hall. The three tiers, from bottom to top, represent the *field controller*, *automation*, and *management* levels in accordance with the framework in [25], respectively. Each tier differs from the other two in the level of networking capabilities and intelligence of the devices involved. A detailed description of each tier follows.

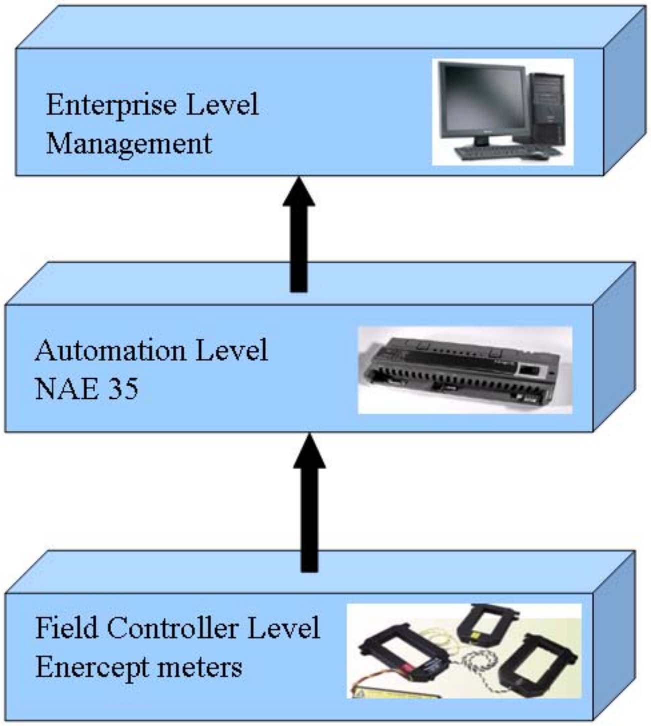


Figure 4.2. Three-tier UMR lighting monitoring system architecture.

Field Controller Level: This level involves the devices at the lowest rung of the ladder, which interface with the various sensors on campus. Examples include occupancy sensors, infrared sensors and lighting fixtures. All of the sensors and light fixtures are connected to their respective circuit breaker panels. The main circuit breaker panel board for lighting is located at Substation 3. McNutt Hall has seven lighting circuit breaker subpanels, namely panels L2B, L1, L1A, L2A, L3, LB, and L2. All lighting circuit wiring terminates in these subpanels, making the panel board the logical location for installation of monitoring equipment.

The Enercept™ meters are the most important components of the field controller level. The meters from the three substations in McNutt Hall are serially connected in daisy chain fashion using N2 cabling. They are also connected to the serial port of the NAE. Figure 4.3 depicts the field controller level of the architecture. The figure shows only meters from Substation 3, as this substation houses all of the lighting circuits. Energy consumed by other devices is out of the scope of this thesis, and not of interest.

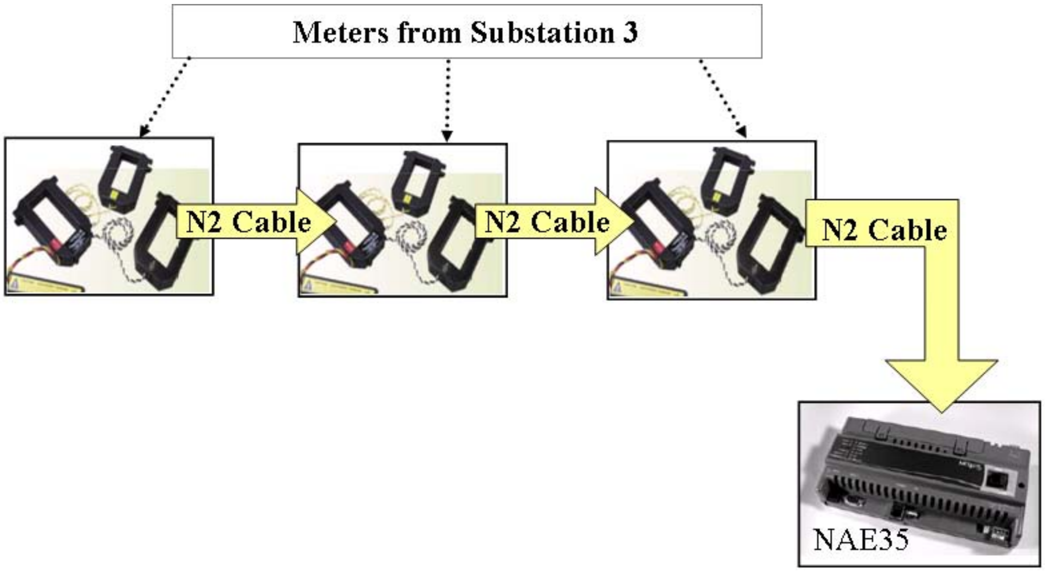


Figure 4.3. Field controller level of monitoring architecture.

Automation Level: This level, depicted in Figure 4.4, forms the crux of the modular architecture, and is comprised of controllers with greater processing capabilities than the terminal controllers. As mentioned in Section 4, the NAE-35 is used as the supervisory controller in the UMR lighting control BAS architecture. If multiple NAEs are used, one can be configured as a site director and serve as a data repository.

The NAE-35 serves as the gateway for communication of data over the campus backbone, using several RS-485 serial ports and one Ethernet port. As shown in Figure 4.4, the Enercept™ meters from the field controller level are daisy chained to the serial port of the NAE-35, and NAE-35's Ethernet port is connected to the database servers or workstations through the campus LAN. The NAE-35 supports both of the major building automation protocols. Specifically, it can interface to a maximum of 64 LONWorks network devices and can provide BACnet over Ethernet tunneling, facilitating future integration with other systems, and ensuring scalability.

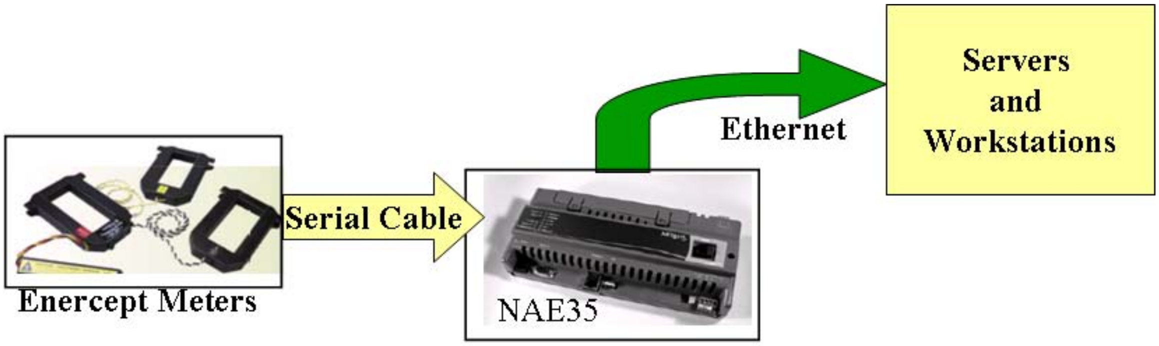


Figure 4.4. Automation level of monitoring architecture.

Management Level: This is the highest level of the modular architecture, and represents the interface of the monitoring system to facility managers and building automation technicians. As depicted in Figure 4.5, data from the NAE-35 is sent over Ethernet cables to the Johnson Controls ADS server. This extended database server provides authorized users such as operators and facility managers with continuous access to the collected data from any web-enabled computer.

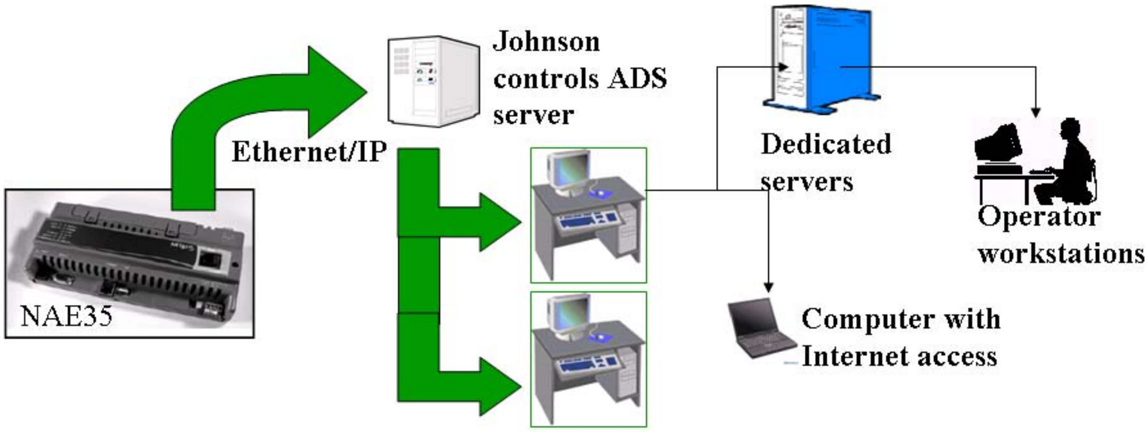


Figure 4.5. Management level of monitoring architecture.

5 PROJECTION OF SAVINGS IN LIGHTING ENERGY

The ultimate goals of the lighting monitoring system are collection of data to be used in profiling the consumption of lighting energy, identifying areas where savings can be achieved, and calculating these savings. This section presents the energy savings projected for the lighting retrofit of McNutt Hall. Throughout this section, any figure representing power or energy refers to these values for lighting alone. Other energy-consuming devices and systems are outside the scope of this thesis.

The first step in calculating the lighting energy savings is to determine the total nominal pre- and post-retrofit power consumption. The lights in McNutt Hall fall into three categories: room (office, laboratory and classroom), corridor, and outdoor lights. Any circuit used for room lighting is connected to one of seven lighting panels: L1, L1A, L2, L2A, LB, L2B, and L3. Appendix A details the energy consumption of the lighting circuits on each panel, both before and after the retrofits.

Equation 5.1 can be used with data from Tables A.1, A.3, A.5, A.7, A.9, A.11, and A.13, to determine the total pre-retrofit wattage for the lighting panels. Similarly, Tables A.2, A.4, A.6, A.8, A.10, A.12, and A.14 are used to calculate the total post-retrofit wattage. The tables provide the nominal values.

$$\begin{aligned}\text{Total wattage of room lights} &= \sum \text{power rating of each fixture} \\ &= \begin{cases} 218.189\text{ kW} & \text{pre-retrofit} \\ 92.5\text{ kW} & \text{post-retrofit} \end{cases}\end{aligned} \tag{5.1}$$

The lighting monitoring system was deployed on July 31, 2007. Fall classes began on August 20, 2007. The intent was to measure power consumption for a full month when classes are in session, specifically, September 1 to October 1, 2007. By this time, only a subset of the light fixtures had been retrofitted, specifically, the fixtures identified in Appendix C. The total pre- and post-retrofit wattage of the room fixtures in this subset, as of October 1, 2007, are 65,442 W and 28,893 W, respectively. This data is used in Equation 5.2 to refine the estimate for the total wattage of all room fixtures. As of October 1, 2007:

$$\begin{aligned}\text{Total wattage of room lights} &= \text{Total pre-retrofit wattage of room lights} \\ &\quad - \text{Pre-retrofit wattage of retrofitted room lights} \\ &\quad + \text{Post-retrofit wattage of retrofitted room lights} \\ &= 218,189 - 65,442 + 28,893 \text{ W} \\ &= 181,640 \text{ W}\end{aligned} \tag{5.2}$$

Based on an estimated annual operating time of 3000 hours for rooms (laboratories, classrooms and offices), the annual and monthly energy consumption of the retrofitted room fixtures are calculated using Equations 5.4 and 5.5, respectively.

$$\text{Annual kWh} = \frac{\text{Operating hours/day} * 365 * \text{Total wattage}}{1000} \tag{5.3}$$

$$\begin{aligned}\text{Total annual kWh of room lights} &= \frac{3000 * 181,640}{1000} \\ &= 544,920 \text{ kWh}\end{aligned} \tag{5.4}$$

$$\begin{aligned}\text{Total monthly kWh of room lights} &= \frac{544,920}{12} \\ &= 45,410 \text{ kWh}\end{aligned} \tag{5.5}$$

In addition to room lights, energy is also consumed by corridor fixtures, which can be divided into two groups based on their estimated annual operating time. Some of the corridor lights are on for 24 hours a day, resulting in an annual operating time of 8760 hours. The annual operating time for the rest of the corridor fixtures is estimated to be 4680 hours. During the monitored period of September 1 to October 1, 2007, the total nominal wattage of the continually operating corridor lights was 5860 W. The total wattage of the remaining fixtures during the same period was 4940 W.

$$\begin{aligned}\text{Total wattage of corridor lights} &= 5860 + 4940 \\ &= 10,800 \text{ W}\end{aligned} \tag{5.6}$$

The resulting annual and monthly energy consumption of the corridor fixtures is given by Equations 5.7 and 5.8, respectively.

$$\begin{aligned}\text{Total annual kWh of corridor lights} &= \frac{4680 * 4940}{1000} + \frac{8760 * 5860}{1000} \\ &= 74,452 \text{ kWh}\end{aligned} \tag{5.7}$$

$$\begin{aligned}\text{Total monthly kWh of corridor lights} &= \frac{74,452}{12} \\ &= 6204 \text{ kWh}\end{aligned} \tag{5.8}$$

Equations 5.2 and 5.6 can be used to determine the total wattage of room and corridor lights as of October 1, 2007:

$$\begin{aligned}\text{Total wattage of room and corridor lights} &= 181,640 + 10,800 \\ &= 192,440 \text{ W}\end{aligned} \tag{5.9}$$

The estimated total energy consumption for room and corridor lighting over the period of September 1 to October 1, 2007 is given by the sum of Equations 5.5 and 5.8.

$$\begin{aligned} \text{Estimated monthly kWh of room and corridor lights} &= 45,410 + 6204 \quad (5.10) \\ &= 51,614 \text{ kWh} \end{aligned}$$

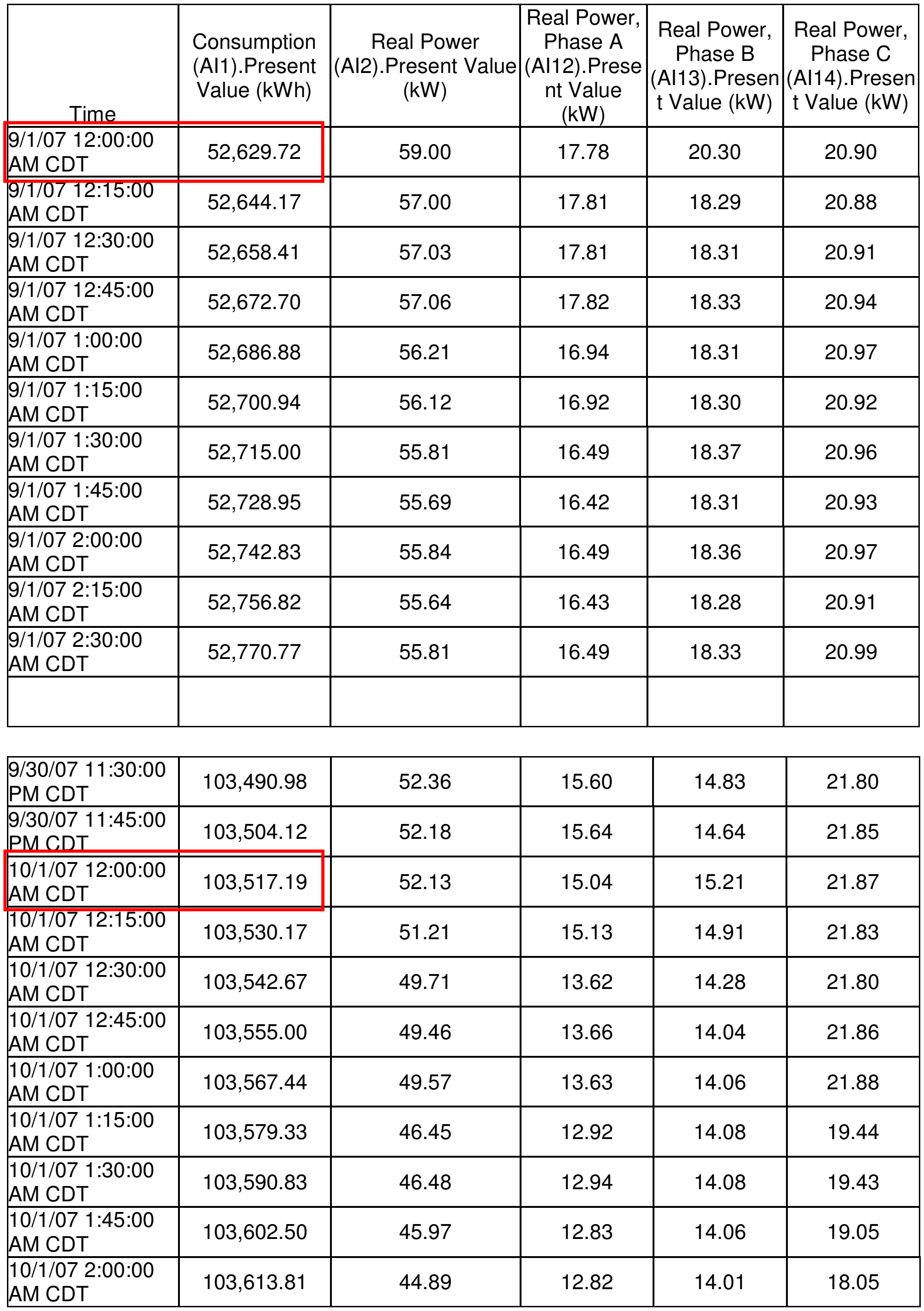
The next step in calculating the energy savings is to compare the estimated monthly kWh of lighting energy, given by Equation 5.10, to the actual value reported by the Johnson Controls server for the period of September 1 to October 1, 2007. If these readings are close, it shows that the estimated operating times are a good approximation of the actual usage patterns.

Figures 5.1 and 5.2 show the data updates sent every 15 minutes from the Johnson Controls extended architecture server. Snapshots from the Metasys® software are provided in Appendix B. This software is used by facility managers located in the Physical Facilities building to track data from McNutt Hall.

The first row of the Johnson Controls server readings in Figure 5.1 shows that the total lighting energy consumed from installation of the monitoring system to 12:00:00 AM on September 1, 2007 is 52,629 kWh. The figure also shows that the total energy consumed by 12:00:00 AM on October 1st is 103,517 kWh. Therefore, the total lighting energy consumed between September 1 and October 1, 2007, according to the server readings, is:

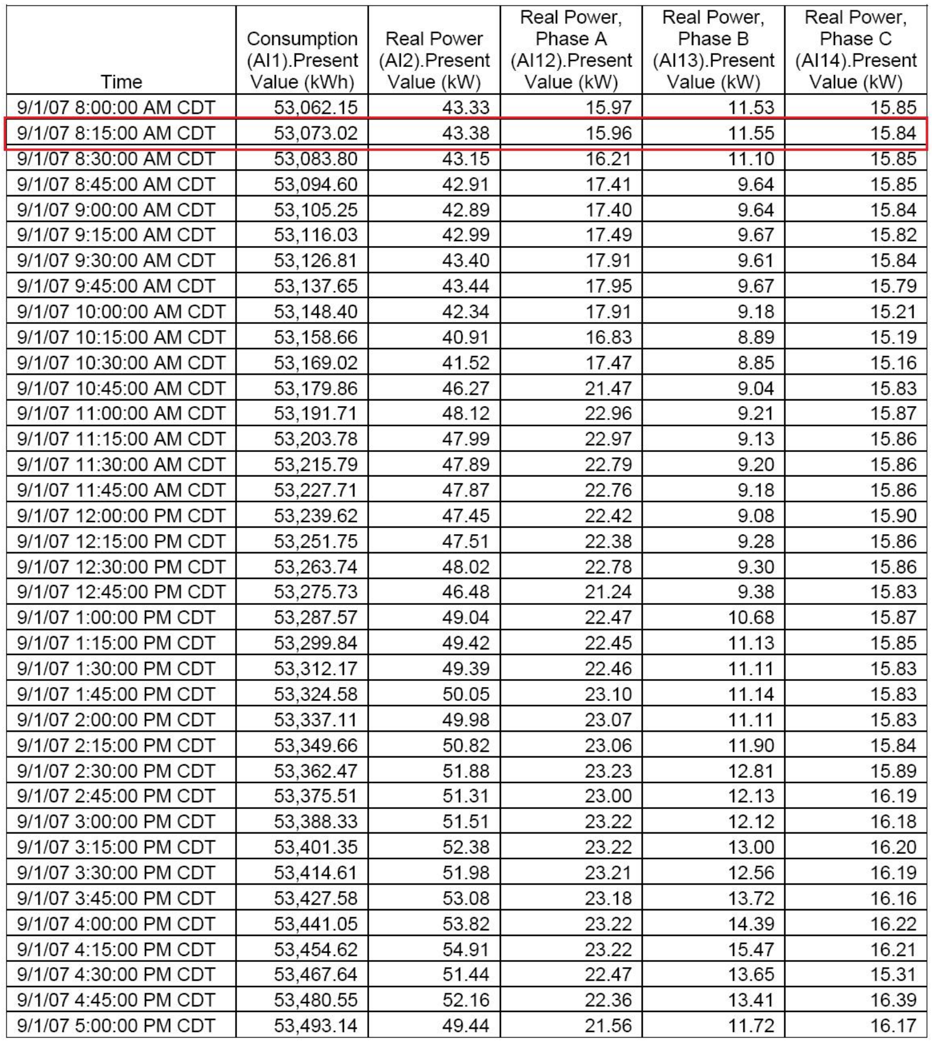
$$\begin{aligned} \text{Energy consumption reported for Sept. 2007} &= 103,517 - 52,629 \quad (5.11) \\ &= 50,888 \text{ kWh} \end{aligned}$$

The calculations in Equation 5.10 have not taken outdoor fixtures into account, but the server readings include them. Thus, in order to have a correct estimate, it is



Time	Consumption (AI1).Present Value (kWh)	Real Power (AI2).Present Value (kW)	Real Power, Phase A (AI12).Present Value (kW)	Real Power, Phase B (AI13).Present Value (kW)	Real Power, Phase C (AI14).Present Value (kW)
9/1/07 12:00:00 AM CDT	52,629.72	59.00	17.78	20.30	20.90
9/1/07 12:15:00 AM CDT	52,644.17	57.00	17.81	18.29	20.88
9/1/07 12:30:00 AM CDT	52,658.41	57.03	17.81	18.31	20.91
9/1/07 12:45:00 AM CDT	52,672.70	57.06	17.82	18.33	20.94
9/1/07 1:00:00 AM CDT	52,686.88	56.21	16.94	18.31	20.97
9/1/07 1:15:00 AM CDT	52,700.94	56.12	16.92	18.30	20.92
9/1/07 1:30:00 AM CDT	52,715.00	55.81	16.49	18.37	20.96
9/1/07 1:45:00 AM CDT	52,728.95	55.69	16.42	18.31	20.93
9/1/07 2:00:00 AM CDT	52,742.83	55.84	16.49	18.36	20.97
9/1/07 2:15:00 AM CDT	52,756.82	55.64	16.43	18.28	20.91
9/1/07 2:30:00 AM CDT	52,770.77	55.81	16.49	18.33	20.99
9/30/07 11:30:00 PM CDT	103,490.98	52.36	15.60	14.83	21.80
9/30/07 11:45:00 PM CDT	103,504.12	52.18	15.64	14.64	21.85
10/1/07 12:00:00 AM CDT	103,517.19	52.13	15.04	15.21	21.87
10/1/07 12:15:00 AM CDT	103,530.17	51.21	15.13	14.91	21.83
10/1/07 12:30:00 AM CDT	103,542.67	49.71	13.62	14.28	21.80
10/1/07 12:45:00 AM CDT	103,555.00	49.46	13.66	14.04	21.86
10/1/07 1:00:00 AM CDT	103,567.44	49.57	13.63	14.06	21.88
10/1/07 1:15:00 AM CDT	103,579.33	46.45	12.92	14.08	19.44
10/1/07 1:30:00 AM CDT	103,590.83	46.48	12.94	14.08	19.43
10/1/07 1:45:00 AM CDT	103,602.50	45.97	12.83	14.06	19.05
10/1/07 2:00:00 AM CDT	103,613.81	44.89	12.82	14.01	18.05

Figure 5.1. Nighttime snapshot of data updates from the server.



Time	Consumption (AI1).Present Value (kWh)	Real Power (AI2).Present Value (kW)	Real Power, Phase A (AI12).Present Value (kW)	Real Power, Phase B (AI13).Present Value (kW)	Real Power, Phase C (AI14).Present Value (kW)
9/1/07 8:00:00 AM CDT	53,062.15	43.33	15.97	11.53	15.85
9/1/07 8:15:00 AM CDT	53,073.02	43.38	15.96	11.55	15.84
9/1/07 8:30:00 AM CDT	53,083.80	43.15	16.21	11.10	15.85
9/1/07 8:45:00 AM CDT	53,094.60	42.91	17.41	9.64	15.85
9/1/07 9:00:00 AM CDT	53,105.25	42.89	17.40	9.64	15.84
9/1/07 9:15:00 AM CDT	53,116.03	42.99	17.49	9.67	15.82
9/1/07 9:30:00 AM CDT	53,126.81	43.40	17.91	9.61	15.84
9/1/07 9:45:00 AM CDT	53,137.65	43.44	17.95	9.67	15.79
9/1/07 10:00:00 AM CDT	53,148.40	42.34	17.91	9.18	15.21
9/1/07 10:15:00 AM CDT	53,158.66	40.91	16.83	8.89	15.19
9/1/07 10:30:00 AM CDT	53,169.02	41.52	17.47	8.85	15.16
9/1/07 10:45:00 AM CDT	53,179.86	46.27	21.47	9.04	15.83
9/1/07 11:00:00 AM CDT	53,191.71	48.12	22.96	9.21	15.87
9/1/07 11:15:00 AM CDT	53,203.78	47.99	22.97	9.13	15.86
9/1/07 11:30:00 AM CDT	53,215.79	47.89	22.79	9.20	15.86
9/1/07 11:45:00 AM CDT	53,227.71	47.87	22.76	9.18	15.86
9/1/07 12:00:00 PM CDT	53,239.62	47.45	22.42	9.08	15.90
9/1/07 12:15:00 PM CDT	53,251.75	47.51	22.38	9.28	15.86
9/1/07 12:30:00 PM CDT	53,263.74	48.02	22.78	9.30	15.86
9/1/07 12:45:00 PM CDT	53,275.73	46.48	21.24	9.38	15.83
9/1/07 1:00:00 PM CDT	53,287.57	49.04	22.47	10.68	15.87
9/1/07 1:15:00 PM CDT	53,299.84	49.42	22.45	11.13	15.85
9/1/07 1:30:00 PM CDT	53,312.17	49.39	22.46	11.11	15.83
9/1/07 1:45:00 PM CDT	53,324.58	50.05	23.10	11.14	15.83
9/1/07 2:00:00 PM CDT	53,337.11	49.98	23.07	11.11	15.83
9/1/07 2:15:00 PM CDT	53,349.66	50.82	23.06	11.90	15.84
9/1/07 2:30:00 PM CDT	53,362.47	51.88	23.23	12.81	15.89
9/1/07 2:45:00 PM CDT	53,375.51	51.31	23.00	12.13	16.19
9/1/07 3:00:00 PM CDT	53,388.33	51.51	23.22	12.12	16.18
9/1/07 3:15:00 PM CDT	53,401.35	52.38	23.22	13.00	16.20
9/1/07 3:30:00 PM CDT	53,414.61	51.98	23.21	12.56	16.19
9/1/07 3:45:00 PM CDT	53,427.58	53.08	23.18	13.72	16.16
9/1/07 4:00:00 PM CDT	53,441.05	53.82	23.22	14.39	16.22
9/1/07 4:15:00 PM CDT	53,454.62	54.91	23.22	15.47	16.21
9/1/07 4:30:00 PM CDT	53,467.64	51.44	22.47	13.65	15.31
9/1/07 4:45:00 PM CDT	53,480.55	52.16	22.36	13.41	16.39
9/1/07 5:00:00 PM CDT	53,493.14	49.44	21.56	11.72	16.17

Figure 5.2. Daytime snapshot of data updates from the server.

necessary to deduct the consumption by outdoor fixtures from the total energy of Equation 5.11. McNutt Hall has 35 outdoor fixtures of 80W each. Eight of these 35 fixtures operate continually, for an annual total of 8760 hours. The remaining 27 fixtures are on for 13 hours per day, for a total of 4745 hours per year. The nominal and reported monthly energy consumption of the outdoor light fixtures is calculated in Equation 5.12.

$$\begin{aligned} \text{Total monthly kWh of outdoor lights} &= \frac{8760 * 8 * 80 + 4745 * 27 * 80}{12,000} \quad (5.12)\\ &= 1321 \text{ kWh} \end{aligned}$$

The actual monthly energy consumption reported by the server, given in Equation 5.11 is adjusted by this value to facilitate comparison of the estimated and reported values of lighting energy.

$$\begin{aligned} \text{Reported monthly kWh of room and corridor lights} &= 50,888 - 1321 \quad (5.13)\\ &= 49,567 \text{ kWh} \end{aligned}$$

Comparison of the estimated and reported values of monthly lighting energy, given in Equations 5.10 and 5.13, respectively, indicates that the values are within 4% of each other. This validates the assumptions made regarding the operating times of room and corridor lights.

Complete characterization of the energy savings achieved by the lighting retrofit requires examination of the peak demand. The total power consumption of the room and corridor lights during September 2007 is estimated to be 192.44 kW, as given in Equation 5.9. After the retrofit is completed, the total power consumption of the room lights is estimated to be 92.5 kW, according to Equation 5.1. Using this value and Equation 5.6:

$$\begin{aligned} \text{Wattage of room and corridor lights after full retrofit} &= 92.5 + 10.8 \quad (5.14)\\ &= 103.3 \text{ kW} \end{aligned}$$

The peak demand reported by the server for the room and corridor lights during the month of September 2007 is 124.7 KWD, corresponding to 64.7% of the total power estimated for these lights during the same period. This measurement was taken during daylight hours, when the outdoor fixtures are switched off. Assuming the same ratio will hold when all retrofits are completed, the peak demand is projected to be:

$$\begin{aligned}\text{Peak demand after full retrofit} &= .647 * 103.3 \\ &= 66.8 \text{ KWD}\end{aligned} \tag{5.15}$$

This leads to annual peak demand savings of:

$$\begin{aligned}\text{Annual peak demand savings of full retrofit} &= 124.7 - 66.8 \\ &= 57.9 \text{ KWD}\end{aligned} \tag{5.16}$$

The peak demand savings are calculated on an annual basis, as shown in Equation 5.17, where $8.73311 is assumed to be the monthly KWD rate.

$$\begin{aligned}\text{Peak demand cost savings of full retrofit} &= (57.9) * 12 * 8.73311 \\ &= \$6068 \text{ per year}\end{aligned} \tag{5.17}$$

The total power savings achieved by retrofitting the room lights is, from Equation 5.1:

$$\begin{aligned}\text{Total power savings of room light retrofit} &= 218.189 - 92.5 \\ &= 125.689 \text{ kW}\end{aligned} \tag{5.18}$$

This corresponds to estimated annual energy savings of 377,067 kWh:

$$\begin{aligned}\text{Total annual savings of room light retrofit} &= 125.689 * 3000 \\ &= 377,067 \text{ kWh}\end{aligned} \tag{5.19}$$

Retrofit of the continually operating and intermittently operating corridor fixtures is estimated to achieve annual savings of 3630 W and 4281 W, respectively. Hence:

$$\begin{aligned} \text{Total power savings of corridor retrofit} &= 3.630 + 4.281 \\ &= 7.911 \text{ kW} \end{aligned} \tag{5.20}$$

$$\begin{aligned} \text{Total annual savings of corridor retrofit} &= \frac{4680 * 3630 + 8760 * 4281}{1000} \\ &= 52,489 \text{ kWh} \end{aligned} \tag{5.21}$$

From Equations 5.19 and 5.21:

$$\begin{aligned} \text{Total annual energy savings} &= 377,067 + 52,489 \\ &= 429,556 \text{ kWh} \end{aligned} \tag{5.22}$$

Equation 5.10 can be used to express these savings as a percentage, which better demonstrates the magnitude of the impact:

$$\begin{aligned} \text{Percentage energy savings of retrofit} &= \frac{\text{Total savings}}{\text{Total pre-retrofit consumption}} \\ &= 100 * \frac{429,556}{12 * 51,614} \\ &= 69.4\% \end{aligned} \tag{5.23}$$

Figures 5.3 and 5.4 depict the changes in the lighting load between 7 am and midnight on several different dates. Both pre- and post-retrofit dates have been chosen to illustrate the impact of the retrofit.

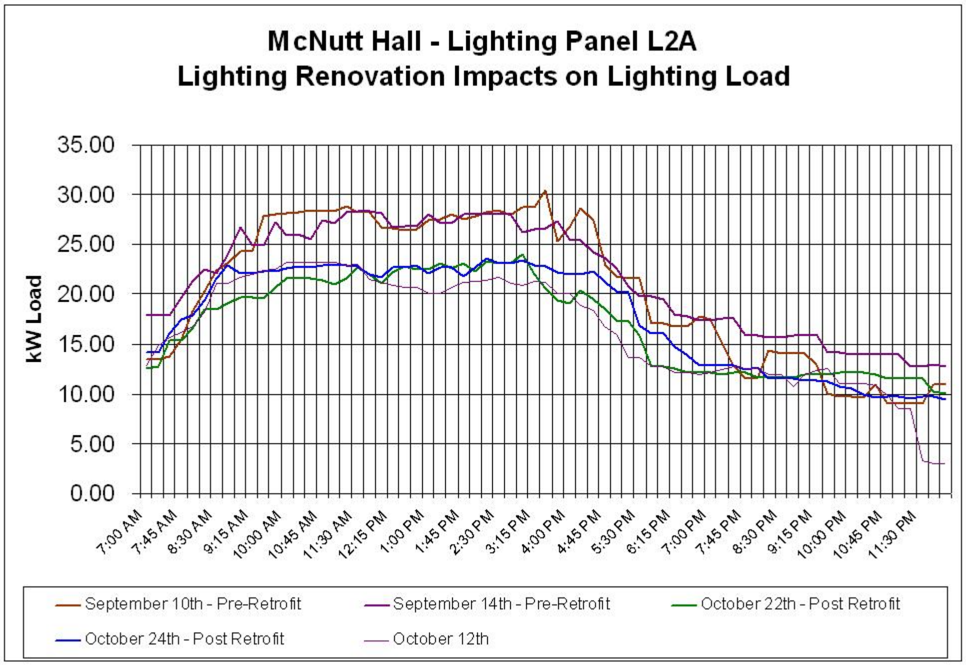


Figure 5.3. Impact of retrofit on the load of Panel L2A.

As an aside, the total power savings achieved by the retrofit can be calculated from Equations 5.18 and 5.20:

$$\begin{aligned} \text{Total power savings of retrofit} &= \text{room savings} + \text{corridor savings} \qquad (5.24) \\ &= 125.689 + 7.911 \\ &= 133.6 \text{ kW} \end{aligned}$$

Expressing power savings as a percentage underscores the impact of the retrofit:

$$\begin{aligned} \text{Percentage power savings of retrofit} &= \frac{\text{Total savings}}{\text{Total pre-retrofit consumption}} \qquad (5.25) \\ &= 100 * \frac{133.6}{218.189 + 10.8} \\ &= 58.3\% \end{aligned}$$

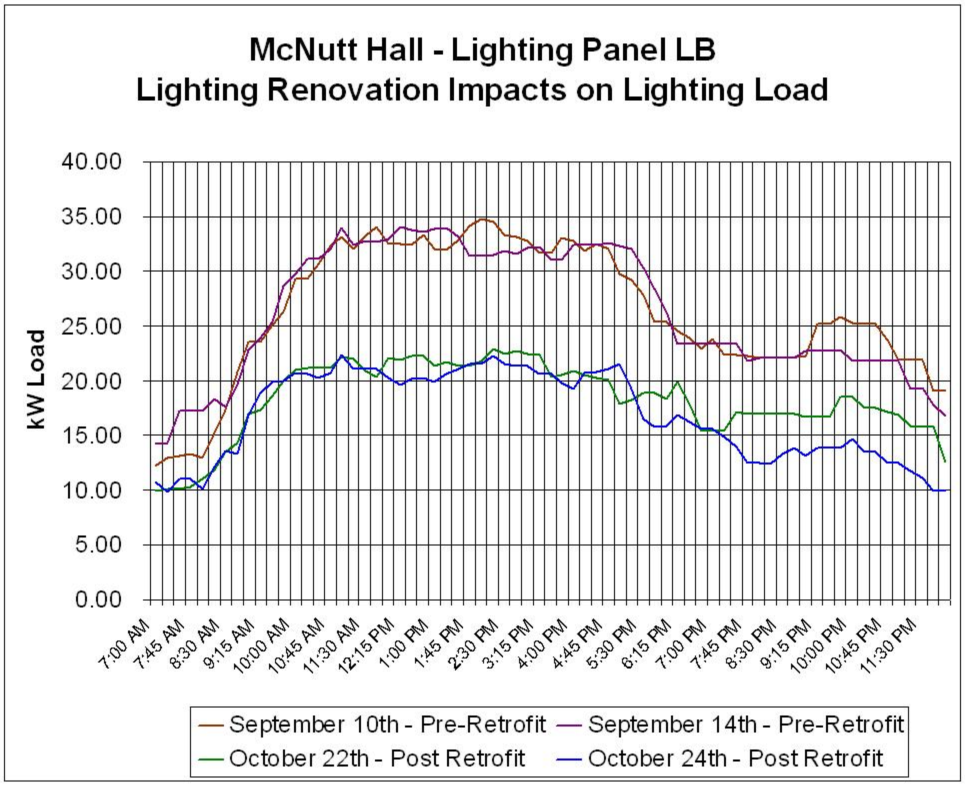


Figure 5.4. Impact of retrofit on the load of Panel LB.

Assuming the rate of \$0.06884/kWh, the dollar value of the energy savings achieved by the McNutt hall retrofits is:

$$\begin{aligned} \text{kWh cost savings of retrofit} &= 429{,}556 * 0.06884 \qquad (5.26) \\ &= \$29{,}571 \text{ per year} \end{aligned}$$

From Equations 5.17 and 5.26:

$$\begin{aligned} \text{Total cost savings of retrofit} &= \text{KWD savings} + \text{kWh savings} \qquad (5.27) \\ &= \$6068 + \$29{,}571 \\ &= \$35{,}639 \text{ per year} \end{aligned}$$

Additional savings are achieved through reductions in air conditioning, as the new fixtures generate less heat than the older fixtures. These savings are not reflected in the calculations of this section, due to the difficulty of accurately measuring them. The total retrofit cost of a given fixture is due to replacement of the ballast and bulbs, recycling of the tube and ballast, labor, and overhead charges. The total retrofit cost for all lighting panels other than panel L2B is \$125,226. The total retrofit costs for the corridor fixtures and panel L2B are \$15,128. Both figures include the costs of purchasing the fixtures, as well as installing and maintaining them. Therefore, the total retrofit costs for McNutt Hall are:

$$\begin{aligned}\text{Total cost of McNutt Hall retrofits} &= \$125,226 + \$15,128 \\ &= \$140,195\end{aligned} \tag{5.28}$$

Payback time, which is an important factor in determining the success of a retrofit project, is calculated as:

$$\begin{aligned}\text{Payback time} &= \frac{\text{Total retrofit cost}}{\text{Annual savings in energy costs}} \\ &= \frac{\$140,195}{\$35,639} \\ &= 3.93 \text{ years}\end{aligned} \tag{5.29}$$

Equation 5.29 does not consider net present values resulting from inflation, but provides a good approximation. This estimate indicates that the investment made in full lighting retrofit of McNutt Hall has a payback time of less than four years, which is an impressive result considering the magnitude of the project.

6 CONCLUSIONS AND FUTURE WORK

The objective of the research described in this thesis was the development and deployment of an automated, networked system for real-time monitoring of lighting energy. These objectives have been fulfilled, and the system developed per the guidelines of this thesis was deployed in McNutt hall on July 31, 2007. This system helps the facility managers monitor energy consumption throughout the building, by collecting data from power meters, communicating them to a server, and reporting trends and analysis results through user-friendly software. The networked architecture of the system presents a suitable channel for data communication among the power meters, serves as an interface to the campus LAN, and facilitates transfer of data among servers running the monitoring software, meters, and controllers.

The tiered design of the lighting monitoring system provides separation of concerns and facilitates understanding of the different stages involved in monitoring power consumption. The power data is gathered from numerous metering points around the building and transported to the facility managers' servers, where analysis is carried out to determine usage patterns and identify opportunities for conservation. Submetering is essential to this goal.

Lighting fixtures, as any other category of electric devices, should be periodically upgraded to benefit from advances in technology. The lighting retrofit program at UMR is carried out with this goal, specifically seeking to reduce energy consumption through the use of new, efficient lighting fixtures. Due to the scale of the UMR campus, this retrofit program promises considerable reduction in energy costs. Preliminary estimates of these savings were given in Section 5, where the payback time of retrofitting every fixture in McNutt Hall was determined to be less than four years.

The retrofit was also shown to result in a 69.4% reduction in annual energy consumption. Both results underscore the impact of the retrofit project, as well as the importance of a monitoring system capable of accurately measuring power consumption.

The success of the retrofit of McNutt Hall provides motive and justification for pursuing the ultimate goal of full campus retrofit, which is projected to save 2.1 million kWh of energy. This program also encourages further investment in occupancy sensors, which can considerably reduce the operating time of lights. Future extensions to this work may include projections that include the installation of occupancy sensors in any location undergoing lighting retrofit. Another interesting extension to the work is the addition of a simple availability monitor that indicates whether each submeter is functional, and generates alerts as needed. Finally, the network connectivity of the monitoring system can be used for full interfacing to building automation systems across campus, facilitating automatic generation of alerts and actuation of countermeasures.

APPENDIX A

PRE- AND POST-RETROFIT DATA

Table A.1: Panel L3 pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
308	115	16	2976
	115	8	
	72	3	
307A	115	2	230
307	115	19	2674
307BD	115	3	
	72	2	
310	115	7	1035
	115	2	
309	115	18	2070
312	115	16	2976
312BD	115	8	
	72	3	
317	72	2	2099
	115	12	
	115	3	
	115	2	
317A	115	8	920
314	115	9	1035
319	144	8	1152
316	115	16	2976
	115	8	

Table A.1: Panel L3 pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
	72	3	
304	115	3	345
305	115 175	9 3	1560
305L	115	2	230
305A	115 72 100	6 2 2	1034
305F	115 175 150	4 1 5	1385
305G	115 175	4 1	635
305H	115 175	4 1	635
305J	115 175	4 1	635
319A	72	6	432
319B	72	2	144
317B	72	2	144
317C	72	1	72
313	45	1	45

Table A.1: Panel L3 pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
311	41 22	3 1	145
315	72 45	3 1	261
318	115	4	460
320	115	2	230
322	115	2	230
324	115	2	230
326	115	2	230
328	115	2	230
330	115	2	230
332	115	2	230
334	115	2	230
336	115	2	230
306	45	1	45
302	72	3	216
305C	45	1	45
305D	72	1	72
305E	72	1	72
303	72	32	2304
			Total = 33.129 KW

Table A.2: Panel L3 post-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
308	72 60 40	8 8 3	1056
307A	48	2	96
307 307BD	60 40	19 2	1220
310	40	7	280
309	60	18	1080
312 312BD	72 60 40	8 8 3	1176
317	60 60 40	12 3 2	980
317A	48	8	384
314	48	6	288
319	71	8	568
316	72 60 40	8 8 3	1176
304	60	3	180
305	60	9	621

Table A.2: Panel L3 post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
	27	3	
305L	60	2	120
305A	60 40 42	6 2 2	524
305F	60 42 27	4 1 5	417
305G	48 42	4 1	234
305H	48 42	4 1	234
305J	48 42	4 1	234
319A	61	6	366
319B	61	2	122
317B	61	2	122
317C	48	1	48
313	22	1	22
311	41 22	3 1	145
315	40	3	142

Table A.2: Panel L3 post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
	22	1	
318	40	4	160
320	72	2	144
322	72	2	144
324	72	2	144
326	72	2	144
328	72	2	144
330	72	2	144
332	72	2	144
334	72	2	144
336	72	2	144
306	22	1	22
302	48	3	144
305C	22	1	22
305D	40	1	40
305E	40	1	40
303	48	32	1536
			Total = 15.09 KW

Table A.3: Panel L2A pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
254	154	45	6930
253	144	9	1296
251	144	1	144
249	144	16	2304
241	144 144	12 5	2448
239	144	7	1008
238	62	18	1116
238A	114	2	228
238B	115	3	345
236	144	10	1440
268	115	8	920
266A	87	2	174
266B	72	6	432
233B	115	3	345
231	115	8	920
230	87	6	522
232	115	6	690
267	144	2	288
267A	87	4	348
254D	115	5	575
254C	115	8	920

Table A.3: Panel L2A pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
254B	72	6	432
254A	115	4	460
252	115	6	690
256	144	4	576
260	144	4	576
262	144	8	1152
258	144	7	1008
266	144 82	10 4	1768
259	115	14	1610
257	115	8	920
257A	115	4	460
259A	115	8	920
249A	144	12	1728
233A	72	2	144
233	144 144 45	8 22 12	4860
234	144	15	2160
218	62	6	372
220	52	5	310
222	62	4	248

Table A.3: Panel L2A pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
224	115	4	460
226	87	4	348
228	115	4	460
223	115	3	345
225	115	3	345
227	62	3	186
271	115	2	230
273	45	1	45
270	115	2	230
272	115	2	230
274	115	2	230
278	115	2	230
280	115	2	230
282	115	2	230
284	115	2	230
288	115	2	230
290	115	2	230
292	115	2	230
219A	45	3	135
221	72 75	2 1	219
294	72	2	144

Table A.3: Panel L2A pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
217	72	3	216
214	45	1	45
204B	144	1	144
			Total = 49.139 KW

Table A.4: Panel L2A post-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
254	48	45	2160
253	71	9	639
253A	48	6	288
251	48	1	48
249	61	16	376
241	71 48	12 5	1092
239	61	7	427
238	62	18	1116
238A	71	2	142
238B	60	3	180
236	48	10	480

Table A.4: Panel L2A post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
268	60	8	480
266A	76	2	152
266B	48	6	288
233B	60	3	180
231	60	8	480
230	76	6	456
232	48	6	288
267	48	2	96
267A	76	4	304
254D	40	5	200
254C	40	8	320
254B	48	6	288
254A	40	4	160
252	40	6	240
256	40	4	160
260	48	4	192
262	48	8	384
258	61	7	427
266	61	14	854
259	60	14	840
257	48	8	384
257A	40	4	160

Table A.4: Panel L2A post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
259A	40	8	320
249A	48	12	576
233A	48	2	96
233	71 48 22	8 22 12	1888
234	61	5	915
218	40	6	240
220	48	5	240
222	62	4	248
224	60	4	240
226	76	4	304
228	60	4	240
223	60	3	180
225	60	3	180
227	62	3	186
271	72	2	144
273	22	1	22
270	48	6	288
272	72	2	144
274	72	2	144
278	72	2	144

Table A.4: Panel L2A post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
280	72	2	144
282	72	2	144
284	72	2	144
288	72	2	144
290	72	2	144
292	72	2	144
219A	22	3	66
221	40 22	2 1	102
294	48	2	96
217	40	3	120
214	22	1	22
204B	80	1	80
			Total = 22.370 KW

Table A.5: Panel LB pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
27	115	14	1727
27BD	72	1	

Table A.5: Panel LB pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
23	45 115 72 72 45	1 5 1 2 1	836
21	115	8	920
9	115	5	575
11	115 115	7 4	1265
5	115	7	805
5A	115	4	460
12A	115	2	230
12B	115 115	3 1	460
12C	115	12	1380
12D	115	6	690
12	115 200	14 1	1810
18A	115 200	3 2	745
18B	115 200	2 2	630

Table A.5: Panel LB pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
18C	115	2	230
18D	115	2	230
18	115	9	1035
18E	115 200	3 3	945
18F	115 200	3 3	945
18G	115	4	460
22	144	18	2592
26	144	12	1728
32	72	8	576
34A	72	1	72
34	144 200	9 6	2496
36	144	8	1152
36A	115	4	460
38A	115	4	460
38	115	12	1380
25	115 200	12 6	2580
19A	115	4	460
19B	115	4	460

Table A.5: Panel LB pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
19	144	11	1584
19D	144	3	432
19C	72	1	72
7	144 45	9 3	1431
8	115	4	460
10	115 72	18 2	2214
10A	115	2	230
14	115 72 200	12 2 10	3524
16	115 72	7 1	877
20	144	8	1152
20A	115	4	460
20B	115	2	230
24	115 200 115	3 3 6	1635
24A	115 200	2 2	630

Table A.5: Panel LB pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
24B	115	2	230
24C	115	4	460
24D	115	4	460
28	144	12	1728
42	144	14	2016
40	115 115 72	12 9 2	2559
40A	115	2	230
40B	115	4	460
44	144	16	2304
2	72	2	144
33	45	1	45
59	72	1	72
35	115	2	230
37	115	2	230
39	115	2	230
43	115	2	230
45	115	2	230
47	115	2	230
49	115	2	230
53	115	2	230

Table A.5: Panel LB pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
55	115	2	230
57	115	6	690
6	72	7	504
4	40 22	3 1	142
31	22	9	198
3	22	1	22
			Total = 60.059 KW

Table A.6: Panel LB post-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
27 27BD	40 40 22	14 1 1	622
23	60 40 22	5 1 1	362
21	60	8	480
9	60	5	300

Table A.6: Panel LB post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
11	60	7	420
5	72	7	504
5A	72	4	288
12A	60	2	120
12B	60	3	180
12C	48	12	576
12D	60	4	240
12	60	14	840
18A	60	3	180
18B	72	2	144
18C	72	2	144
18D	72	2	144
18	60	9	540
18E	40	3	120
18F	40	3	120
18G	40	4	160
22	48	18	864
26	61	12	732
32	48	8	384
34A	48	1	48
34	40 27	9 6	522

Table A.6: Panel LB post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
36	48	8	384
36A	40	4	160
38A	40	4	160
38	60	12	720
25	40 27	12 6	642
19A	40	4	160
19B	40	4	160
8	60	4	240
10	48 40	18 2	944
10A	72	2	144
14	60 40	12 2	800
16	60 40	7 1	460
20	61	8	488
20A	40	4	160
20B	60	2	120
24	48	6	288
24A	115 200	2 2	630

Table A.6: Panel LB post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
24B	48	2	96
24C	40	4	160
24D	40	4	160
28	71	12	852
42	71	14	994
40	76 40	12 2	992
40A	72	2	144
40B	40	4	160
44	71	16	1136
2	48	2	96
33	22	1	22
19	61	11	671
19D	48	3	144
19C	48	1	48
7	48 22	9 3	498
6	72	7	504
4	40 22	3 1	142
31	22	9	198
3	22	1	22

Table A.6: Panel LB post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
59	48	1	48
			Total = 22.781 KW

Table A.7: Panel L1A pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
103	115	17	1955
117	72	4	288
113	115	6	690
114	115 115 72	12 4 2	1984
115	144 200	18 6	3792
114A	115	3	345
114B	115	3	345
112	144 200	19 6	3936
108 zone1	115	18	2070
108 zone2	115	5	575

Table A.7: Panel L1A pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
108 zone3	200	2	400
110A	144	1	144
112A	144	2	288
110	144 72	9 1	1368
106	115 115	12 1	1495
104	144	18	2592
104A	115	3	345
101	72	1	72
105	72 45	2 2	234
109	72	1	72
			Total = 22.99 KW

Table A.8: Panel L1A post-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
103	-	14	-
117	40	4	160

Table A.8: Panel L1A post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
113	72	6	432
114	40 60	2 12	800
115	61	18	1098
114A	40	3	120
114B	40	3	120
112	48	19	912
108 zone1	60	18	1080
108 zone2	-	-	-
108 zone3	-	-	-
110A	48	1	48
112A	61	2	122
110	61 48	9 1	597
106	60	12	720
104	72	18	1296
104A	60	3	180
101	48	1	48
105	40 22	2 2	124
109	40	1	40
			Total = 7.9 KW

Table A.9: Panel L2 pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
242C	77	12	924
242B	154 154	16 1	2618
242D	62 115	2 1	239
242E	72	4	288
242F	72	3	216
242	71 77 135 154 154	6 1 5 3 16	4104
242G	72	3	216
244D	154	6	924
244E	154	8	1232
244G	154	6	924
244H	115 54	2 2	538
244	77 154	19 32	5791
248B	115	1	115

Table A.9: Panel L2 pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
244K	115	4	460
248A	115	2	230
248	115 115	11 5	1840
240A	100	1	100
240B	100	1	100
240C	100	1	100
246	115	1	115
			Total = 21.074 KW

Table A.10: Panel L2 post-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
242C	48	12	576
242B	61 48	16 1	1024
242D	62 60	2 1	184
242E	48	4	192
242F	72	3	216

Table A.10: Panel L2 post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
242	71 61 61 61 61	6 1 5 2 16	1890
242G	72	3	216
244D	40	6	240
244E	-	-	-
244G	48	6	288
244H	60 61	2 2	242
244	48 61	19 32	2864
248B	60	1	60
244K	48	4	192
248A	60	2	120
248	60	11	660
240A	42	1	42
240B	42	1	42
240C	42	1	42
246	62	1	62
			Total = 9.152 KW

Table A.11: Panel L1 pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
146D	154	5	770
146A	154	4	616
144A	154	9	1386
146	154	9	1386
144	154	6	924
142	154	18	2772
130	-	-	-
126	115	6	690
124	115	8	920
140	115	15	1725
138	115	15	1725
118	115	2	230
120	115	4	460
122	115	4	460
128	115	4	460
139	115	2	230
141	115	2	230
143	115	2	230
147	115	2	230
149	115	2	230
151	115	2	230

Table A.11: Panel L1 pre-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
153	115	2	230
157	115	2	230
159	115	2	230
161	115	6	690
144B	144	2	288
144C	115	1	115
146B	115	115	115
146C	115	1	115
135	72	3	216
134	45	1	45
137	45	1	45
127	115	6	690
129	115	6	690
132	45	1	45
132A	72	3	216
136	72	2	144
			Total = 20.008 KW

Table A.12: Panel L1 post-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
146D	61	5	305
146A	61	4	244
144A	61	9	549
146	61	9	549
144	48	6	288
142	71	18	1278
130	-	-	-
126	60	6	360
124	72	8	576
140	60	15	900
138	48	15	720
118	60	2	120
120	48	4	192
122	48	4	192
128	40	4	160
139	72	2	144
141	72	2	144
143	72	2	144
147	72	2	144
149	72	2	144
151	72	2	144
153	72	2	144

Table A.12: Panel L1 post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
157	72	2	144
159	72	2	144
161	48	6	288
144B	61	1	61
144C	60	1	60
146B	60	1	60
146C	60	1	60
135	48	3	144
134	22	1	22
137	22	1	22
127	40	6	240
129	40	6	240
132	22	1	22
132A	40	3	120
136	40 22	2 1	102
			Total = 9.17 KW

Table A.13: Panel L2B pre-retrofit.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
204	108 45	32 5	3681
206	108 45	19 5	2232
212	108 45	15 5	1845
216	108 45	16 5	1973
211	108 45	17 5	2061
			Total = 11.79 KW

Table A.14: Panel L2B post-retrofit.

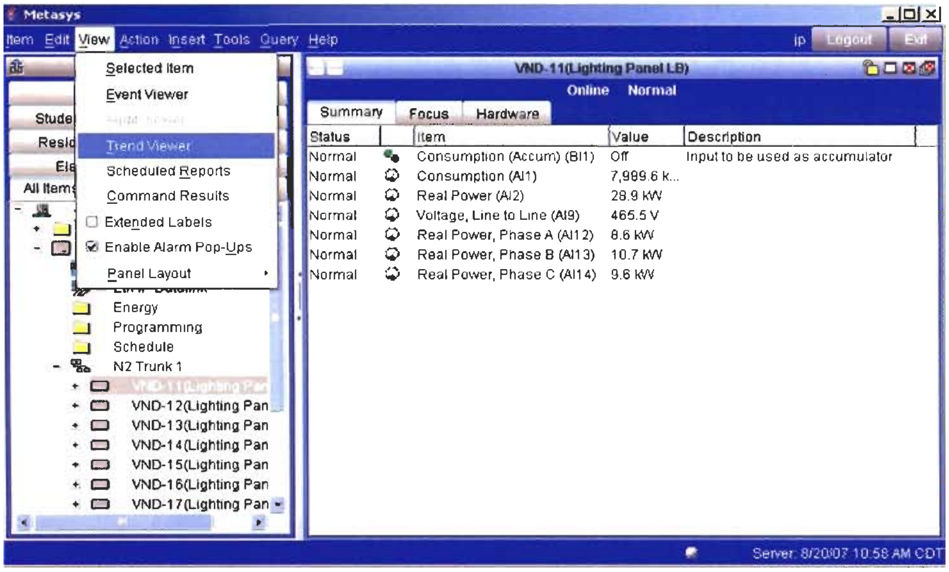
ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
204	60 20.4	32 5	2022
206	62 20 77	1 4 14	1220

Table A.14: Panel L2B post-retrofit (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
212	60 20.4	13 5	882
216	60 20.4	14 5	942
211	60 20.4	15 5	1002
			Total = 6.06 KW

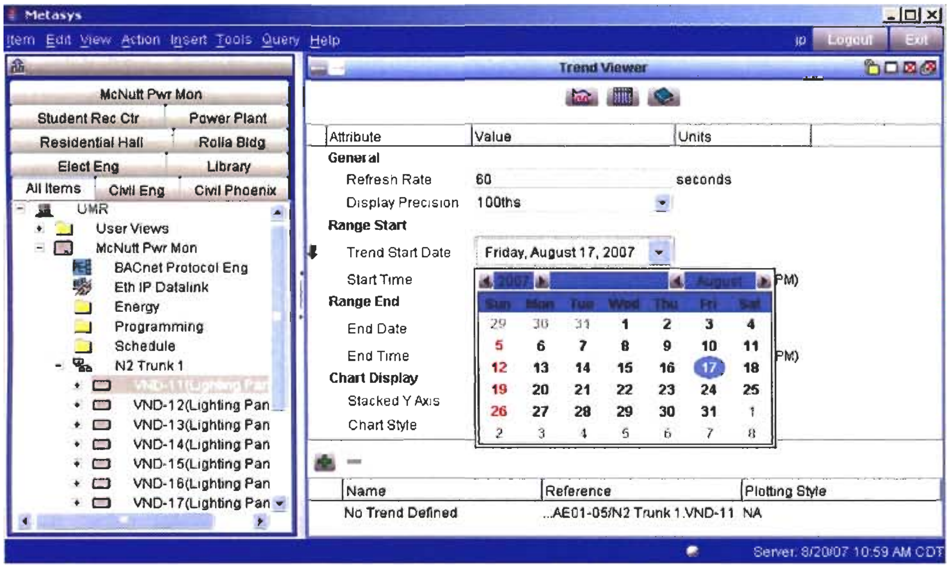
APPENDIX B

SNAPSHOTS FROM THE METASYS® SOFTWARE



Status	Item	Value	Description
Normal	Consumption (Accum) (BI1)	Off	Input to be used as accumulator
Normal	Consumption (AI1)	7,999.6 k...	
Normal	Real Power (AI2)	28.9 kW	
Normal	Voltage, Line to Line (AI9)	465.5 V	
Normal	Real Power, Phase A (AI12)	8.6 kW	
Normal	Real Power, Phase B (AI13)	10.7 kW	
Normal	Real Power, Phase C (AI14)	9.6 kW	

Figure B.1. Snapshot of the Johnson Controls Metasys® software.



Attribute	Value	Units
General		
Refresh Rate	60	seconds
Display Precision	100ths	
Range Start		
Trend Start Date	Friday, August 17, 2007	
Start Time		
Range End		
End Date		
End Time		
Chart Display		
Stacked Y Axis		
Chart Style		

Name	Reference	Plotting Style
No Trend Defined	...AE01-05/N2 Trunk 1.VND-11	NA

Figure B.2. Another Snapshot of the Johnson Controls Metasys® software.

APPENDIX C

FIXTURES RETROFITTED BY OCTOBER 1, 2007

Table C.1: Fixtures retrofitted by Oct. 1, 2007.

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
4	40 22	3 1	142
105	40 22	2 2	124
109	40	1	40
132	45	1	45
132A	40 48	3 2	216
136	40 22	2 1	102
140	60	15	900
219	66	1	66
221	40 22	2 1	102
233	71 48 22	8 22 12	1888
233A	48	2	96
233B	60	3	180
238	62	18	1116
238A	71	2	142
238B	60	3	180

Table C.1: Fixtures retrofitted by Oct. 1, 2007 (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
239	61	7	427
241	71 48	12 5	1092
242	-	-	1890
242B	61 48	16 1	1024
242C	48	12	576
242D	62 60	2 1	184
242E	48	8	192
242F	72	3	216
242G	72	3	216
244	48 61	19 32	2864
244D	40	6	240
244G	48	6	288
244H	60 61	2 2	242
244K	48	4	192
254	48	45	2160
305	27	3	81
305A	42	2	84

Table C.1: Fixtures retrofitted by Oct. 1, 2007 (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
305F	42 27	1 5	177
305G	42	1	42
305H	42	1	42
305J	42	1	42
308	60 72 40	8 8 3	1056
309	60	8	1080
311	71	2	142
312	-	-	1176
315	40 22	3 1	142
316	-	-	1176
319	71	8	568
204	60 20.4	32 5	2022
206	71 48	12 5	1092
212	60 20.4	13 5	882
216	60	14	942

Table C.1: Fixtures retrofitted by Oct. 1, 2007 (cont.)

ROOM NUMBER	WATTAGE/FIXTURE	NUMBER OF FIXTURES	TOTAL WATTAGE
	20.4	5	
211	60 20.4	15 5	1002
			Total = 28.893 KW

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