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Networked Occupancy Sensor System

Marissa Ann Imperiali
Worcester Polytechnic Institute

Patrick Brodeur
Worcester Polytechnic Institute

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Final Report

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Submitted to:

Professor John Orr (Advisor)

Submitted by:

Patrick Brodeur

Marissa Imperiali

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Abstract

Energy is often wasted on systems that are used to provide services such as light, heating, air conditioning and ventilation. If these services were intelligently controlled, there is potential for significant improvements in energy conservation. A system including room sensors, database, and webserver was designed, constructed, and implemented over the course of this project. Sensors report occupancy and light status and temperature. Real-time room data is available via the webserver and is archived in the database. The system is networked via Ethernet and powered using the power over Ethernet (802.3af) standard.

Executive Summary

Recently there has been a growing need for ways to reduce energy usage. According to the World Climate Conference, industrialized nations of the world need to cut back on their greenhouse gas emissions, largely due to the combustion of fossil fuels for automobiles and electricity production. One way to cut back on overall usage is by simply using the same amount of energy more efficiently. This is not only good for the environment but it is also beneficial economically. Energy is often wasted on systems that are used to provide services such as light, heating, air conditioning and ventilation. These services are typically not intelligently-controlled and are on and running even when unnecessary (e.g. lights left on in an unoccupied building).

A low-cost system for collecting and analyzing occupancy and usage data might assist building managers in operating various systems more efficiently. The goal of this MQP is to develop a networked occupancy sensor system in order to help manage energy usage more effectively. The system is intended to provide sensory data for control applications in a full- or semi-automatic building automation system. It will also serve a secondary purpose to provide real-time data about room occupancy status, lighting status, and current temperature in different rooms, which will be available to building managers separate from the building automation system. The data, all put together, can aid in more-responsibly managing the building's energy usage.

The modules are networked through Ethernet over twisted pair copper cables. To further utilize the Ethernet connectivity, the system is also powered through the Ethernet cables (i.e. Power over Ethernet). An off-the-shelf IEEE802.3af compliant PoE module was implemented provide the regulated 3.3V necessary to power the system. This module performs all of the PoE interfacing with minimal additional configuration.

Each unit of the networked room occupancy sensing system contains two PIR sensors, a temperature sensor, and a light sensor. To detect room occupancy, two PIR sensors are used together to determine if there is a warm body moving in the room. The temperature sensor used is a linear thermistor integrated circuit and the light sensor is a photodiode integrated circuit with an output voltage that is linear with light intensity. The microcontroller updates the server with data gathered from the sensors. After sending one update to the server, there is a flag that prevents sending another update for one minute. For the PIR sensors, the one-minute interval may be interrupted, but then the PIR sensor cannot update for another five minutes. In this way, temperature and light updates may be sent to the server at a maximum interval of 60 updates/hour, while occupancy updates may be sent only 12 times/ hour.

An application server is necessary to this project for hosting the website and for processing data collected by the sensors. The interface development relies on the operation of a database server and an application server. The interface itself runs on the application server, and it retrieves data from the database server. The microcontroller transmits data from the sensors to the database (via the application server), updating the data tables. User interface with the MySQL server is done through Oracle MySQL Workbench, any changes made on one physical server are propagated across the others.

From the MySQL database, the data from the sensors is displayed on a website designed for mobile devices.

Ultimately, the devices primarily include core system functionality. They are able to detect occupancy, light, and temperature and send that data back to a server using Ethernet networking. In addition, the server-side software is complete and could theoretically be used to control building systems. Future work could be done to expand the system to improve upon certain features and to increase the versatility of the devices.

Acknowledgements

We would like to thank the following people and departments for their support on this MQP.

Bill Spratt, Director of Facilities Operations

Provided insight into real world problems dealing with building automation systems and gave us an overview of the building automation system used at WPI. Also, recommended features that would differentiate our system from existing equipment.

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Gave us information on networking options and generously provided us a PoE injector for use while testing our devices.

Jeremy Francisco, Friend and Fellow Student

Assisted significantly in getting server side software to properly interface with the database and the sensor modules.

John Orr, Advisor and Professor of Electrical and Computer Engineering

Provided prompt useful feedback on all aspects of the project and guided us in times of confusion. Gave us a viewpoint outside the development process and consistently challenged our design decisions while taking an advisory role.

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Acronyms

ABS – Acetyl Butyl Styrene (a common plastic)

ADC – Analog-Digital Converter

AES – Advanced Encryption Standard

BACnet – Building Automation and Control Network

BOM – Bill of Materials

CPLD – Complex Programmable Logic Device

DHCP – Dynamic Host Configuration Protocol

FPGA – Field-Programmable Gate Array

HTML – Hypertext Markup Language

IIS – Internet Information Services

MQP – Major Qualifying Project

PHP – PHP: Hypertext Preprocessor

PIR – Passive Infrared

SPI – Serial Peripheral Interface

SQL – Scripted Query Language

UDP – User Datagram Protocol

WPI – Worcester Polytechnic Institute

1 Introduction

Within the past three decades, there has been a major shift in the public's awareness of current environmental issues and climate change. In 1979, the first World Climate Conference was held to investigate global climate change (United Nations Framework Convention on Climate Change, 2011). More specifically, this conference focused on how technology was affecting the global climate. Since then, other conferences were held, including the popular Kyoto Protocol conference. Among other findings, these conferences concluded that industrialized nations of the world need to cut back on their greenhouse gas emissions largely due to the combustion of fossil fuels. One way these nations could cut back is by simply using energy more efficiently, which is beneficial to all countries, large and small.

Systems found in buildings account for approximately 50% of the total overall energy usage in developed nations (Salsbury, 2009). Many of these systems are to provide comfort for the people within even when conditions outside may be unpleasant. However, these systems are not always efficiently managed and a typical building may continue providing comfort services (lights, heating, air conditioning) even while vacant. This causes a large amount of energy to be wasted, increasing operating expenses. Most buildings do not have an intelligent way of controlling systems. The last person out of a room is responsible to remember to turn off the lights; otherwise the lights may be left on, wasting energy, for hours or even days at a time. Another case where a large amount of energy is wasted is when somebody turns their air conditioner up for the workday, but forgets to set it back down when they leave for the night. By better controlling these systems, a building's energy consumption may be greatly reduced.

In addition to the environmental implications of high energy usage, there is also a large cost associated with the generation and transmission of the energy. This cost is passed on from energy companies and accounts for approximately 19% of a commercial building's annual operating expense (E Source Companies LLC, 2002). The average annual energy usage in a commercial building is about $1.34 per square foot for electricity, and this cost doesn't include other energy sources such as natural gas or oil used for heating. It is clearly evident that there is a significant cost motivator for reducing a building's energy consumption.

A low-cost system for collecting and analyzing occupancy and usage data might assist building managers in operating various systems more efficiently. The goal of this MQP is to develop a networked occupancy sensor system in order to help manage energy usage more effectively. This system is intended to provide sensory data for control applications in a full- or semi-automatic building automation system. It will also serve a secondary purpose to provide real-time data about room occupancy status, lighting status, and current temperature in different rooms, which will be available to building managers separate from the building automation system. The data, all put together, can aid in more-responsibly managing the building's energy usage. Further discussion into the specific project goals may be found in Section 2: Goals & Specifications.

2 Goals & Specifications

The end-result of this project will be a functional prototype system that will collect data on occupancy status, lighting status, and temperature in multiple rooms in a building. The system will use the data to control building systems (e.g. lighting, heating, ventilation) and generate room occupancy, lighting, and temperature statistics that can later be reviewed by building managers. Ideally, the prototype system would have been able to integrate with WPI's existing building automation system; however, this was not possible due to integration challenges and the existing environment, where accidental damage was a concern. Beyond performing simple sensory data collection, each module in the system will be networked together using a standard communication protocol. The information should be available to any authorized internet-enabled device for remote building management. Figure 1 below shows how the devices would be connected in a building automation system.

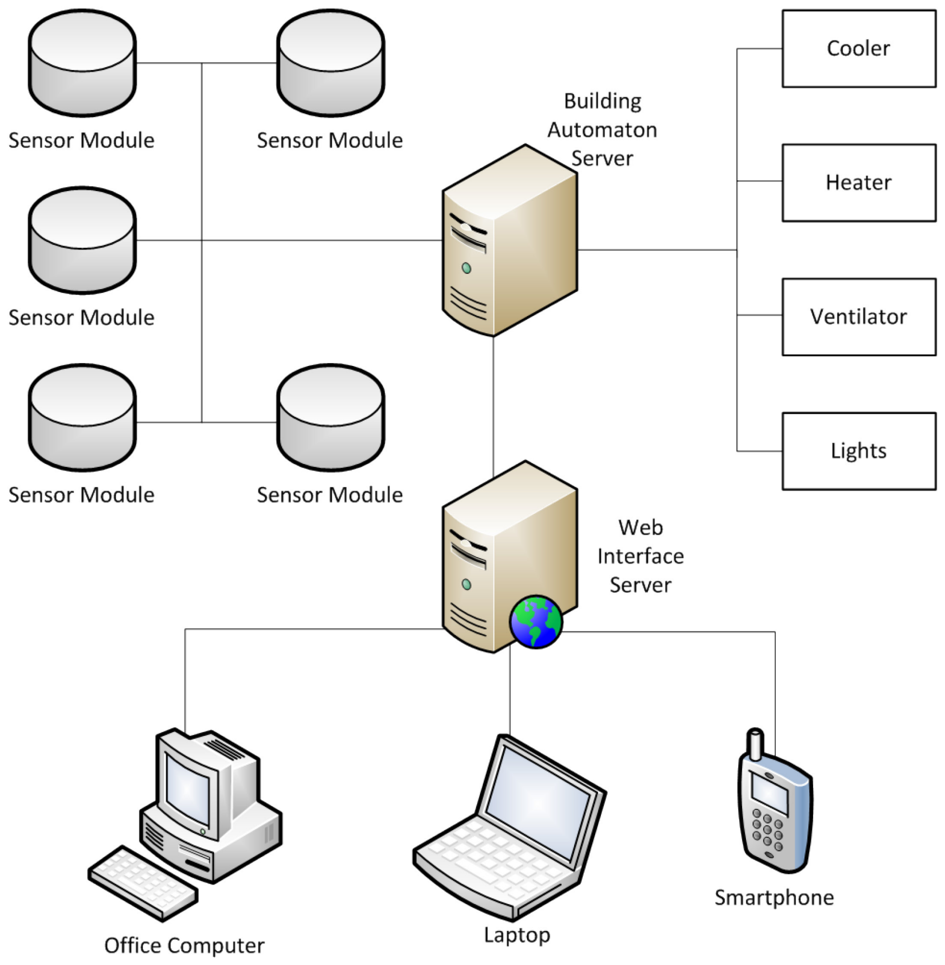

Figure 1: Network Diagram

In the diagram above, there are three major functions occurring. On the left-hand side, sensor modules are reporting data back to the building automation server. On the right-hand side, various building systems are being controlled by the building automation server, while the sensors provide feedback as to the effectiveness of those systems. The building automation server then provides data to the web interface server so that it can report back to the user. Note that the building automation server and web interface servers are not necessarily different machines, as both functions can run concurrently on one piece of computing hardware.

During the course of the project, a set of design goals were outlined that include the development of core device functions. The following list describes the goals for these features:

1. Individually-Configurable Devices

Each of the devices should be configurable such that they can identify which room in which they are located. For the purpose of the prototype system, each device has a hard-coded identifier. Future work could include the implementation of a software interface to configure the devices dynamically rather than during production.

2. Multiple Sensors in One Device

The devices should be able to report multiple values. The primary purpose of the devices is to detect room occupancy, measure temperature and the current light levels, and report this data to the building automation system. This system is more useful than a simple occupancy detector by providing additional information that can be used to control the subsystems in the building more efficiently.

3. Reliable Detection

The devices should be able to detect occupancy reliably by any single available method or by multiple occupancy-detection technologies. In addition, a software algorithm may be used to reduce the occurrence of false positives from sensor hardware limitations. An individual device should be able to reliably detect occupancy within a 25-foot radius that covers a 90° or more “pie slice”. The temperature sensor circuit will be designed to maintain operational accuracy (within ±4°C) over typical interior temperatures (50°F-120°F). To achieve these specifications, complex sensors may be used (i.e. not a simple thermistor).

4. Long-term Power Supply

To reduce maintenance costs and simplify operation, the devices should have a consistent power supply that can last over very long intervals of at least two years. This also implies that the system should be a low-power device, particularly if it is run on battery power. The intent of this design goal is to prevent the need for manual replacement of batteries as much as is possible.

5. Data Accessibility

The devices should provide data to a central hub, which may be the building automation system and/or a separate processing platform. Once collected, the data should be accessible to building management so that they can track building usage and adjust resources accordingly. This may include the implementation of a web-based portal through which authorized users can access the data. Ideally, the information would be accessible on any device, including smart phones.

A consideration is the availability of data to users and to the internal elements of the overall automation system. For the automation system, it is assumed that there is one central control device (e.g. a server) and the individual sensor modules would report all data back to that controller. With that data, the controller could then manage building resources and provide real-time statistics for viewing, either through a public interface or via a private control terminal.

Another goal of this project is to make it standards compliant and therefore compatible with existing systems and with new designs. To make the system interoperable with existing building automation systems, it will be important to make use of the most widely-used (non-proprietary) HVAC communications standard. The final devices created should be general enough to be integrated into building automation systems manufactured by multiple vendors.

6. Cost

In a typical installation, each sensor "point" in an HVAC system costs approximately $800 on average (Spratt, Second Meeting, 2012). This includes the cost of the unit and the cost to install necessary underlying infrastructure including communications and power connections. For a large system with multiple buildings, the cost may reach into the millions. To be competitive in the building automation market, this system must be as economical as possible without compromising functionality. Ideally, each sensing unit would cost under $100 for the unit itself, not including additional installation costs.

7. Physical Characteristics

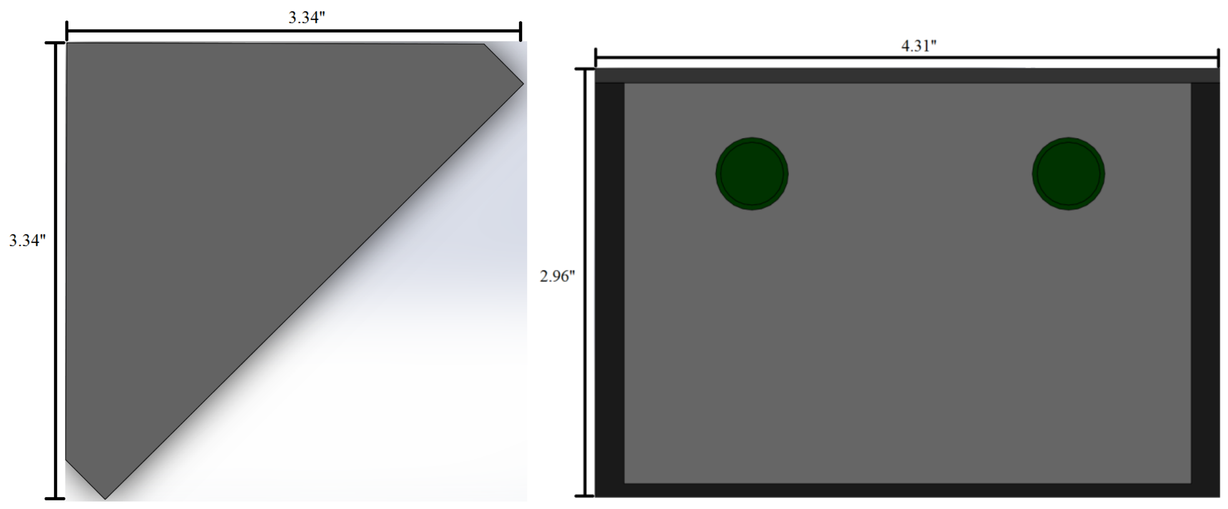

Figure 2: Sensor Module Top View (left) and Front View (right)

Each sensor module will fit into the corner of a room with edges on the walls. The dimensions are shown above. The face of the prototype will be plain and functional, but for production the enclosure would ideally be more aesthetically-pleasing. Sensors will be strategically positioned on the unit for accuracy and visual appeal. As can be seen in the Front View above, there are two openings in the front of the enclosure. The passive infrared sensors will poke through where the green-colored sections are in that image. The prototype's body will be composed of acetyl butyl styrene (ABS), and will be printed using a rapid prototyping machine. The unit will weigh less than one pound and will be mounted directly to the wall. The units would be corner-mountable and unobtrusive in a typical office:

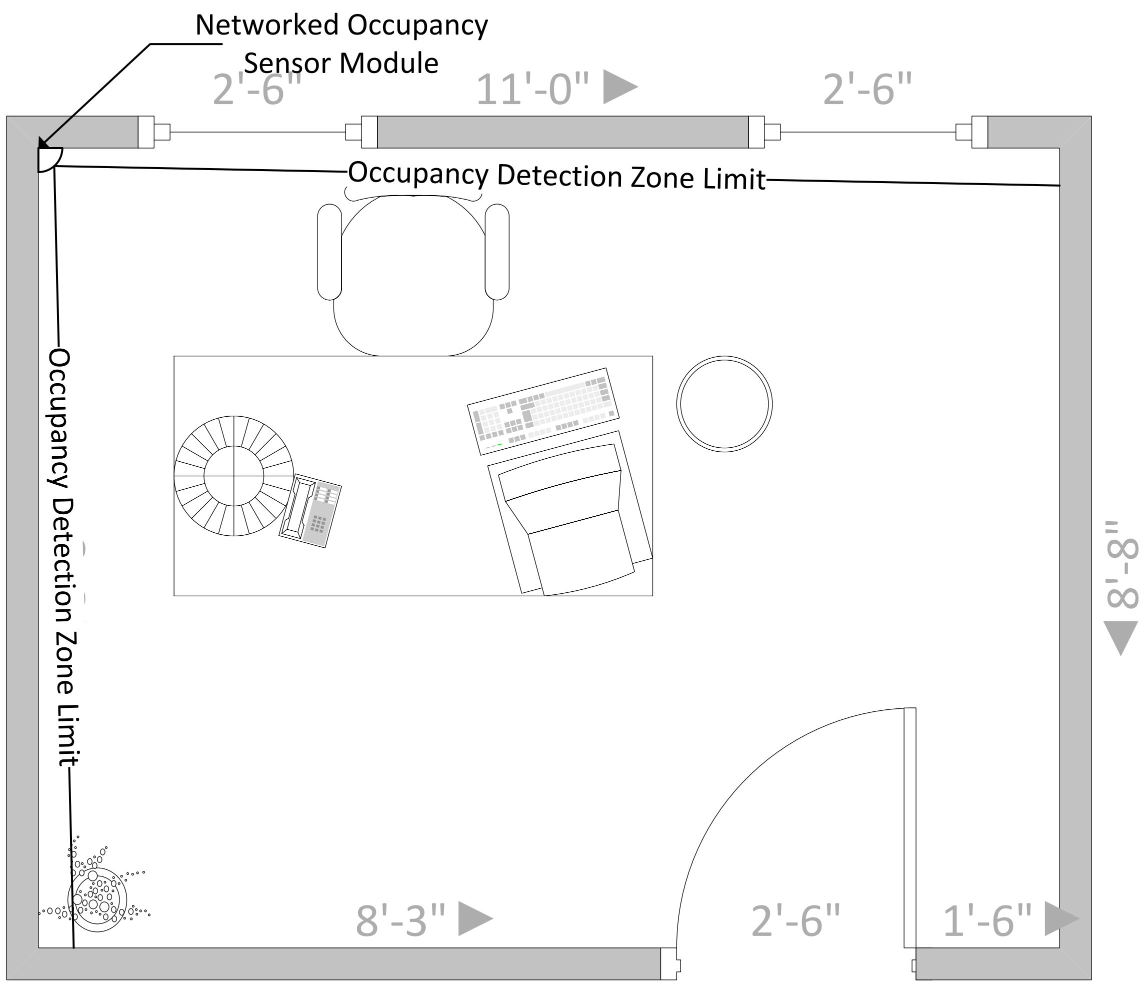
Networked Occupancy Sensor Module
2'-6"
11'-0"
2'-6"
Occupancy Detection Zone Limit
Occupancy Detection Zone Limit
8'-8"
8'-3"
2'-6"
1'-6"

Figure 3: A Sample Office, with Sensor Installed

3 Background

There are many factors that must be considered in designing a multi-room system. Before any development can begin, it is important to know what kind of existing technology can be implemented in the design, and how it might affect the success or failure of the device. An even more important factor is how useful the device could become in a real life implementation. The major goal of this project is to develop a practical device to aid in reducing energy usage.

3.1 Communications Methods

In industry, many proprietary systems exist for building automation systems. Multiple standards are available for use in communication between modules. It is important in the system design to know not only what the device needs, but also what modifications would be necessary to building infrastructure to accommodate the device. Although conforming to an industry standard is a good goal, this system is primarily meant to be a sensory system and will have generic I/O capabilities regardless of which method of communication is chosen for the operation of the reporting system that is in use.

3.1.1 Wi-Fi / WPI Wireless

Having access to a building-wide Wi-Fi network could be very beneficial to a multi-room system. The network infrastructure would already be in place, and no additional hardware or network design would really be necessary. However, there are some significant disadvantages and considerations to take into account regarding Wi-Fi. The largest deterrents against using Wi-Fi are existent traffic on the unlicensed 2.4GHz band and the complex security procedures commonly employed on enterprise wireless networks.

3.1.1.1 Traffic / Reliability

Largely due to the use of Wi-Fi-enabled computers, phones, and tablets, there are often many devices attempting to communicate on the same shared radio frequencies at the same time. Although many businesses have been rolling out IEEE 802.11N wireless access points, many devices still connect using the IEEE 802.11G or B standard. A major problem with Wireless-G and B is that they operate in the 2.4GHz band along with hundreds of other devices, including Bluetooth devices, microwave ovens, cordless telephones, ZigBee radios, restaurant coaster calls, and various other systems (Estrin, 2011). With so many other devices trying to use the network, each one has to “fight” against the others to communicate. Even if devices using these networks are not actively connected, they still generate traffic by “pinging” networks to request access. Wireless-N and a new (draft) standard, 802.11ac would allow for operation on the 5GHz band, thereby avoiding the congestion in the 2.4GHz band (Cox, 2012).

What happens, particularly in high-traffic locations, is that the hardware used for Wireless-G and B communications becomes saturated with radio traffic and simply cannot effectively communicate with additional devices, often disrupting devices that are already connected (Estrin, 2011). Cases of this have been documented during sporting events where unexpected traffic brought down coordinators’ wireless networks. Using an alternative radio band or alternative data transmission system could potentially alleviate some of the over-usage and increase reliability, but newer Wi-Fi infrastructure is still not present in most places. The potential traffic and security on enterprise Wi-Fi makes wireless operation on most existing Wi-Fi infrastructures a poor choice for reliability and long term support.

3.1.1.2 Wireless Security Settings

Many enterprise-scale wireless networks, including the WPI Wireless network, use the Advanced Encryption Standard (AES) and certificate-based authentication to prevent potential intruders from gaining access to resources on the network. Rather than using a simple passphrase as is used in other wireless security systems, there are two certificate files that computers need to use in order to authenticate with the WPI network. One certificate is used as a server "public key", and a second certificate is used as a user-level "private key" (Microsoft Technet, 2003). The encryption level for certificates at WPI was increased in 2011 from 128-bit encryption to 256-bit encryption, which may pose a problem for older systems.

Although the public key certificate doesn't change very often, the private key changes every year. Connecting the devices via WPI Wi-Fi or a similar network would necessitate downloading the new certificate(s) to each module every year. This is problematic for devices that are not centrally-managed by Microsoft group policy, as each device would require a user to manually update the certificates. The WPI Network Operations department advised that there is no feasible work-around for this limitation (Sweetser, 2012).

3.1.2 ZigBee

Another option for wirelessly connecting each sensor module is low-power radio operating separately from the building's Wi-Fi network (ZigBee Alliance, 2012). ZigBee is a set of specifications regulated by a group called the ZigBee Alliance for communication using low-power digital radios. It is optimized for systems that have a low data rate and require a long battery life, but it is also useful in general low-power applications. In a ZigBee network there is no central unit for transmitting and receiving data to each device. Each device can transmit and receive data with any other device and can be used in a mesh network to transmit over long distances. Another advantage is that ZigBee is free to use for non-commercial purposes. "ZigBee's main advantages include product interoperability, vendor independence, thriving and competitive ecosystem and accessibility to broader markets." (ZigBee Alliance, 2012)

ZigBee works well for communications over distances of 10 to 100 meters, depending on power and environmental characteristics, and for low cost and low power consumption situations; this makes ZigBee an excellent option for building automation, control, and monitoring applications (Kay, 2006). ZigBee devices can be distanced ten to seventy-five meters apart in most situations and communicate on unlicensed bands of 2.4GHz. ZigBee boasts low power consumption; conserving power by having the individual nodes in the network spending most of their time in sleep mode. They connect to the network, communicate with other nodes, and then go to sleep. Because of the low duty cycle of the nodes, the ZigBee network is able to lower its power consumption making it a very energy efficient technology.

3.1.3 Building Automation Standards

There are many building automation standards in use today. There are two main open standards, known as BACnet and LonWorks, but there are very many proprietary systems that are still in use in various existing installations and some that are used by even the large automation companies

(Snoonian, 2003). In general, most building automation companies are now using BACnet as their communications platform of choice, even if they still have non-standard, legacy systems in place.

3.1.3.1 BACnet

BACnet (short for Building Automation and Control NETwork) is "a data communication protocol for building automation and control networks" and its intent was to standardize communications between different elements in an HVAC system (Newman, 1998). One major feature was that it would also allow expandability for other systems that had similar I/O characteristics. Part of this is the ability of BACnet to inter-operate with other systems, including legacy systems (Delta Controls, 2007). BACnet specifies a protocol for controlling building automation elements at every level, from workstations to networking hardware to individual devices. In addition, BACnet incorporates multiple media for data transmission, including Ethernet; ARCNET; master/slave token passing (a BACnet twisted pair specification); point-to-point (another BACnet specification); LonTalk; and BACnet/IP. This makes BACnet one of the most widely-usable systems. Where older systems exist, a "BACnet gateway" may be used to translate to and from the legacy signals so that replacement of equipment isn't immediately necessary.

3.1.3.2 Other Standards

Although BACnet is most popular, there are some other standards in use by various companies. The number of old "standards" is large, but some of the more common ones are:

- CEBus
- EIB
- Local Control Network (LCN)
- Modbus
- LonWorks (LonTalk)

(Schor, Sommer, & Wattenhofer, 2009), (Siemens Industry, Inc., 2012)

Among those listed above, the most popular alternative to BACnet is LonTalk, which is another open standard more common in Europe (described in more detail below). Modbus is the standard formerly created and used by Schneider Electric, one of the largest building automation companies in the world (Modbus Organization, Inc.). Most of these building automation systems have been discontinued in favor of the open standards offered by BACnet and LonTalk.

3.2 Smart Buildings

Smart buildings are buildings that use integrated sensory systems in order to control heating, ventilation, and air conditioning (HVAC), lighting, and/or other devices/systems that do not always need to be running (Sinopoli, 2010, p. 3). The level of a building's "intelligence" is dependent not only on what sensory and control hardware is installed, but also on the algorithms and control software that manages the system (Salsbury, 2009, p. 1081). Smart buildings can range from massive buildings with sophisticated, centrally-managed systems (e.g. the Pentagon) to simpler buildings with many individual sensors that don't necessarily link together, such as a personal residence (Snoonian, 2003).

3.2.1 Systems with Central Control

There are many systems for controlling various HVAC and lighting systems. A major problem in large systems is that there are many proprietary systems that cannot be easily used with each other (Snoonian, 2003). BACnet's major competitor, LonWorks, is meant "to facilitate the need to integrate multiple system components using a common system architecture and infrastructure" (LonMark International, 2012). Both structures have the same goal, and either technology would be suitable for use in designing new sensors that would be used for building control. Both of these control systems are proven and effective, even in very large installations such as the Le Coeur Défense building in Paris, which uses 17,000 individual LonWorks devices (Snoonian, 2003).

3.2.2 Systems with Non-Networked Control

Other systems are much simpler. The most basic version of non-networked control is the light controller one might see in a public restroom. Many restaurants, offices, schools, and other locations have lights that turn on as you walk in, and turn off after a certain amount of time. Typically these are sensors that are only connected to the light switching circuit, but are otherwise not connected.

A similar system can be seen walking through the corridors of East Hall. As one walks down the hall, lights switch on automatically. A short time afterwards, the lights turn back off. Similarly, in many classrooms the lights will turn on as somebody enters, then turn off after a period of time. This system is suitable for most purposes, though it may be inefficient if a person is only in the room for a short time. This type of smart building is still significantly more energy efficient than buildings with no automation, but without a central "brain" in the system, the building provides less control to building management personnel.

3.2.3 Demand for Smart Buildings

The demand for smart buildings has increased over the last decade. This can be clearly seen in the Worcester area, where there have been multiple building projects that incorporate smart building principles. Recently, institutions of higher education and corporate partners have begun working together collaboratively towards energy saving programs (SynergE Worcester, 2012).

In addition, the demand for smart buildings can be seen by the growth of companies in the building automation and control sector. Figure 4 (Microsoft, 2012) below demonstrates the growth of building automation companies as compared to the S&P500 index:

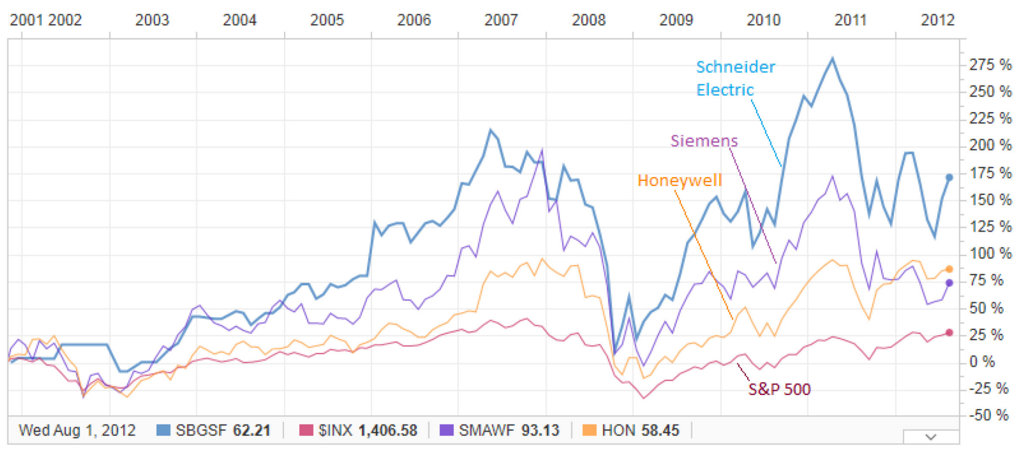

Figure 4: Stock Price Trend of Three Major Building Automation Manufacturers

As Figure 4 demonstrates above, building automation and control manufacturers including Schneider Electric, Honeywell, and Siemens have been consistently outperforming companies in other sectors as measured by their stock prices. As can be seen in the graph, many companies were hard-hit by the recession in early 2008, yet building automation companies were able to recover faster than other industries. It is reasonable to conjecture that there is a mature market for this type of device that is growing even more as people are more conscious of energy costs and environmental impacts.

3.3 Existing WPI Building Automation Systems

There are many different systems and technologies in use even just at WPI (Spratt, Initial Meeting with Facilities Staff, 2012). BACnet is primarily used in the building's automation system. At WPI there are two BACnet systems that cover 85% of the buildings.

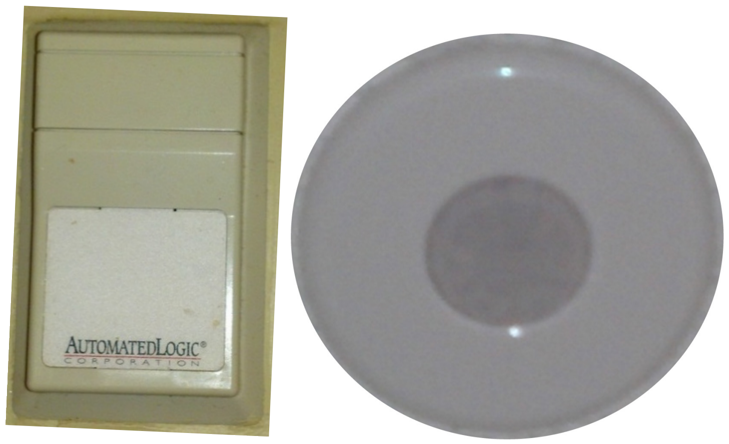

Figure 5: Existing Sensor Examples

Pictured above in Figure 5 are two existing sensors in buildings on the WPI campus. As can be seen on the left, some elements were provided by the Automated Logic Corporation. Sensors like the box at left are simple temperature sensors. One additional feature is that some of these temperature sensors include simple switches that people can press to indicate the room is occupied, or to override the normal set temperature for intervals up to a time limit set by building management (Spratt, Initial Meeting with Facilities Staff, 2012). The sensor on the right is a passive infrared (PIR) sensor that checks for people moving in the room. These sensors are the type that is often used to turn the lights on or off.

Despite having many sensors, many zones are not finely controlled. The WPI Campus Center, for example, runs based on a timer. At 6:00 AM, the system sets its zones to “occupied” and then cools or heats the rooms to their specified set points. Then at midnight, the system sets the zones to “unoccupied” and virtually ceases managing the temperature and ventilation, only turning on to prevent damage to the building (i.e. not too hot to damage equipment, not too cold to freeze pipes). The system at present will also allow for major inefficiencies such as running air conditioning equipment in addition to running the heating boilers.

Newer buildings including East Hall and the Recreation Center as well as many updated rooms have been equipped with at least basic occupancy sensors to manage the light controls.

3.4 Power

Each unit in the system will need to be individually powered. When choosing the method of powering these devices, it is important to take into consideration; the availability of the power source where each unit will be located, the ease of installation, and any safety concerns regarding the power source. The three main power sources that were investigated were batteries, mains voltage, and power over Ethernet. Photovoltaics, while a popular method of powering low-power devices, would not be a realistic option for this application because fluorescent lights are used in each room where the units would be located. Photovoltaics work best in direct sunlight or other locations with high energy radiation (e.g. ultraviolet rays) but do not work well with fluorescent lighting, which is much lower-energy radiation.

3.4.1 Batteries

Using batteries to power each unit in the system would make the design and construction of the system very easy. Batteries are also generally safe to people who come into contact with them. They can explode but that only occurs when they have been used improperly. Also, batteries can spontaneously leak dangerous chemicals; this is a fairly rare occurrence. While batteries are mostly safe when in use, batteries are very harmful to the environment when not properly disposed of. Some batteries produce toxic metal pollution by letting dangerous elements like lead, mercury, and cadmium into the environment.

However, the main disadvantage of using batteries to power the system is that that the batteries would need to be regularly replaced. Someone would have to go around to each room with a unit installed and replace the batteries. Constantly replacing batteries can be time consuming and very expensive. But if the batteries are capable of lasting for a couple years at a time without needing to be changed, then using batteries as the unit’s power source may be possible.

The networked occupancy sensor system will consist of units that would ideally require very little power. Since a significant part of this project’s purpose is to reduce the energy usage of a building the system should be designed to use energy efficiently and to conserve power. Given their advantages batteries are a potential option for powering the system, but may not be a sustainable choice due to manufacturing and disposal concerns.

3.4.2 Mains (AC) Voltage

Powering each device from the mains is feasible because generally wall outlets will be available for use. Since outlets already exist is each room, installation would be simple. In most cases it would not be necessary to do any additional wiring in the building to power each unit, provided that the sensor was located near an available outlet. Mains voltage in the United States is standardized to 120V. This provides a much higher voltage than is necessary to power each device. While, to most professionals, 120V is considered low-voltage and not dangerous, significant electrical injury can still occur (Morse, 2006).

Since the mains voltage is much higher than what would be needed for each device, dedicated power lines could be installed to provide a lower voltage. Dedicated power lines are special low-voltage wiring that connects to the mains voltage. When installed, it provides readily available low-voltage power sources. However, these dedicated power lines would need to be installed in every room where there is a unit. This makes installation more difficult but these power lines have a much lower voltage than the mains voltage, making dedicated power lines somewhat safer than directly using mains voltage.

3.4.3 Power over Ethernet

Power over Ethernet (PoE) is a viable method for powering a device as well as sending and receiving data through a single cable. Unlike its competition, the Universal Serial Bus (USB) which is limited to a maximum cable length of five meters and can support less than 2.5 W of power, PoE can provide up to 12 W of power with a cable of 100 meters. PoE has major advantages over other technologies that include:

- Easier deployment – Access to hard-to-reach locations or places with a lack of space for power deployment, such as roadside, external walls and internal ceilings, becomes much simpler and easier to maintain.
- Lower cost – Costs can quickly escalate when the installation of separate power outlets are factored into a project, PoE switches save both time and money by avoiding the need for separate installation of Power outlets.
- Multi-location – Wherever there is an Ethernet connection, a powered device can be used.
- Increased uptime – If a UPS is used in the power supply for the PoE switch, reliability rises towards the optimum “five nines” due to reliance not being placed on the mains AC voltage supply.
- Improved safety – 48 Volt Direct Current levels are much safer than AC mains voltage.
- Plug and play – Equipping applications with PoE switches is simple and enables interoperability with a growing variety of devices. (Power over Ethernet)

This method is standardized according to IEEE 802.3at-2009. The standard requires using a category 5 or higher cable. CAT 5 cables consist of four twisted pairs and the power would be supplied using two of them; leaving the remaining two differential pairs for data.

Power over Ethernet is a convenient method for powering devices because it utilizes existing infrastructure without relying on AC power outlets, which are not always available for use in every room. The most common way to implement power over Ethernet is to use a mid-span hub. Each device is tethered with a cable to the mid-span hub and the hub sits next to a switch. Mid-span hubs were developed as a way to power devices over Ethernet without having to replace existing network switches with new switches specifically designed to enable power over Ethernet (Dagan, 2005).

Another attractive feature of powering the devices using Ethernet is that data can be transmitted through the same cable that is powering the device. This would allow for a simpler system and easier installation than a system that required multiple cables per device or an alternative and more complicated method of powering the device. Also, Ethernet can communicate using BACnet, one system that WPI uses to communicate between building devices.

3.5 Sensors

It is necessary for each unit of the networked occupancy sensor system to be capable of detecting, measuring, and providing data on the temperature, light status, and occupancy of the room being monitored. The types of sensors included in the design will be; temperature sensors to be used to monitor the room temperature, light detection sensors to be used to determine whether or not the lights are on in a room, and motion detecting sensors to monitor the occupancy status of the room.

3.5.1 Temperature Sensors

There are seven basic types of temperature sensors; thermocouples, resistive temperature devices (RTDs), infrared sensors, thermometers, change-of-state sensors, and silicon diode sensors (OMEGA, 2000). However the design of this system requires the sensor to electronically output the temperature, therefore, bimetallic devices, thermometers, and change-of-state sensors would not work for this application. Using infrared sensors to measure the temperature of the room may have issues with accuracy when there are people in the room. Also, silicon diode sensors were designed to be used in the cryogenic temperature range which is well below the temperature range that is necessary. Thermocouples measure temperature with a change in voltage and RTDs measure temperature with a change in resistance. Voltage, with thermocouples, and resistance, with RTDs, will change when temperature increases or decreases. Both sensor types can positively increase with increasing temperature, but RTDs are much more linear than thermocouples. This could make resistive temperature devices easier to work with than thermocouples.

A temperature sensor using a thermistor would be easy to design. Its resistance varies notably with its temperature and could be placed in series with another resistor with a known and constant resistance. Thus, voltage between the two resistances (compared to the voltage applied over both) could be digitized, allowing calculations to be done to determine the applied temperature. The resistivity of the thermistor varies with its temperature. It may increase or decrease (a feature specified by the manufacturer). Thermistors are partially characterized by their error, which is given in %/°C. They can require calibration (which complicates design) but they are cheap.

While designing a custom temperature sensing module would be relatively simple, purchasing a pre-constructed temperature sensor component is often a better option. By purchasing an existing temperature sensing component the overall system design is simplified and reduces potential for calibration error.

3.5.2 Light Detection Sensors

Each unit in the system needs to be able to detect whether or not the light in the room is on. Photodetectors can be used to determine the light status in the room. Three types of photodetectors that are frequently used for similar applications are; photoresistors, photodiodes, and light-emitting diodes (LEDs) (Andromeda, 2013).

Photoresistors measure light with changes in resistance. As the light intensity increases, the photoresistor's resistance decreases. This type of photodetector has an analog output. Preferably a photodetector whose output is digital would be used in order to reduce the complexity of the design.

Photodiodes can be used in photodetector applications. The output of a photodiode can either be analog or digital depending on how it is designed to be used. To be used for measuring the amount of light present, an analog output can be generated. Or it can be designed to generate a digital output that can be used for control or switching applications. Digital output would be ideal for this light detection application because it will simply output whether or not the light is on in the room.

It is also possible to use an LED as light sensor. This is an attractive option for a light detection sensor because it can reduce the cost of the system by using a single component for multiple functions. The LED can switch between emitting light and detecting it. To detect light it works like a photodiode but it is only sensitive to light with wavelengths that are equal in length or shorter than the wavelength of the light that the LED emits.

3.5.3 Motion Detecting Sensors

There are many different types of motion detecting sensors currently on the market. Some are active sensors; they send out energy usually in the form of either light, microwaves or sound and then wait for that energy to come back. When the returning signal has been received, calculations are made to determine whether or not something has moved in front of it. Then there are passive sensors that do not send out any energy, for example the passive infrared sensor that simply detects ambient energy levels.

3.5.3.1 Passive Infrared

Passive infrared sensors work by detecting changes in levels of infrared radiation. A PIR sensor module will detect a human by noticing the difference radiation that it emits compared to the room because everything emits some radiation, with warmer things emitting more than cooler things. "The sensor in a motion detector is actually split in two halves. The reason for that is that we are looking to detect motion (change) not average IR levels. The two halves are wired up so that they cancel each other out. If one half sees more or less IR radiation than the other, the output will swing high or low." (PIR Motion Sensors, 2012)

This type of motion detecting sensor is very common and widely used because it is small, inexpensive, low-power, and easy to use. Using passive infrared sensors in the room occupancy detection system is one of the better options because of its ease of implementation and accuracy. The low-power consumption is an attractive feature because the purpose of this design is to ultimately assist the user in lowering unnecessary energy usage in their building so it is necessary to design a system that will save more energy than it consumes.

3.5.3.2 Ultrasonic

Ultrasonic sensors detect motion by generating high frequency sound waves and detecting the change in time it takes to send and receive the signal. This type of sensor is used to detect the presence of something and to measure how far away it is. By using sound rather than light, this sensor can be used in certain applications that are impossible for other sensors; detecting objects that are translucent.

One disadvantage in using ultrasonic sensors to detect objects is that "there's no way to tell the difference between small objects and large objects because the pulse that's emitted is cone shaped. Because of the shape, an echo will be returned by all objects the pulse comes into contact with." (Garcia).

For this application, ultrasonic sensors may not be a practical option. A major problem is that if something is added to the room (not a person) after the sensor has been calibrated, the ultrasonic sensor will continuously report false positives since it cannot differentiate between an inanimate object and a person. However, if coupled with another type of sensor, it could potentially greatly improve the accuracy of the system as a whole.

3.5.3.3 Microwave

Microwave sensors send out microwave radio energy and wait for it to come back. When a person walks in front of this sensor, the sensor detects the change in the returning energy. This type of sensor is often used in automatic door openers.

There are two main microwave sensor designs; monostatic or bistatic. In monostatic systems, the emitter and receiver are together in one unit but in bistatic systems they are in separate units. The main differences between the two designs is that with a monostatic unit the detection range is smaller, but users can define the area of detection more accurately than with bistatic units. Also, bistatic are more likely to report false positives.

While microwaves are capable of passing through many material types, it cannot penetrate metal objects (Microwave Motion Detector Guide). Most obstacles that would inhibit other sensors are not a problem for microwave sensors. Being able to detect motion behind various objects is a very attractive characteristic of this type of sensor. However, this is limited to objects that are not metal. Large metal objects (e.g. desks, tables) in a room would create areas in the room where motion detection would not be possible.

3.5.3.4 Acoustic

Acoustic sensors detect occupancy by listening for sounds from people in the room. This type of sensor is prone to false positives because of environmental noise. While alone the acoustic sensor is not very reliable, it can enhance the capabilities of other sensors when the sensors are combined in one unit. Acoustic sensors are inexpensive and can easily be integrated with other sensors to reduce the occurrence of false positives.

3.6 Data Access

The data that is collected from each unit should be available for building managers to view so that they can track building usage and adjust resources accordingly. Also, the data gathered from the units can be used to provide real-time statistics to be viewed. It is necessary to make this data easily accessible from anywhere. This could be done by developing a mobile platform or a mobile website interface.

3.6.1 Mobile Platform Development

There are only a few major players in the smartphone market. A recent press release from comScore (a network market analysis group) shows that the Android operating system has achieved a 52.2% market share in the United States (comScore, 2012). Following Android, the next big systems in use are Apple iOS at 33.4% and RIM Blackberry at 9.5%. This data doesn't factor in the increasingly popular tablet format for computing, so there are definitely more Android and iOS devices on the market that are unaccounted for in these percentages. Conveniently, most applications (apps) written for mobile phones will run properly on tablets in the same operating system family (i.e. iPhone apps will work on iPads, Android apps will run on Android tablets).

Android and Blackberry apps are both written in Java (Kowalski, 2010). This being the case, it should be possible to more easily re-use common code for creating a Blackberry app from the Android app's codebase. However, iOS apps are written in C# ("C-Sharp"), a derivative of the C programming language.

3.6.2 Mobile Website Interface

In general, creating a website is very easy and there are a plethora of internet resources and information to assist in the design and creation of a website. Creating a website is a viable option to present room occupancy data to users of the system. Websites can be accessed on virtually any computer or mobile device (including smartphones) with access to the internet. Generally, websites are not designed with smart phones in mind. In a situation where a mobile-friendly site isn't created, a website may be very difficult to navigate. However, it is possible to design a website that can be specifically optimized for mobile device use by simply making minor adjustments in the design and adding a couple tags in the `<head>` section of the webpage. "Mobile META tags can be used in XHTML-MP and HTML markup to tag the document as optimized for mobile devices … A lightweight and responsive full-HTML mobile web experience provides the best user experience across a mobile network and on the smartphone browser." (Rahn, 2009)

Implementing a mobile website interface may be the best option for presenting the data on room occupancy rather than immediately making a smartphone app. A webpage can be accessed not only from any computer but also on any type of mobile device; it does not matter whether the device is an Apple or Android product. This is unlike a smartphone app where it would need to be designed for either iOS or Android. Therefore, at least two apps would need to be designed in order to make the data on room occupancy readily available to most people.

4 Methodology

As stated above, this system is primarily meant to be used in collecting room occupancy data. The usage data would be used to manage light controllers and other system controls in order to reduce energy consumption of buildings. The data will also be made available to authorized individuals. The intermediate stages required to develop a robust product include:

1. Researching and analyzing various room occupancy sensing systems and networking technologies
2. Identifying the best combination of technologies
3. Identifying hardware and processing needs for chosen technologies
4. Designing and constructing a prototype system
5. Evaluating accuracy and scalability of the system
6. Determining areas for improvement *(see* Conclusions*)*

4.1 Research and Analysis

Background research, found primarily in the previous section (Section 3: Background), comes from academic journals as well as publications such as press releases from industry and the government. In addition, to provide a clear assessment of currently-available systems and technologies, distributor and manufacturer websites and/or catalogs and other marketing literature were used in preparing the background research section. The demand/market for the new devices was found by interviewing WPI employees who work with relevant building systems and by observing the general market trend in the building automation and control industry.

Background research was conducted in various major aspects of the system design. This included research into networking, power supply options, existing systems with similar functionality, types of sensors, and interface designs that would be available for use in this project. The results of the research were used to analyze systems that are available on the market to determine the best approach for the design of this MQP.

4.2 System Design

After researching available occupancy-detection hardware, networking hardware, and power supply hardware, the availability and ease of integration for each option was compared against the alternatives. First the network and communication option was chosen, which led to the selection of the power supply. The general type of controller/processing unit to use was chosen based on personal experience with different devices. With clear expectations on which inputs and outputs would be necessary, specific sensors were chosen to be integrated into the system. Finally, a processor was selected that could handle the necessary control operations.

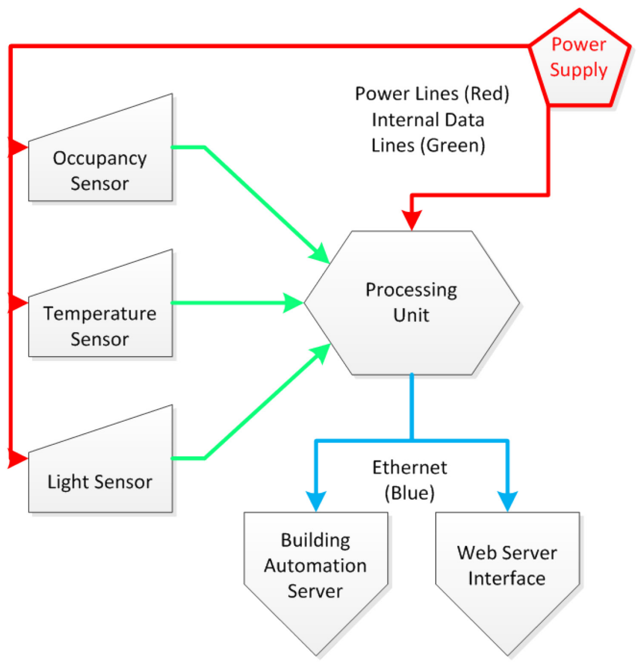

Figure 6: High-Level Module Hardware Diagram

4.2.1 Power and Communications

The networking option chosen for this project is Ethernet over twisted pair copper cable. This led logically into using Power over Ethernet as the system power supply, as it reduces overall complexity. After the options were weighed, it was decided that using a wireless system in the 2.4GHz range would be a poor plan for the reasons described in sections 3.1.1 and 3.1.2 (Wi-Fi and ZigBee, respectively). In addition, the convenience of Power over Ethernet made Ethernet as a data service a highly-attractive design choice. This design is also simpler to integrate into the BACnet system, as Ethernet is one of the primary infrastructure options in BACnet and is widely available in many buildings. As described in the background section, BACnet specifies how the individual devices communicate to and from the building automation server.

In the system, each module will need to be powered individually and communicate to the system. Utilizing Power over Ethernet (PoE), the system can be powered using the same cable over which data is transmitted within the system. This simplifies the installation of the system since it relies primarily on preexisting infrastructure.

Originally, the power supply was designed to use Power over Ethernet to produce a stable, low-voltage power supply for the rest of the circuit. However, the complexity of 802.3af made creating a new PoE power supply too difficult. To solve this problem, an off-the-shelf IEEE802.3af compliant PoE module was added to the design to provide the necessary regulated 3.3V output. This module performs all of the PoE interfacing with minimal additional configuration.

4.2.2 Sensors

Each unit of the networked room occupancy sensing system contains two PIR sensors, a temperature sensor, and a light sensor. When choosing specific sensors, the main deciding factors were ease of implementation and cost. The only additional component necessary for interfacing the sensors with the microcontroller is a 3.0V reference that is used for analog-to-digital conversions.

To detect room occupancy, instead of using two different types of motion detectors, only PIR sensors are used. By using only one type of sensor, the cost per unit is reduced. The sensors chosen are long-range sensors and therefore have limited sensitivity across the full range. To compensate for this loss of sensitivity, two PIR sensors are used together to determine if there is a warm body moving in the room. The specific PIR sensor chosen provides a digital output that has integrated false-positive reduction, which allows for two sensors to be used without causing more false-positives.

For ambient temperature measurement, a linear thermistor integrated circuit was chosen. This is a low-cost device that does not require an additional signal-conditioning circuit like many other resistive sensors would. The ambient temperature is converted to an analog signal.

Equation 1: Ambient Temperature Equation

$$T_A = \frac{V_{out} - V_{0°C}}{T_C}$$

Equation 1 above is the equation to determine the ambient temperature based on the output voltage from the sensor where; T_A is the ambient temperature, V_{out} is the sensor output voltage, $V_{0°C}$ is the sensor output voltage at 0°C (400mV), and T_C is the temperature coefficient (19.5mV/°C).

The light sensor is a photodiode integrated circuit and its output voltage is linear with light intensity. The sensor's datasheet lists values only for a supply voltage of 5V, but the supply voltage from the sensor module circuit is only 3.3V. This value is within operating specifications, but the output voltage corresponding to an illuminated room needed to be found empirically. A well-lit sensor output around 2.5V, and a moderately-lit sensor output around 1V.

4.2.3 Processor

It is necessary in the design to have a microprocessor integrated into each unit in the system. Embedded microprocessor systems are very inexpensive because they use a relatively standard hardware architecture that fits a large variety of applications. Also, software is significantly easier to develop than custom hardware is to design in order to do the same task.

There are many options for embedded systems-on-chip to choose from. For this design it is not necessary to purchase microcontrollers that have a state-of-the-art CPU, GPU, off-chip memory interface, or 2-level cache designed for smartphone and tablet applications. DSP processors may also be over-powered for this application and have the disadvantage of being vendor dependent and relatively high in power consumption.

Instead, this project requires a small CPU with a small amount of memory and control-oriented peripherals (e.g. timers, digital/analog I/O, etc.). Microcontrollers like this are generally designed for sensors and control, simple appliances/toys, and low-power applications. These microcontrollers are very low-power devices; this project needs to be as energy efficient as possible to reduce strain on PoE sourcing equipment. The main types of microcontrollers in this category are; Texas Instruments MSP430's, Microchip PIC's, and Atmel AVR's. It was decided to go with a PIC microcontroller because they are extremely cheap, easy to setup (have internal EEPROM and RAM, and most do not require an external oscillator), and are well-documented and there are a plethora of resources on the internet to assist in integrating it into this system's design.

Two desired features that are not included in many feature-limited processors are Power over Ethernet circuitry and Ethernet physical layer control. One major disadvantage with the more sophisticated chips is that they are almost always surface mount and are hard (or impossible) to work with on a normal prototyping board. For ease of development, these systems are instead handled by dedicated additional hardware, described more in the section Final Design.

4.2.4 Application Server

An application server is necessary to this project for hosting the website and for processing data collected by the sensors. A single server provides both functions, and is built on a legacy Dell Optiplex GX260 workstation. The server is running Microsoft Windows Server 2003 R2 and provides a stable development environment for the project. A minor difference between the development server and one that might be found in an enterprise environment is that it is not domain controlled, does not have server-class virus protection or firewalls in place, and is used frequently as a workstation.

The server is modest, especially by modern standards. This implies that the system could be implemented on antiquated hardware and could potentially be used by home users. Some system specifications for the application server are listed below:

- 1.7GHz Intel Celeron CPU
- 1GB RAM
- 64MB Integrated Graphics
- 10/100MB Ethernet Card (connection to occupancy system network)
- 1000MB Ethernet Card (connection to primary local area network)

The web hosting component is handled by the Microsoft Internet Information Services component of the operating system, and data processing element is handled by a Java application running on the server. See Appendix 10.8.3 for details on the web hosting set-up. The Java application listens for data coming from the sensor modules. It then parses the useful data from the Ethernet packets, converts the temperature raw data into a value in degrees Fahrenheit, and sends a query to the MySQL database to update the information. See Appendix 10.6 for the source, as well as comments describing the program.

4.2.5 MySQL Database

The interface development relies on the operation of a database server and an application server. The interface itself runs on the application server, and it retrieves data from the database server. The microcontroller transmits data from the sensors to the database (via the application server), updating the data tables. Figure 7 is the database's entity-relationship chart. It outlines the information contained in each table within the database and the relationship between those tables.

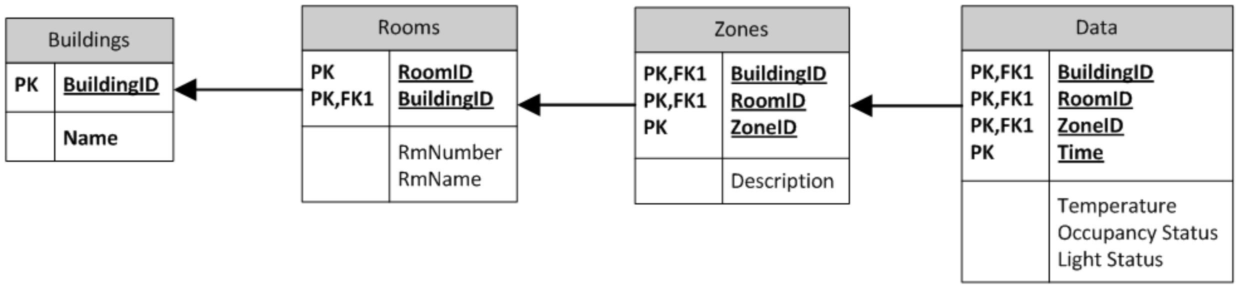

Figure 7: Database Entity-Relationship Chart

The database is hosted on the WPI Computing and Communications Center (CCC) MySQL server, which is hosted across multiple physical servers. User interface with the MySQL server is done through Oracle MySQL Workbench, any changes made on one physical server are propagated across the others (Oracle, 2013). MySQL Workbench is a graphical tool that can be used to create tables in the database and edit data within the database tables. The database server is typical for enterprise environments, running the enterprise version of MySQL database server.

The database is updated with information from the microcontroller as it is received by the application server. The application server hosts an application that analyzes data coming from the microcontroller and separates out the useful data. The data are then uploaded to the MySQL server where they are simply added to the existing data tables.

4.2.6 Mobile Website

From the MySQL database, the data from the sensors is displayed on a website designed for mobile devices. The layout and navigation of the mobile website is specifically designed for use on smartphones. Mobile websites need to accommodate the low-resolution, typically vertical, screens of mobile devices. The mobile website for this project is designed with all of the content formatted in a single-column interface. Along with constraining all scrolling to the vertical axis, text size and all clickable areas are auto-scaled to be large enough to be easily read and to be accurately "clicked".

To retrieve data from the MySQL database, the website uses PHP (see Appendix 10.7 for the mobile website's code). PHP stands for PHP: Hypertext Preprocessor (The PHP Group, 2013). PHP is an open-source scripting language and PHP files may contain text, HTML, and JavaScript code along with the PHP code. The server executes the PHP code and returns the result to the browser as plain HTML (along with JavaScript, if used). PHP can easily be used to output data from a database to web pages.

4.2.7 Electronics Assembly & Enclosure

Most electronic components will be mounted directly to a custom printed circuit board. The circuit board will be designed and then manufactured off-site. Before making the circuit board, each electronic subsystem will be tested in a laboratory environment. A risk involved in using a custom PCB is that if anything is overlooked, it can cause problems later on that are much harder to fix.

The enclosure protects the electronics from environmental hazards (e.g. dust, curious people) and allows for easier installation in a room. The enclosure will be designed to fit the electronics assemblies. Some considerations in designing the enclosure are ease of access to the circuit board, size constraints, and manufacturability.

4.3 Evaluation of Complete Prototype System

Electrical testing was performed on individual portions of the design. Each sensor module was tested on breadboards, and the sensors' output was read on a laboratory digital multimeter. After electrical testing, the sensors were tested with the microcontroller to observe proper communication between the sensors and the microcontroller. After the electronics assemblies were completed, additional testing was done to verify that the PCB and the rest of the circuit were working.

With the completed modules, the whole system was tested to verify that it can sense occupancy in a room in accordance with the design guidelines set forth in Goals & Specifications. In addition to verifying that humans work to set off the sensors within the expected range, attempts were made to generate false positives by "tricking" the sensors (e.g. using a hair dryer to blow hot air past an IR sensor). The modules were also set up to provide visual feedback to demonstrate that the temperature and light sensing subsystems were operational.

In the event that networking did not work properly, hardware and software debugging techniques could be used to prove that the sensing system operates correctly. With an operational networking system, data were collected and checked for errors while the system was running in a "steady state".

The web interface is largely dependent on data from the sensors. Prior to getting real data from sensors, dummy data was used to test the web interface. The web interface was tested by viewing it on multiple mobile devices and on computers, and it was shown that the data is being generated dynamically from the database.

5 Final Design

The overall design has gone through much iteration. Despite many setbacks, many of the originally-intended features now function. However, some things had to be cut from the design. This section details the design process and many of the final design decisions.

5.1.1 Schematic Design

ExpressSCH, a free software tool, was used for designing the schematic because of its cost and ease of use. It is a very useful program for designing small printed circuit boards. Since this project is a relatively simple design, ExpressSCH worked very well.

For all of the major components in the circuit, custom symbols had to be created to represent them in the schematic. This involved using the datasheets for each component to recreate them with the correct pin-outs in ExpressSCH. Standard components, like capacitors and resistors, were already included in the ExpressSCH database and were easily inserted.

The schematic underwent three major revisions prior to making the PCB, and a fourth revision, available in Appendix 10.1, after testing. The first revision includes the original microcontroller chosen for the project, as well as designs for power supply circuitry. In addition, this version included the originally-chosen light sensor, which was replaced by a through-hole component later in the design. The second revision includes the new microcontroller, the new light sensor, and the PoE module. The third revision has the addition of the 3.0V reference and additional connections for the in-circuit programming system. The final fourth revision, found in Appendix 10.1: Schematic includes changes that were made after testing the modules on the PCB.

5.1.2 Circuit Verification

Prior to designing the PCB around the schematic, individual portions of the schematic were tested on prototyping boards. The elements that were tested were the ones that could be tested individually. This includes each of the sensors, as well as the PoE module.

During the initial testing of the sensors, all sensors functioned generally as expected. The PIR sensors had an output voltage between 3.2-3.3V when motion was detected. They were sensitive enough to detect most slight movements. However, when approaching the sensor directly from a distance exceeding 25' it is possible to go undetected. To reduce the impact of this blind spot, the module should be installed in a corner of the room at least 5' up from the ground, with the PIR sensors angled very slightly downwards.

The thermal sensor's output voltage varied as temperature changed, closely to how the characteristic equation describes. No testing was done at this point to verify the accuracy of the sensor. The light sensor outputs a voltage of ~2.5V when the lights are on and 0V when the lights are off. The temperature sensor and light sensor both produce analog outputs that must be read into the microcontroller using the analog-to-digital converter (ADC) module. Once data from the two sensors are read in, they must be translated by the microcontroller to make the data useful.

The ADC was tested by using a reference voltage generated by a lab power supply. By calculating the ADC resolution and comparing the expected value for the reference voltage, then outputting the actual value on I/O pins, it was determined that is was possible to read in the voltages to a margin of error of approximately 0.04V, which is sufficiently accurate for the design.

The Power over Ethernet module was tested to verify that it could obtain a 3.3V supply voltage from the Ethernet line. Initially,the data ports used were not connected to a PoE sourcing device, but after borrowing a PoE injector, the PoE module was able to output a useful voltage.

Two parts that should have been tested were the voltage reference regulator and the Ethernet oscillator. Both of these parts did not arrive until after the deadline for ordering the PCB, and were therefore untested until on the PCB. These two parts caused additional problems on the PCB, as described below.

5.1.3 PCB

ExpressPCB, another free software tool related to ExpressSCH, was used for component placement and routing on the circuit board (see Figure 9 and Figure 10 in Appendix 10.3). Since ExpressSCH was used to create the schematic, it was possible to link that schematic to the PCB design to verify the net list. Linking the schematic to the PCB file made routing significantly easier; when drawing traces, the program showed which pins to connect based off of the net list for the schematic that was linked to the PCB file.

The PCB went through four major revisions. Due to the errors in the schematic, a few routing errors were not discovered during the review process. Wires were added to switch the connections to the LEDs on the MagJack and to connect the center tap pin to V_{DD}. The only other error on the PCB was related to the 3.0V regulator. The regulator was not set up properly in the schematic, and it required an additional resistor to be soldered in between its input and V_{DD}. Conveniently, the no-connection pin of the regulator provided another solder point to fix the error. One last minor problem on the PCB was non-ideal placement of a few components on the secondary side of the board; which caused pins to inconveniently extend through the board hindering the positioning of the Power over Ethernet module. This was fixed with extra solder on the other side, and close trimming of capacitor leads under the PoE module.

5.1.4 Microcontroller

The main program running on the microcontroller is what determines what the system does. In general, the whole of the program can be broken down into a couple control loops and a few major steps. On a high-level view, the main procedure involves initialization followed by a loop during which sensors are checked and data is sent to the server.

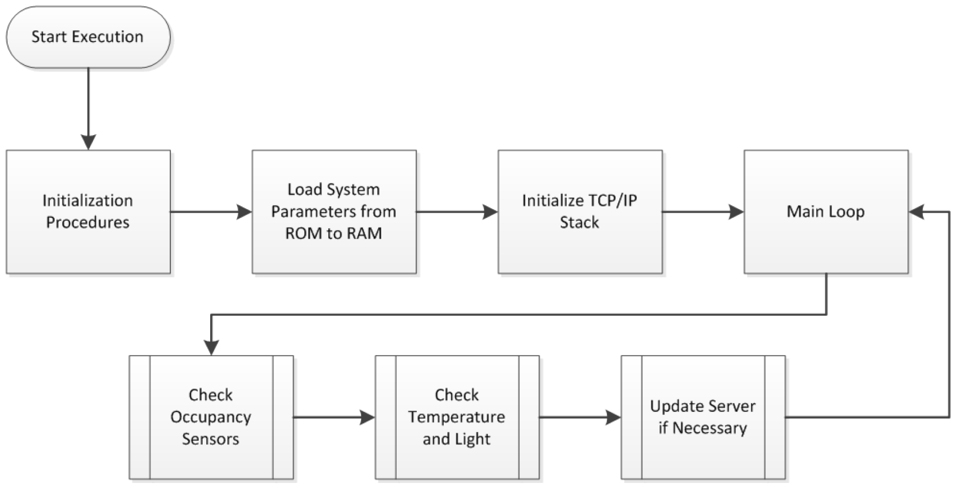
Start Execution
Initialization Procedures
Load System Parameters from ROM to RAM
Initialize TCP/IP Stack
Main Loop
Check Occupancy Sensors
Check Temperature and Light
Update Server if Necessary

Figure 8: Top-Level Software Block Diagram

All of the code in the main function and the user files are well-documented with line-by-line comments that explain what the code does.

5.1.4.1 Initialization Procedure

The initialization of the sensor modules involves a lot of one-time setup. The configuration bit code may be found in Appendix 10.5.4.2. First, the code includes establishing the configuration bits of the processor. The two most important configuration bits to the project are `WDTEN` (watchdog timer enable) and `FOSC` (oscillator selection). `WDTEN` was set to off and `FOSC` was set to `INTIO67`, which meant that the watchdog timer was disabled and the oscillator would use the internal oscillator while providing port function on pins RA6 and RA7.

Next, the PIC sets up its oscillator to use the `HFINTOSC` (high frequency internal oscillator) to directly drive the processor. The oscillator set-up code can be found in Appendix 10.5.3. This gives a processor clock of 16MHz, with an instruction clock of 4MHz. Then the processor sets up its analog and digital input/output pins. This is done by setting the `TRIS` registers and the `ANSEL` registers (see Appendix 0). Once the digital and analog I/O pins are set up, the PIC initializes its peripherals. This sets up the default values for the ADC and for the SPI module. After those peripherals, the processor enables all interrupts.

At this point, the PIC is almost ready to run application code. Before it does, it loads several configuration values from the ROM to RAM for use by the TCP/IP stack (see first section of `main()` in Appendix 10.5.1). The stack is initialized immediately afterwards, which also sends configuration instructions to the Ethernet controller. The stack initialization is a library function from the Microchip TCP/IP stack. At that point, the chip is ready to start sending and receiving data.

The initialization sequence is as follows:

1. Configure oscillator
2. Set up microcontroller I/O pins
3. Set up Tick timer

4. Load configuration data from ROM to RAM
5. Run TCP/IP stack initialization routine
6. Set initial values for control variables

5.1.4.2 *Cooperative Multitasking Main Code*

Within the main loop, there are several processes that must all run at the same time. This is performed by creating elements to act like state machines. As the system processes all the different tasks, it will fall through any that are waiting for something else to happen, thereby allowing other tasks to run while one task waits. The major function calls are StackTask and StackApplications, which are TCP/IP stack library functions that process commands that go to the Ethernet controller chip. Following these two tasks are the “user task”, which is where the sensors are polled and data is prepared to be sent to the server. This code is available in Appendix 10.5.1: main.c (user code), after initialization is complete and the main “while” loop is entered.

The control loops are fairly simple. After sending one update to the server, there is a flag (`UpdateEnable`) that prevents sending another update for one minute. For the PIR sensors, the one-minute interval may be interrupted, but then the PIR sensor cannot update for another five minutes. In this way, temperature and light updates may be sent to the server at a maximum interval of 60 updates/hour, while occupancy updates may be sent only 12 times/ hour. See the full code for details.

5.1.5 Enclosure

The enclosure went through two revisions, one fairly simple and one complex. The first revision was effectively a hollow triangular prism that was 3D printed out of ABS. This model was determined to be difficult to work with since it only provided access through a removable top plate. In addition, it didn’t provide much room for position of the electronics. This model served as a guide for the features that the second revision would incorporate.

In the second revision, a more-complex pentagon-footprint was used to accommodate the thickness of the assembled PCB. This new revision had a removable top and a removable, sliding front face. This allows for the PCB to be directly removed from the enclosure so that it can be accessed from the back. Accessing the front side of the board is still very limited, but because of the through-hole components used, most components may still be accessed from the back of the board. In addition, the second revision was modeled around a 1:1 scale model of the assembled PCB. In this way, it was shown to fit properly in a Solidworks assembly with the holes in the appropriate places for PIR sensors and the Ethernet jack. However, holes were omitted for the light and temperature sensors, and were added later.

For simple dimensions, please see Figure 2 in Section 2 above. See Appendix section 10.4 for images of the 3-D Solidworks models. For full details, please see the accompanying Solidworks models.

5.1.6 Standards Compliance

Part of the design is to make use of industry standards. The utilization of a pre-built PoE module allows compliance with IEEE 802.3af in the system power supply. Implementing Power over Ethernet is a challenging task, and could have been a full project by itself. The device communicates over twisted pair data connections terminated in RJ-45 connectors. This part of the design involves 802.3at-2009-compliant Ethernet communication, which was achieved by the combination of the microcontroller/software and Ethernet controller chip. BACnet was originally intended to be a part of this design. However, due to time constraints and design challenges, BACnet compliance was cut from the final design in favor of a much simpler connectivity strategy.

6 Testing

The overall design had to be tested after everything was in place on the printed circuit board. This involved a combination of probing individual pins while the system was on, using LED indicators and instrumentation code, and using a debugger on the microcontroller to “see” what was going on in the system. Since preliminary test results were already promising for the sensors, the microcontroller and Ethernet controller were tested first. Additionally, the Power over Ethernet module worked immediately after being soldered on to the board and energized.

6.1 Circuit Testing

During design, there were a few errors that got overlooked through all revisions of the schematic. First, capacitance values were never corrected for the load capacitors connected to the crystal oscillator for the Ethernet controller. The capacitance on the schematic remained at .1µF, although it should have actually been 18pF. This was found during testing because it prevented the oscillator from running properly.

Another problem was with symbol creation. The 3.0V regulator for the ADC voltage reference was created with the wrong labels on its pins. This caused some confusion when it was put into the schematic, and the error was not found until it was powered up but not working properly. Again related to symbol creation, the polarity of the LED pins on the MagJack (RJ45 jack) was swapped. The anodes and cathodes for each LED were reversed, so the LEDs did not light up as expected. Unrelated to symbol creation, a wire was missing that was meant to connect the common center tap pin of the MagJack to V_{DD}. Two other parts affected by symbol creation were the thermal sensor and the PIR sensors. For both of these parts, the symbols were created from the bottom view of the parts. This meant that on the circuit board, the pins were correct for the part, but only if it was placed on the bottom-side of the board.

6.2 Microcontroller

The first thing that was tested once the microcontroller was soldered on to the PCB was to verify that it could be successfully programmed. At the same point in time as the first PCB was assembled, a more sophisticated programmer with in-circuit debugging capabilities was acquired for use during the remaining part of the project. The new programmer/debugger did not provide power to the board, unlike the programmer for which some of the external connections were designed. On subsequent PCB assemblies, the now-unused pins and components were omitted (reflected in the schematic included in this report). The new programmer worked perfectly for loading test code onto the microcontroller.

Many elements of the sensor system rely on accurate timing. Despite attempting to set up the internal oscillator on the PIC to run at 16MHz, it was not operating as expected. Test software was developed that would toggle an LED on/off at a known frequency (e.g. every 5 seconds). The actual time between LED pulses was measured with a stopwatch. From this test, it was evident that the oscillator was not running at the frequency that was expected (16MHz), but appeared to be running at 1MHz. After several code iterations that changed oscillator configuration registers, the code was tested using a different compiler (C18 instead of XC8). To improve the accuracy of the “stopwatch test”, external testing hardware was employed to measure the period at which the LED was toggled.

An FPGA with a 50MHz crystal oscillator was used to measure the time between LED flashes to an accuracy of ~20ns. In addition the description here, the procedure and primary findings of this test are described in Appendix 10.5.6. After computing the time between pulses, the FPGA output the data on a four-digit display module, where the value was shown to the hundredth of a second. By using the data from the FPGA, the clock was verified to be running at 16MHz within a very small margin of error when using the C18 compiler with the test code.

All other microcontroller-related tasks were more specifically related to the other subsystems and are described below.

6.3 Ethernet System

When attempting to achieve Ethernet connectivity, the first goal was to establish a serial connection between the PIC microcontroller and the ENC28J60 Ethernet controller. To accomplish this, commands were sent over the serial interface that would set the LEDs integrated into the Ethernet jack from showing Link/Activity to operating Always-On/Blinking. By using the debugger, it was established that the program on the PIC was getting caught in a loop while trying to connect to the Ethernet controller. After attempting to debug this issue in software, it was determined to be a hardware issue. When reviewing the design again, compared with other designs implementing the ENC28J60, it was found that the oscillator load capacitors were of an incorrect value. By replacing them, the program was able to proceed beyond the point at which it had been stalling.

With the debugger providing "proof" that the connection between the microcontroller and Ethernet controller was active, again the integrated LEDs were set to run in Always-On/Blinking mode. After multiple code iterations attempting to achieve LED activity, the polarity of one of the LEDs was manually reversed, demonstrating another design flaw on the PCB. By setting the LEDs back to Link/Activity mode, debugging could proceed to attempt a connection to another Ethernet device.

With a laptop connected over a crossover category-5 (cat-5) Ethernet cable, the Link/Activity lights still did not turn on. The same was true using a standard cat-5 Ethernet cable between the sensor module and a router. The problem was again investigated in software, but determined to be another hardware error. Eventually it was found that a connection was missing in the schematic and on the PCB between power and the center-tap pin (pin 2) of the Ethernet jack. The center tap pin connects to the center tap of an isolation transformer within the Ethernet jack. It is there to provide the energy needed to send data over the network. Ethernet communication requires that the center tap of the Ethernet jack is always energized, and data is put on the physical lines by differential signaling on either of the other pins of the transformer. Once a wire was soldered between the center tap pin and a power pin, the Link light came on, but there was still no activity.

Activity was missing because the microcontroller was again entering a non-breaking loop. Upon investigation with the debugger, it was found that there was an interrupt flag that was never being cleared. Additionally, the interrupt code was not being run. A missing bit flag needed to be set to globally-enable interrupts, which are by default disabled on the microcontroller. With that bit set, Ethernet began to work.

To test bi-directional transmission capability, the sensor module was connected to a non-internet-connected router with a laptop as a peer on the router. It was shown that the sensor module acquired an IP address by using DHCP, and then an ICMP ping request was sent to the sensor from the laptop. The sensor promptly replied to the ICMP ping each time that a packet was sent. Additionally, on each ping packet, the activity light on the sensor module would flash.

6.4 Sensors

The sensors were tested with the microcontroller similarly to how they were originally tested before making the PCB. The light sensor was tested first, as its indication of "on" or "off" is determined by a simple digital value. Code ran that handled all networking tasks, as well as reading both the thermal sensor (not installed on hardware) and the light sensor. Then, the light sensor's output was compared against a threshold value and an LED was turned on in the presence of light, and turned off when the light level dropped below the threshold.

The thermal sensor was tested by sending data to the server at frequent intervals. In this way, many samples could be compared against the expected values for the room's temperature. The calculation of the temperature happens on the server since the PIC lacks the arithmetic capabilities to perform the necessary calculations.

The passive infrared sensors were tested by setting up the sensor at a point in the room, using an LED to show if they were tripped. To test the range and sensitivity of the PIR sensors, a voluntary assistant walked across the room at various speeds and at different distances from the sensor. Unless the volunteer actively tried to evade the sensor (very slow movements), they were detected. It was reasonably reliable up to 25ft, but its ability to detect smaller movements were greatly reduced at that range. To test the reliability of the sensor's accuracy within the design's goal range, a 25ft string was used to define the area the module can detect occupancy. During this portion of the test, the volunteer was limited to staying with the 25ft radius outlined by the string. Evading detection within this range was much more difficult for the volunteer; this demonstrates satisfactory functionality of the PIR sensors.

7 Ethical Implications

This project poses two main concerns. The first is that the sensor effectively monitors when people are present in a room. The second is that the system makes information available to building administrators, who have no restrictions on how they use the information.

The issue of personal privacy is focused on installation of the device in a room that only one person normally uses (e.g. an office). In public spaces, the system does not provide any identifying data that could tie someone to their activities in a room. In addition, this system is intended for use in commercial/enterprise environments, where there is no expectation of privacy in most areas of the campus. In the case of a personal office, it is unlikely that there would be any real concern, since a camera is not used to detect occupancy, and therefore only *occupancy,* not actions, is detected. Since this system is meant for a building automation system and not a security system, the information is further restricted to use for building automation tasks, and would not normally be reviewed in detail.

When the information is reviewed, it would normally be restricted to key personnel involved in managing the building automation system. In the prototype system the web page is unsecured, but if further developed, the system could have security in place to make it so that the information would not be publicly available. Even so, none of the information alone could be used to identify a person.

8 Conclusions

The project overall is mostly successful. There were many unforeseen design challenges and a lot of time was lost debugging hard-to-see problems. Beginning with a development board would have greatly smoothed over the design process although at a higher cost. However, by doing everything "from scratch", the whole system design was a greater challenge and a more significant demonstration of the students' abilities to create a system, rather than just an application running on hardware designed by somebody else.

8.1 System Functionality

Most elements of the system work normally. There are three design elements that deviate substantially from the original goals and specifications. BACnet communications are not implemented, historical trend data is not available, and the original temperature sensitivity goal of ±2°F was not achieved. Each board is able to acquire data from the sensors, send UDP packets over Ethernet that contain the building, room, and zone designations, as well as the current temperature, light, and occupancy status. The server can then parse data from the UDP packets and upload it to the MySQL database. The web interface also works, retrieving the data from the database server using PHP. Since historical data is not implemented, only the most recent updates are recorded on the website.

Power over Ethernet is another fully-functional feature of the device. When connected through a PoE injector, the device can power up and begin processing its main functions. As previously stated, Ethernet works and packets can be sent from the devices. In addition, the modules will automatically acquire their network configurations (IP address, gateway, etc.) through DHCP.

BACnet communications were not implemented due to the difficulty involved in integrating the BACnet communication stack. The temperature sensor used is also not up to the original specifications. The temperature sensor was chosen based on price and availability, and the accuracy was overlooked until late into the design. Instead, the accuracy is closer to ±7°F. Historical data was not implemented because of inexperience with database systems and the lack of sufficient time to dedicate to developing the SQL code necessary for managing large data sets.

8.2 Future Work

As previously discussed, there are features that were cut from the final design and features that did not work as well as expected (e.g. temperature sensing). The following are design changes that would improve the overall function of the system:

- More-accurate temperature sensor
- More powerful processor
    - Inclusion of proper real-time operating system
    - Floating point calculations
- BACnet integration
    - Requires implementation of the BACnet stack within the code
    - Respond to BACnet queries instead of simple blind updates
- Implementation of individual device configuration

    - Could be done using a simple webpage running on the devices
- Full implementation of trend data
- Re-implementation of light sensor as an analog data source
- Better communication between server and modules
    - In particular, automatic acquisition of IP/MAC address pairs for the server

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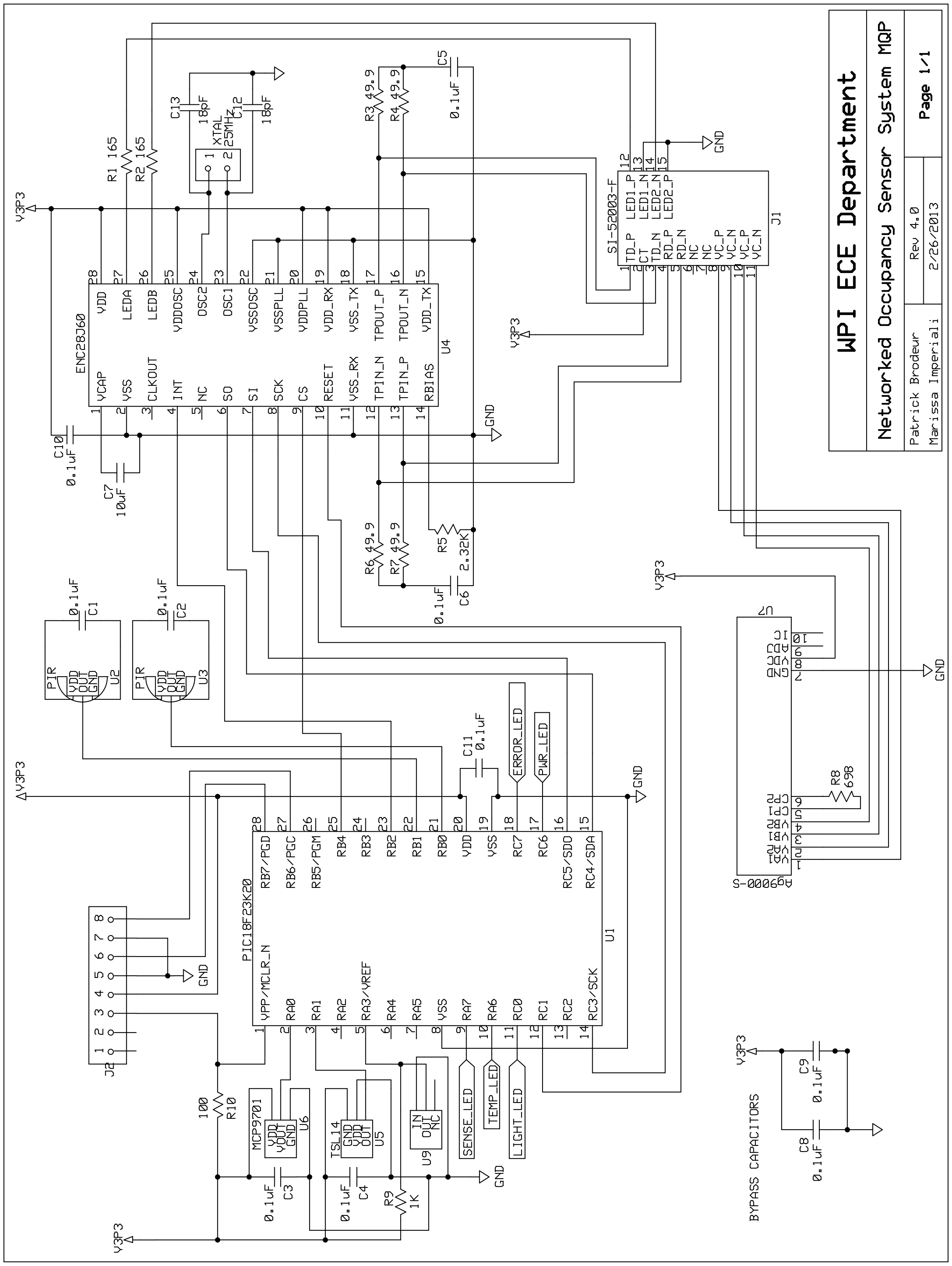
10 Appendix

10.1 Schematic



10.2 BOM

Table 1: Bill of Materials

Manufacturer Part Number	Description	Quantity	Unit Price @1000	Extended Price
PIC18F23K20-E/SP	IC PIC MCU FLASH 4KX16 28SDIP	1	1.74	1.74
ENC28J60-I/SP-ND	IC ETHERNET CTRLR W/SPI 28SDIP	1	2.51	2.51
AG9033S	POE SOLUTION 1500V DC-DC CONVERTER 3.3V	1	10.64	10.64
SI-52003-F	CONN MAGJACK 1PORT 100 BASE-T	1	3.834	3.834
9B-25.000MAAJ-B	CRYSTAL 25.000MHZ 18PF THRU	1	0.182	0.182
LM4040D30ILP	IC VREF SHUNT PREC 3V T092-3	1	0.2916	0.2916
AMN34111	SENSOR MOTION 10M DETECT BLK LEN	2	10.74325	21.4865
TSL14S-LF	IC SENSOR LIGHT-VOLTAGE SIDELOOKER	1	0.6174	0.6174
MCP9701-E/TO-ND	IC SENSOR THERMAL 3.1V	1	0.19	0.19
9-1879026-0	RES 49.9 OHM 1/4W 0.1% AXIAL	4	0.13163	0.52652
MFR-25FRF-52-165R	RES 165 OHM 1/4W 1% METAL FILM	2	0.00784	0.01568
RNF14FTD2K32	RES MF 1/4W 2.32K OHM 1% AXIAL	1	0.00652	0.00652
RNF14FTD1K00	RES MF 1/4W 1K OHM 1% AXIAL	1	0.00652	0.00652
RNF14FTD698K	698 OHM RES	1	0.0095	0.0095
FK24X5R0J106K	CAP CER 10UF 6.3V 10% RADIAL	1	0.10804	0.10804
SR295E104MAR	CAP CER 0.1UF 50V 20% RADIAL	10	0.04865	0.4865
K180J15C0GF5TH5	CAP CER 18PF 50V 5% RADIAL	2	0.03024	0.06048

Total Cost per Unit	**42.71126**

Bill of Materials excludes the cost of the enclosure and the PCB manufacturing.

10.3 PCB

The PCB has two layers of copper on either side of a fiberglass board. All components are located on the top side of the board except for the Ethernet jack (J1), programming header (J2), PoE module (U7), and the voltage reference circuit (U9). Not shown is a resistor from the cathode of U9 to a V_{DD} pin. Also not shown are five wires that connect components that were not properly connected when the PCBs were manufactured. See Section 6: Testing for details on the missing connections.

Also not pictured are power and ground planes. Each layer is mostly-filled by copper, except for the space around traces and holes. In addition, any area surrounded by dashed lines is a "keep out" area, free of the copper layer.

Legend:

- Red: Top-layer traces
- Blue: Silkscreen layer
- Green: Bottom-layer traces

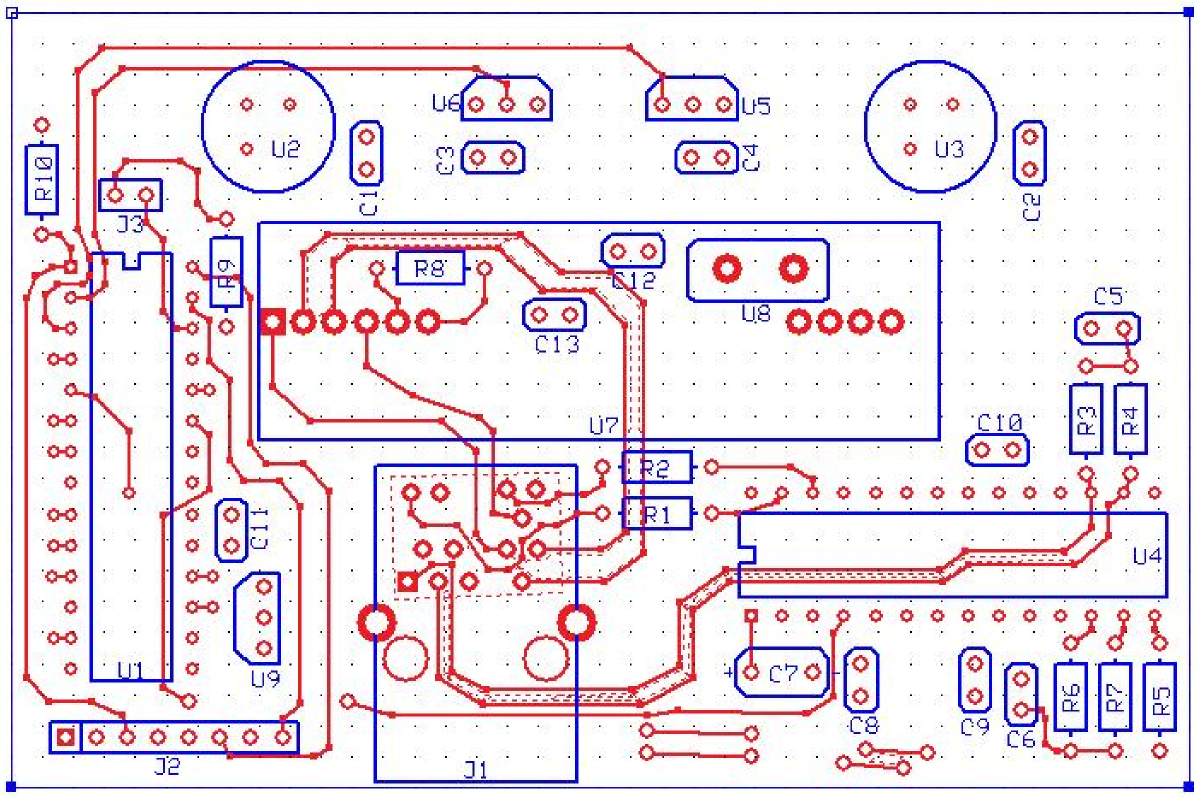


Figure 9: Top (Component) Layer of PCB

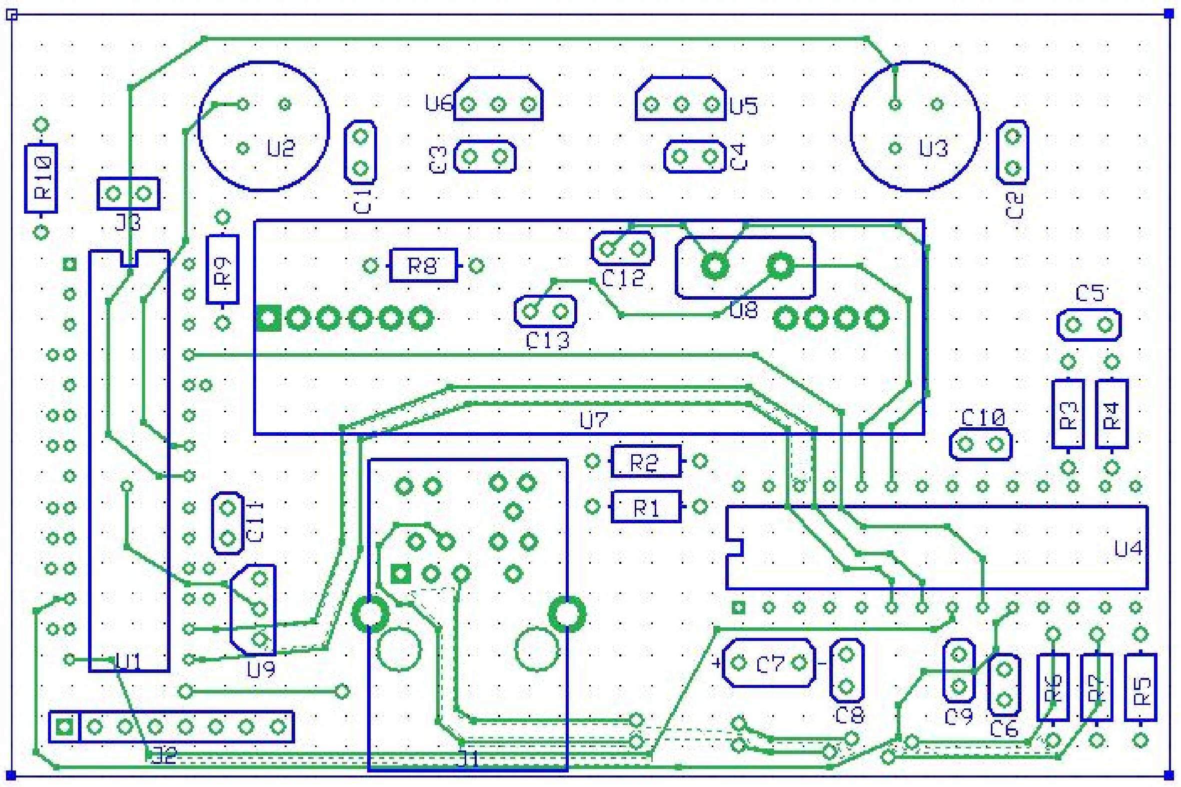


Figure 10: Bottom Layer of PCB

10.4 Enclosure

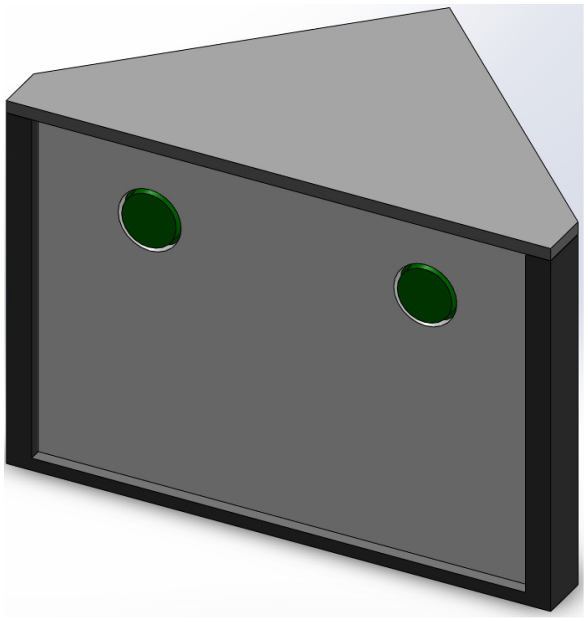


Figure 11: Assembled Enclosure

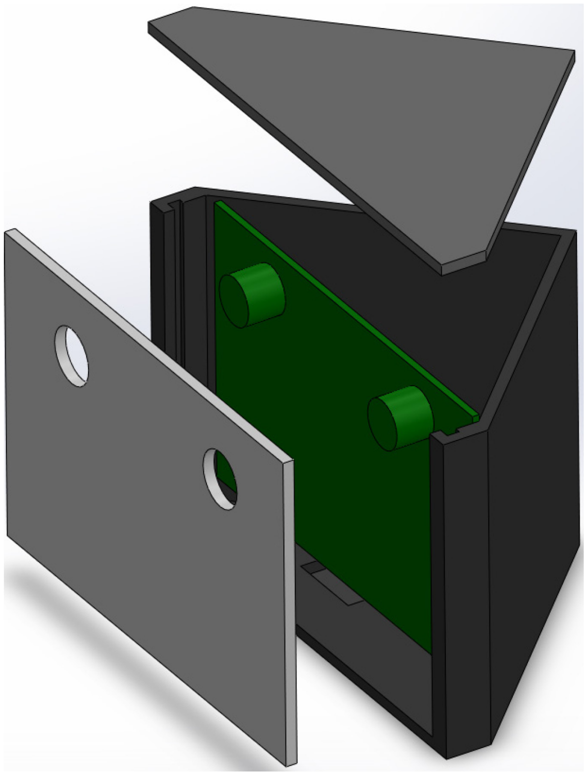


Figure 12: Enclosure "Exploded" View with Board Model

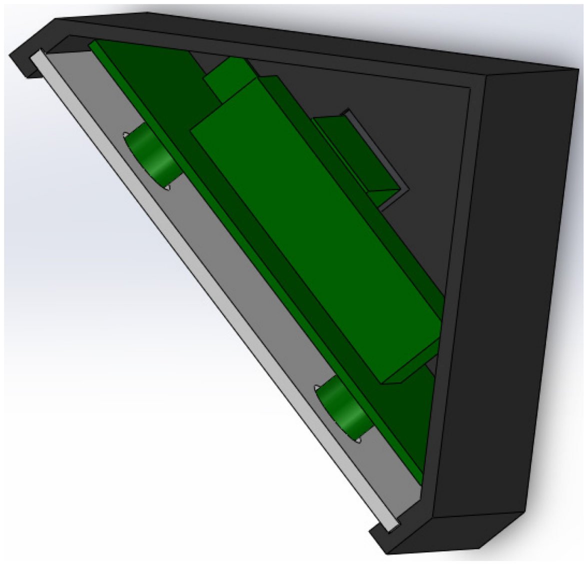


Figure 13: Top View of Enclosure with Dummy Board

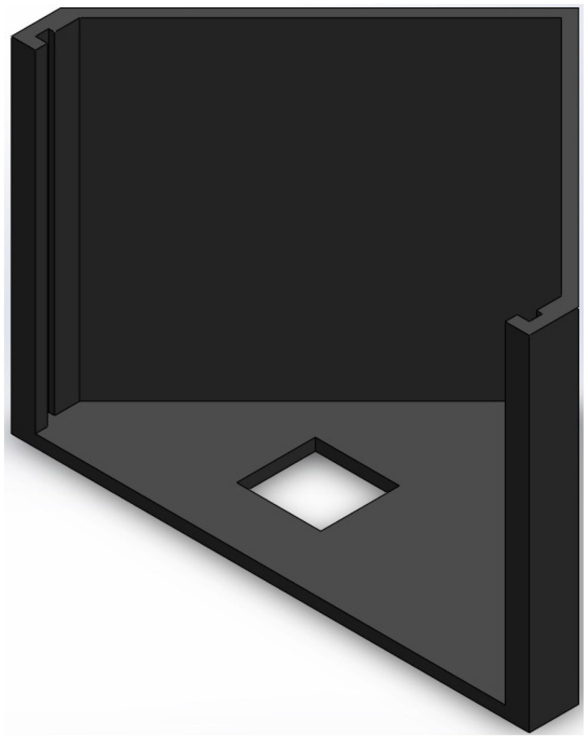


Figure 14: Enclosure Main Body

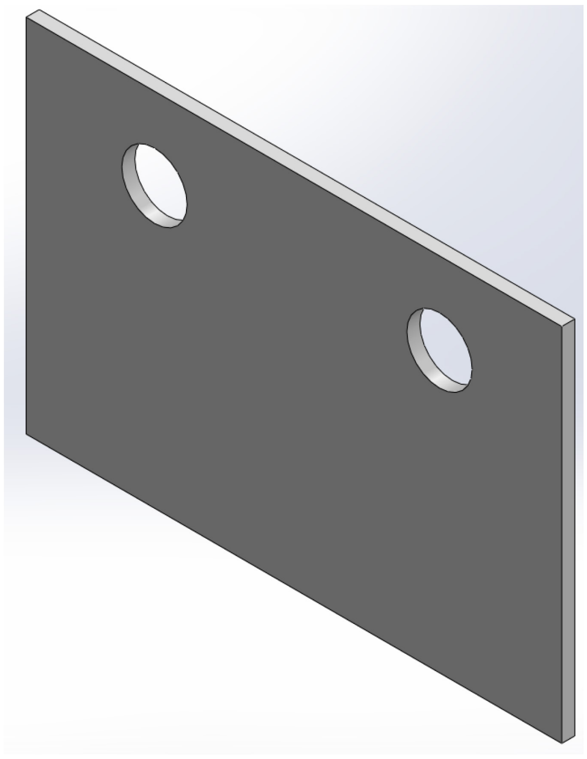


Figure 15: Enclosure Front Panel

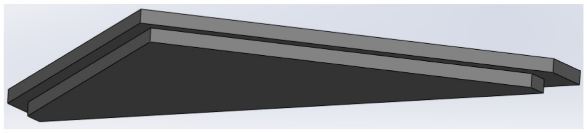


Figure 16: Enclosure Top Panel, Showing Mating Side

10.5 Microcontroller Code

10.5.1 main.c (user code)

```
/******************************************************************************/
/* Files to Include                                                           */
/******************************************************************************/
#include <p18cxxx.h>   /* C18 General Include File */

#include "system.h"        /* System funct/params, like osc/peripheral config */
#include "user.h"          /* User funct/params, such as InitApp */

#include "TCPIPConfig.h"
#include "TCPIP Stack/TCPIP.h"

void UpdateProcess(void);
void PollSensors(void);
void WriteWORD(WORD data);


/******************************************************************************/
/* User Global Variable Declaration                                           */
/******************************************************************************/
APP_CONFIG AppConfig; // TCPIP Stack Configuration Variable
unsigned Temperature, Occupied, Light, tempval;  // Sensor data storage
unsigned char UpdateReady = 1, UpdateEnable = 1; // Control variables
unsigned char LastOccUpdate = 0;
DWORD UpdateTimer;   // Controls update interval

// Defines the server to be accessed for this application
NODE_INFO BASserver; // Holds information for server that the modules talk to


/******************************************************************************/
/* Main Program                                                               */
/******************************************************************************/

void main(void)
{
    // Local variable declarations
    unsigned int i, occval;
    static DWORD Timer, PIRTimer;

    /* Configure the oscillator for the device */
    ConfigureOscillator();

    /* Initialize I/O and Peripherals for application */
    InitApp();
    TickInit(); //setup the tick timer

    // Set up configuration for TCP/IP stack
    AppConfig.Flags.bIsDHCPEnabled = TRUE;  // Enable DHCP module
    AppConfig.Flags.bInConfigMode = TRUE;
    AppConfig.MyMACAddr.v[0] = MY_DEFAULT_MAC_BYTE1;    // Default MAC address bytes at physical layer
initialization
    AppConfig.MyMACAddr.v[1] = MY_DEFAULT_MAC_BYTE2;
    AppConfig.MyMACAddr.v[2] = MY_DEFAULT_MAC_BYTE3;
    AppConfig.MyMACAddr.v[3] = MY_DEFAULT_MAC_BYTE4;
    AppConfig.MyMACAddr.v[4] = MY_DEFAULT_MAC_BYTE5;
    AppConfig.MyMACAddr.v[5] = MY_DEFAULT_MAC_BYTE6;
    // Below: Set default values for network interface
    AppConfig.MyIPAddr.Val = MY_DEFAULT_IP_ADDR_BYTE1 | MY_DEFAULT_IP_ADDR_BYTE2<<8ul |
MY_DEFAULT_IP_ADDR_BYTE3<<16ul | MY_DEFAULT_IP_ADDR_BYTE4<<24ul;
    AppConfig.DefaultIPAddr.Val = AppConfig.MyIPAddr.Val;
    AppConfig.MyMask.Val = MY_DEFAULT_MASK_BYTE1 | MY_DEFAULT_MASK_BYTE2<<8ul |
MY_DEFAULT_MASK_BYTE3<<16ul | MY_DEFAULT_MASK_BYTE4<<24ul;
    AppConfig.DefaultMask.Val = AppConfig.MyMask.Val;
    AppConfig.MyGateway.Val = MY_DEFAULT_GATE_BYTE1 | MY_DEFAULT_GATE_BYTE2<<8ul |
MY_DEFAULT_GATE_BYTE3<<16ul | MY_DEFAULT_GATE_BYTE4<<24ul;
    AppConfig.PrimaryDNSServer.Val = MY_DEFAULT_PRIMARY_DNS_BYTE1 | MY_DEFAULT_PRIMARY_DNS_BYTE2<<8ul  |
MY_DEFAULT_PRIMARY_DNS_BYTE3<<16ul  | MY_DEFAULT_PRIMARY_DNS_BYTE4<<24ul;
    AppConfig.SecondaryDNSServer.Val = MY_DEFAULT_SECONDARY_DNS_BYTE1 |
MY_DEFAULT_SECONDARY_DNS_BYTE2<<8ul  | MY_DEFAULT_SECONDARY_DNS_BYTE3<<16ul  |
MY_DEFAULT_SECONDARY_DNS_BYTE4<<24ul;

    // Set Building Automation Server IP
    BASserver.IPAddr.v[0] = SERVER_IP0;
    BASserver.IPAddr.v[1] = SERVER_IP1;
    BASserver.IPAddr.v[2] = SERVER_IP2;
    BASserver.IPAddr.v[3] = SERVER_IP3;

    // Set Building Automation Server MAC Address
    BASserver.MACAddr.v[0] = SERVER_MAC0;
    BASserver.MACAddr.v[1] = SERVER_MAC1;
    BASserver.MACAddr.v[2] = SERVER_MAC2;
    BASserver.MACAddr.v[3] = SERVER_MAC3;
    BASserver.MACAddr.v[4] = SERVER_MAC4;
    BASserver.MACAddr.v[5] = SERVER_MAC5;

    StackInit();    // Initialize stack, prepare hardware for data transmission

    // Initilize a few control variables
    i = 0;
    UpdateEnable = 1;
    UpdateReady = 1;
    Timer = TickGet();

    while(1)
    {
        // Let Stack Manager perform its task
        StackTask();
        // Let any Stack application perform its task.
        StackApplications();    // e.g. DHCP, ICMP, Announce

        // Application code:

        // Occupied only locks on when we have multiple changes, then stays
        //      locked on for 5 minutes.
            // Unlock at end of 5 minutes
                // Checks for occupancy locked on and releases if it has been 5 minutes
        if((TickGet() - PIRTimer) >= (5 * TICK_MINUTE))
        {
            Occupied = 0;//TICK_MINUTE
        }
            // Locking code
        tempval = PIRR | PIRL;
        if(occval != tempval)
        {
            i++;
            occval = tempval;   // Data is collected over 5 cycles of the main loop
        }

        if(i >= 5)  // If the occupancy sensor has pulsed then it has detected motion
        {
            PIRTimer = TickGet();
            if(!Occupied)
            {   // If not set to occupied before this bit, it will update the server immediately
                UpdateEnable = 1;
                UpdateReady = 1;
            }
            i = 0;
            Occupied = 1;
            LastOccUpdate = 1; // Set last occupancy to 1 so we know to reset it later
        }
        else if(Occupied == 0 && LastOccUpdate == 1)
            {   // If currently unoccupied, but the last update to the server says we are occupied,
                // tell the server that we're unoccupied now.
            UpdateEnable = 1;
            UpdateReady = 1;
            LastOccUpdate = 0;
        }

        // Sensor-polling
        if((TickGet() - Timer) >= (3 * TICK_SECOND))
        {
            PollSensors();      // Poll sensors -- See definition below.
            Timer = TickGet();  // Update timer variable
        }

        LED = Occupied; // Debug use

        if(UpdateEnable) UpdateProcess(); // process updates if allowed.
            // Reset update enable to allow updates after 1 minute.
        else if((TickGet() - UpdateTimer) >= TICK_MINUTE) UpdateEnable = 1; // TICK_MINUTE
    }

}


void PollSensors(void)      // Poll sensors
{
    unsigned int LightLevel;
    int absvar;
    // Measure Light and Temperature Levels
    ADCON2bits.ADFM = 1; // Right-justify
    ADCON0=0b00000011;          // Set up the ADC for CH0 and trigger it
    while(ADCON0bits.GO_DONE);  // Wait for ADC result to be ready
    tempval = Temperature;      // Record temperature
    Temperature = ADRESH * 256; // Move temperature high bits to the correct positions
    Temperature |= ADRESL;      // Add the low bits

    // If the temperature is different enough, send update request.
    absvar = Temperature - tempval;
    if(absvar < 0) absvar = 0 - absvar;
    if(absvar > 15) UpdateReady = 1;


    ADCON2bits.ADFM = 0; // Left-justify
    ADCON0=0b00000111;          // Set up the ADC for CH1 and trigger it
    while(ADCON0bits.GO_DONE);  // Wait for ADC result to be ready
    LightLevel = ADRESH;           // Store result into LightLevel


    tempval = Light;
    if(LightLevel > LIGHT_THRESHOLD) Light = 1; // Compare analog light level vs. threshold.
    else Light = 0;

    // If the light level has changed, update the system.
    if(Light != tempval) UpdateReady = 1;
    ADCON0=0x00;                // Turn off the ADC

    return;
}

void UpdateProcess(void)
{
    static DWORD Timer;
    static UDP_SOCKET MySocket = INVALID_UDP_SOCKET;
    static enum _UpdateProcessState
    {
        SM_HOME = 0,
        SM_SOCKET_OBTAINED,
        SM_DISCONNECT,
        SM_DONE
    } UpdateProcessState = SM_DONE;
    switch(UpdateProcessState)
    {
        case SM_HOME:
            // Connect a socket to the remote UDP building automation server
            MySocket = UDPOpen(4413,&BASserver,BACnet_PORT);

            // Abort operation if the BACnet socket is unavailable
            if(MySocket == INVALID_UDP_SOCKET) break;

            UpdateProcessState++; // Go to next state
            Timer = TickGet();
            break;

        case SM_SOCKET_OBTAINED:
            // Check the buffer for enough space
            if(UDPIsPutReady(MySocket) < 80u) // size we're sending.
                    break;

            // Place the application protocol data into transmit buffer
            WriteWORD(BUILDING);
            WriteWORD(ROOM);
            WriteWORD(ZONE);
            WriteWORD(Occupied);
            WriteWORD(Light);
            WriteWORD((Temperature-TEMPERATURE_ADJUST));

            // Send the packet
            UDPFlush();
            UpdateProcessState++;
            break;

        case SM_DISCONNECT:
            // Close the socket so it can be used by other modules
            UDPClose(MySocket);
            MySocket = INVALID_UDP_SOCKET;
            UpdateReady = 0; // Reset update ready flag
            UpdateEnable = 0; // Reset enable flag
            UpdateTimer = TickGet(); // Reset update timer
            UpdateProcessState = SM_DONE;
            break;

        case SM_DONE:
            // Wait until an update is ready.
            if(UpdateReady == 1) UpdateProcessState = SM_HOME;
            break;
    }
}


// Writes one word to the UDP data buffer
void WriteWORD(WORD data)
{
    int i;
    unsigned char temp;
    for(i = 3; i>-1; i--)
    {
        temp = data >> (8*i);
        UDPPut(temp);
    }
}


}
```

10.5.2 user.h and user.c

10.5.2.1 user.h

```
// User.h
#include "system.h"

/******************************************************************************/
/* User Level #define Macros                                                  */
/******************************************************************************/
#define PIRL PORTBbits.RB1 // Left PIR sensor
#define PIRR PORTBbits.RB0 // Right PIR sensor


/*************************************
******CONFIGURATION DEFINITIONS******
*************************************/
#define BUILDING 0x00000000
#define ROOM 0x00000003
#define ZONE 0x00000000

// Fill in the IP address for the server's network connection with the
    // sensor modules.
    // 0-5 is left to right (e.g. 0.1.2.3)
#define SERVER_IP0 192
#define SERVER_IP1 168
#define SERVER_IP2 0
#define SERVER_IP3 7

// Fill in the MAC address for the server's network card
    // 0-5 is left to right (e.g. 00-11-22-33-44-55)
#define SERVER_MAC0 0x00
#define SERVER_MAC1 0x10
#define SERVER_MAC2 0x5A
#define SERVER_MAC3 0x15
#define SERVER_MAC4 0xA9
#define SERVER_MAC5 0x44

// Light threshold and temperature adjustment
    // Light threshold should normally be between 80-120 or so
#define LIGHT_THRESHOLD 90
    // The temperature adjustment allows for reducing the temperature output
        // The units tested tended to be high. This should work with
        // negative values as well (to increase the temperature reading)
#define TEMPERATURE_ADJUST 10



/******************************************************************************/
/* User Function Prototypes                                                   */
/******************************************************************************/
void InitApp(void);         /* I/O and Peripheral Initialization */
```

10.5.2.2 user.c

```
/******************************************************************************/
/* Files to Include                                                           */
/******************************************************************************/
#include <p18cxxx.h>    /* C18 General Include File */
#include "user.h"

/******************************************************************************/
/* User Functions                                                             */
/******************************************************************************/
void InitApp(void)
{
    /* Setup analog functionality and port direction */
    // Pin/Port Direction Settings
    TRISA = 0b00111011; // Set port A in/out settings //RA4 & 5 are inputs
    TRISB = 0b00000111; // Set port B in/out settings
    TRISC = 0b00010000; // Set port C in/out settings

    // Set analog/digital pins
    ANSEL = 0b00001011; // Disable digital buffer on analog inputs
    ANSELH = 0x00;  // Enable all of Port B as digital

    /* Initialize peripherals */
    // ADC Initialization
    ADCON1 = 0b00010000; // Vref- = VSS, Vref+ = External, pin 5
    ADCON2 = 0b00001011; // Use ADC clock, Wait 2 Tad before acquiring
        /* IGNORE THIS // ADC result is right aligned so xxxxxx11 11111111 */

    /* Set RC6 to always be ground, for the debug LED*/
    PORTCbits.RC6 = 0;
    LED = 0;

    // SPI Initialization
    PORTBbits.RB4 = 1; // Bring chip select high (no transfer)
    SSPSTAT = 0b01000000;
    SSPCON1 = 0b00100000;


    /* Configure the IPEN bit (1=on) in RCON to turn on/off int priorities */
    RCONbits.IPEN = 1;
    /* Enable interrupts */
    INTCONbits.GIEH = 1;
    INTCONbits.GIEL = 1;
}
```

10.5.3 system.h and system.c

10.5.3.1 system.h

```
/******************************************************************************/
/* System Level #define Macros                                                */
/******************************************************************************/
/* Debug LED. This lets you say LED = 1 (on) or LED = 0 to turn off.*/
#define LED PORTCbits.RC7

/* Microcontroller MIPs (FCY) */
#define SYS_FREQ        16000000UL
#define FCY             SYS_FREQ/4

extern unsigned char Transmit;

/******************************************************************************/
/* System Function Prototypes                                                 */
/******************************************************************************/

/* Custom oscillator configuration funtions, reset source evaluation
functions, and other non-peripheral microcontroller initialization functions
go here. */

void ConfigureOscillator(void); /* Handles clock switching/osc initialization */
```

10.5.3.2 system.c

```
/******************************************************************************/
/** System.c **/
#include <p18cxxx.h>    /* C18 General Include File */
#include "system.h"

void ConfigureOscillator(void)
{
    OSCCONbits.IDLEN = 0; // Device enters sleep on sleep instr. 1 enters idle.
    OSCCONbits.IRCF = 0b111; // HFINTOSC drives clock directly
    OSCCONbits.SCS = 0b11;     // Use HFINTOSC

    OSCTUNEbits.INTSRC = 0; // Internal 31kHz clock directly from LFINTOSC
    OSCTUNEbits.PLLEN = 0;  // Phase Locked Loop disabled
    OSCTUNEbits.TUN = 0;    // Use factory calibrated setting
}
```

10.5.4 interrupts.c and configuration_bits.c

10.5.4.1 interrupts.c

```
/******************************************************************************/
/*Files to Include                                                            */
/******************************************************************************/
#include <p18cxxx.h>    /* C18 General Include File */

#include "system.h"
#include "TCPIP Stack\Tick.h"

/******************************************************************************/
/* Interrupt Routines                                                         */
/******************************************************************************/

/* High-priority service */

#if defined (__18CXX)
#pragma code high_isr=0x08
#pragma interrupt high_isr
```

```
void high_isr(void)
#else
#error "Invalid compiler selection for implemented ISR routines"
#endif

{
    // No high-priority interrupts
}

/* Low-priority interrupt routine */
#if defined (__18CXX)
#pragma code low_isr=0x18
#pragma interruptlow low_isr
void low_isr(void)
#else
#error "Invalid compiler selection for implemented ISR routines"
#endif
{
    TickUpdate();
}
```

10.5.4.2 configuration_bits.c

```
/******************************************************************************/
/* Files to Include                                                           */
/******************************************************************************/
#include <p18cxxx.h>    /* C18 General Include File */

/******************************************************************************/
/* Configuration Bits                                                         */
/******************************************************************************/
// PIC18F26K20 Configuration Bit Settings
#include <p18F26K20.h>

// CONFIG1H
#pragma config FOSC = INTIO67   // Oscillator Selection bits (Internal oscillator block, port function on
RA6 and RA7)
#pragma config FCMEN = OFF      // Fail-Safe Clock Monitor Enable bit (Fail-Safe Clock Monitor disabled)
#pragma config IESO = OFF       // Internal/External Oscillator Switchover bit (Oscillator Switchover mode
disabled)

// CONFIG2L
#pragma config PWRT = OFF       // Power-up Timer Enable bit (PWRT disabled)
#pragma config BOREN = OFF      // Brown-out Reset Enable bits (Brown-out Reset disabled in hardware and
software)
#pragma config BORV = 30        // Brown Out Reset Voltage bits (VBOR set to 3.0 V nominal)

// CONFIG2H
#pragma config WDTEN = OFF      // Watchdog Timer Enable bit (WDT is controlled by SWDTEN bit of the
WDTCON register)
#pragma config WDTPS = 1        // Watchdog Timer Postscale Select bits (1:1)

// CONFIG3H
#pragma config CCP2MX = PORTBE  // CCP2 MUX bit (CCP2 input/output is multiplexed with RB3)
#pragma config PBADEN = OFF     // PORTB A/D Enable bit (PORTB<4:0> pins are configured as digital I/O on
Reset)
#pragma config LPT1OSC = OFF    // Low-Power Timer1 Oscillator Enable bit (Timer1 configured for higher
power operation)
#pragma config HFOFST = OFF     // HFINTOSC Fast Start-up (The system clock is held off until the HFINTOSC
is stable.)
#pragma config MCLRE = ON       // MCLR Pin Enable bit (MCLR pin enabled; RE3 input pin disabled)

// CONFIG4L
#pragma config STVREN = ON      // Stack Full/Underflow Reset Enable bit (Stack full/underflow will cause
Reset)
#pragma config LVP = OFF //TODO: TURN BACK ON         // Single-Supply ICSP Enable bit (Single-Supply ICSP
enabled)
```

```
#pragma config XINST = ON       // Extended Instruction Set Enable bit (Instruction set extension and
Indexed Addressing mode enabled)

// CONFIG5L
#pragma config CP0 = OFF        // Code Protection Block 0 (Block 0 (000800-003FFFh) not code-protected)
#pragma config CP1 = OFF        // Code Protection Block 1 (Block 1 (004000-007FFFh) not code-protected)
#pragma config CP2 = OFF        // Code Protection Block 2 (Block 2 (008000-00BFFFh) not code-protected)
#pragma config CP3 = OFF        // Code Protection Block 3 (Block 3 (00C000-00FFFFh) not code-protected)

// CONFIG5H
#pragma config CPB = OFF        // Boot Block Code Protection bit (Boot block (000000-0007FFh) not code-
protected)
#pragma config CPD = OFF        // Data EEPROM Code Protection bit (Data EEPROM not code-protected)

// CONFIG6L
#pragma config WRT0 = OFF       // Write Protection Block 0 (Block 0 (000800-003FFFh) not write-protected)
#pragma config WRT1 = OFF       // Write Protection Block 1 (Block 1 (004000-007FFFh) not write-protected)
#pragma config WRT2 = OFF       // Write Protection Block 2 (Block 2 (008000-00BFFFh) not write-protected)
#pragma config WRT3 = OFF       // Write Protection Block 3 (Block 3 (00C000h-00FFFFh) not write-
protected)

// CONFIG6H
#pragma config WRTC = OFF       // Configuration Register Write Protection bit (Configuration registers
(300000-3000FFh) not write-protected)
#pragma config WRTB = OFF       // Boot Block Write Protection bit (Boot Block (000000-0007FFh) not write-
protected)
#pragma config WRTD = OFF       // Data EEPROM Write Protection bit (Data EEPROM not write-protected)

// CONFIG7L
#pragma config EBTR0 = OFF      // Table Read Protection Block 0 (Block 0 (000800-003FFFh) not protected
from table reads executed in other blocks)
#pragma config EBTR1 = OFF      // Table Read Protection Block 1 (Block 1 (004000-007FFFh) not protected
from table reads executed in other blocks)
#pragma config EBTR2 = OFF      // Table Read Protection Block 2 (Block 2 (008000-00BFFFh) not protected
from table reads executed in other blocks)
#pragma config EBTR3 = OFF      // Table Read Protection Block 3 (Block 3 (00C000-00FFFFh) not protected
from table reads executed in other blocks)

// CONFIG7H
#pragma config EBTRB = OFF      // Boot Block Table Read Protection bit (Boot Block (000000-0007FFh) not
protected from table reads executed in other blocks)
```

10.5.5 HardwareProfile.h and TCPIPConfig.h

10.5.5.1 HardwareProfile.h

```
/*********************************************************************
 *  Originally:
 *  Hardware specific definitions for:
 *    - PIC18 Explorer
 *    - PIC18F8722 and other PIC18s
 *    - Ethernet PICtail (ENC28J60)
 *********************************************************************
 * FileName:        HardwareProfile.h
 * Dependencies:    Compiler.h
 * Processor:       PIC18
 * Compiler:        Microchip C18 v3.36 or higher
 * Company:         Microchip Technology, Inc.
 **********************************************************************
 * Modified by Patrick Brodeur for MQP
 ********************************************************************/
#ifndef HARDWARE_PROFILE_H
#define HARDWARE_PROFILE_H

#include "system.h"
#include "Compiler.h"

// Define a macro describing this hardware set up (used in other files)
#define PIC18_NOSS

// Clock frequency values
// These directly influence timed events using the Tick module.  They also are used for UART and SPI baud
rate generation.
#define GetSystemClock()    SYS_FREQ
#define GetInstructionClock()   (GetSystemClock()/4)    // Should be GetSystemClock()/4 for PIC18
#define GetPeripheralClock()    (GetSystemClock()/4)    // Should be GetSystemClock()/4 for PIC18


// Hardware I/O pin mappings

// LEDs
#define LED0_TRIS           (TRISAbits.TRISA7)  // Ref A7
#define LED0_IO             (LATAbits.LATA7)    // PIR Sense LED
#define LED1_TRIS           (TRISAbits.TRISA6)  // Ref A6
#define LED1_IO             (LATAbits.LATA6)    // Temp out of range LED
#define LED2_TRIS           (TRISCbits.TRISC0)  // Ref C0
#define LED2_IO             (LATCbits.LATC0)    // Light low LED
#define LED3_TRIS           (TRISCbits.TRISC6)  // Ref C6
#define LED3_IO             (LATCbits.LATC2)    // Unassigned
#define LED4_TRIS           (TRISAbits.TRISA2)
#define LED4_IO             (LATAbits.LATA2)    // Unassigned
#define LED5_TRIS           (TRISDbits.TRISD5)  // Ref D6
#define LED5_IO             (LATDbits.LATD5)
#define LED6_TRIS           (TRISDbits.TRISD6)  // Ref D7
#define LED6_IO             (LATDbits.LATD6)
#define LED7_TRIS           (TRISDbits.TRISD7)  // Ref D8
#define LED7_IO             (LATDbits.LATD7)
#define LED_GET()           (0xFF)
#define LED_PUT(a)          (LED = 1)

// Momentary push buttons
#define BUTTON0_TRIS        (TRISAbits.TRISA4)
#define BUTTON0_IO          (PORTAbits.RA4)
#define BUTTON1_TRIS        (TRISAbits.TRISA5)
#define BUTTON1_IO          (PORTAbits.RA5)
#define BUTTON2_TRIS        (TRISBbits.TRISB3)  // No Button2 on this board
#define BUTTON2_IO          (1u)
#define BUTTON3_TRIS        (TRISBbits.TRISB3)  // No Button3 on this board
#define BUTTON3_IO          (1u)
```

```
// ENC28J60 I/O pins
#define ENC_RST_TRIS        (TRISCbits.TRISC1)  // RESET_N on RC1
#define ENC_RST_IO      (LATCbits.LATC1)
#define ENC_CS_TRIS     (TRISBbits.TRISB4)
#define ENC_CS_IO       (LATBbits.LATB4)
#define ENC_SCK_TRIS        (TRISCbits.TRISC3)
#define ENC_SDI_TRIS        (TRISCbits.TRISC4)
#define ENC_SDO_TRIS        (TRISCbits.TRISC5)
#define ENC_SPI_IF      (PIR1bits.SSPIF)
#define ENC_SSPBUF      (SSPBUF)
#define ENC_SPISTAT     (SSPSTAT)
#define ENC_SPISTATbits     (SSPSTATbits)
#define ENC_SPICON1     (SSPCON1)
#define ENC_SPICON1bits     (SSPCON1bits)
#define ENC_SPICON2     (SSPCON2)

#endif // #ifndef HARDWARE_PROFILE_H
```

10.5.5.2 TCPIPConfig.h

```
/*********************************************************************
 *
 *  Microchip TCP/IP Stack Demo Application Configuration Header
 *
 *********************************************************************
 * FileName:        TCPIPConfig.h
 * Dependencies:    Microchip TCP/IP Stack
 * Processor:       PIC18, PIC24F, PIC24H, dsPIC30F, dsPIC33F, PIC32
 * Compiler:        Microchip C32 v1.10 or higher
 *                  Microchip C30 v3.12 or higher
 *                  Microchip C18 v3.34 or higher
 *                  HI-TECH PICC-18 PRO 9.63PL2 or higher
 * Company:         Microchip Technology, Inc.
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 *      used in conjunction with a Microchip ethernet controller for
 *      the sole purpose of interfacing with the ethernet controller.
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 * SIMILAR COSTS, WHETHER ASSERTED ON THE BASIS OF CONTRACT, TORT
 * (INCLUDING NEGLIGENCE), BREACH OF WARRANTY, OR OTHERWISE.
 *
 *
 * V5.36   ---- STACK_USE_MPFS support has been removed
 ********************************************************************/
#ifndef __TCPIPCONFIG_H
#define __TCPIPCONFIG_H

#include "GenericTypeDefs.h"
#include "Compiler.h"

#define GENERATED_BY_TCPIPCONFIG "Version 1.0.4612.18258"

// =======================================================================
//   Application Options
// =======================================================================

/* Application Level Module Selection
 *   Uncomment or comment the following lines to enable or
 *   disabled the following high-level application modules.
 */
//#define STACK_USE_UART                    // Application demo using UART for IP address display and
stack configuration
//#define STACK_USE_UART2TCP_BRIDGE     // UART to TCP Bridge application example
//#define STACK_USE_IP_GLEANING
#define STACK_USE_ICMP_SERVER           // Ping query and response capability
#define STACK_USE_ICMP_CLIENT           // Ping transmission capability
//#define STACK_USE_HTTP2_SERVER            // New HTTP server with POST, Cookies, Authentication, etc.
//#define STACK_USE_SSL_SERVER          // SSL server socket support (Requires SW300052)
//#define STACK_USE_SSL_CLIENT          // SSL client socket support (Requires SW300052)
#define STACK_USE_AUTO_IP               // Dynamic link-layer IP address automatic configuration protocol
#define STACK_USE_DHCP_CLIENT           // Dynamic Host Configuration Protocol client for obtaining IP
address and other parameters
//#define STACK_USE_DHCP_SERVER         // Single host DHCP server
//#define STACK_USE_FTP_SERVER          // File Transfer Protocol (old)
//#define STACK_USE_SMTP_CLIENT         // Simple Mail Transfer Protocol for sending email
//#define STACK_USE_SNMP_SERVER         // Simple Network Management Protocol v2C Community Agent
//#define STACK_USE_SNMPV3_SERVER           // Simple Network Management Protocol v3 Agent
//#define STACK_USE_TFTP_CLIENT         // Trivial File Transfer Protocol client
#define STACK_USE_GENERIC_TCP_CLIENT_EXAMPLE    // HTTP Client example in GenericTCPClient.c
//#define STACK_USE_GENERIC_TCP_SERVER_EXAMPLE  // ToUpper server example in GenericTCPServer.c
//#define STACK_USE_TELNET_SERVER           // Telnet server
#define STACK_USE_ANNOUNCE              // Microchip Embedded Ethernet Device Discoverer server/client
#define STACK_USE_DNS                   // Domain Name Service Client for resolving hostname strings to IP
addresses
//#define STACK_USE_DNS_SERVER          // Domain Name Service Server for redirection to the local device
//#define STACK_USE_NBNS                    // NetBIOS Name Service Server for repsonding to NBNS hostname
broadcast queries
#define STACK_USE_REBOOT_SERVER         // Module for resetting this PIC remotely.  Primarily useful for a
Bootloader.
//#define STACK_USE_SNTP_CLIENT         // Simple Network Time Protocol for obtaining current date/time
from Internet
//#define STACK_USE_UDP_PERFORMANCE_TEST    // Module for testing UDP TX performance characteristics.
NOTE: Enabling this will cause a huge amount of UDP broadcast packets to flood your network on the discard
port.  Use care when enabling this on production networks, especially with VPNs (could tunnel broadcast
traffic across a limited bandwidth connection).
//#define STACK_USE_TCP_PERFORMANCE_TEST    // Module for testing TCP TX performance characteristics
//#define STACK_USE_DYNAMICDNS_CLIENT       // Dynamic DNS client updater module
//#define STACK_USE_BERKELEY_API            // Berekely Sockets APIs are available
//#define STACK_USE_ZEROCONF_LINK_LOCAL // Zeroconf IPv4 Link-Local Addressing
//#define STACK_USE_ZEROCONF_MDNS_SD        // Zeroconf mDNS and mDNS service discovery



// =======================================================================
//   Network Addressing Options
// =======================================================================

/* Default Network Configuration
 *   These settings are only used if data is not found in EEPROM.
 *   To clear EEPROM, hold BUTTON0, reset the board, and continue
 *   holding until the LEDs flash.  Release, and reset again.
 */
#define MY_DEFAULT_HOST_NAME            "NOSS1"

#define MY_DEFAULT_MAC_BYTE1            (0x00)  // Use the default of 00-04-A3-00-00-00
#define MY_DEFAULT_MAC_BYTE2            (0x08)  // if using an ENCX24J600, MRF24WB0M, or
#define MY_DEFAULT_MAC_BYTE3            (0x74)  // PIC32MX6XX/7XX internal Ethernet
#define MY_DEFAULT_MAC_BYTE4            (0x2E)  // controller and wish to use the
#define MY_DEFAULT_MAC_BYTE5            (0xF8)  // internal factory programmed MAC
#define MY_DEFAULT_MAC_BYTE6            (0xF6)  // address instead.

#define MY_DEFAULT_IP_ADDR_BYTE1        (169ul)
#define MY_DEFAULT_IP_ADDR_BYTE2        (254ul)
#define MY_DEFAULT_IP_ADDR_BYTE3        (1ul)
#define MY_DEFAULT_IP_ADDR_BYTE4        (5ul)

#define MY_DEFAULT_MASK_BYTE1           (255ul)
#define MY_DEFAULT_MASK_BYTE2           (255ul)
#define MY_DEFAULT_MASK_BYTE3           (255ul)
#define MY_DEFAULT_MASK_BYTE4           (0ul)

#define MY_DEFAULT_GATE_BYTE1           (169ul)
#define MY_DEFAULT_GATE_BYTE2           (254ul)
#define MY_DEFAULT_GATE_BYTE3           (1ul)
#define MY_DEFAULT_GATE_BYTE4           (1ul)

#define MY_DEFAULT_PRIMARY_DNS_BYTE1    (169ul)
#define MY_DEFAULT_PRIMARY_DNS_BYTE2    (254ul)
#define MY_DEFAULT_PRIMARY_DNS_BYTE3    (1ul)
#define MY_DEFAULT_PRIMARY_DNS_BYTE4    (1ul)

#define MY_DEFAULT_SECONDARY_DNS_BYTE1  (0ul)
#define MY_DEFAULT_SECONDARY_DNS_BYTE2  (0ul)
#define MY_DEFAULT_SECONDARY_DNS_BYTE3  (0ul)
#define MY_DEFAULT_SECONDARY_DNS_BYTE4  (0ul)

// =======================================================================
//   PIC32MX7XX/6XX MAC Layer Options
//   If not using a PIC32MX7XX/6XX device, ignore this section.
// =======================================================================
#define ETH_CFG_LINK            0       // set to 1 if you need to config the link to specific following
parameters
                                        // otherwise the default connection will be attempted
                                        // depending on the selected PHY
    #define ETH_CFG_AUTO        1       // use auto negotiation
    #define ETH_CFG_10          1       // use/advertise 10 Mbps capability
    #define ETH_CFG_100         1       // use/advertise 100 Mbps capability
    #define ETH_CFG_HDUPLEX     1       // use/advertise half duplex capability
    #define ETH_CFG_FDUPLEX     1       // use/advertise full duplex capability
    #define ETH_CFG_AUTO_MDIX   1       // use/advertise auto MDIX capability
    #define ETH_CFG_SWAP_MDIX   1       // use swapped MDIX. else normal MDIX

#define EMAC_TX_DESCRIPTORS     2       // number of the TX descriptors to be created
#define EMAC_RX_DESCRIPTORS     8       // number of the RX descriptors and RX buffers to be created

#define EMAC_RX_BUFF_SIZE       1536    // size of a RX buffer. should be multiple of 16
                                        // this is the size of all receive buffers processed by the ETHC
                                        // The size should be enough to accomodate any network received
packet
                                        // If the packets are larger, they will have to take multiple RX
buffers
                                        // The current implementation does not handle this situation right
now and the packet is discarded.


// =======================================================================
//   Transport Layer Options
// =======================================================================

/* Transport Layer Configuration
```

```
 *   The following low level modules are automatically enabled
 *   based on module selections above.  If your custom module
 *   requires them otherwise, enable them here.
 */
//#define STACK_USE_TCP
#define STACK_USE_UDP

/* Client Mode Configuration
 *   Uncomment following line if this stack will be used in CLIENT
 *   mode.  In CLIENT mode, some functions specific to client operation
 *   are enabled.
 */
#define STACK_CLIENT_MODE

/* TCP Socket Memory Allocation
 *   TCP needs memory to buffer incoming and outgoing data.  The
 *   amount and medium of storage can be allocated on a per-socket
 *   basis using the example below as a guide.
 */
    // Allocate how much total RAM (in bytes) you want to allocate
    // for use by your TCP TCBs, RX FIFOs, and TX FIFOs.
    #define TCP_ETH_RAM_SIZE                    (610ul)
    #define TCP_PIC_RAM_SIZE                    (0ul)
    #define TCP_SPI_RAM_SIZE                    (0ul)
    #define TCP_SPI_RAM_BASE_ADDRESS            (0x00)

    // Define names of socket types
    #define TCP_SOCKET_TYPES
        #define TCP_PURPOSE_GENERIC_TCP_CLIENT 0
        #define TCP_PURPOSE_GENERIC_TCP_SERVER 1
        #define TCP_PURPOSE_TELNET 2
        #define TCP_PURPOSE_FTP_COMMAND 3
        #define TCP_PURPOSE_FTP_DATA 4
        #define TCP_PURPOSE_TCP_PERFORMANCE_TX 5
        #define TCP_PURPOSE_TCP_PERFORMANCE_RX 6
        #define TCP_PURPOSE_UART_2_TCP_BRIDGE 7
        #define TCP_PURPOSE_HTTP_SERVER 8
        #define TCP_PURPOSE_DEFAULT 9
    #define END_OF_TCP_SOCKET_TYPES

    #if defined(__TCP_C)
        // Define what types of sockets are needed, how many of
        // each to include, where their TCB, TX FIFO, and RX FIFO
        // should be stored, and how big the RX and TX FIFOs should
        // be.  Making this initializer bigger or smaller defines
        // how many total TCP sockets are available.
        //
        // Each socket requires up to 56 bytes of PIC RAM and
        // 48+(TX FIFO size)+(RX FIFO size) bytes of TCP_*_RAM each.
        //
        // Note: The RX FIFO must be at least 1 byte in order to
        // receive SYN and FIN messages required by TCP.  The TX
        // FIFO can be zero if desired.
        #define TCP_CONFIGURATION
        ROM struct
        {
            BYTE vSocketPurpose;
            BYTE vMemoryMedium;
            WORD wTXBufferSize;
            WORD wRXBufferSize;
        } TCPSocketInitializer[] =
        {
            {TCP_PURPOSE_GENERIC_TCP_CLIENT, TCP_ETH_RAM, 125, 100},
            {TCP_PURPOSE_GENERIC_TCP_SERVER, TCP_ETH_RAM, 20, 20},
            //{TCP_PURPOSE_TELNET, TCP_ETH_RAM, 200, 150},
            //{TCP_PURPOSE_TELNET, TCP_ETH_RAM, 200, 150},
            //{TCP_PURPOSE_TELNET, TCP_ETH_RAM, 200, 150},
            //{TCP_PURPOSE_FTP_COMMAND, TCP_ETH_RAM, 100, 40},
            //{TCP_PURPOSE_FTP_DATA, TCP_ETH_RAM, 0, 128},
            {TCP_PURPOSE_TCP_PERFORMANCE_TX, TCP_ETH_RAM, 200, 1},
            //{TCP_PURPOSE_TCP_PERFORMANCE_RX, TCP_ETH_RAM, 40, 1500},
            //{TCP_PURPOSE_UART_2_TCP_BRIDGE, TCP_ETH_RAM, 256, 256},
            //{TCP_PURPOSE_HTTP_SERVER, TCP_ETH_RAM, 200, 200},
            //{TCP_PURPOSE_HTTP_SERVER, TCP_ETH_RAM, 200, 200},
            //{TCP_PURPOSE_DEFAULT, TCP_ETH_RAM, 200, 200},
        };
        #define END_OF_TCP_CONFIGURATION
    #endif

/* UDP Socket Configuration
 *   Define the maximum number of available UDP Sockets, and whether
 *   or not to include a checksum on packets being transmitted.
 */
#define MAX_UDP_SOCKETS     (8u)
#define UDP_USE_TX_CHECKSUM     // This slows UDP TX performance by nearly 50%, except when using the
ENCX24J600 or PIC32MX6XX/7XX, which have a super fast DMA and incurs virtually no speed pentalty.


/* Berkeley API Sockets Configuration
 *   Note that each Berkeley socket internally uses one TCP or UDP socket
 *   defined by MAX_UDP_SOCKETS and the TCPSocketInitializer[] array.
 *   Therefore, this number MUST be less than or equal to MAX_UDP_SOCKETS + the
 *   number of TCP sockets defined by the TCPSocketInitializer[] array
 *   (i.e. sizeof(TCPSocketInitializer)/sizeof(TCPSocketInitializer[0])).
 *   This define has no effect if STACK_USE_BERKELEY_API is not defined and
 *   Berkeley Sockets are disabled.  Set this value as low as your application
 *   requires to avoid waisting RAM.
 */
#define BSD_SOCKET_COUNT (5u)


// =======================================================================
//   Application-Specific Options
// =======================================================================
#define MDD_ROOT_DIR_PATH       "\\"

// -- BACnet options ------------------------------------------------
    #define BACnet_PORT (47808u)
```

10.5.6 FPGA Testing Analysis

Used the following code on the PIC microcontroller to confirm clock speeds:

```
#include <delays.h>

while(1)
  {
     Delay10KTCYx(0);
     Delay10KTCYx(0);
     Delay10KTCYx(0);
     Delay10KTCYx(0);
     LED = 1;
     PORTAbits.RA2 = 1;
     PORTAbits.RA2 = 0;
     Delay10KTCYx(0);
     Delay10KTCYx(0);
     Delay10KTCYx(0);
     Delay10KTCYx(0);
     LED = 0;
     PORTAbits.RA2 = 1;
     PORTAbits.RA2 = 0;
  }
```

What it does:
1 Waits FPGA can be started up to measure time
2 Turns on indicator LED for human benefit
3 Generates a rising edge to input to the FPGA
4 Waits 10.24 megacycles
5 Turns off the indicator LED
6 Sends another rising edge to input to the FPGA
7 Loops for additional trials.

Results of the test:
2.56 seconds consistently across multiple runs.
10.24 * 10^6 cycles / 2.56 seconds = 4MHz = 16MHz / 4

Discussion:
The results show that the INSTRUCTION clock rate is 4MHz. Remembering that the system uses the PIC18 architecture, the instruction clock is SYS_FREQ/4, consistent with the results.

```
#define SYS_FREQ      16000000ul
#define FCY           SYS_FREQ/4
```

10.6 Server Application Code

```
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.awt.event.FocusEvent;
import java.math.BigInteger;
import java.net.DatagramPacket;
import java.net.DatagramSocket;
import java.net.InetAddress;
import java.sql.Connection;
import java.sql.DriverManager;
import java.sql.PreparedStatement;
import java.sql.ResultSet;
import java.sql.SQLException;
import java.sql.Statement;
import java.util.logging.Level;
import java.util.logging.Logger;
import javax.swing.DefaultListModel;
import javax.swing.JFrame;
import javax.swing.ListModel;


public class databaseManager {

    // Initialize variables for room data
    private static Connection connection;
    byte[] sentence = new byte[24];
    int building    = 0x00000000;
    int room        = 0x00000000;
    int zoneID      = 0x00000000;
    int occupancy   = 0x00000000;
    int light       = 0x00000000;
    int temp        = 0x00000000;

    public databaseManager()
    {
         try {
                // Connect to the MySQL Database
                connection =
DriverManager.getConnection("jdbc:mysql://mysql.wpi.edu/noss", "noss",
"gSYc2J");
            } catch (SQLException ex) {

Logger.getLogger(databaseManager.class.getName()).log(Level.SEVERE, null,
ex);
            }
    }
    public void processData(byte[] data)
    {
        // Breaks up the received packet containing the room's data to be
used to update the database
        this.building = data[3];
        this.room = data[7]| (data[6] << 8) | (data[5] << 16) | (data[4] <<
24);
        this.zoneID = data[11]| (data[10] << 8) | (data[9] << 16) | (data[8]
<< 24);
        this.occupancy = data[15];
        this.light = data[19];
        this.temp = data[23]| (data[22] << 8) | (data[21] << 16) | (data[20]
<< 24);


        processQuery();
    }

    public void processQuery()
    {
        // Converts the temperature value from the ADC to degrees F
        double adjustedTemp = temp*2.9297;  // Convert ADC value to
millivolts
        adjustedTemp -=400; // Subtracts offset
        adjustedTemp /=19.53; // Divides by slope of temperature-voltage
curve
        adjustedTemp *=1.8;   // Multiply by 9/5 to convert deg C to deg F
        adjustedTemp +=32;    // Add 32 to finish C to F conversion

        try {
            Statement statement = connection.createStatement();
            // Result set get the result of the SQL query

            // Update the MySQL Database
            statement.execute("UPDATE noss.Data SET  Temperature=\'" +
adjustedTemp + "\', OccupancyStatus=\'" + this.occupancy + "\',
LightStatus=\'" + this.light + "\' WHERE Data.RoomID=\'" + this.room +
"\';");
            System.out.println("UPDATE noss.Data SET  Temperature=\'" +
adjustedTemp + "\', OccupancyStatus=\'" + this.occupancy + "\',
LightStatus=\'" + this.light + "\' WHERE Data.RoomID=\'" + this.room +
"\';");
        } catch (SQLException ex) {

Logger.getLogger(databaseManager.class.getName()).log(Level.SEVERE, null,
ex);
        }
    }

    public static void main(String[] args) {

        databaseManager manager = new databaseManager();
        try {
                // This will load the MySQL driver, each DB has its own
driver
                Class.forName("com.mysql.jdbc.Driver");
                // Setup the connection with the D
            }
        catch (Exception e)
        {
            e.printStackTrace();
        }

        try{
            int port = 0xbac0;
            byte[] ip = new byte[4];
            ip[0]=(byte) 255; //192;
            ip[1]=(byte) 255; //168;
            ip[2]=(byte) 255; //0;
            ip[3]=(byte) 255; //5;
            InetAddress IPAddress = InetAddress.getByAddress(ip);
            //int port = args.length == 0 ? 47808 :
Integer.parseInt(args[0]);
            DatagramSocket serverSocket = new DatagramSocket(port);
            //serverSocket.connect(IPAddress, port);
            byte[] receiveData = new byte[24];

            System.out.println(serverSocket.getLocalPort());
            System.out.println(serverSocket.getPort());
            System.out.printf("Listening on udp:%s:%d%n",
                InetAddress.getLocalHost().getHostAddress() , port);

            while(true)
               {
                  // Receive Data from the Module
                  DatagramPacket receivePacket = new
DatagramPacket(receiveData,
                               receiveData.length);
                  serverSocket.receive(receivePacket);
                  byte[] sentence = (receivePacket.getData());
                  manager.processData(sentence);
                  System.out.println("RECEIVED: " + sentence);
               }
          } catch (Exception e) {
                  System.out.println(e);
          }
    }
}
```

10.7 Mobile Website Code

```
<html>
<head>
<meta name="viewport" content="width=320" />

<meta charset="utf-8">
<title>Networked Occupancy Sensor System</title>
<link href="http://code.jquery.com/mobile/1.0/jquery.mobile-1.0.min.css" rel="stylesheet"
type="text/css"/>
<script src="http://code.jquery.com/jquery-1.6.4.min.js" type="text/javascript"></script>
<script src="http://code.jquery.com/mobile/1.0/jquery.mobile-1.0.min.js" type="text/javascript"></script>
</head>
<body>

<!--Main Page (page)-->
<div data-role="page" id="page">
        <div data-role="header">
                <center><font size=6><br>Networked Occupancy <br> Sensor System<br><br> </font></center>
        </div>
        <div data-role="content">
                <!--Links to each building-->
                <ul data-role="listview">
                        <li><a href="#page2"><big>Atwater Kent</big></a></li>
            <li><a href="#page3"><big>Building 2</big></a></li>
                        <li><a href="#page4"><big>Building 3</big></a></li>
                </ul>
        </div>
        <div data-role="footer">
                <!-- <h4>Footer</h4> -->
        </div>
</div>

<!--Atwater Kent Page (page2)-->
<div data-role="page" id="page2">
        <div data-role="header">
                        <center><font size=6><br>Atwater Kent <br><br> </font></center>
        </div>
        <div data-role="content">
                <ul data-role="listview">
                        <!--Links to the floors within Atwater Kent-->
                        <li><a href="#page5"><big>1st Floor</big></a></li>
            <li><a href="#page6"><big>2nd Floor</big></a></li><br><br><br><br><br><br><br>
                        <li><a href="#page"><big>Back</big></a></li>
                        <li><a href="#page"><big>Main Page</big></a></li>
                </ul>
        </div>
        <div data-role="footer">
                <!-- <h4>Footer</h4> -->
                <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
        </div>
</div>

<!--Atwater Kent 1st Floor (page 5)-->
    <div data-role="page" id="page5">
        <div data-role="header">
                        <center><font size=6><br>Atwater Kent <br> 1st Floor <br> </font></center>
        </div>
        <div data-role="content">
            <ul data-role="listview">
                                <!--Links to each room on 1st floor that contain a sensing module-->
                                <li><a href="#page8"><big>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Rooms WHERE RoomID = '02 ' ";
        //      <------- RoomID
```

```
                                 $rs = mysql_query($strSQL);
                                 while($row = mysql_fetch_array($rs)) {
                                 echo $row['RmName'];
                                 }
                                 mysql_close();
                                 ?>
                                 </big></a></li>
                  <br><br><br><br><br><br><br><br><br><br><br>
                 <li><a href="#page2"><big>Back</big></a></li>
                 <li><a href="#page"><big>Main Page</big></a></li>
             </ul>
         </div>
         <div data-role="footer">
             <!-- <h4>Footer</h4> -->
                         <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
         </div>
     </div>

<!--Atwater Kent 2nd Floor (page6)-->
     <div data-role="page" id="page6">
         <div data-role="header">
                         <center><font size=6><br>Atwater Kent <br> 2nd Floor <br> </font></center>
         </div>
         <div data-role="content">
             <ul data-role="listview">
                                 <!--Links to each room on the 2nd floor that contain a sensing module-->
                 <li><a href="#page7"><big>
                                 <?php
                                 $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                 mysql_select_db('noss');
                                 $strSQL = "SELECT * FROM Rooms WHERE RoomID = '01 ' ";
         //      <------- RoomID
                                 $rs = mysql_query($strSQL);
                                 while($row = mysql_fetch_array($rs)) {
                                 echo $row['RmName'];
                                 }
                                 mysql_close();
                                 ?>
                                 </big></a></li>
                 <li><a href="#page9"><big>
                                 <?php
                                 $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                 mysql_select_db('noss');
                                 $strSQL = "SELECT * FROM Rooms WHERE RoomID = '03 ' ";
         //      <------- RoomID
                                 $rs = mysql_query($strSQL);
                                 while($row = mysql_fetch_array($rs)) {
                                 echo $row['RmName'];
                                 }
                                 mysql_close();
                                 ?>
                                 </big></a></li> <br><br><br><br><br><br><br><br>
                 <li><a href="#page2"><big>Back</big></a></li>
                 <li><a href="#page"><big>Main Page</big></a></li>
             </ul>
         </div>
         <div data-role="footer">
             <!-- <h4>Footer</h4> -->
                         <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
         </div>
     </div>

<!--AK Room 1 (page7)-->
         <div data-role="page" id="page7">
             <div data-role="header">
```

```
                <center><font size=5><br>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Rooms WHERE RoomID = '01 ' ";
        //      <------- RoomID
                                $rs = mysql_query($strSQL);
                                while($row = mysql_fetch_array($rs)) {
                                echo "Room " . $row['RmNumber'];
                                echo "<br><br/>" . $row['RmName'];
                                }
                                mysql_close();
                                ?>
                                <br><br> </font></center>
            </div>
            <div data-role="content">
                <ul data-role="listview">
                                <center><table><tr><td><br><br><font size=4>
                                Temperature: <br><br>
                                Occupied: <br><br>
                                Lights: <br><br></td><td width=20></td><td><br><br><br><br><big>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Data WHERE RoomID = '02 ' ";
        //      <------- RoomID
                                $rs = mysql_query($strSQL);
                                while($row = mysql_fetch_array($rs)) {
                                echo $row['Temperature'] . " &degF<br><br />";
                                  $x = $row['OccupancyStatus'];
                                  $y = $row['LightStatus'];
                                if ($x == 1) {
                                   echo "Yes <br><br></p>";
                                   }
                                else{
                                        echo "No <br><br></p>";
                                }
                                if ($y == 1) {
                                   echo "On </p>";
                                   }
                                else{
                                        echo "Off </p>";
                                }
                                  }
                                mysql_close();
                                ?>
                </big></font><br><br><br></td></tr></table></center>
                    <li><a href="#page6"><big>Back</big></a></li>
                    <li><a href="#page"><big>Main Page</big></a></li>

                                </ul>
            </div>
            <div data-role="footer">
                <!-- <h4>Footer</h4> -->
                                <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
            </div>
        </div>

<!--AK Room 2 (page7)-->
        <div data-role="page" id="page8">
            <div data-role="header">
                <center><font size=5><br>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Rooms WHERE RoomID = '02 ' ";
        //      <------- RoomID
                                $rs = mysql_query($strSQL);
                                while($row = mysql_fetch_array($rs)) {
                                echo "Room " . $row['RmNumber'];
                                echo "<br><br/>" . $row['RmName'];
                                }
                                mysql_close();
                                ?>
                                <br><br> </font></center>
            </div>
            <div data-role="content">
                <ul data-role="listview">
                                <center><table><tr><td><br><br><font size=4>
                                Temperature: <br><br>
                                Occupied: <br><br>
                                Lights: <br><br></td><td width=20></td><td><br><br><br><br><big>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Data WHERE RoomID = '02 ' ";
        //      <------- RoomID
                                $rs = mysql_query($strSQL);
                                while($row = mysql_fetch_array($rs)) {
                                echo $row['Temperature'] . " &degF<br><br />";
                                  $x = $row['OccupancyStatus'];
                                  $y = $row['LightStatus'];
                                if ($x == 1) {
                                   echo "Yes <br><br></p>";
                                   }
                                else{
                                        echo "No <br><br></p>";
                                }
                                if ($y == 1) {
                                   echo "On </p>";
                                   }
                                else{
                                        echo "Off </p>";
                                }
                                  }
                                mysql_close();
                                ?>
                </big></font><br><br><br></td></tr></table></center>

                    <li><a href="#page5"><big>Back</big></a></li>
                    <li><a href="#page"><big>Main Page</big></a></li>

                                </ul>
            </div>
            <div data-role="footer">
                <!-- <h4>Footer</h4> -->
                                <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
            </div>
        </div>

<!--AK Room 3 (page9)-->
        <div data-role="page" id="page9">
            <div data-role="header">
                <center><font size=5><br>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Rooms WHERE RoomID = '03 ' ";
        //      <------- RoomID
                                $rs = mysql_query($strSQL);
                                while($row = mysql_fetch_array($rs)) {
```

```
                                echo "Room " . $row['RmNumber'];
                                echo "<br><br/>" . $row['RmName'];
                                }
                                mysql_close();
                                ?>
                                <br><br> </font></center>
            </div>
            <div data-role="content">
                <ul data-role="listview">
                                <center><table><tr><td><br><br><font size=4>
                                Temperature: <br><br>
                                Occupied: <br><br>
                                Lights: <br><br></td><td width=20></td><td><br><br><br><br><big>
                                <?php
                                $connection = mysql_connect ('mysql.wpi.edu','noss','gSYc2J') or die
(mysql_errno().": ".mysql_error()."<BR>");
                                mysql_select_db('noss');
                                $strSQL = "SELECT * FROM Data WHERE RoomID = '03 ' ";
        //      <------- RoomID
                                $rs = mysql_query($strSQL);
                                while($row = mysql_fetch_array($rs)) {
                                echo $row['Temperature'] . " &degF<br><br />";
                                  $x = $row['OccupancyStatus'];
                                  $y = $row['LightStatus'];
                                if ($x == 1) {
                                   echo "Yes <br><br></p>";
                                   }
                                else{
                                        echo "No <br><br></p>";
                                }
                                if ($y == 1) {
                                   echo "On </p>";
                                   }
                                else{
                                        echo "Off </p>";
                                }
                                  }
                                mysql_close();
                                ?>
                </big></font><br><br><br></td></tr></table></center>

                    <li><a href="#page6"><big>Back</big></a></li>
                    <li><a href="#page"><big>Main Page</big></a></li>

                                </ul>
            </div>
            <div data-role="footer">
                <!-- <h4>Footer</h4> -->
                                <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
            </div>
        </div>

<!--Building 2 Page (page3)-->
<div data-role="page" id="page3">
        <div data-role="header">
                <center><font size=6><br>Building 2 <br><br> </font></center>
        </div>
        <div data-role="content">
                <ul data-role="listview">
                        <li><a href="#"><big>1st Floor</big></a></li>
            <li><a href="#"><big>2nd Floor</big></a></li><br><br><br><br><br><br><br><br>
                        <li><a href="#page"><big>Back</big></a></li>
                        <li><a href="#page"><big>Main Page</big></a></li>
                </ul>
        </div>
        <div data-role="footer">
                <!-- <h4>Footer</h4> -->
                <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
        </div>
</div>

<!--Building 3 Page (page4)-->
<div data-role="page" id="page4">
        <div data-role="header">
                <center><font size=6><br>Building 3 <br><br> </font></center>
        </div>
        <div data-role="content">
                <ul data-role="listview">
                        <li><a href="#"><big>1st Floor</big></a></li>
            <li><a href="#"><big>2nd Floor</big></a></li><br><br><br><br><br><br><br><br>
                        <li><a href="#page"><big>Back</big></a></li>
                        <li><a href="#page"><big>Main Page</big></a></li>
                </ul>
        </div>
        <div data-role="footer">
                <!-- <h4>Footer</h4> -->
                <br><br><center><font size=5> Networked Occupancy <br><br> Sensor
System</font></center><br><br>
        </div>
</div>

</body>
</html>
```

10.8 Development Environment Setup

The project development environment is described as the collection of software and systems that are used to make functional blocks in the project design. The three main development environments are for the microcontroller, the database, and the application server.

10.8.1 Microcontroller Programming Environment Setup

The programming environment used in this MQP is the Microchip MPLAB X IDE version 1.60. This software is freely available from Microchip directly, at http://www.microchip.com/pagehandler/en-us/family/mplabx/. In addition, the compiler used is the Microchip C18 compiler standard/evaluation version 3.45, also available on the Microchip website. A third development package necessary is the Microchip Applications Libraries package, which includes the Microchip TCP/IP stack.

Once the IDE, compiler, and TCP/IP stack are installed, either of two courses of action can be taken. The preferred approach is to import the existing project directory as a project. The alternative is to create a new project to begin working with the system from a fresh setting.

10.8.1.1 Preferred Method – Import Project Folder

The easiest and least error-prone approach is to import the project directory. First, the project directory should be copied to a convenient location on the hard drive. Then the project can be imported by opening the MPLAB X IDE and going to the menu File>Open Project and finding the project on the hard drive. Everything should be set up already, and the code should be buildable immediately. To make any modifications to the code, skip to Section 10.8.1.3.

10.8.1.2 Alternative Method – Rebuild Project from Blank Slate

The first steps in this process are to go to File>New Project. Then, moving on to the next screen the PIC18 Template project may be used (Samples>Microchip Embedded). From there, an appropriate project name should be used and the wizard can be finished.

The new template will have some files that share the same names as the files used for this project. The next step is to change project configuration settings. Right-click the project name on the left-hand side of the screen and go to Properties. Then, open “Manage Configurations” at the bottom-left. Create a new configuration, and then close the Manage Configurations dialog. Choose the new configuration at left, and fill in the fields with the PIC microcontroller in use (PIC18F26K20) and the programmer/debugger in use. For this project, the primary programmer/debugger used was the PICKit 3 in-circuit programmer/debugger. For the compiler, choose C18 (v3.45). On the left-hand side, choose C18 global options, and check the box that allows the extended instruction set.

Next, locate the TCP/IP stack include files on the computer’s hard drive. They will likely be installed in “C:\Microchip Solutions v2012-10-15\Microchip\Include\”. Copy the folder “TCPIP Stack” into the project directory for the new project. Additionally, copy “compiler.h” and “GenericTypeDefs.h” form the include folder and paste them into the project folder. Then, go into the TCP/IP stack source folder, likely installed in “C:\Microchip Solutions v2012-10-15\Microchip\TCPIP Stack”. Copy the following list of “.c” files to the project directory:

Announce	ARP	AutoIP
Delay	DHCP	DHCPs
DNS	ENC28J60	Hashes
Helpers	ICMP	IP
NBNS	Random	Reboot
SNTP	SSL	StackTsk
TCP	Tick	UDP

Replace the main.c, user.h, user.c, system.h, system.c, configuration_bits.c, and interrupts.c with the ones with this project. Then, add all the loose (.h) include files under the "Header Files" folder within the IDE. Once those are added, choose "Add Existing Items from Folders" and add the "TCPIP Stack" folder that is in the project directory. Next, add "HardwareProfile.h" and "TCPIPConfig.h" to the header files. Finally, add all of the ".c" files from the project directory into the "Sources" folder in the IDE.

At this point, it should be possible to compile and load the code onto a board using the appropriate programmer.

10.8.1.3 Modifying System Configuration Code

There are two major values that must be changed for the system to properly work. These values are the destination IP address and MAC (hardware) address of the application server. Other values may also be changed within the code to set the sensor's designated building, room, and zone settings.

The values that are most likely to be changed depending on the system setup are all located in `user.h`. See Section 10.5.2.1 for the code. Before the server can process any data from the sensor modules, `user.h` will need to be updated with the IP and MAC address for the server. At the same time, modifications to the light calibration and temperature calibration can be made.

10.8.2 MySQL Database Setup

To create a MySQL database on the WPI network, the process is very simple. First, go to https://www.wpi.edu/Academics/CCC/Services/Databases/MySQL.html. This portal allows users to manage their databases. The page has all the instructions necessary for creating an empty database on the MySQL server.

Once the MySQL database is created, you can begin to create the actual database structure. See the Setup and User's Manual (below, Appendix 10.9) for more details.

10.8.3 Application Server Setup

The first step in setting up the application server is to acquire a physical piece of equipment (e.g. a spare computer) and installing a server-class operating system on it. It is recommended that the operating system should be installed by somebody who has experience with installing operating systems, especially if they have experience with a server-class operating system. This project was done using the 32-bit version of Microsoft Windows Server 2003 R2 Enterprise Edition with Service Pack 2. More details on the physical machine used for this project are available above in Section 4.2.4.

Once the server is running and attached to the network, it is necessary to set it up to perform its roles as an application server. The component of Windows server-class operating systems that handles web sites is known as Internet Information Services. The version in use for this project is IIS 6.0. IIS can be set up by first configuring a server role using the "Manage Your Server" tool, and then going to IIS Manager from the control panel. Information about getting IIS configured can be found at http://www.iis.net/learn.

Another step necessary in getting the example web interface to work is the inclusion of PHP. This project uses PHP 5.3.5, which is available for Windows directly from Microsoft at http://www.microsoft.com/web/platform/phponwindows.aspx. This website also includes information for setting up the server to use PHP and to properly render PHP documents to website visitors.

From that point, the web interface .php file should be placed into the root directory of the web site configured in IIS. If using the default web page, this is located in a location such as "C:\Inetpub\wwwroot". After the file is moved over, it should then be added to the list of documents to serve to visitors. This can be done by opening the IIS manager, then going into the web site's properties, and then adding it to the "Documents" tab.

10.9 Setup and User Manual

The following pages are the Setup and User Manual that would be distributed with the sensor modules. Its page numbers and headings have been preserved.

Networked Occupancy Sensor System

Setup & User's Manual

Preface

This document is intended to accompany Networked Occupancy Sensor System modules. The modules are built and configured for the user's particular application. No additional software development is necessary. This document provides a brief introduction and useful information to get started with this system. It includes instructions for installation and operation of the modules and the complete system.

It is assumed that the user has the module hardware fully assembled, and that the system has already been loaded with the appropriate software. This includes the software running on the application server. The web interface has been tested with a server running Windows Server 2003R2 with Internet Information Services 6.0 and PHP 5.0. The primary topics of this document are the user-configurable settings and getting the hardware installed in a room.

Table of Contents

List of Figures

1 Positioning the Sensor Modules

Two major things must be established before installing a sensor module in a room. First, the room must have a live Ethernet jack, connected to the same network as the building automation system. Second, the Ethernet jack must be connected to an IEEE 802.3af (Power over Ethernet) power supply, at the network switch or as an additional component in between the network switch and the sensor module.

The sensor should be positioned in a corner away from the main room entrance and should not be easily blocked by furniture or other room features. If the room is shaped, such that one sensor module cannot cover the entire desired sensing range; it may be necessary for multiple sensors to be installed.

Sensors should be mounted at least 5 feet from the ground on the wall, but no more than 9.5ft without verifying that the sensing area will be sufficient for the room. If the light sensor is used, the module must be mounted with its top side up and low enough on the wall to point generally towards the source of light in the room.

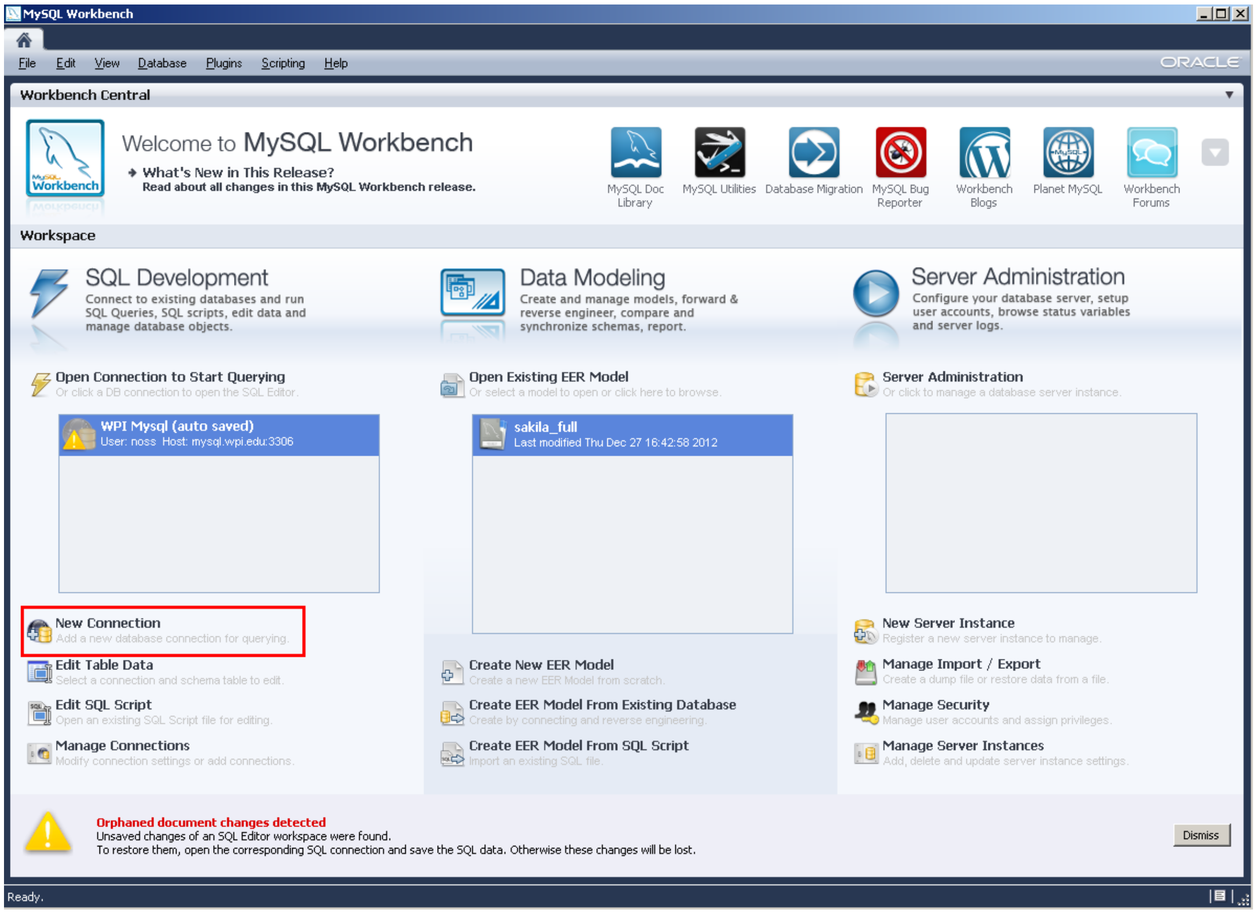
2 Database Setup

The database used is dependent on the particular building automation system in use. This section provides details on how to set up a simple system using a MySQL database that records occupancy, light, and temperature data from the sensor modules.

2.1 Setting up an Editor

Once the database is created on the MySQL server, it is just a matter of creating tables to match the data that is collected from the device. It is recommended that a tool with a graphical user interface is used to create these tables. For this section, the tool in use is Oracle MySQL Workbench, an open-source database editor at http://www.mysql.com/downloads/workbench/.

To set up MySQL Workbench, first open the program, and then select "New Connection" in the SQL Development section:



Read about all changes in this MySQL Workbench release.

Connect to existing databases and run SQL Queries, SQL scripts, edit data and manage database objects.

Create and manage models, forward & reverse engineer, compare and synchronize schemas, report.

Configure your database server, setup user accounts, browse status variables and server logs.

Or click a DB connection to open the SQL Editor.

Or select a model to open or click here to browse.

Or click to manage a database server instance.

User: noss Host: mysql.wpi.edu:3306

Last modified Thu Dec 27 16:42:58 2012

Add a new database connection for querying.

Select a connection and schema table to edit.

Open an existing SQL Script file for editing.

Modify connection settings or add connections.

Create a new EER Model from scratch.

Create by connecting and reverse engineering.

Import an existing SQL file.

Register a new server instance to manage.

Create a dump file or restore data from a file.

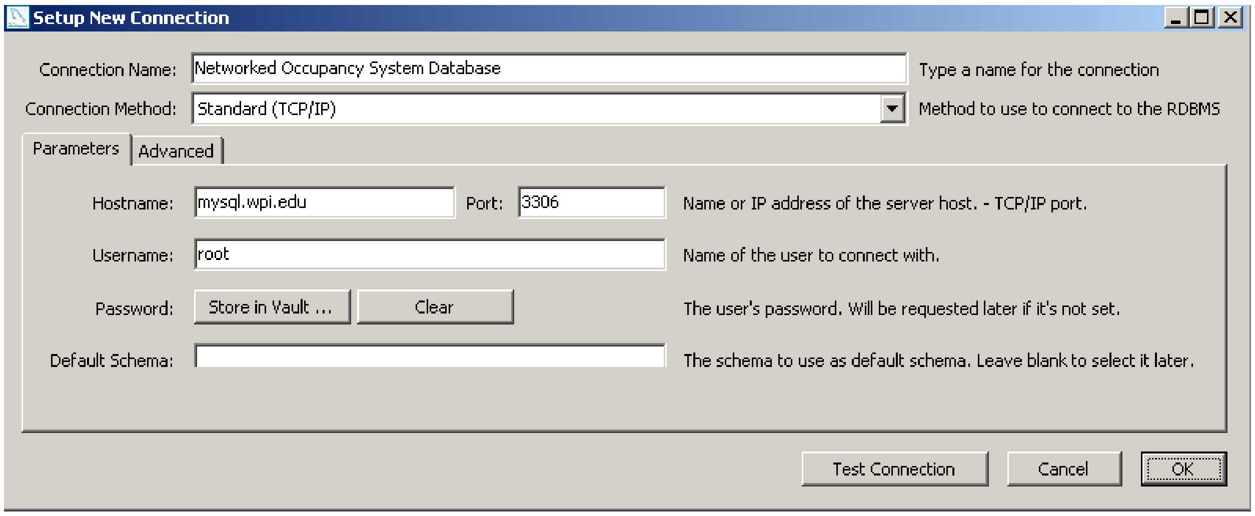
Manage user accounts and assign privileges.

Add, delete and update server instance settings.

Orphaned document changes detected
Unsaved changes of an SQL Editor workspace were found.
To restore them, open the corresponding SQL connection and save the SQL data. Otherwise these changes will be lost.

Figure 1: Choosing "New Connection"

Next, fill in the server information as necessary for your database:



Setup New Connection

Connection Name: Networked Occupancy System Database — Type a name for the connection

Connection Method: Standard (TCP/IP) — Method to use to connect to the RDBMS

Parameters | Advanced

Hostname: mysql.wpi.edu Port: 3306 — Name or IP address of the server host. - TCP/IP port.

Username: root — Name of the user to connect with.

Password: Store in Vault ... Clear — The user's password. Will be requested later if it's not set.

Default Schema: — The schema to use as default schema. Leave blank to select it later.

Figure 2: New Connection Window

2.2 Adding Tables to the Database

Open your database connection. Find your database at the left, expand it, and right click "Tables" to open up the menu. Then click "Create Table":

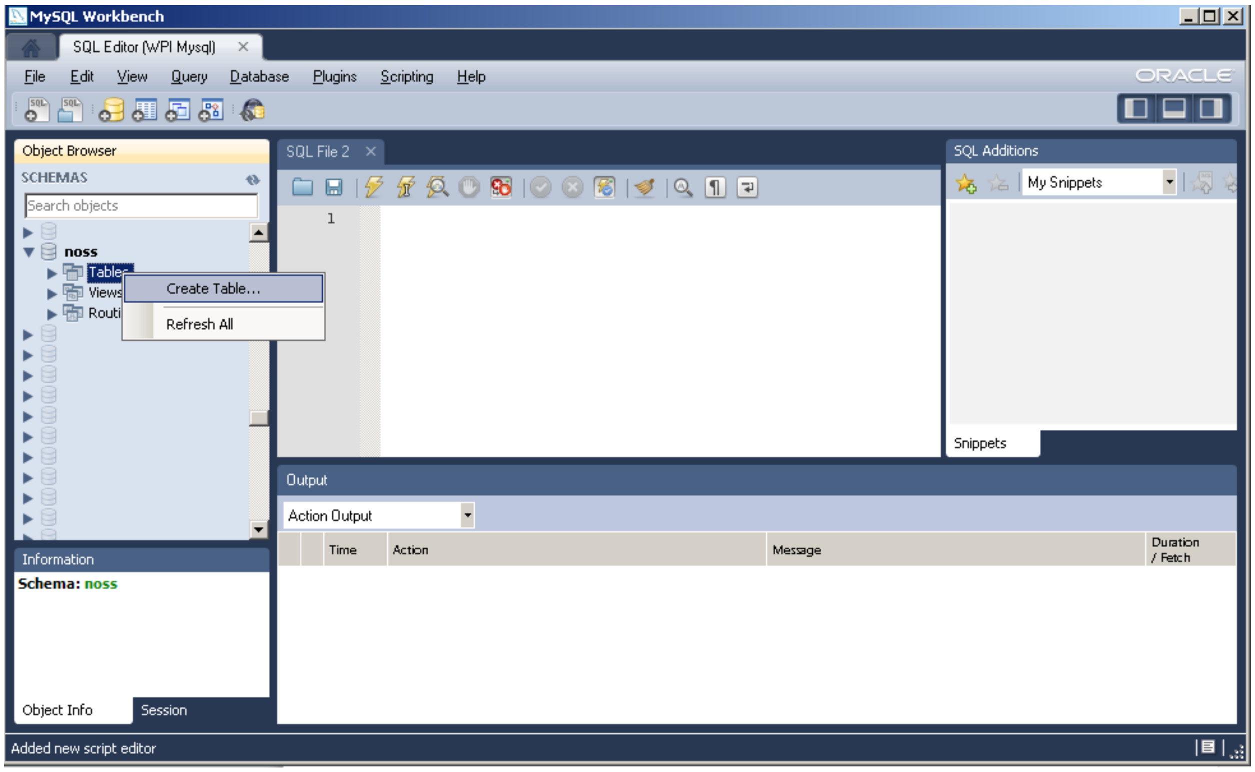


Figure 3: Creating a New Table

The create table button will bring up a dialog to enter information about the table. Fill in the table name, “Buildings” and enter in the columns, as shown below:

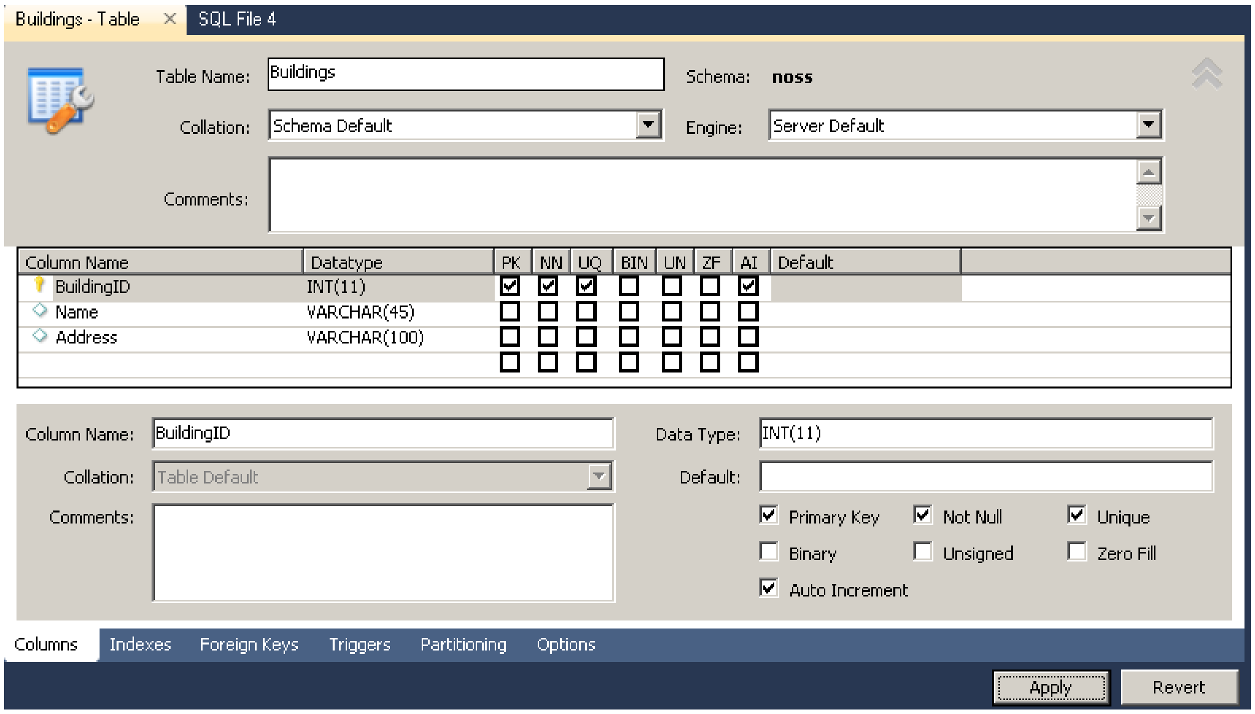


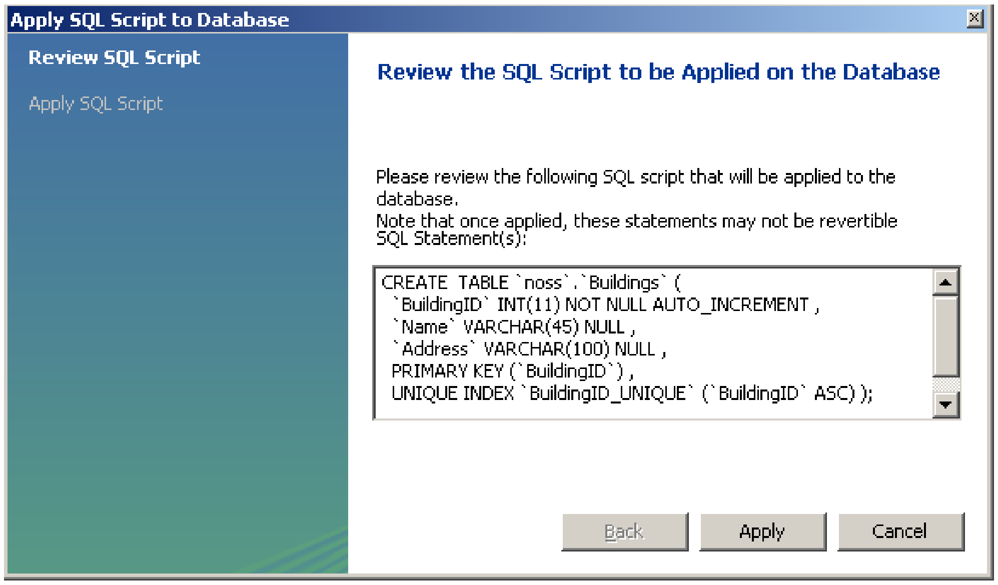
Table Name: Buildings
Schema: noss
Collation: Schema Default
Engine: Server Default
Comments:

Column Name	Datatype	PK	NN	UQ	BIN	UN	ZF	AI	Default
BuildingID	INT(11)	✓	✓	✓	☐	☐	☐	✓	
Name	VARCHAR(45)	☐	☐	☐	☐	☐	☐	☐	
Address	VARCHAR(100)	☐	☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	☐	

Column Name: BuildingID
Data Type: INT(11)
Collation: Table Default
Default:
Comments:
[✓] Primary Key [✓] Not Null [✓] Unique
[ ] Binary [ ] Unsigned [ ] Zero Fill
[✓] Auto Increment

Figure 4: Adding Table Data

After clicking “Apply”, another window will open, requesting that you confirm the SQL code generated by the workbench software. Unless you think there is a mistake, click “Apply” again.



Review the SQL Script to be Applied on the Database

Please review the following SQL script that will be applied to the database.
Note that once applied, these statements may not be revertible
SQL Statement(s):

```
CREATE  TABLE `noss`.`Buildings` (
  `BuildingID` INT(11) NOT NULL AUTO_INCREMENT ,
  `Name` VARCHAR(45) NULL ,
  `Address` VARCHAR(100) NULL ,
 PRIMARY KEY (`BuildingID`) ,
 UNIQUE INDEX `BuildingID_UNIQUE` (`BuildingID` ASC) );
```

Figure 5: Review SQL Script Window

The next table to generate is the Rooms table. Enter the Rooms table using the same process, with the following columns. Remember to check the Primary Key (PK) box for BuildingID and RoomID.

Table 1: "Rooms" Table Layout

Table Name:	Rooms
Column	**Data Type**
RoomID	int(11) PK
BuildingID	int(11) PK
RmNumber	varchar(45)
RmName	varchar(45)

Before creating the table, you will also need to associate BuildingID with the previous table, as shown below. First, go to the "Foreign Keys" tab. Then, enter a foreign key name (e.g. fkbuildingID) and select the Buildings table from the list under "Referenced Table". Then, check the box next to BuildingID. Finally, click Apply.

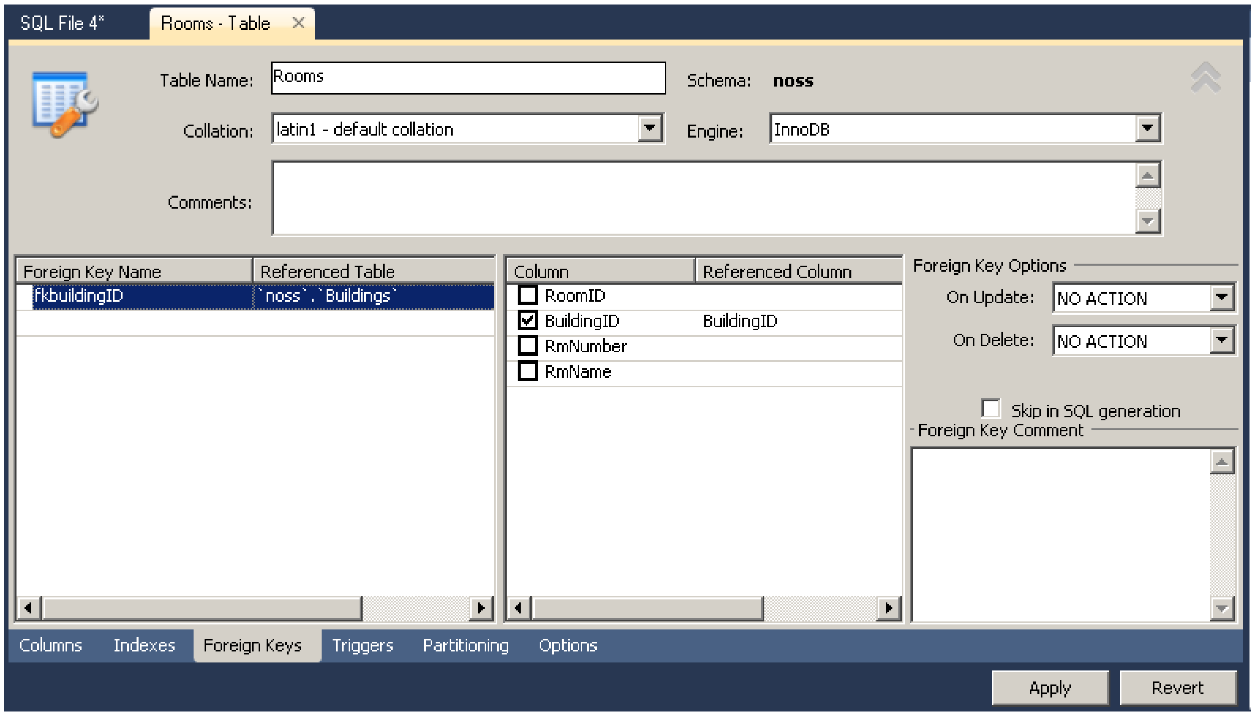


Table Name: Rooms
Schema: noss
Collation: latin1 - default collation
Engine: InnoDB
Comments:

Foreign Key Name	Referenced Table
fkbuildingID	\`noss\`.\`Buildings\`

Column	Referenced Column
☐ RoomID	
☑ BuildingID	BuildingID
☐ RmNumber	
☐ RmName	

Foreign Key Options
On Update: NO ACTION
On Delete: NO ACTION
☐ Skip in SQL generation
Foreign Key Comment

Figure 6: Foreign Key Addition

The rest of the tables are set up the same way as for the Rooms Table. Their column information is below. For Zones, RoomID and BuildingID are both foreign keys, from the tables "Rooms" and

“Buildings”, respectively. For the “Data” table, BuildingID, RoomID, and ZoneID are all foreign keys. The referenced table for ZoneID is “Zones”.

Table 2: "Zones" and "Data" Layout

Table Name:	Zones
Column	**Data Type**
RoomID	int(11) PK
BuildingID	int(11) PK
ZoneID	int(11) PK
Description	varchar(60)

Table Name:	Data
Column	**Data Type**
BuildingID	int(11) PK
RoomID	int(11) PK
ZoneID	int(11) PK
Time	datetime PK
Temperature	int(11)
Occupancy Status	bit(1)
Light Status	bit(1)

2.3 Adding Initial Data to Database

Once all of the tables are set up, it is time to start adding buildings and rooms that are connected to the system. It is expected that each module has a known BuildingID, RoomID, and ZoneID associated with it. With this information, the data tables can be populated.

For each of the tables, use MySQL workbench to edit the data. This can be done using the “Edit Table Data” option on a table:

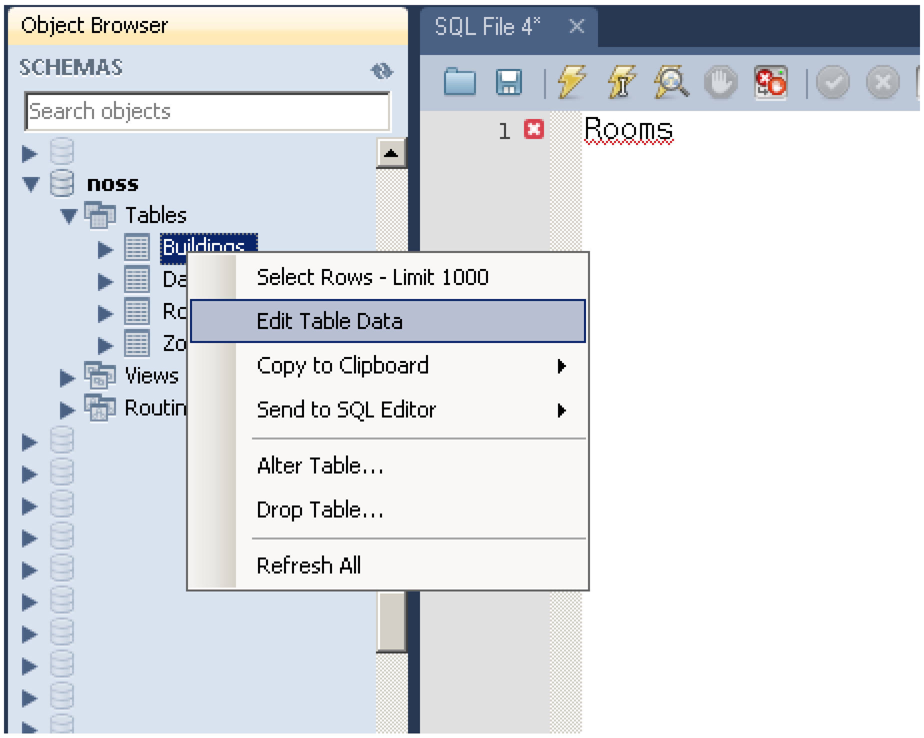
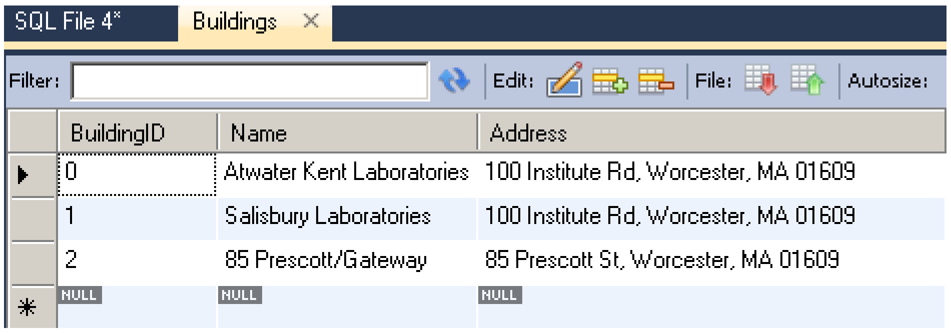


Figure 7: Showing "Edit Table Data" Button

Next, enter in data by selecting an empty field and entering data. Remember, the Name can have up to 45 characters, and the address can have up to 100 characters.



BuildingID	Name	Address
0	Atwater Kent Laboratories	100 Institute Rd, Worcester, MA 01609
1	Salisbury Laboratories	100 Institute Rd, Worcester, MA 01609
2	85 Prescott/Gateway	85 Prescott St, Worcester, MA 01609
NULL	NULL	NULL

Figure 8: Example "Buildings" Data

Repeat the same process for the other tables. Remember to accurately associate the Building, Room, Zone combinations according to the values given for the modules.

2.4 Tying in the Database

Once the database is put together, it can be displayed by using the supplied web interface. The web interface will automatically generate web pages according to the data in the database, with some modifications. The modifications necessary involve changing the database server information within the PHP. If the application server is running on the same network as the sensor modules, the database will be automatically updated as the sensor modules transmit data to the application server.

3 Navigating the Mobile Website

Navigating the Mobile Website is easy! The main page greets users with a list of buildings that they can choose from. If there are many buildings, they can be scrolled by swiping a finger from bottom to top to reveal more, or by going top to bottom to go back to the top. To select a building, simply tap its name.

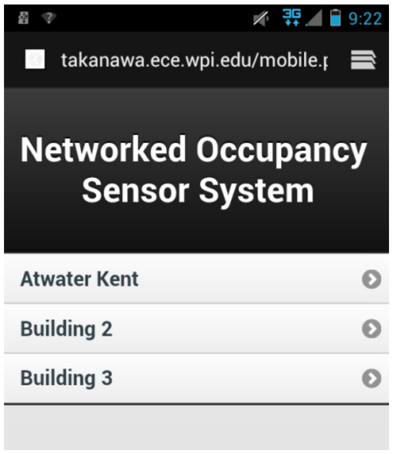

9:22
takanawa.ece.wpi.edu/mobile.p
Networked Occupancy Sensor System
Atwater Kent
Building 2
Building 3

Figure 9: Main Screen of Mobile Website

After selecting a building, a list of floors is shown. Select a floor by tapping its label. After selecting a floor, another screen will show the rooms available on that floor. The room may again be selected by tapping its label.

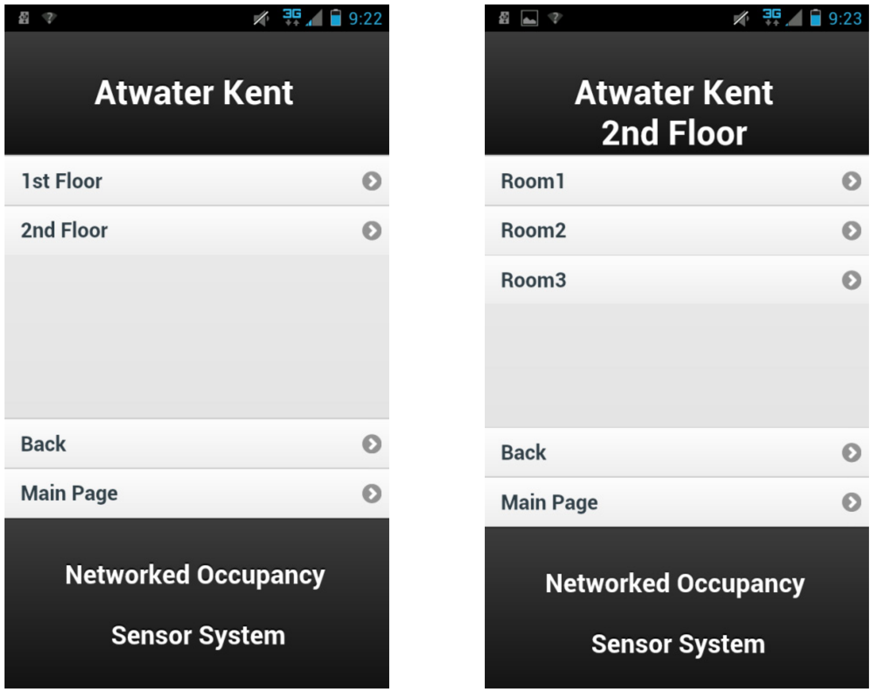
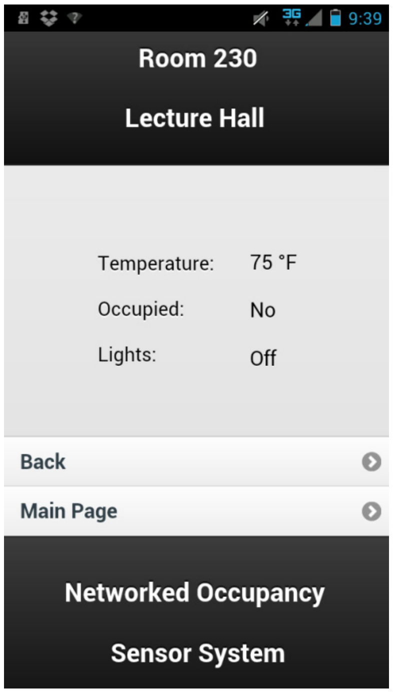


Figure 10: Floor Selection Page and Room Selection Page

With a room selected, you will be presented with the room's current light, occupancy, and temperature status, according to the most recently-captured data set. As can be seen on the last three screenshots, there are Back buttons and Main Page buttons that help you navigate quickly to other pages.



Room 230

Lecture Hall

Temperature:	75 °F
Occupied:	No
Lights:	Off

Networked Occupancy

Sensor System

Figure 11: Sample "Room" Page

4 Troubleshooting

- No network connectivity
  - Check that the device is on and has a link light showing on its Ethernet jack. This may indicate an incompatibility with the sensor module and the network that it is connected to.
  - If there is a link light but no data is coming from the device, there may be a problem with how the device is obtaining its network information. Please ensure that the network-side is running a DHCP server.
- Light sensor is reading “off” when lights are on
  - There is not enough light hitting the sensor. Check to make sure that there is nothing blocking the light sensor.
  - You may also wish to test by shining a light at the light sensor for a period of 18 minutes to see if the light sensor is operating properly. If it is working, then it should report that the lights are on. If it does not report the lights are on when it has a light shining at it, then it may have a defective sensor.
- Device is not powering on
  - Ensure that the device is connected to a Power over Ethernet power sourcing device.
  - Try a different cable, in case the one in use is damaged.
  - If it still does not work, attempt to connect it to a known-working PoE source to verify that the problem is on the sensor module and not somewhere in between.
- Device does not detect people entering the room
  - Ensure that the entry point is within the detection range. For optimal results, people entering should cross horizontally across the sensors’ view.
- Web page does not show correctly on mobile device
  - Try using another browser. The system should work on most browsers, but some (especially on older devices) do not load the mobile web page.
- Occupancy sensor trips when nobody is in the room
  - Check that there are no sources of infrared radiation that may be tripping the occupancy sensors. This may include heating vents or remote controls.
- The lights do not automatically turn on when I enter the room
  - The sensor modules do not control any systems directly. They rely on the building automation system to make any decisions regarding the room and are not connected directly to the lighting infrastructure.