Efficient HVAC / Humidity Control and Feedback System

EEL 4914

Group 6

Summer 2010

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Section 1: Introduction / Definition

1.1 Executive Summary

Electrical Engineering is a diverse field with applications that affect everyone in the world on a daily basis. Currently, one of the most vitally relevant and important topics is the practical use and application of energy efficient devices. An area in need of improvement is heating, cooling, and ventilation systems. Heating, cooling and ventilation systems are important because they are found in all residential and commercial buildings varying from amusement parks and movie theaters, to apartments and homes. Without the service of air conditioners people in hot climates would have a hard time surviving in the house in order to perform their daily activities or routines and without heat it would be unrealistic to live in cold climates.

HVAC systems primarily serve to deliver air for heating, cooling, and ventilation for people. Florida's summer season from May to August encounters periods where the extreme weather causes residents to stay inside due to high temperature and humidity conditions. During these periods the HVAC systems of all buildings work full time and become the largest power consumer of the building. This situation presents the need for a control system to maintain an indoor temperature and humidity while being as energy efficient as possible.

Our group is proposing to develop an HVAC control and feedback system. It will control the conditions of temperature and relative humidity in the building. This HVAC control system is intended to reduce the energy consumed by the user. As a result of decreased energy consumption, the cost of running the HVAC system will also be lowered. It will perform the traditional functions of an HVAC system as well as have enhanced options to allow the user to select temperature and relative humidity set points, introduce fresh air into the building, and select from multiple system settings ranging from "Max Comfort" to "Max Energy Savings." The user will be able to introduce fresh air into the building based on a set schedule, or current exterior conditions. By selecting a comfort setting the user will have control of the amount of variance from the set temperature and relative humidity points required to initiate heating or cooling.

The HVAC control and feedback system will send commands to a 1 ton air conditioner and 2 ton air conditioner as well as a dehumidifier. The remote sensing unit will communicate information (such as the temperature and humidity values) to the main microcontroller which will then send signals to the appropriate components. Based on current conditions the system will choose the most efficient way to meet the demands of the user. The temperature and humidity levels will be monitored from both inside and outside the building. Relays are the hardware component that will act as the switch to turn the HVAC components on or off. The control unit will have a LCD touch screen display preferably either resistive or surface wave acoustic touch screen. The touch screen on the control unit can be commanded by the finger or a stylus. When purchasing the LCD touch screen it will be composed of a touch sensor, a microcontroller, and a software driver with the appropriate operating system.

Our system will communicate wirelessly with the internet using routers to connect. . An integrated circuit chip embedded in the printed circuit board inside the control unit will send and receive information from the router back to the control system. Ideally, we would employ the 802.11 protocol to connect the system to a network. The IC chip used will ideally have a built-in RF transceiver. Whenever the user has internet connectivity, they will be able to manipulate the system. For inter system wireless data communication, there must be a distance of less than 100 feet between the two wireless chips for an accurate and dependable signal.

This chip on the circuit board inside the HVAC control system will utilize the Zigbee form of wireless communication with the 802.15 protocol. While searching the internet we are going to be using a smart phone so that users can control and view the air conditioner conditions online when they are away from the building. The smart phone features various applications that include programming schedules and a clock that incorporates the current day, month, and year. It will also inform the user of the current interior and exterior conditions, current states of the HVAC components, and the correct time in hours, minutes, and seconds.

1.2 Motivation

In our Senior Design class, we formed a group of four Engineering students: Derick Holzmacher (EE), Andrew Mertens (EE), Cory Glass (EE), and Joshua New (CpE). We came to a preliminary decision to pursue the Senior Design project named iTemp. We explained the project proposal to Dr. Samuel Richie and received approval along with a sponsor who had similar interests and goals relating to iTemp.

Being a Florida resident, air conditioning is a necessity for the majority of the year. HVAC systems are one of the leading energy consuming appliances in use in any residential or commercial setting. Over the years HVAC systems have become more efficient, but with the recent push toward green technology and overall energy efficiency, demand for a new HVAC system has presented itself. The design of the system will incorporate components to make an intelligent decision to satisfy the requirements set by the user in the most efficient way possible.

Figure 1 shown below shows a pie chart of typical energy use in a residential setting obtained from the National Academy of Sciences website. According to the graph, space heating and cooling accounts for 43% of the home's total energy consumption. A significant improvement in efficiency for heating and cooling systems would be able to lower monthly energy costs by a sizeable margin.

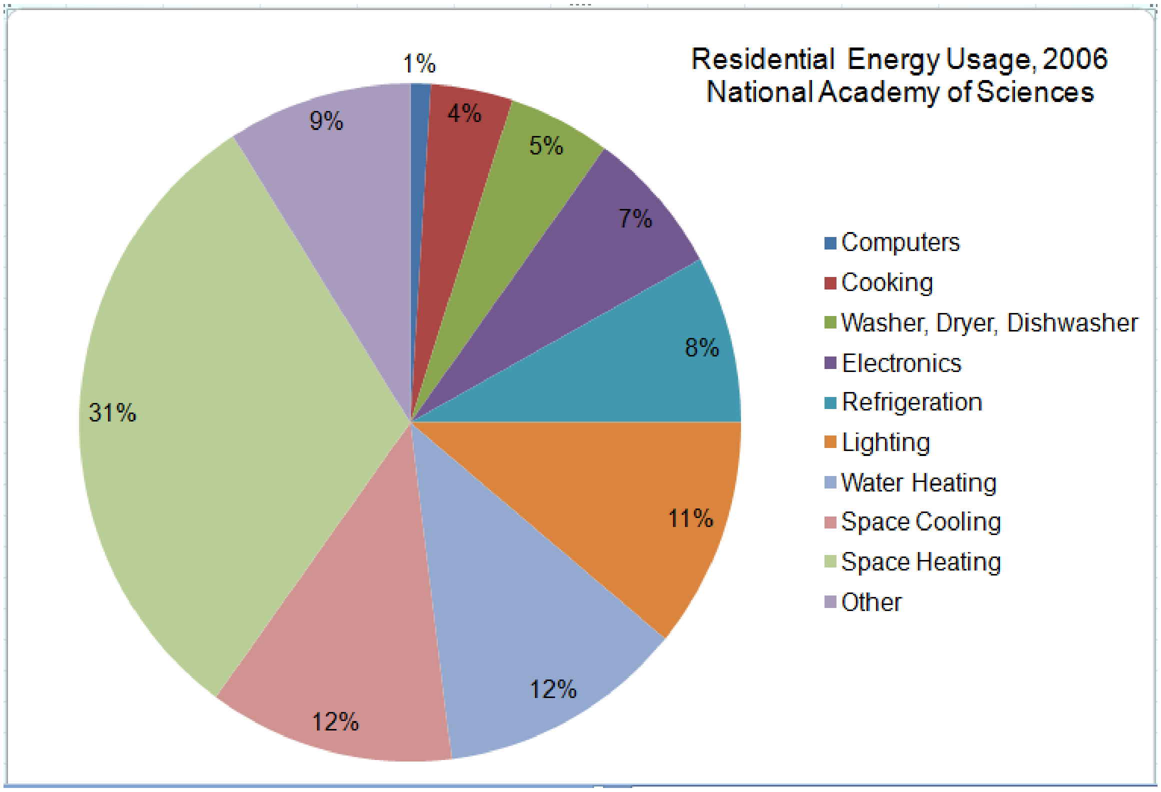

Figure 1 Residential Energy Use (Permission Pending from National Academy of Sciences)

As the cost of energy increases, the need for a low power, energy efficient HVAC system becomes a more prominent concern. An intelligent HVAC control and monitoring system would allow the user to track their energy costs throughout the month and the year. Month to month cost tracking will allow the user to determine their optimal climate settings based on how much they are willing to spend on electric. The user should also be informed by the system as to how much of their equipment is running at a specific time so they can adjust the settings to reduce the number of units running and use less energy, or allow the system to use more resources to keep the condition inside as close to ideal as possible.

HVAC systems should be environmentally friendly to provide good indoor air quality, have excellent ventilation, filter stagnant air out of the building, and also give sufficient comfort to the consumer. Introducing fresh air into the residential or commercial environment provides many benefits for the occupants of the building. It will allow the air inside to be fresh air while moving the old air out of the building.

Another drawback to current HVAC systems is maintenance. The average consumer does not have the background knowledge to identify the problem when something in the system malfunctions and therefore is forced to call a technician to come to the building and find the problem. This is expensive and inconvenient for the user. A smart HVAC control system would have a diagnostic element that would present the user with the expected problem and a solution for the problem.

Remote control of the HVAC system is another motivation behind a smart control system. Since such a large percentage of the population have internet ready mobile devices in their pocket whenever they are on the go, there is a need to allow these people to control their HVAC systems while away from the building it is installed in. The LCD interface should connect to the internet and allow the user to connect via mobile device to change settings and view current conditions wherever internet is available.

1.3 Objective

The system is expected to sense data, wirelessly report it to a main control unit where that data is analyzed, a decision is made, and the proper components are activated. The system is designed to be installed relatively easily and therefore the components must communicate wirelessly so that processes such as running new wiring for the system can be avoided. There are several elements that must be met in order to satisfy our sponsors.

1. The system must accurately read temperature and relative humidity outside the building.
2. The system must accurately read the temperature and relative humidity inside the building.
3. The system must wirelessly transmit data to a main control unit.
4. The main control unit must take the temperature and relative humidity as inputs along with the user determined settings and make a decision of how to cool, heat, raise or lower the humidity in the building in the most energy and cost efficient manner.
5. The main control unit must control relays that will provide the necessary components with the power they need.
6. The main control unit must have an LCD touch screen interface that must be large enough for the user to easily see and operate.
7. The main control unit must communicate with the internet so that the user can manipulate it from a remote location via mobile device.

1.3.1 Remote Sensing Unit

A remote sensing unit is to be set up outside the building. This unit must accurately measure the temperature and relative humidity outside the building. The values of temperature and relative humidity must be passed from a sensor to a microcontroller located on the same printed circuit board as the sensor. The microcontroller must then pass the values to a wireless chip that will wirelessly report these values to the main control unit. The remote sensing unit is designed to operate outdoors and therefore must be able to withstand harsh elements such as wind, rain, extreme heat and extreme cold. The point of implementing an outdoor sensor is so the system can check the exterior air conditions and determine whether or not the outdoor air is suitable to be brought into the building.

Another objective of the remote sensing unit is to be easily installed. The remote sensing unit is to be battery powered and report all information to the main control unit wirelessly. By specifying these two characteristics the person installing the unit has the difficulty of their job greatly decreased. If the remote sensing unit required power to be delivered by wires or required wires to report back the data it collects the installation person would be forced to run new wires when retrofitting the system to an existing building. Running new wiring in an existing building is an exhausting process that requires many hours and therefore produces labor costs that would drive up the cost of the system. By making the remote sensing unit battery powered and report data wirelessly the only installation that is required is to pick an appropriate place on the exterior of the building to mount the unit and then to mount the unit.

The ease of installation is one of the main objectives the group started with when they first began the design of the remote sensing unit. The only downfall of meeting the ease of installation objective is that all batteries eventually run out, but with enough research about battery technology a battery can be chosen such that battery replacement is minimized.

1.3.2 Main Control Unit

The main control unit is the most complex part of the system. It must accept values that represent the outdoor temperature and relative humidity via a wireless chip and pass these values to the main microprocessor. The main microprocessor must store this information so that it can be used when making a decision on whether the outdoor air is suitable to be exchanged with the current air inside the building. The main control unit must also accept values from a local sensor that will provide the temperature and relative humidity inside the building (at the main control unit). This information must be stored so that it can be used to tell the user the current inside temperature.

The main microprocessor must communicate with the LCD display. It must recognize what buttons are being manipulated on the LCD and provide the display unit the information it needs to update its output. The main control unit must send and receive information to and from the web so that the user can remotely check current settings and, if necessary, change them via mobile device. The user should be able to manipulate both the desired temperature and relative humidity for inside the building from the mobile device and have real time temperature and relative humidity values from inside the building displayed on the phone from anywhere they can access the internet.

1.3.3 LCD Touch Screen Display

The objective of the LCD touch screen display is to provide the user an intuitive, easy to manipulate means of controlling the system. The display should be large in size so that it is easy to see when mounted on a wall. The buttons should be of ample size so that they are easily manipulated with a normal sized finger. The display should be color, and look professional. It should be regularly updated with the current temperature and relative humidity inside the building so the user is aware of the current inside conditions. The touch display must be graphically advanced so it is pleasing to look at. The LCD touch screen display is likely the only part of the system the user will ever see or interact with and therefore appearance and functionality is of utmost importance when developing the LCD touch screen display. The LCD touch screen display is to be fully operated by any person, and require no training or previous touch screen experience by the user.

1.4 Specifications and Requirements

1.4.1 Detailed Specifications

The following specifications are derived from several meetings with our sponsor, AC3 Development Group, LLC. Although these values are estimates, careful consideration has gone into developing realistic specifications necessary for the design of a practical HVAC control system. These are only initial estimates of what is necessary and will most likely change as problems arise, however we are going to try to stick to these initial values as much as possible as they are what we have determined to be ideal for this system.

- Total cost of $1500 or less for initial prototype
- Wireless transmission of temperature and relative humidity data over a distance of at least 100 feet
- Ability to connect to a web server to allow for remote control of main control unit via mobile device
- Must be able to provide 24V AC to control HVAC components
- Must be able to measure realistic outdoor temperature (0 ˚F – 110 ˚F) and relative humidity (0% - 100%) values for all climates
- Must be able to measure indoor temperature (+- 0.5 ˚C) and relative humidity (+- 5%) with specific accuracy

1.4.2 Detailed Requirements

The requirements for our project have been provided by our sponsor, AC3 Development Group, LLC. Our system is required to sense temperature and relative humidity from inside and outside a building (residential or commercial), read the settings determined by the user, and make an intelligent decision to satisfy the preset temperature and relative humidity levels in the most effective and energy efficient manner.

The system is intended to be able to be retrofitted to an existing HVAC system, and therefore several requirements must be taken into consideration. In order to avoid running wire inside an existing structure, the temperature and relative humidity measurements are required to be transmitted to the main control unit wirelessly. In order to achieve wireless data transmission the sensor must make its measurements and pass the data to a microcontroller which then must pass the data to a ZigBee wireless chip that will communicate with another ZigBee wireless chip on the main control unit.

The wiring for the air conditioning units to be controlled is already installed in the building, and therefore controlling the power relays that turn the air conditioning units on and off can be done via wire. AC units typically run on 220 Volts AC. To supply the units with this voltage, a power relay must be switched to essentially complete a circuit connecting the units to the main 220 V power supply for the building. Our control system has to switch control relays to send 24 Volts to the 220 V power relays which turn on the AC units.

If a dehumidifier is not already installed in the HVAC system, the control system is required to wirelessly control the dehumidifier. Ducts must also be controlled by the main control unit in order to route new air into the building and old air out when the system determines this is necessary. In this case, a remote unit will be installed that will communicate to the main control unit the same as the remote sensing unit, but will control a relay instead of reading temperature and relative humidity.

The LCD touch screen user interface is required to allow the user to manipulate every setting of the system using only their fingers. The LCD touch screen is also required to display current temperature and relative humidity conditions both inside and outside the building. The requirements of the LCD touch screen are as follows:

- Display current temperature and relative humidity conditions at the main control unit
- Display current temperature and relative humidity conditions outside the building
- Display the logos of the sponsors
- Allow the user to input desired temperature and relative humidity settings
- Allow the user to view their current power costs
- Display the current percentage of total system energy being used via “energy usage” bar
- Allow the user to select between “maximum savings” and “maximum comfort” settings that specify a +- tolerance level for the user selected temperature and humidity settings
- Update the settings on the LCD panel when the settings are changed remotely from a mobile device

The system needs to be able to expand for features to be added in the future. Later on the sponsors may want to develop another version of the system with an expanded feature list. The microcontroller is required to have extra memory available to add these features. Possible features to be added to the system are listed below:

- Scented Air
- Air Purification
- Air flow rate component to provide an alert for the user when a new filter is necessary
- Possibility of integration with a weather server to provide the user with a "severe weather alert"
- Expanded controls for larger HVAC systems consisting of more than 2 AC units
- CO2 sensors to alert the user of CO2 inside the building

1.5 Roles and Responsibilities

1.5.1 Division of Labor

In order for our group to be successful, the project must be decomposed into parts and each part must be assigned to a group member. Our group is composed of three Electrical Engineers, and one Computer Engineer and we have divided the work according to our group member's area of expertise. Each member is responsible of a particular component of the design process as shown in Figure 2. Collaboratively we are all striving to reach the same goal of designing and implementing a useful and efficient HVAC control system that meets the specifications and requirements of both our Senior Design course, as well as our sponsors. Diving labor amongst the group members will allow each member to focus on a specific component of the overall design, and when problems arise during the build of the system the group will know who is best prepared to produce a solution.

Derick's primary responsibility was the design of the printed circuit boards and power supply distribution. This area is extremely important because the printed circuit boards determine the layout of how each component of the HVAC control system will operate. The printed circuit boards provide a means for components such as the microcontrollers, wireless devices, and sensors to communicate to the control unit via the router and vice versa. In any control system data transfer is essential so that the correct decisions can be made and feedback can accurately be assessed.

Josh's primary responsibility in the project is integration of the web server into the system and lead programmer. Although all group members will be involved in the programming process, Josh is the only Computer Engineer therefore he has the most programming experience in the group and is best fit for the role of lead programmer. He is also the only group member with experience in setting up a web server therefore he is best fit for that responsibility as well. The web server is an extremely important part of the project because it is what allows the LCD control panel to be viewed and manipulated remotely from a mobile device. Our sponsors have repeatedly informed us that this is one of the most important application features of all the requirements they have given our group.

Andrew's primary responsibility is wireless communication within the HVAC control system. We are using a ZigBee wireless protocol (802.15.4) to communicate between remote sensing units and the main control unit. Our sponsors have specified they want as much wireless communication as possible in order to keep the system easy to install and avoid having to install new wires in a preexisting building. The temperature and relative humidity data that is measured must be transmitted to indoor and outdoor sensors so that it is important to make sure this data is accurate and not distorted in any way. Also, dampers must be controlled wirelessly to direct air flow through the air ducts to introduce new air into the system. A wireless signal must be sent from the main control unit to control 24V AC relays to direct airflow how the user prefers according to the specified conditions set at the control unit.

Cory's main responsibility is integration of microcontrollers into the system along with Project Budgeting and Financing Goals for the project. The microcontrollers are the main "brain" of the system and have overall control of the system. This is obviously an important part as it will be the chief decision maker. The main microcontroller will make the decision of which units to turn on and what is necessary to meet the requirements set by the user. Cory is also responsible for the communication between the main microcontroller and the user interface. He must make sure that the microcontroller understands what the user is touching on the LCD and that it responds accurately. The Project Budgeting and Financing is important to both the group and the sponsor so that both parties know the budget requirement is being met and that if the group buys parts with out of pocket money they are reimbursed. An Excel spreadsheet will be kept during the design and build processes to keep track of this information. Figure 2 below is a flowchart to describe the each group member's responsibilities pertaining to the Senior Design 1 paper.

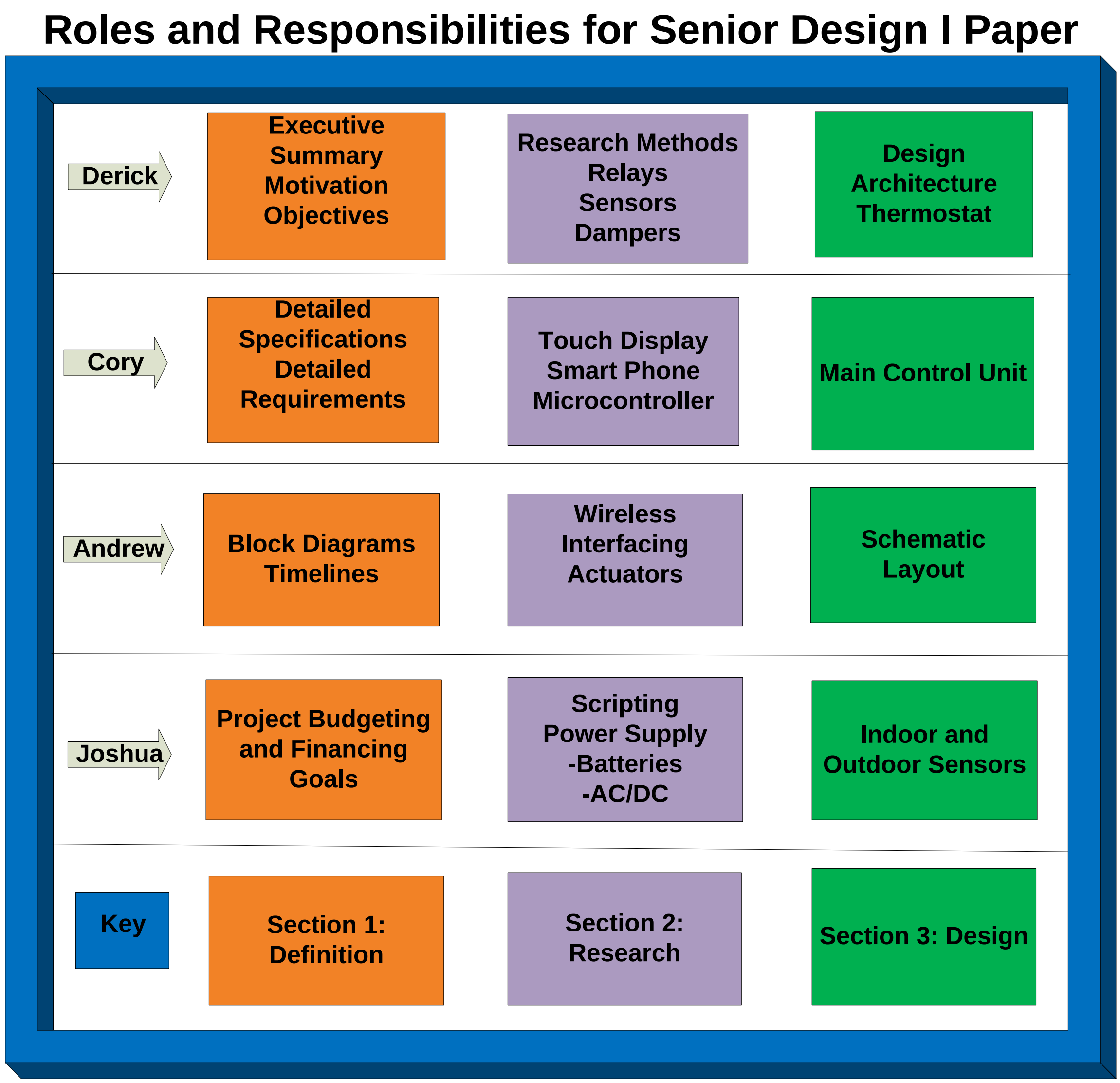

Figure 2 Roles and Responsibilities

1.5.2 Coding Breakdown

Most of the coding for the HVAC control system will take place during the second semester of the project, but the group deemed it appropriate to split up the coding responsibilities as early as possible so each member could begin research on their specific portion and coding language. There will be three main parts of the system that require programming. First, the remote sensing unit microcontroller will require coding. This is probably the simplest of the programs to write. The remote sensing unit microcontroller is only required to receive a binary number from the temperature and relative humidity sensor as an input, and reproduce this same binary number to the ZigBee wireless chip so that the information can be sent to the main control unit. The main microcontroller is the portion of the system that is going to require the most programming. The main microcontroller has multiple inputs (user settings, indoor temperature and relative humidity conditions, and outdoor temperature and relative humidity conditions) that it must accept as input. We are required to create a program to load onto the main microcontroller that will take these inputs into account and will control the appliances associated with the HVAC system. The LCD controller is the other component that requires programming. The LCD controller must be programmed so that it can communicate the necessary images to the LCD screen, and communicate the user inputs to the main microcontroller.

Josh will mainly be working on setting up the web server to allow the main control unit to connect to the internet. Connecting to the Internet will allow the user to manipulate the system remotely from a mobile device. Josh has the most programming experience of the group members so he is being considered the “lead programmer”. The web server is extremely important because mobile connectivity is one of the main features of the system. Most current HVAC control systems lack the capability to be manipulated via web server so the sponsors believe this is on feature that will set their product apart from many competitors. Since the number of people today with Internet ready mobile devices is so high, there is a large market for a product that allows the user to manipulate their home or business HVAC system anywhere they can get phone and Internet service.

None of the members of our group have any experience programming any type of touch screen device and therefore everyone will be working on getting the display just how we want it. The display is probably the most important part of the system because it is the only part that the user will see. The rest of the components will be either out of site or at a remote location and therefore the display is what the user will visualize when they think of the HVAC control system. Because this is mainly what the user will be associating the system with, we want to make sure it is very aesthetically pleasing, reliable, and intuitive to operate so that anyone who is familiar with the operation of a regular thermostat will be able to operate the display immediately. Because this portion of the system is what the customer will interact with, we all want to have a hand in the development of this crucial element of our project. With the LCD screen, the controller board and related software, we will be able to implement bitmap images and macros to make the LCD look and respond exactly how we want. The sponsors have provided us with fairly exact requirements for the appearance of the home screen for the LCD but have left the design of the other screens mainly up to us. We will all program the controller board to be capable of producing multiple screens that will incorporate all of the settings and commands the user is able to give the system.

Andrew, Derick, and Cory will be working on the programming of the microcontrollers. Most of the programming in this project will be associated with the microcontrollers since they will contain all of the logic and decision making. Development kits made by the same company that makes the microcontrollers will allow us to write the code in the C language which we are all familiar with. This part of the programming determines how the building will be cooled or heated so we plan on confirming all of the logic with our sponsor prior to starting to code everything into C. This coding is probably the most important coding aspect because it determines if the system functions properly. The overall success of the system depends on the main control unit analyzing multiple inputs (inside temperature and relative humidity, outside temperature and relative humidity, and multiple user inputted settings) and making a decision on how it is going to cool, heat, ventilate, or dehumidify the building. The following Figure describes the group breakdown of coding responsibilities for our group.

Coding Responsibilities Broken Down By Group Member

Group Member	Responsibility
Joshua New	Web Server LCD Touch Screen User Interface
Andrew Mertens	Main Microcontroller Remote Sensing Unit Microcontroller LCD Touch Screen User Interface
Derick Holzmacher	Main Microcontroller Remote Sensing Unit Microcontroller LCD Touch Screen User Interface
Cory Glass	Main Microcontroller Remote Sensing Unit Microcontroller LCD Touch Screen User Interface

Table 1 Coding Responsibilities Broken Down By Group Member

1.6 Block Diagrams

The Figure 3 picture below is a high level system block diagram explaining the efficient HVAC Control and Feedback System. It describes the interaction between the three main components of the system along with the description and requirements of each component. The diagram does not go into detail about each component, but instead is intended to be a general description of overall functions of each component.

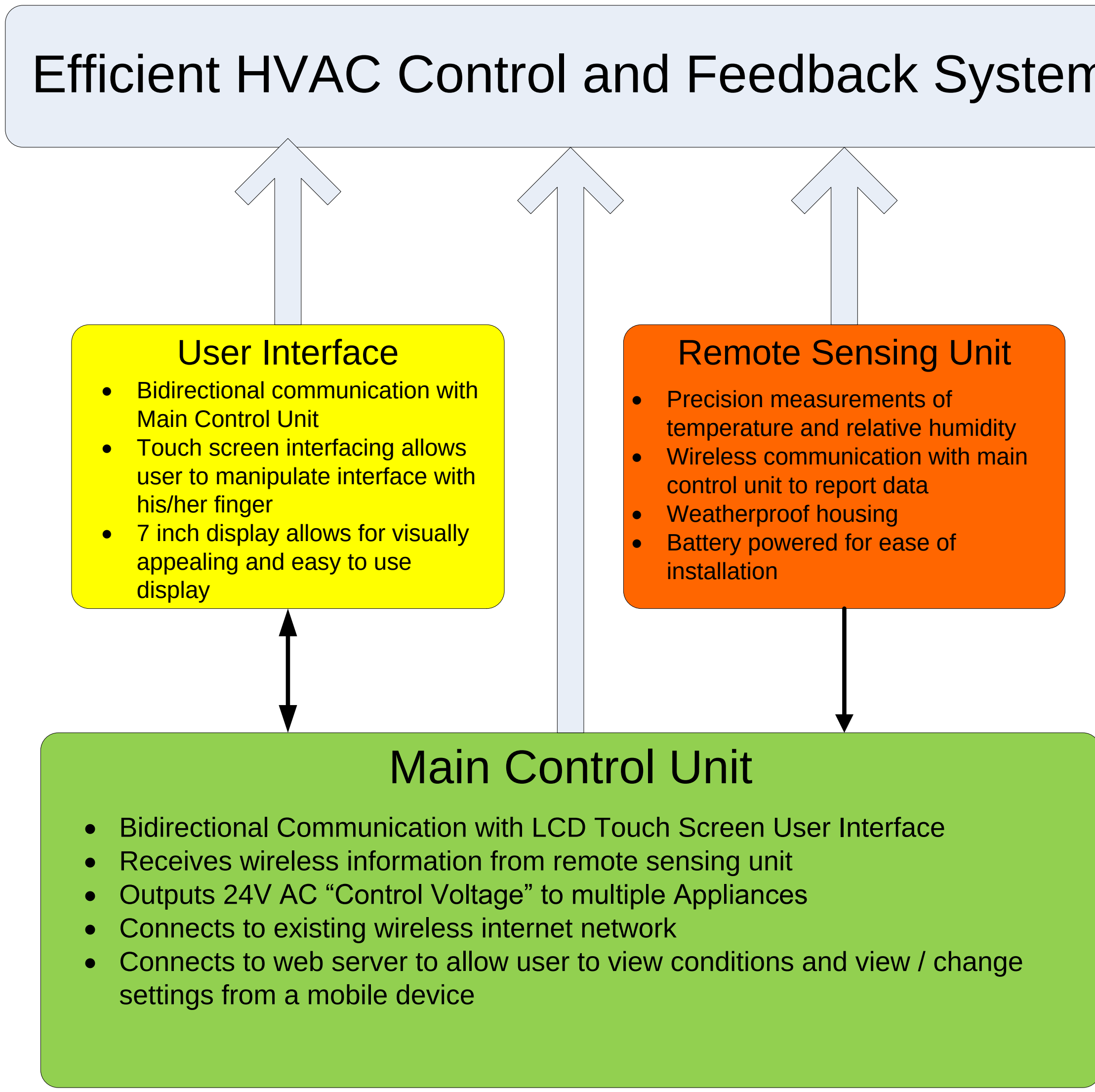

Figure 3 High level system block diagram

1.7 Timelines and Milestones

Our group has decided to meet three times a week in the Harris Engineering Building to discuss individual research that has been completed as well as to share any documentation that has been written. We will typically share our completed work by transferring word documents between our personal computers, or by uploading our completed documents to our Google Docs group that we have established. Setting up the Google Docs site allows us to back up our work on the Internet so if we were to experience problems with our personal computers and our portable media devices our work will not be lost. As well as the benefits of backing up our work, we set up a Gmail account and sent the Username and Password to our sponsors so they can log into the account and track our progress.

Our project was selected during the first meeting with Dr. Richie when he reviewed our “iTemp” project idea and asked us if we would like to accept a project that had been brought to his attention by AC3 Development Group, LLC. After the meeting with Dr. Richie, we decided to set up milestones for our group. The milestones would help us in several ways. They would allow us to better “divide and conquer” the paper, rather than looking at it as one huge assignment. We felt it is easier to think of the paper as multiple smaller reports than one huge assignment. The milestones also would prevent us from getting close to the due date (August 4, 2010) and having so much left to complete that we would be forced to work around the clock to complete the assignment. We looked at the layout of several papers from previous groups and were able to determine the following guidelines for completing the paper in a timely manner. Figure 4 pictured below is a milestone timeline.

- Completion of Introduction/Definition 6/26/2010: This consists the almost all of the Introduction/Definition section including Executive Summary, Motivation, Objective, Detailed Specifications and Requirements, Roles and Responsibilities, Block Diagrams, Timelines and Milestones, and Budget and Financing information. This is the first step in completing our paper and is essential to complete prior to working on research.

- Preliminary Research Completion 7/5/2010: This is the first major milestone for the group. At this point we have picked the majority of the hardware components to be implemented into our system. The components have been picked so they meet the specifications and requirements set by our sponsors. Although they have not been ordered at this point, the group has decided that they are applicable for the system and that they will successfully be integrated together.

- Rough Draft Due 7/19/2010: This is the second major milestone for the group. The rough draft is due at 8:00 AM in class on 7/19/2010. Although the rough draft is not graded, Dr. Richie informed us that he expects somewhere around 60 pages. This is an important date for the group because it shows exactly how much we have done and how much is still needed to complete the paper.

- Completion of Preliminary Design 7/22/2010: This date signifies that the group has documented information from the data sheets for the hardware components. This information should include detailed information about all hardware components and how they will be integrated together. At this point all parts should be ordered.

- Completion of All Content 7/25/2010: At this point all content for the document should be completed and integrated into a single .docx file. The only remaining tasks for the group is to proof read the document for spelling and grammatical errors, making sure all information is properly cited and the necessary steps have been taken to avoid copyright infringement, and to get the document printed, bound, and ready to hand in.

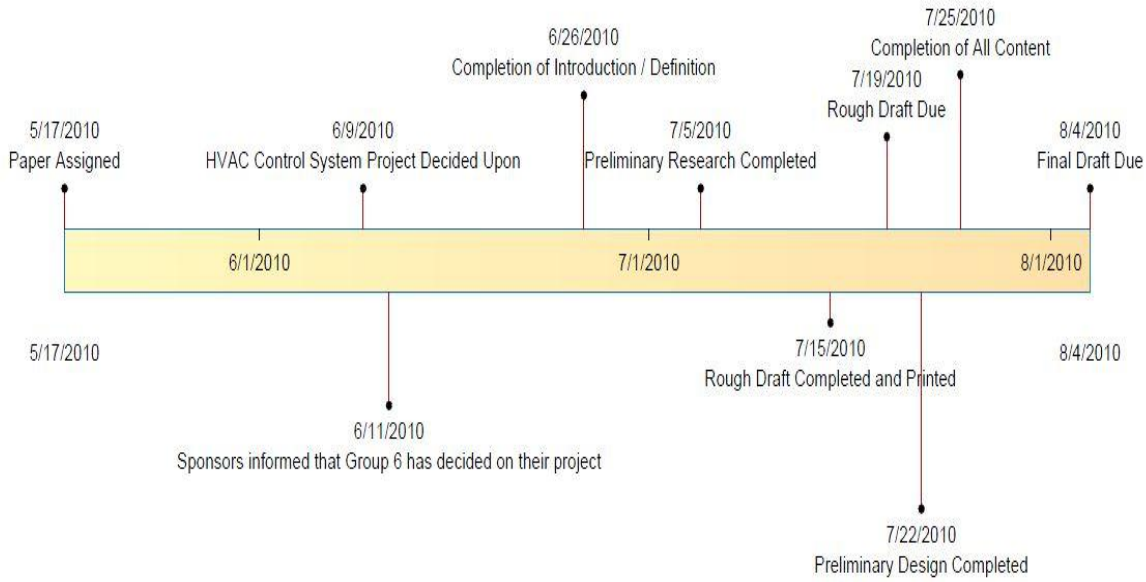

Figure 4 Milestone Timeline

Figure 5 pictured below is another timeline. This timeline describes the meetings that have been set up to discuss the project. The most common of these meetings is between the members of the group. The group on average meets three times per week in the Harris Engineering Building. Group meetings are informal and typically last 1-2 hours. The purpose of these meetings is to collaborate with the group members about progress that has been made on each individual's subsystem that is being worked on. Although each individual is responsible for a subsystem or part of a subsystem, these meetings keep all group members informed about all parts of the project and keeps the group acting as a whole so that everyone has a complete understanding of the project as a whole. These events do not include phone calls, text messages, and Skype conversations pertaining to the project which occur on a daily basis. Due to a high number of group meetings, they are abbreviated to GM on the timeline.

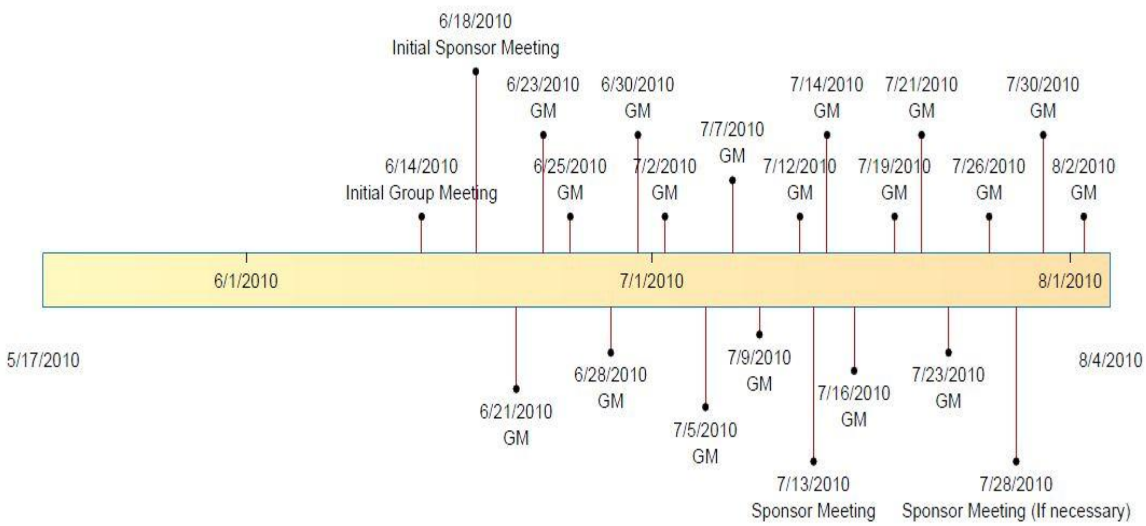

Figure 5 Meeting Timeline

The other type of event in Figure 5 above is sponsor meetings. These do not have a set schedule, but happen when the group decides that they need to meet with the sponsors face to face because email communication is not sufficient. These meetings are slightly more formal in that the group reserves a specific meeting room in the Harris Engineering Building, but casual attire is still acceptable. These meetings are not held often due to the fact that most questions can easily be communicated via E-mail or phone call and the sponsors live over an hour away from the Main UCF Campus. The first of these meetings involved Dr. Richie, but all subsequent meetings are only attended by the sponsors and the group members.

1.8 Budget / Finances

The sponsors of the project are the ones responsible for financing the Efficient HVAC Control and Feedback system. They have come up with a budget of $1500 for the project overall. While designing the system and shopping for parts we have always kept the budget in mind. We realize that if the project goes over budget they will be forced to pay for parts out of their own pocket. Many of the parts involved in the design of this project have very low cost and are not of significance to the sponsors. However, there are several components such as the LCD Touch Screen Display and the microcontroller development board that are of significant cost. These are more business decisions than design decisions and must be made by the sponsors. The group will have meetings with the sponsors where they will provide the sponsors with a list of options that are all suitable for the current design and let the sponsors decide which part they would like to implement. In particular, we will provide the sponsors with a list of several LCD displays and let them pick the display they prefer.

The sponsor will order all of the parts and have them shipped to their place of residence. In order to provide the sponsor with the list of parts to be ordered, we will create an account at the website of the manufacturer of the parts. The group will then select which parts are to be purchased, place them in an online "shopping cart" and provide the sponsor the Username and Password so that the shopping cart can be accessed. Once the sponsor has accessed the account created by the group all that is left to do is for the sponsor to enter the payment and shipping information that is necessary. At this point the group does not see any reason that the project should go over budget. Table 2 below is a list of parts to be ordered by the sponsor along with the Manufacturer, the part number, and the price of each item.

Description	**Part Number**	**Manu-facturer**	**$ per unit**	**Quantity**	**Total**
7" Evervision LCD Development Kit	52-0102-12	Evervision Reach Technology	$499	1	$499
Explorer 16 Kit	DV164037	Microchip	$299	1	$299
MRF24WB0MA PICtail Daughter Board	AC164136-4	Microchip	$60	1	$60
MRF24J40MB PICtail Daughter Board	AC164134-2	Microchip	$30	1	$30
MRF24J40MB ZigBee Wireless Module	MRF24J40MBT-I/RM	Microchip	$17.37	2	$34.74
PIC24F04KA201 Secondary Microcontroller	PIC24F04KA201-I/MQ PIC24F04KA201-I/P PIC24F04KA201-I/SS PIC24F04KA201-I/SO	Microchip	$1.83 $2.05 $1.84 $1.72	2 2 1 1	$3.66 $4.10 $1.84 $1.72
PIC24F16KA102 Plug-in Module (PIM)	MA240017	Microchip	$25	1	$25
dsPIC33FJ256GP710 A Main Microcontroller	DSPIC33FJ256GP710	Microchip	$8.54	2	$17.08
Battery Holder	1024K-ND	Keystone Electronic	$2.53	3	$7.59
				TOTAL	**983.14**

Table 2 Budget and Financing

Section 2: Research

2.1 Research Methods

Our group came together and met generally for 2 days every week and would distribute and assign the various components to the Senior Design project for each group member to do individual research on. For every meeting we had devised how we would tackle individual tasks in accomplishing our main goal in building the Efficient HVAC Control and Feedback System. Everyone made suggestions and posed relevant questions to our sponsors by email. The sponsors themselves served as a research asset because they are licensed professional HVAC contractors. The group required a necessary comprehension as to how an HVAC system works and the sponsors were able to help us with that learning and research process.

The type of wireless device interfaces that could be used, how to program the applications on the smart phone, and how to set up the web server required us to perform extensive research. We also needed to realize how many volts and how much current the relays needed to be and opened or closed and whether they were AC or DC. Other important concerns were what type of communication we would be needed from the mobile device to the main control unit and which touch screen technology we would use. Also for the touch screen we needed to decide on whether it would be packaged together with the driver, microcontroller and touch screen sensor or if we were going to buy individual parts and interface them together ourselves. As the days went along our group went to the library to check out books pertaining to HVAC systems along with general information pertaining to control and feedback systems. We went on the Internet by Googling and browsing various topics related to the project, and also asked questions to our project advisor, Dr. Samuel Richie.

The main researching method that we employed was the Internet. Googling and browsing the web provided a lot of great resources that involve air conditioning systems. One website we used was http://www.deltrol-controls.com/ which provided normally closed and normally open relays with detailed data sheets. This website was a great tool to use because of the 263/268 electronic relay it showed that we looked at purchasing for our Efficient HVAC Control and Feedback system project. Another online resource that we came across was http://www.industrialimage.net/faq.php. This website essentially served a great purpose to us because of the very descriptive and well informed information on touch screens and LCD display panels that it provided for us. The next tool that was used when going to the library was the renting of books. One excellent book that was pertinent to the comprehension of HVAC system was titled HVAC Control and Systems by John Levenhagen and Donald Spethmann. This book covers all commercial AC control systems which include different kinds of servomotors, electric relays, dampers, and thermostats.

For the design section of the report we focused our research on the specific parts we chose for the Efficient HVAC Control and Feedback System. Each part came with either a datasheet or a user manual (sometimes both) provided by the vendor selling the product. These datasheets and user manuals were essential because they provided us with the detailed information that was necessary to explain our subsystem in the design section of the research paper. Even though these resources were used for the design portion of the paper, they provided us with the most important research of the entire design process because of the detail they provided us with pertaining to each individual part associated with the system.

2.2 Main Microcontroller

The main and most integral component in our system is the main microcontroller. The main microcontroller will be the most complex part of the system on both the software and hardware side. The main microcontroller will be located in the main control unit and is the central figure of the entire Efficient HVAC Control and Feedback System. The main microcontroller is required to accept input from a ZigBee wireless transceiver, a temperature and relative humidity sensor (also located in the main control unit), the Internet via an 802.11b wireless internet transceiver, and an LCD touch screen controller board. The main microcontroller is also required to send output to the ZigBee wireless transceiver, the 802.11b wireless transceiver, the LCD touch screen controller board, and to the 24V control relays.

Internally, the microcontroller must be programmed to use these inputs to make the correct decision about how it will choose to cool, heat, or ventilate the building. The programming for this decision making process will be extensive so there must be ample memory on the main microcontroller. Also, the main microcontroller must be able to accept changes in the code so that it has extra storage space to accept new code to be added in the future to incorporate additional features that may be added to the Efficient HVAC Control and Feedback System.

Because the main microcontroller is required to interface with so many other components, it must have a sufficient amount of input and output pins and designated ports such as I^2C, SPI, and UART to be able to accommodate the communication requirements of the other components. Before a microcontroller could be chosen, the requirements and specs of our project had to be considered, and a choice had to be made that provided a microcontroller that had the necessary components to complete the project.

Since the main microcontroller is the main component of the entire system, it must function perfectly for the system to work. The development of the main microcontroller will be one of the most important aspects of the overall project build and everyone in the group will be involved. We will be in close communication with the sponsors prior to beginning the development of the main microcontroller to ensure we develop the main microcontroller to operate to their exact specifications. The performance of the main microcontroller is truly a "make or break" aspect of the Efficient HVAC Control and Feedback System that we are developing. The section below describes the research conducted to find the most appropriate microcontroller for the given set of requirements. The following are some topics that need to be addressed:

Microcontroller Compatibility with Other Components:

The main microcontroller must interface with a ZigBee wireless chip, an 802.11b wireless chip, a Sensirion SHT21 temperature and relative humidity sensor and an Evervision LCD display. Both the ZigBee and the 802.11b chip come from the www.microchipdirect.com website. Since two of the four devices required to interface with the main microcontroller were sold by Microchip, we decided to start our search there.

Footprint and size of microcontroller constraints and mounting style:

All of our components will be placed on printed circuit boards and since pricing for printed circuit boards is dependent on the size, our design will be as space efficient as possible. In order to keep the PCB as small as possible, we will choose the smallest part available that meets our criteria. We plan on surface mounting as many of the components as possible, so when it is an option we will always pick the product that is made to be surface mounted. We have chosen to go with as many surface mount products as possible because they are generally smaller than their through hole counterparts and are more cost effective. The main microcontroller will be small and only account for a small percentage of the overall layout of the main control unit printed circuit board design.

Analog to digital and digital to analog converters:

When exploring microcontroller options, we have found that most microcontrollers have at least one internal analog to digital converter. We may need to make use of a converter when sending wireless information within our system, or when communicating with the router that will connect the system to the internet. Therefore, at this point we are only considering microcontrollers that have at least one analog to digital converter onboard.

Input / Output Ports:

Input / Output ports are how the microcontroller will interface to the other components of the system. For our project, the main microcontroller must communicate with a temperature and relative humidity sensor (2 I/O ports), a ZigBee wireless chip (4 I/O ports), an 802.11b wireless chip (4 I/O ports), and to the LCD display (3 I/O ports). This comes to a total need of 13 I/O ports for the main microcontroller to communicate with the other components of the main control unit. In addition to these components, the main microcontroller is required to connect to relays to control the other components of the HVAC system such as compressors, air handlers, and a dehumidifier. Our sponsors have specified that they would like 20 I/O ports available specifically for controlling relays associated with components of the HVAC system. That specification brings our total needed pin count to 33 I/O ports.

We have been shopping microcontrollers that have between 50 and 100 I/O ports. This range of ports satisfies the requirements set by the sponsors, as well as allows for more features to be added into the system in the future such as control of air purification devices and scent emitting devices. If these features are added, more interfacing with the main microcontroller will be required, along with more software design and implementation.

Memory Type:

We are going to consider microcontrollers with Flash memory for our main microcontroller. Flash memory is a type of EEPROM (electrically-erasable programmable read-only memory) that is a non-volatile storage technology that can easily be electronically erased and reprogrammed. Using flash memory in the microcontroller will allow for changes to be made to the system by the sponsors after the initial prototype is completed. From the research we have done on microcontrollers that meet the specifications of our main microcontroller, Flash memory seems to be the industry standard. The sponsors have made it clear that they wish to add features to the system in the future and therefore we feel that electronically erasable and reprogrammable memory is necessary, and therefore Flash memory seems to be an excellent choice.

Development tools:

The development tool that is recommended by the manufacturer is the Explorer 16 Development board. It is manufactured by Microchip, which is the same company that manufactures the microcontroller. For our project we will be purchasing the Explorer 16 Starter Kit. The Starter Kit includes an MPLAB ICD2 In-Circuit Debugger, the Explorer 16 Development Board, a 9V universal power supply, a serial cable, the MPLAB Integrated Development Environment (IDE), and the Student Edition of the MPLAB C30 C Compiler for Microchip's 16-bit devices, with tutorials and user manuals on CDROM. The Explorer 16 Development Board comes with an Alpha-numeric 16x2 LCD display, Microchip's TC1047A analog output temperature sensor, and the PICTail Plus connector for use with future expansion boards. The Explorer 16 Development Board is designed to easily to a computer via USB or RS232 interface. Full documentation including User Guides, Schematics, and PCB layout is included on a CDROM.

The MPLAB Integrated Development Environment and the MPLAB C30 C Compiler are ideal for our project because it allows us to program the microcontroller in the C language. The C language is a high level language which makes programming the microcontroller much easier. The C language is the language that we are most familiar with as a group, and therefore this is ideal for our programming needs.

The Explorer 16 Development Board is compatible with many daughter boards that can be connected to the Explorer 16 to program the desired chip. For our project we will be purchasing daughter boards form Microchip. Both the ZigBee wireless chip and the 802.11b wireless chip have daughter boards available through Microchip that we will purchase in order to program these devices.

Overall architecture of system:

The components that we will be purchasing use a modified Harvard architecture, and therefore the microcontroller should also use this architecture. The Harvard architecture describes a system with different pathways for instructions and data. Most of the microprocessors we have researched that meet the specifications of our main microcontroller use either the Harvard architecture, or Modified Harvard architecture. Figure 6 below shows a block diagram for Harvard architecture.

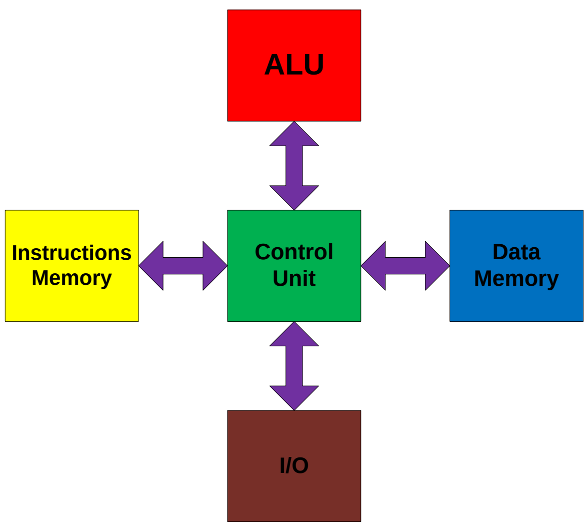

Figure 6 Harvard architecture

Cost:

The microcontroller we purchase should be the least expensive model that meets the necessary requirements of our project. Most microcontrollers within the class that we are going to implement are $10.00 or less and so we would like to stay within the $0 - $10 range. Being between $0 and $10 dollars, the main microcontroller is only a small percentage of the total cost of the system although it is the most important component. The development board is much more expensive than the microcontroller itself, but since we are using multiple parts from the same manufacturer we are able to use the same development board to program multiple devices.

Voltage and current requirements:

The source voltage driving our main control unit is assumed to be 24V AC. This assumption has been made based on the fact that the main control unit will be installed where there was previously a thermostat mounted or installed in a new HVAC system as the main thermostat. Most normal thermostats in HVAC systems are powered by a 24V AC wire that is installed when the building is constructed. The microcontrollers we have been considering normally need between 3.0V and 3.6V AC in order to operate. This will be generated by components on the PCB which will be discussed in the PCB Design section of this paper.

The microcontroller in the main control unit is the component of the system that will do the majority of the processing, make crucial decisions, and send and receive all information. This will be the main "brain" of the system and is required to perform perfectly in order for the system to operate to the standards we have set. We have chosen to use the dsPIC33FJ256GP710A High Performance, 16-Bit Digital Signal Controller manufactured by Microchip. We believe this part has the necessary specifications to complete the tasks required by our design.

2.2.1 General Description

The main microcontroller (dsPIC33FJ256GP710A) has Operation Range, CPU, I/O, Communication, Analog-to-Digital Converter, and other general characteristics as follows:

The operation range of this microcontroller is close to the industry standard. A supply voltage is needed to run the microcontroller and is limited to the range of 3.0 – 3.6V. The typical value for operation voltage is 3.3V DC. When powered by a voltage between these parameters and kept between the temperatures of -40˚C and 85˚C, the microcontroller is capable of up to 40 MIPS (Millions of Instructions Per Second).

Operation Range:

- Supply Voltage of 3 – 3.6V
- Up to 40 MIPS

The microcontroller is optimized to be programmed in the C language which is the programming language preferred by the group. The C language is the language which we have the most background experience in. It contains a 16-bit wide data path which will be sufficient for the data we are required to process, two 40-bit accumulators to store our values of temperature and relative humidity (values should never exceed 14 bits), 32/16 and 16/16 divide operations, and 16 x 16 fractional/integer multiply operations to convert the temperature and relative humidity values from the form they are outputted by the sensor to an understandable form that the user will be able to comprehend. The microcontroller has 256 Kbytes Flash Memory which will hold our programming and allow the program to be modified in the future should more features be added to the system. The 30 Kbytes RAM on the chip should allow the system to run sufficiently fast.

CPU Characteristics:

- C compiler optimized instruction set
- Modified Harvard architecture
- 16-bit wide data path
- 24-bit wide instructions
- Linear program memory addressing up to 4M instruction words
- Linear data memory addressing up to 64 Kbytes
- Two 40-bit accumulators
- Sixteen 16-bit General Purpose Registers
- Software Stack
- 32/16 and 16/16 divide operations
- 16 x 16 fractional/integer multiply operations
- 256 Kbytes Flash Memory
- 30 Kbytes RAM

The microcontroller has 85 I/O pins that can be programmed to work with other devices. This number is above what is required by our design and therefore expansion of the system is possible. System expansion is something that will occur after the initial prototype as been developed. The I/O pins can output between 3.0 and 3.6 V and 4 mA.

I/O Characteristics:

- 85 programmable digital I/O pins
- Output pins can drive from 3.0 – 3.6V
- Wake-up/Interrupt-on-Change on up to 24 pins
- 4 mA sink on all I/O pins
- All digital Input pins are 5V tolerant

The SPI protocol will be used to interface the main microcontroller with the ZigBee wireless chip and the 802.11b wireless chip. The microcontroller only allows for 2 modules to be connected via SPI at one time so our design cannot include any further SPI connections.

3-wire SPI:

- 2 modules supported
- 8-bit and 16-bit data supported
- All serial clock formats and sampling modes supported

The I^2C protocol will be used to interface the main microcontroller to the temperature and relative humidity sensor. The microcontroller can support up to two I^2C modules at one time. This leaves one I^2C port available should another component be added in the future that requires an I^2C connection.

I^2C:

- 2 modules supported
- Full Multi-Master Slave mode support
- 7 and 10 bit addressing

The UART protocol will be set up to be our serial connection to the LCD display. The microcontroller supports up to two modules using UART at any one time. This leaves one UART port available should another component be added in the future that requires a UART connection.

UART:

- 2 modules supported
- Interrupt on address bit detect
- Interrupt on UART error
- Wake-up on start bit from sleep mode

The microcontroller has two ADC modules it can use to transfer input analog voltages into a digital number proportional to the input voltage or current. This will be important for issues where the device connected to the main microcontroller is providing an analog voltage so that the main microcontroller can convert that voltage into a high or low state and proceed as necessary with decision making processing.

Analog-to-Digital Converters:

- 2 ADC modules
- 32 channel

The main microcontroller is where the majority of our processing will be done, and where most of the code we write will be stored. The dsPIC33FJ256GP710A has 256Kb on board Flash memory which will be enough space for all of our instructions. It also has 30Kb RAM which should allow the processing to be done reasonably fast.

During selection of the main microcontroller we considered several options. Most of the options were similar in functionality. We decided on the dsPIC33FJ256GP710A because it met our requirements for number of I/O pins, number of interfacing ports, and was made by Microchip. As we were selecting parts, we found that it was going to be possible to get the majority of our parts from a single manufacturer. We considered this as an advantage as we believed it would be likely that the manufacturer designed their parts to be implemented with one another. We also considered cost of the microcontroller when selecting the dsPIC33FJ256GP710A. The cost of the microcontroller itself is a very small percentage of our overall costs, but we kept in mind that should this system be mass produced, even the cheapest of components amounts to a significant amount of money and therefore cost should be considered for ever component.

During development, we must stay within the specified Absolute Maximum Electrical values. We must avoid subjecting the chip to extreme temperatures, input voltages it is not designed to handle, and drawing or sending too much voltage or current from the I/O pins. The parameters that must be taken into consideration are listed below.

- Ambient temperature under bias: -40˚C to +125˚C
- Storage temperature: -65˚C to +150˚C
- Voltage on V_{DD} with respect to V_{SS}: -0.3V to +4.0V
- Voltage on any pin that is not 5V tolerant with respect to V_{SS}: -0.3V (V_{DD} + 0.3V)
- Voltage on any 5V tolerant pin with respect to V_{SS} when $V_{DD} \geq$ 3.0V: -0.3V to +5.6V
- Voltage on any 5V tolerant pin with respect to V_{SS} when $V_{DD} <$ 3.0V: -0.3V to (V_{DD} + 0.3V)
- Voltage on V_{CAP}/V_{DDCORE} with respect to V_{SS}: 2.25V to 2.75V
- Maximum current out of V_{SS} pin: 300mA
- Maximum current into V_{DD} pin: 250mA
- Maximum output current sunk by any I/O pin: 4mA
- Maximum output current sourced by any I/O pin: 4mA
- Maximum current sunk by all ports: 200mA
- Maximum current sourced by all ports: 200mA

Note: Exposure to maximum rating conditions for extended periods of time may affect device reliability.

2.2.2 Pins

The dsPIC33FJ256GP710A main microcontroller has a total of 100 pins on the chip. Some pins are required to be connected at all times, some will be connected depending on our final main control unit design, and some will be left unconnected or “floating.” Pins that are required to be connected at all times are shown in Table 3 below. The Pin Name, Pin Type, and Description are included in the table.

Pin Name	Pin Type	Pin Description
AV_{DD}	Power	Positive supply for analog modules.
AV_{SS}	Power	Ground reference for analog modules
V_{DD}	Power	Positive supply for peripheral logic and I/O pins
V_{SS}	Power	Ground reference for logic and I/O pins
V_{CAP}/V_{DDCORE}	Power	CPU logic filter capacitor connection
MCLR	Input/Power	Master Clear (Reset) input. This pin is an active low reset.
PGEC1	Input/Output	Clock input pin for programming/debugging comm channel 1
PGED1	Input/Output	Data I/O pin for programming/debugging comm channel 1
OSC1	Input	Oscillator crystal input
OSC2	Input/Output	Oscillator crystal output
$V_{REF}+$	Input	Analog voltage reference (high) input
$V_{REF}-$	Input	Analog voltage reference (low) input

Table 3 Pins to be connected at all times

Also required at all times is the use of decoupling capacitors on every pair of power supply pins. Our printed circuit board design will include these capacitors as well as the resistors pictured. A diagram of this configuration is shown below in Figure 7.

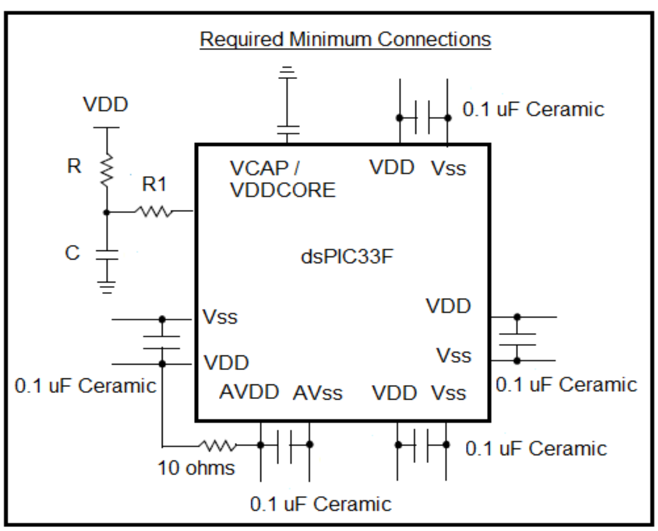

Figure 7 Required Minimum Connections

The main microcontroller shares the main control unit with two devices requiring SPI connections, one device requiring an I^2C connection, and one device requiring a UART connection. Table 4 shown below shows the pin name, type and description of the pins that will be utilized to accomplish this interfacing

Pin Name	Pin Type	Pin Description
SCK1	Input/Output	Synchronous serial clock input/output for SPI1
SDI1	Input	SPI1 data in
SDO1	Output	Spi1 data out
SS1	Input/Output	SPI slave synchronization or frame pulse I/O
SCK2	Input/Output	Synchronous serial clock input/output for SPI2
SDI2	Input	SPI2 data in
SDO2	Output	SPI2 data out
SS2	Input/Output	SPI2 slave synchronization or frame pulse I/O
SCL1	Input/Output	Synchronous serial clock input/output for I2C1
SDA1	Input/Output	Synchronous serial data input/output for I2C1
U1CTS	Input	UART1 clear to send
U1RTS	Output	UART1 ready to send
U1RX	Input	UART1 receive
U1TX	Output	UART1 transmit

Table 4 Pins used for interfacing

2.2.3 Interfacing

The main microcontroller must interface with all of the components in the main control unit. Along with the dsPIC33FJ256GP710A (main microcontroller) the main control unit consists of an SHT21 temperature and relative humidity sensor, an MRF24J40MB ZigBee wireless transceiver, an MRF24WBOMA 802.11b RF wireless transceiver, and a 7 inch Evervision LCD module.

The interfacing for the relays requires a single wire from the microcontroller I/O pin, with a darlington array driver in between the microcontroller and the relay. The array driver is a surface mount chip that contains several internal transistor circuits. This component ensures the correct current will be delivered to the relay and that the I/O pin on the microcontroller will not exceed its maximum current output rating. This component is not included in the following diagram, but will be discussed in detail in the relays section of this paper.

Figure 8 shows the interfacing within the main control unit. It also specifies the type of connection used and the number of wires required for each connection type.

Main Control Unit Interfacing

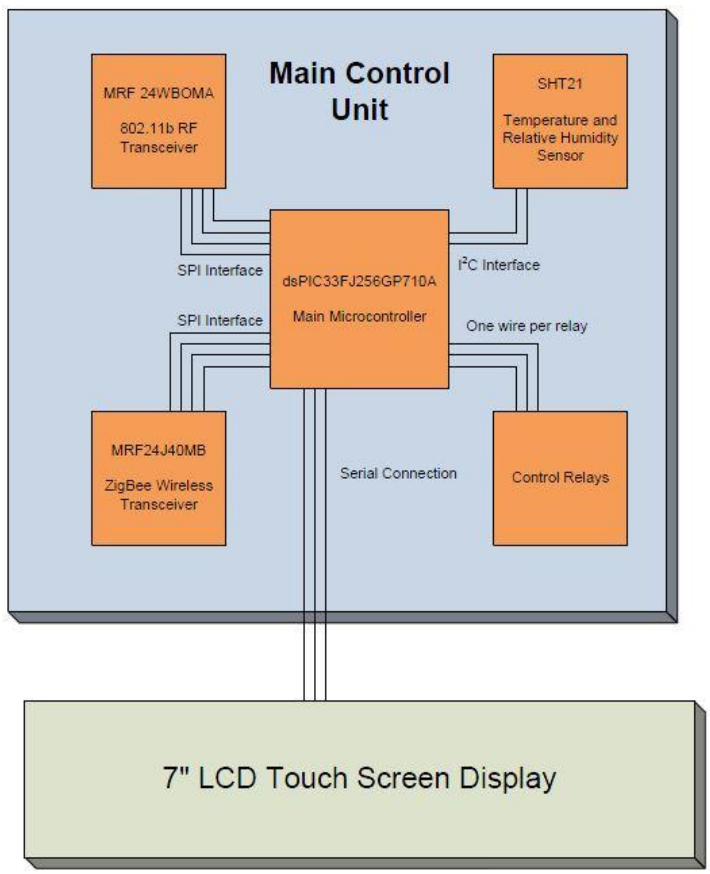

Figure 8 Main Control Unit interfacing

The dsPIC33FJ256GP710A can connect to 2 UART, 2 I^2C, and 2 SPI modules. As the diagram shows, both the ZigBee and the 802.11b chips connect via SPI, the SHT21 temperature and humidity sensor connects via I^2C, and the 7" Evervision LCD touch screen connects via Serial interface that will consume one of the two UART connections. After considering all of the necessary connections, we see that both of the I^2C connections will be used, one of the two SPI connections will be used, and one of the two UART connections will be used. There will be one SPI and one UART connections left floating in the design of the main control unit. The dsPIC33FJ256GP710A will be programmed in the C high level language using the MPLAB C Compiler from MicroChip.

2.3 Secondary Microcontroller

For the secondary microcontroller for the system, we needed a simple and very low power consuming component. This secondary microcontroller will be battery powered as connecting to a permanent power source is not the end goal for the system. The secondary microcontroller will interface with the sensors and 802.15.4 ZigBee wireless chip. We have chosen to use the PIC24F04KA201, 20 Pin general purpose 16 Bit flash microcontrollers manufactured by Microchip®.

2.3.1 General Description and Pin Layout

The secondary microcontroller (PIC24F04KA201) has the operation range, central processing unit (CPU), I/O, Analog-to-Digital Converter and other general characteristics as follows:

Operation Range:

The operation range of this microcontroller is close to the industry standard. A supply voltage is needed to run the microcontroller. Since this microcontroller is going to be attached with the sensor and ZigBee devices, and powered by a battery, it needs to be low powered like those components. This whole sub-system of the secondary microcontroller will be battery powered, and have the low supply voltage is essential to our design specifications and keep between the temperatures of -40˚C and 85˚C. The PIC24F04KA201 features new nanoWatt XLP (eXtreme Low Power) technology for the low power consumption required in our system.

- Supply Voltage of 1.8 V – 3.6 V
- nanoWatt XLP
- -40˚C - 85˚C

The PIC24F04KA201 is also equipped with power saving technology such as On-the-Fly Clock Switching, Doze mode, and Instruction-based power saving modes. PIC24F devices have two special power-saving modes, entered through the execution of a special *PWRSAV* instruction. The Sleep mode halts all code execution; Idle mode halts the CPU and code execution, but allows the peripheral modules to continue operation, such as the ZigBee and temperature/ humidity sensor. Deep Sleep mode stops clock operation, code execution and peripherals. It also freezes the I/O states and removes power to the SRAM and Flash memory. Combinations of these methods can be used to tailor our applications power consumption by selectively managing clocking to the Central Processing Unit (CPU)

CPU Characteristics:

- Up to 16 MIPS
- C complier optimized instruction set
- Modified Harvard architecture
- 16-bit wide data path

- 4 Kbytes Flash Program Memory for storing and executing application code
- 512 Bytes RAM data memory

The microcontroller is also capable of up to 16 MIPS (Millions of Instructions Per Second), which is standard for a microcontroller of this size and power. The microcontroller is optimized to be programmed in the C language, the preferred programming language of the group. The secondary microcontroller will be responsible for taking in the data from the SHT21 sensor. The 16-bit wide data path will be sufficient for process the temperature and humidity data, and then passing the information along to the main microcontroller via the 802.15.4 ZigBee device.

The internal flash program memory for a device is used for storing and executing application code. The 4 Kbytes of Flash memory will hold our programming code, and allow the program to be modified in the future should more features be added to the system. The memory is readable, writable and erasable when operating with a VDD over 1.8V. 512 Bytes of RAM will allow is low data rate RF module to run quickly and effectively.

The secondary microcontroller has 18 I/O pins that can be programmed to work with other devices such as the sensor and the ZigBee RF transceiver. This number of I/O pins is above the required number for our design, in case expansion of the system is needed. The microcontroller also has ADC modules to transfer input analog voltages into a digital number proportional to the input voltage or current.

I/O Characteristics:

- 18 Input/ Output (I/O) pins
- Analog-to-Digital Converters
- 10-bit A/D Convert
- 9 Analog-to-Digital (ADC) input channels

The SPI module protocol will interface the secondary microcontroller with the ZigBee wireless chip. The I2C™ module protocol will be used to interface the temperature and relative humidity sensor with the PIC24F04KA201 microcontroller. The I2C™ module supports both Master and Slave modes of operation, useful for the sensor connection. The secondary microcontroller block diagram in Figure 9 below illustrates the peripheral connection with the different components.

Three Serial Communication Peripherals:

- 1 – SPI module
- 1 – I2C™ module
- 1 – UART module

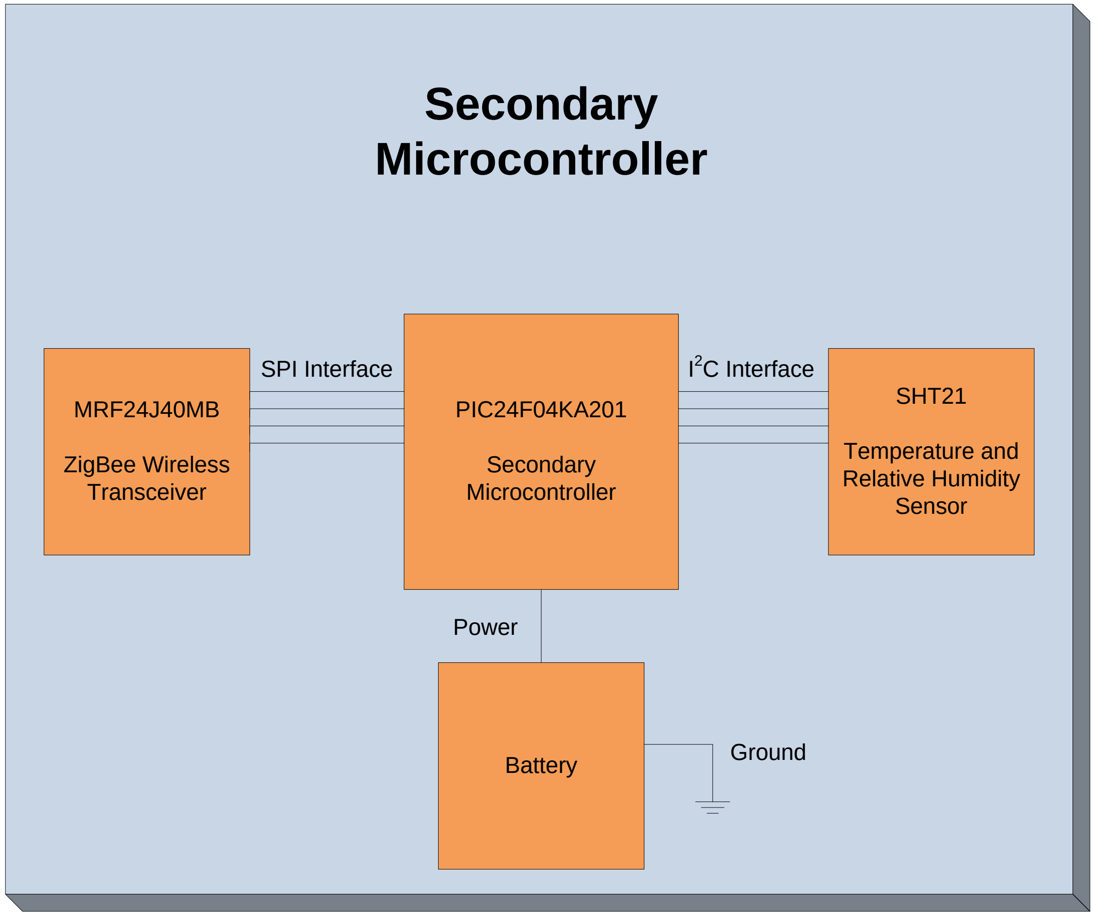

Figure 9 Secondary Microcontroller Interfacing

2.4 Relays

Heating, Cooling, and Air Circulation is accomplished with the help of relays that act as switches to turn on and off these systems. The relays are triggered by digital logic as a result of readings from temperature and humidity sensors. In all of the relays that we have encountered in our research the one that would be best be suited for our design is a normally closed switching electronic relay. In the HVAC control we will use relays to activate the output to the heating, air conditioning and air circulation in response to changes in inside and outside air temperature depending on the settings selected by the user via the LCD touch screen display.

The main control unit will allow the user to set a specified temperature and humidity comfort setting. The NC (normally - closed) relay will be closed and activate the specific circuit, or opened to deactivate the circuit in order for the temperature and humidity to be achieved. The tolerance and range of the temperature and humidity sensors will have a direct affect on the output of the relays and the activation or deactivation of each of the three systems.

Some important factors when choosing the best relay to purchase for the HVAC control system are:

- Affordability, whether it is cost efficient for your budget in designing an HVAC system
- Contact configuration: Single Pole Single Throw, Single Pole Double Throw, Double Pole Double Throw, Three Pole Single Throw, Four Pole Single Throw, or Four Pole Double Throw
- Coil voltage, how much voltage do you want the coils of the relay to operate at from the available supply source in order for it to switch the Heating, Cooling, and Air Circulation as a result of the measured temperature and humidity.
- Type of mounting preferred: Usually surface mounting requires a soldering iron, socket mounted for plugging into a circuit board for easy replacement.
- Contact protection: This involves the relay's contacts that, due to arching wear over time. Contact protection is the number one concern and priority in relays. Relays that use relatively small contacts for the voltage and current in an inductive circuit will result in arching and excess wear over time.
- Low Power Consumption: Low voltage relay coils are less dangerous to persons working with them, easier to install and do not come under the stricter codes that apply to wiring over 30 volts.
- Max voltage sink by microcontroller: Depending on your microcontroller of choice, there is a maximum voltage that the I/O pins can produce.
- The voltage produced by the microcontroller determines how the buffer circuit must be set up so that the relay receives the correct voltage and current.

In typical HVAC control systems there are two types of relays involved. These relays are the control relays and the power relays. The control relays are switched on by the main control unit when a decision to turn their specific component on has been made. The output of each control relay is 24V AC, and is known as the control voltage. This control voltage is the input to the next relay which is the power relay. There is typically a power relay located outside at the compressor and another located at the inside air handler. When the power relay is switched to the on position, 220/240V AC is connected to the compressor or air handler and it runs until the main control unit determines it is time to stop and the relay is switched back to the off position. Figure 10 below is shown to better illustrate this system.

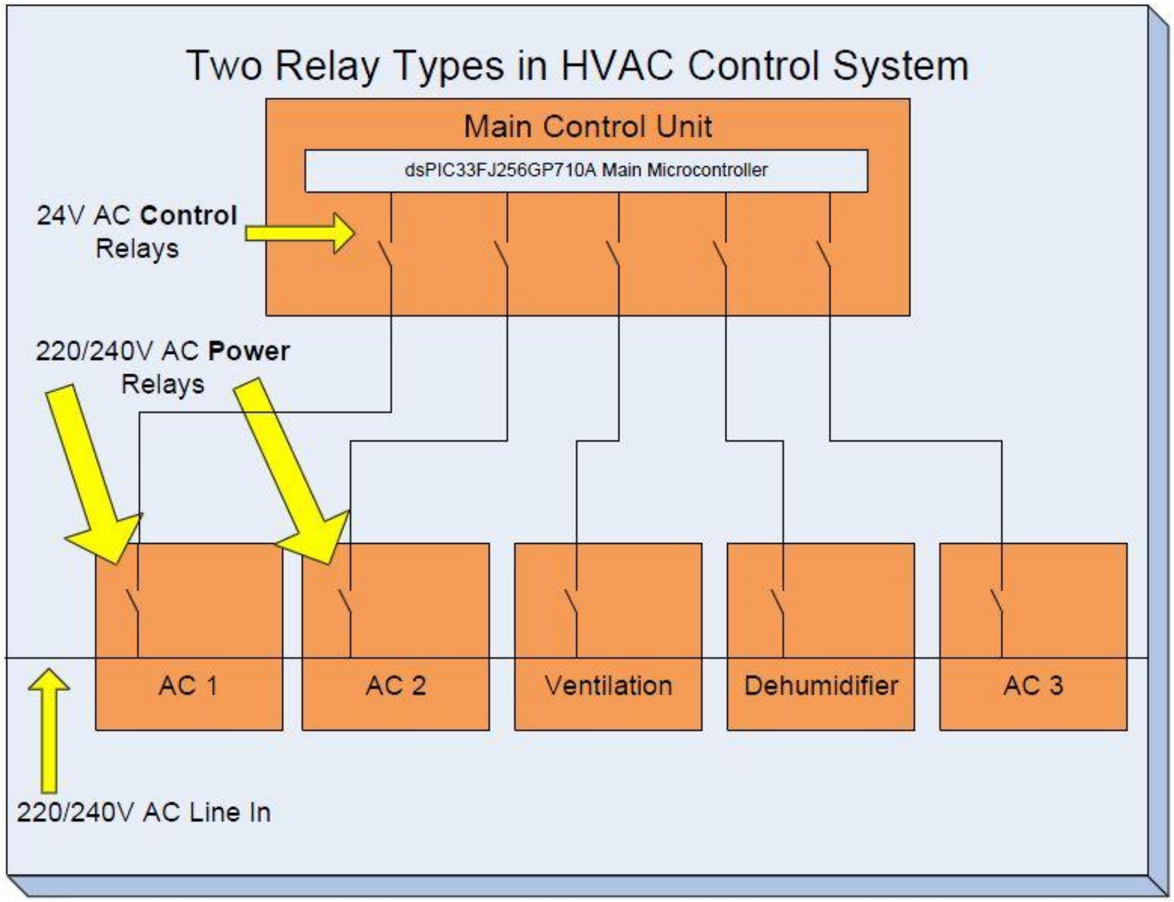

Figure 10 Typical HVAC relay setup

Researching different types of relays led us to come across the website: http://www.deltrol-controls.com/. This website is pretty good because deltrol-control is a leader in the design and manufacturing of electronic components. They also have very detailed and well explained part specification sheets that list what type of relays are used for certain applications. The relay that our group is interested in is the 263/268 series relay. These relays can either be surface mounted by using a soldering gun or can be directly plugged into the circuit board. Both the 263 and 268 series relay can carry a maximum of 15 Amps as well as have an ambient AC temperature ranging from -45 degrees to 65 degrees Celsius. Our HVAC control system will have multiple different sets of relays; one relay to activate 1st Stage Heating, one for 2nd Stage Heating, one for Blower / Fan, one for Compressor, one for Reversing Valve, and one for 24V Common.

The 268 series relay is readily available with a 24V AC coil having a DPDT configuration that meets our systems requirements. The 24 V AC coil has an electronic tolerance of ± 10% ranging above or below 72 ohms. It also has a nominal coil powered at 2.2 VA.

Another consideration when researching relays is how to interface them to the microcontroller. This involves designing a circuit that uses a transistor to ensure the relay receives the correct current and voltage. Another option for this step is to use a relay driver which is a surface mount chip with several transistor circuits inside. The advantage of this type of device is that the design is simplified because the designer does not have to implement multiple complex circuits into the design of the printed circuit board. This will be discussed further in the Relay subsection of the Design portion of this paper.

2.5 LCD Touch Screen

For the Efficient HVAC Control and Feedback System, system navigation and the user inputted settings can be achieved via the touch display or touch screen feature. Many electronic appliances now use touch screen displays such as laptops, palm pilots, blackberries, and music players. These devices all utilize a touch screen sensor, a controller, and software driver. The various touch display technologies that are available today are resistive touch screen, surface acoustic wave technology, and the capacitance touch display panel. All of these touch display technologies are touch sensors which normally have an electric signal go through the layers of the screen causing the a voltage to change. The voltage change will directly link to help telling it the location of the finger touching the screen.

In the resistive touch screen system, it primarily contains two electrically conductive layers separated by a narrow gap called a spacer. A current flows through the two layers of the touch display screen while the monitor is still running. This system is composed of a glass panel and when the finger is pressed down on it, it will lock on that exact point in the x-y coordinate plane. The concept of the voltage divider is used to calculate the x-y coordinate that has been touched. When the electric field in the touch screen system is changed, the software driver translates the touch information to the operating system so the location of the touch can be identified. Figure 11 below includes a step by step process as to what occurs in a resistive touch screen system.

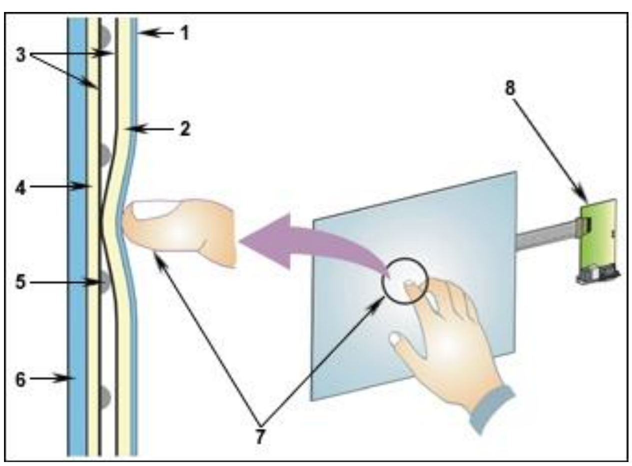

Figure 11 Resistive touch screen (Reprinting Permission Requested from 3M Touch)

The surface acoustic wave technology features two transducers so that when the panel is touched it can find the coordinate accordingly. These transducers are positioned on the x and y axes of the coordinate plane of the screen's insulated plate. The controller calculates the time at which the height of the acoustic wave falls to determine the x and y coordinates position on the x-y coordinate plane. This technology can also figure out how much pressure is applied to by the screen. The Z axis (is going into the screen) will determine this depth information. Once the touch screen locates the finger touched on the panel it will relay information to the microcontroller. The surface acoustic wave system has the best image graphics on the screen because 100% light is transmitted. There are no metallic layers on the screen to block light from going through it. Figure 12 pictured below undergoes the surface acoustic wave touch screen technology process.

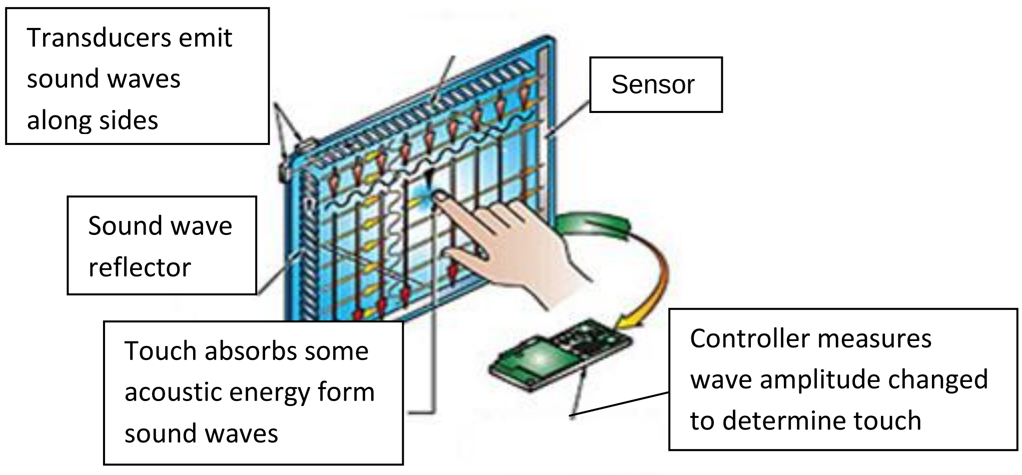

Figure 12 Surface Acoustic Wave touch screen (Reprinted with Permission from 3M Touch)

The capacitive touch screen system stores an electrostatic charge while placing your finger on the glass insulated panel. The electrostatic charge is displaced when the user places their finger on the monitor. Therefore the capacitive layer is reduced. An advantage of the capacitive touch screen system is that it sends 90% of light from the monitor to give the screen a crisper and clearer picture than the resistive system. Figure 13 is a detailed overview as to what happens in a capacitive touch screen display.

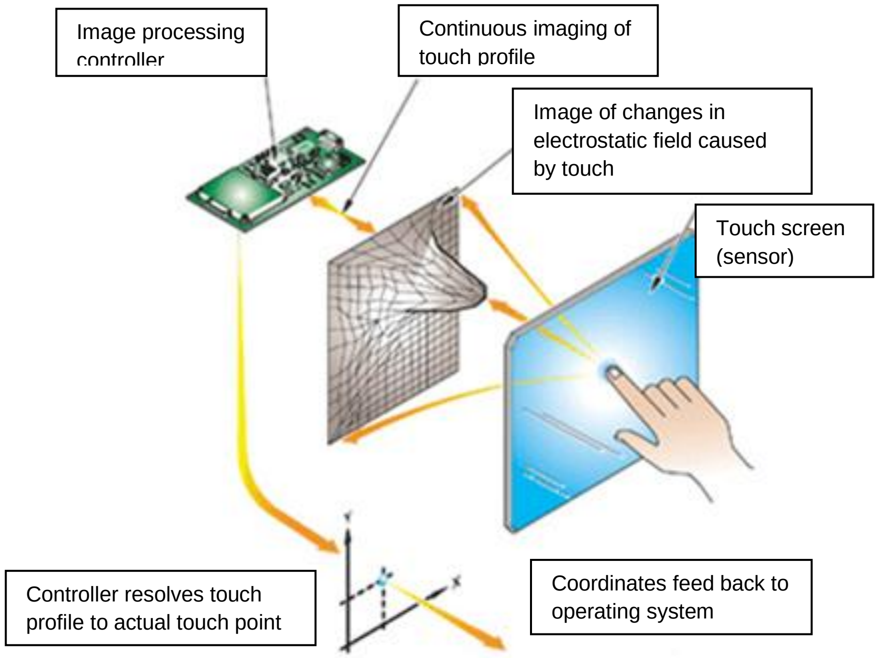

Figure 13 Capacitive touch screen (Reprinting Permission Requested from 3M Touch)

To differentiate all three different varieties of touch screens, the resistive touch technology is the cheapest to purchase on the market whereas its graphics and quality are the worst out of all of them. The next touch screen is the capacitive touch screen and ranks in the middle in terms of cost. According to consumers who purchase touch screen displays these are the most reliable and most popular electronic applications on the market. Finally the surface acoustic wave technology is the most expensive touch screen with the best picture clarity, pixel resolution, and longer durability. Some of these touch screen technologies have gloves to allow the user to use the screen numerous times without scratching or damaging the glass. Even without gloves some of these technologies use special protective coating on the glass filament layers. Table 5 shown below compares the discussed touch screen technologies.

Technology	**Resistive (4 Wire or 5 Wire)**	**Surface Acoustic Wave (SAW)**	**Capacitive**
Transparency	75 - 85 %	85 – 92 %	85 – 92%
Accuracy	Low	Low	Moderate
Resolution	High	High	High
Touch / Input Methods	Anything	Finger or Stylus	Finger
Durability (How long do they	3 years for 4 Wire	5 years	2 years

last?)	5 years for 5 Wire		
Cost	Inexpensive	Expensive	Average cost
Sensitivity	Very sensitive to scratch	Sensitive to scratch	Sensitive to dirt
Advantages	Inexpensive, can detect any object, not sensitive to water, humidity or dust	Can be used on curved surface, not sensitive to water	Average cost, scratch resistant, not sensitive to humidity or temperature
Disadvantages	Sensitive to scratch, low fidelity, and reduce visibility of the touch screen	Very expensive, sensitive to scratch	Can only use your finger, reduces illumination, can't move your finger (so it can be able to detect it for position)
Color Fidelity	Low	Low	Low
Response time	For 4 wire: Less than 10 ms For 5 wire: Less than 15 ms	10 ms	Less than 15 ms
Installation	Built - in or Onwall	Built - in or Onwall	Built - in
Following Speed	Good	Low	Good
Stability	High	Best stability out of all 3	Ok
Light Resistant	Good	Good	Bad

Table 5 Touch screen technology comparison

Next on the list of components for a touch screen display is the controller. The two controller configurations used are the ISA Bus and the Serial RS232. ISA Bus controllers are limited only to a printed circuit board. The serial controllers are built on printed circuit boards and are surface mounted using a soldering gun. These different types of controllers are basically PC cards that attach the touch sensor to the PC. It holds information from the touch sensor and relays the information to the PC so it can understand it better.

Finally the software driver is an essential part in the HVAC system control that we will be developing for the Efficient HVAC Control and Feedback System. The driver will permit the touch screen and the computer to work together. The most commonly used touch screen driver is the mouse-emulation type driver which functions the same way as clicking the mouse at the same place on the screen. The touch screen can coexist together with existing software and will permit new technological applications to occur without the need for programming.

Another concept that a person needs to be aware of when trying to determine what would be the best touch screen panel is to know what an NIT is. Candelas per meter square is a measurement of light in the determining the brightness of a touch screen display panel. Candelas per square meter is often referred to as an NIT and this is equal to footlamberts * 3.43. Below are some formulas used to figure out touch screen illumination, screen brightness, and total light outputted from the screen:

- $\text{Screen brightness(footlambert)} = \text{illumination} * \text{screen reflectance(gain)}$
- $\text{Screen illumination(footcandle)} = \text{lumens per square foot}$
- $\text{Total light output} = \text{lumens}$
- $\text{Illuminance} = \text{luminous flux} \div \text{Area of touch screen monitor}$

A vital term that becomes important when considering touch screen displays is the contrast ratio (CR). The contrast ratio is defined as being the proportion of luminance to white and dark light that is formed on a touch screen display. This takes place when figuring out the best picture quality between the various touch screen displays: resistive touch screen, surface acoustic wave, and capacitive touch screen. To have an enhanced sharp picture, a user must purchase a touch screen with a high contrast ratio. The contrast ratio changes when measuring the ambient illumination in a dark room compared to the touch screen being calculated outside in the sunlight.

Last of all is the viewing angle terminology. A viewing angle for a touch screen display is the angle at which the pixel resolution and image quality gets bad enough and unacceptable for the user to view. In order for the viewing angle to degrade on the touch screen it will go through three processes. The first course goes through a drop in luminance or luminous flux. Next the contrast ratio will fall at large angles and as a result the pixel or resolution colors on the touch screen may start to deviate. Criteria based on viewing angles consist of the luminance and contrast ratio.

2.6 Wireless Interfacing

One of the most important features for our HVAC design is to be able to communicate wirelessly between the different components. The feedback and control system will not use wires to connect the subsystems like the secondary microcontroller and the main control unit. Wireless components are making industries and systems like HVAC units easier to install, operate and fix as wireless technology is becoming easier and more reliable to implement.

2.6.1 Ethernet and Wireless Routers

Ethernet is a branch of wired technologies under the Local Area Network communication. Ethernet's standard practice used is the 802.3 which has been created since the 1980's. Changes have occurred in the recent years to make the Ethernet have higher bandwidth quality and improved media access control methods. The standard connector used to connect the Ethernet port from the computer to the Ethernet jack in the wall is called the RJ45 connector. This connection is used in most home computers where it is an alternative way to obtain internet access. In our system, we will have the Ethernet connection with the wireless router to provide the network on which our wireless technology will be able to connect to the Internet.

The system also needs to include a wireless method for connecting the smart phone application with the main control unit. The use of a wireless router allows our system to establish a network so that the smart phone can communicate with the main control unit. Wirelessly routers connect the devices to the Internet through the use of wireless chips embedded inside. The smart phone application will be able to access the feedback and control system features anywhere, whether it is inside the house included in the range of the wireless router, or out on the wireless networks in virtual every corner of the nation.

Wireless routers that will be considered for use and purchase are either going to be the 802.11g router or the 802.11n router. The n router has faster signal strength than the g router with double the range. Other factors in considering the n router vs. the g router is that n routers cost more but are backwards-compatible meaning that n routers can still transmit data as g routers. In the 21 century the wireless g routers is a fading technology they are being replaced with wireless n routers.

An application can be developed for smart phones that simulate the control panels display screen right on the smart phone. With the smart phone you can access and control the comfort features from anywhere while connected to the internet. While designing the smart phone application, connection speed is a concern as we want real time data from the system and the ability to make changes to the system.

2.6.2 Wireless Protocols

One of the main features of our system is having the different components communicating wirelessly. The sensors recording temperature and humidity data are going to report that data back to the main microcontroller, so that the correct decision can be made to chose the most effective option for the desired settings. The main microcontroller also has to be able to connect to the internet wirelessly, for viewing and controlling for the end user. Additionally, once the system makes a decision based on the settings the user has set, a signal will be sent to the relays controlling the different heating and cooling options so that the appropriate action can be carried out.

The question becomes which form of wireless technology will be most effective for caring out these decisions and actions. With so many different choices of wireless communication, certain key features must be accounted for and analyzed before we can select the best option. The three biggest options in the wireless technology field that can give us a better understanding are: Bluetooth, ZigBee and Wi-Fi®. Each of these wireless protocols have pros and cons that will help us choose the best communication system for our components. The sections following outline and describe these communication protocols.

2.6.3 IEEE 802.15.4 – ZigBee

ZigBee is a specification for a suite of high-level protocols using small, low-powered digital radios based on IEEE 802.15.4 standard for low-rate wireless personal area networks (LR-WPANs). The 802.15.4 protocol offers the lower network layers of wireless personal area networks (WPANs) which are focused on the simple, low-cost, low-power consumption, simultaneous communication between devices. ZigBee is targeted for radio-frequency applications that require low data rate, a long battery life, and secure mesh networking. Mesh networking provides high reliability with a more extensive range. The low cost of the ZigBee protocol allows the technology to be widely deployed in wireless control and monitoring applications and the low-power usage allows for longer life with smaller batteries. ZigBee is less expensive and simpler to operate compared with other WPANs like Bluetooth.

The ZigBee wireless standard is a great option for this project. An external ZigBee device could interface with both our main and secondary microcontroller. Many microcontrollers' have ZigBee transceivers already built in; saving space on our printed circuit board (PCB). Other house appliances like the home telephone, microwave, Wi-Fi and Bluetooth share the 2.4 GHz ISM band, causing noise for the ZigBee device. ZigBee has low data rates, meaning that less data needs to be transmitted, making the noise a non factor for the system. The low power physical layer of the ZigBee allows the ability to transmit of a range up to 75 meters, which is more than enough for the scale of this project. Another great fact is that for an individual device to pass the ZigBee certification, it must have a battery life of at least two years, proving how low power ZigBee communication is. Table 6 pictured below illustrates the pros and cons of the zigbee wireless standard protocol.

Pros	Cons
Transmission range between 10 – 75 meters (33 -264 feet) and up to 1500 meters for ZigBee pro	On the cluttered 2.4 GHz ISM band
Maximum output power is generally 0dBm (1mW)	Low data rates up to 720 kbits/s
Easily implemented	
Flexible network structure	
Small size	
Individual devices must have batter life of at least two years	
Many manufacturers are integrating microcontrollers with ZigBee transcievers	

Table 6 Pros and Cons of ZigBee

ZigBee has many appealing features, extremely low power, great battery life, and a good transmission range. These features make a ZigBee device a great choice for our secondary microcontroller to communicate with the other devices. The secondary microcontroller will send very low data rates, need to be battery powered for a longer life, and need to communicate with the main microcontroller. All of which can be handled by the ZigBee technology.

2.6.4 Bluetooth

Bluetooth was another option to consider for wireless technology that could work in exchanging data in our system. Bluetooth is an open wireless protocol used for exchanging data over short distances from fixed and mobile devices. This creates personal area networks (PANs). This technology was originally designed as a wireless alternative for RS232 data cables. It could connect several devices at the same time overcoming synchronization problems. Many small electronic devices utilize Bluetooth as an alternative to wires.

Using radio technology called frequency-hopping spread spectrum, Bluetooth can chops up the data that is being sent and transmits chunks of it on up to 79 frequencies. It can achieve a gross data rate of 1Mbps for Bluetooth 1.0, 1-3 Mbps for Bluetooth 2.1 and 54 Mbps for Bluetooth 3.0. Bluetooth operates and exchanges information through the secure, globally unlicensed Industrial, scientific, and medical (ISM) 2.4 GHz short range radio frequency (RF) band. There are three classes of Bluetooth: Class 1 uses up to 100mW of power and can transmit approximately 100m, Class 2 uses up to 2.5mW of power and can transmit approximately 10m and Class 3 uses up to 1mW of power and can transmit approximately 1m.

Like any protocol, there are drawbacks and problems with Bluetooth. Bluetooth has problems with wall penetration, which is a major concern for our system. Bluetooth also uses more power for the distance the data is traveling compared to ZigBee. Another drawback is that other house appliances, like wireless home telephone, ZigBee and Wi-Fi signals clutter the 2.4 GHz ISM band. This could be a problem when dealing with noise corrupting packets of data being sent. The Bluetooth protocol has a way to deal with this type of interference and limiting those problems. Users using Bluetooth must also initiate a pairing between the devices initial, making more work later for the end user. Overall though, it looks like using the Bluetooth protocol is not the best solution for our system.

2.6.5 IEEE 802.11 – Wi-Fi

IEEE 802.11 (Wireless Local Area Network) protocol is the most widely used and recognized computer related wireless communication system. The term Wi-Fi ® is a registered trademark of the Wi-Fi Alliance ® and is often used as a synonym for IEEE 802.11 technology. This protocol has been constantly upgrading and developing since its release in 1999. The availability of Wi-Fi® microchips for embedded devices along with its wide range of use makes IEEE 802.11 an excellent option to consider for our system. The 802.11 protocol has a few network standards that are compared in Table 7 below.

802.11 Protocol	Release	Frequency (GHz)	Bandwidth (MHZ)	Approx. range indoors (meters)	Approx. range indoors (feet)
-	June 1997	2.4	20	20	66
a	Sept. 1999	5	20	35	115
b	Sept. 1999	2.4	20	38	125
g	June 2003	2.4	20	38	125
n	Oct. 2009	2.4 / 5	20 / 40	70	230

Table 7 802.11 Network Standards

Before determining if Wi-Fi® is the way to go, we must first analyze the capabilities of Wi-Fi® to see if it will meet the requirements of our project. Some of the capabilities of Wi-Fi® include excellent range. The IEEE 802.11 b protocol's typical range of 38 m (125ft) is more than enough distance required by our system. 802.11 b also has throughput up to 11 Megabytes per second

(Mbps), which is overkill for our system. By adjusting throughput to 1 Mbps, we can extend the indoor range from 30 meters, to 90 meters, which is again more than enough for our system. Additionally, Wi-Fi® has many security measures in place, such as Wi-Fi Protected Access (WPA, WPA2) and Wired Equivalent Privacy (WEP) encryptions to protect the wireless networks security.

After analyzing the capabilities of IEEE 802.11 b Wi-Fi®, it is clear that this method is perfect for meeting the system's requirement of connecting to the internet wirelessly. With an internet connection, data can be exchanged and the user will have access to the system and the settings, and can monitor and control the system.

Bluetooth, ZigBee and Wi-Fi® are all excellent forms of wireless communication. With so many pros and cons of each, choosing the correct method for optimal performance is essential. Table XX below outlines the wireless methods. For the requirement of the secondary microcontroller wirelessly communication, the 802.15.4 ZigBee protocol is the ideal choice. And for the main microcontroller's connection to the internet, 802.11 b Wi-Fi® is an excellent choice. Table 8 shown below outlines key features of the wireless protocol.

Wireless Protocols	**Bluetooth (Class 1)**	**ZigBee (802.15.4)**	**Wi-Fi® (802.11 b)**
Optimal Range (indoor):	~100 meter	10 – 75 meters	30 meters
Frequency Band:	2.4 GHz ISM band	2.4 GHz ISM band	2.4 GHz ISM band
Communication type:	WPANs	PANs	WLAN
Power required to operate:	100mW	1mW	100mW
Cost of implementation:	Low Cost	Low Cost	Medium Cost
Bandwidth:	1 Mbps	0.250 Mbps	11 Mbps
Encrypted:	Yes	Yes	Yes
Primary Use:	Data exchange over short distances	Small, low powered devices	Mobile Internet

Table 8 Wireless protocols key features

Now that we have selected the wireless methods and protocols that are capable of completing the necessary tasks required, finding the appropriate wireless module chips is the next step. The wireless module for connecting the main microcontroller to the internet must have some basic requirements which are listed below in Table 9. For the secondary microcontroller to communicate with the main microcontroller through the ZigBee method, it too must have some basic requirements, which are also listed below in Table 9.

Main Microcontroller Wireless Module Requirements	**Secondary Microcontroller Wireless Module Requirements**
Low power consumption	Low power consumption
Easy integration to the system	Easy integration to the system
Small size and surface mountable	Small size and surface mountable
Have security protocols	Low current consumption
Wi-Fi® certified	Different modes for different uses
Low current consumption	Handles low data rates
Different modes for different uses	Excellent range
Excellent range	

Table 9 Main and Secondary microcontroller wireless module requirements

Microchip's® Wireless Design Center (http://www.microchip.com/wireless) was an excellent resource when searching for wireless solutions for our project. The MRF24WB0 Wi-Fi module product family meets the requirements for connecting the MCU to the internet for our project. The MRF24WB0MA has an integrated PCB antenna, while the MRF24WB0MB has an external antenna option with an ultra miniature coaxial connector for extended range. For the scope and requirements of this project, having the integrated PCB antenna instead of an external antenna will make for a smooth implementation into the embedded system. The MRF24J40 ZigBee module product family meets the secondary microcontroller requirements for communication of the different devices in our system. Both MRF24J40MA and MRF24J40MB modules have an integrated PCB antenna, the only difference is that MRF24J40MA has a 400 ft range, while the MRF24J40MB has a range of 4000 ft. Have that extended range makes MRF24J40MB a great choice for our ZigBee wireless module. In the sections below, are detail specifications about each of the two wireless chips from Microchip®.

2.7 Smart Phone Application

2.7.1 Remote Access

The purpose of having remote access in the Efficient HVAC Control and Feedback System is to provide the end user instant feedback and control of the system. This is a key feature of the overall system. This is important because the number of people with internet ready mobile devices is constantly growing.

This means there is a huge market for applications to allow consumers to access and manipulate their home or office appliances and HVAC systems while away from the building. This also ensures optimum settings to save energy and money when the user is away from the building. Below is a discussion on how such a system would be implemented in order to provide remote access.

2.7.2 TCP/IP

The Internet Protocol Suite, or TCP/IP, is a set of communication protocols used for the Internet. A TCP/IP will be required to connect our system to the internet. This abstraction allows encapsulation of the data as it travels from one layer to the next. Each layer uses a set of protocols to send its data down the layers, being further encapsulated at each level. This suite is constructed as a set of layers as seen in Figure 14 below.

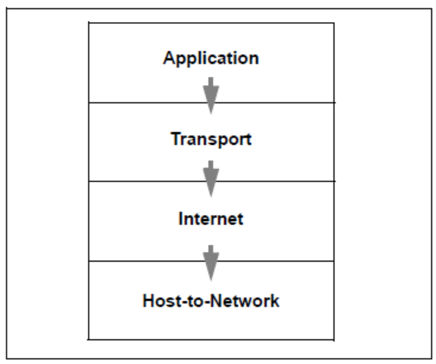

Figure 14 Layers of the TCP/IP reference model

2.7.3 Host-to-Network Layer

This layer interfaces the higher layer protocols to the local network. This layer is primarily representative of the physical connection between two devices and often does not run any TCP/IP protocols as they are simply not needed. Its primary functions are to provide logical link control (LLC) and Media Access Control (MAC). LLC refers to the functions required to establish and control logical links between local devices on the network. Most LAN devices use the IEEE 802.2 LLC protocol. MAC refers to the methods used by devices to control access to the network medium. Since most networks use devices that share a medium, it is necessary to have a rule set in place to manage the connection to avoid collisions. One example is that Ethernet uses CSMA/CD while Token Rings uses token passing. In addition to the two different control methods used, this layer is also responsible for the final encapsulation of higher-level messages into frames that are sent over the network; with the frames in place, the Host-to-Network layer must also manage the address of the receiving device. Finally the Host-to-network Layer is also responsible for error detection and handling.

2.7.4 Internet Layer

The Internet layer helps define how interconnected networks function. This layer is the lowest layer concerned with devices that are located on a remote network, where as the Host-to-Network layer was only concerned about locally connected devices. In order to communicate with remote networks, the Internet layer provides logical addressing via Internet Protocol (IP). These are logical identifiers (not physical identifiers like MAC at the Host-to-Network layer) and they must be unique over the entire internetwork. To move data across a series of interconnected networks, the Internet Layer provides routing. Devices and software that function at this layer provide functionality to handle incoming packets from various sources, determine their final destination, and then figure out where they need to be sent to get them where they are supposed to go. The data at this layer gets encapsulated into messages called datagrams with a network layer header. In order to send this information down to the Host-to-Network layer, the Internet Layer must also handle fragmentation and reassembly of datagrams to fit within the size limitations of the lower layer.

2.7.5 Transport Layer

The overall job of this layer is to provide the appropriate functions to enable communication between software application processes on different computers. This layer is also called the host-to-host transport layer as it is responsible for that exact function. To transmit, the layer keeps track of what data arrives from each application, then combines the data into a single flow to send to the lower layers. On the receiving end, the operation is revered, splitting the data and funneling it to the appropriate software process.

Another function of this layer is to provide connection services for the protocols and applications that run at the application layer. In order to determine which process will receive a specific price of data requires a process-level address. This is defined using port numbers within TCP/UDP packets. Each application uses a specific port for receiving and transmitting information that gets encapsulated into outgoing packets. When a receiving device receives a packet, it can see what destination port it was being sent to and will provide the data to the processes assigned to that port.

In addition to providing host-to-host services, the Transport Layer must also be able to acknowledge received data and be able to retransmit information when it is lost. Each time data is sent, a timer is started; if it is received, the recipient sends back an acknowledgment to the transmitter to indicate a successfully received packet. If the timer runs out, the data is retransmitted. In order to make sure that the sender and receiver send and receive packets efficiently, this layer is also taxed with flow control. This allows a device to specify to another that it must throttle back the rate at which it is sending the information.

2.7.6 Application Layer

The application layer is that which network applications operate at. Applications that operate at this layer are, for example, HTTP, FTP, SMTP, DHCP, NFS, Telnet, SNMP, POP3, NNTP and IRC. The function of this layer is that it provides services to programs that want to use the network and to issue the appropriate commands to properly use the services provided by the lower levels.

2.7.7 Microchip TCP/IP Stack

Microchip provides a freely available TCP/IP stack for use with their microprocessors. Figure 15 below shows how it is implemented and compares it to the TCP/IP Reference Model.

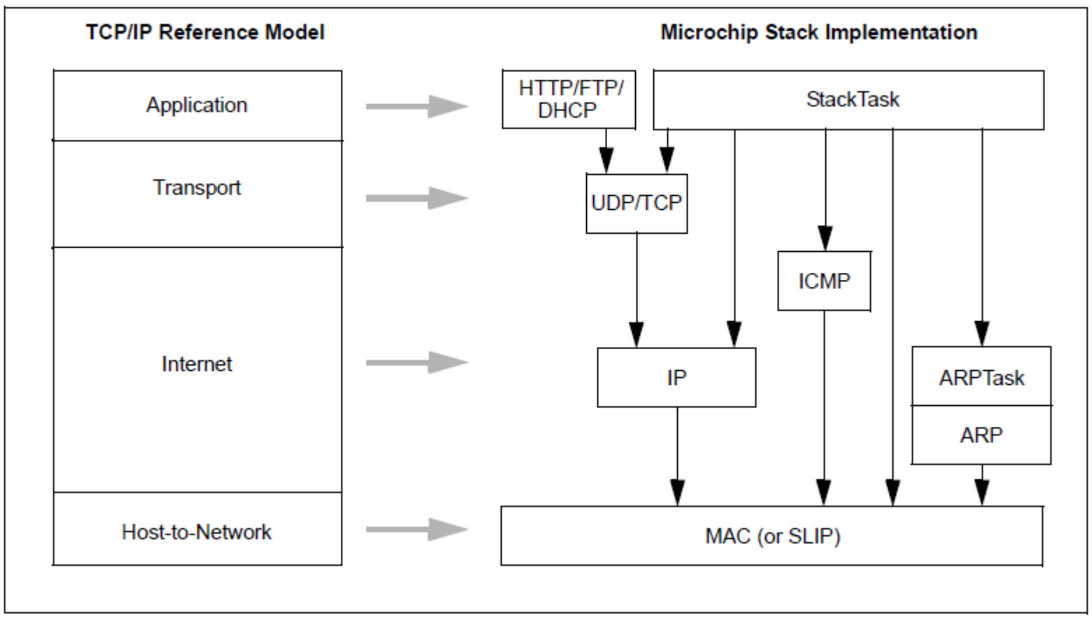

Figure 15 Comparing the Microchip TCP/IP stack structure to the TCP/IP reference model (Reprinted with Permission from Microchip)

Unlike the Reference model, some layers in the Microchip TCP/IP Stack have direct access layers which are not immediately below it. The decision for when a layer would bypass its adjacent module was made based on the amount of overhead and whether a given service needs intelligent processing before it can be passed to the next layer or not.

With Microchip's design, they depart from traditional TCP/IP Stack implementation by adding StackTask and ARPTask. StackTask manages the operations of the stack and all of its modules, while ARPTask manages the services of the Address Resolution Protocol Layer.

Microchip's TCP/IP stack is a live stack; some of the layers must be able to perform timed operations asynchronously. To meet the requirement, Microchip's

TCP/IP Stack uses a multitasking technique called cooperative multitasking. In a cooperative multitasking system, there is more than one task; each performs its job and returns its control so that the next task can perform its job. StackTask and ARPTask are cooperative tasks.

Normally cooperative multitasking is implemented in the operating system or in the main application, but with Microchip's design, it is independent of any operating system; it implements its own cooperative multitasking system. This allows it to be used in any system, regardless of whether it uses a multitasking operating system or not. In order to use an application utilizing the Microchip TCP/IP Stack, it must be written using a cooperative multitasking method. This can be accomplished by either dividing the job into multiple tasks, or organizing its main job into a Finite State Machine and dividing a long job into multiple smaller jobs.

2.7.8 Implementation

In order for the TCP/IP stack to function, you must use C compiler "defines" to configure to program. In order for the server to operate properly, the clock frequencies need to be configured. Those options are found within the Tick.C file. Table 10 below describes the purpose of each of those configurable values.

Define	Values	Purpose
CLOCK_FREQ (compiler.h)	Oscillator Frequency (hz)	Define system oscillator frequency to determine tick counter value
TICKS_PER_SECONDS	10-255	To calculate a second
TICK_PRESCALE_VALUE	2, 4, 8, 16, 32, 64, 128, 256	To determine tick counter value

Table 10 Configuration used by Tic C

The file system needs to be configured to know where to look for an image. These configuration options can be located in MPFS.c. Table 11 below contains a description of each of those values.

Define	Values	Purpose
MPFS_USE_PGRM	N/A	Uncomment this if program memory will be used for MPFS storage
MPFS_USE_EEPROM	N/A	Uncomment this if external serial EEPROM will be used for MPFS storage
MPFS_RESERVE_BLOCK	0-255	Number of bytes to reserve before MPFS storage starts
EEPROM_CONTROL	External Data EEPROM Control Code	To address external data EEPROM

MPFS_WRITE_PAGE_SIZE(mpfs.h)	1-255	To define writable page size for current MPFS storage media

Table 11 Configuration used by MPFS.C

StackTsk.c manages the operations of the stack and its modules. Which modules you enable are defined within the configurable defines. The values related to StackTsk.c are provided in Table 12 below.

Define	Values	Purpose
STACK_USE_ICMP	N/A	Comment this if ICMP is not required
STACK_USE_IP_GLEANING	N/A	Comment this if IP Gleaning is not required
STACK_USE_DHCP	N/A	Comment this if DHCP is not required
STACK_USE_FTP_SERVER	N/A	Comment this if FTP Server is not required
STACK_USE_TCP	N/A	Comment this if TCP module is not required. This module will be automatically enabled if there is at least one high-level module requiring TCP.
STACK_USE_UDP	N/A	Comment this if UDP module is not required. This module will be automatically enabled if there is at least one high-level module requiring UDP.
STACK_CLIENT_MODE	N/A	Client related code will be enabled

Table 12 Configuration used by StackTsk.c

TCP.c provides the operation of all the transport host-to-host operations. This includes managing sockets and confirming ACKs on packets sent. Table 13 below is a table with the configurable options that this file relies on.

Define	Values	Purpose
TCP_NO_WAIT_FOR_ACK	N/A	TCP will wait for ACK before transmitting next packet
MAX_SOCKETS	1-253	To define the total number of sockets supported (limited by available RAM). Compile-time check is done to make sure that enough sockets are available for selected TCP applications.
MAX_TX_BUFFER_SIZE	201-1500	To define individual transmit buffer size
STACK_CLIENT_MODE	N/A	Client related code will be enabled
STACK_USE_TCP	N/A	Comment this if TCP module is

		not required. This module will be automatically enabled if there is at least one high-level module requiring TCP.

Table 13 Configuration used by TCP.c

User Applications have access to default network setting values as well as access to actual network setting values. Default values are defined within the configuration, whereas the actual values are saved by applications that are currently running. Below is Table 14 which provides a list of definitions and the values they can be.

Define	Values	Purpose
MY_DEFAULT_IP_ADDR_BYTE? MY_DEFAULT_MASK_BYTE? MY_DEFAULT_GATE_BYTE? MY_DEFAULT_MAC_BYTE?	0-255	Define default IP, MAC, gateway and subnet mask values. Default values are: 10.10.5.15 for IP address 00:04:163:00:00:00:00 for MAC 10.10.5.15 for gateway 255.255.255.0 for subnet mask
MY_IP_BYTE? MY_MASK_BYTE? MY_GATE_BYTE? MY_MAC_BYTE?	0-255	Actual IP, MAC, gateway and subnet mask values as saved/defined by application. If DHCP is enabled, these values reflect current DHCP server assigned configuration

Table 14 Configuration used by User Application

UDP.c implements the user datagram protocol. This uses a simple transmission model without implicit hand-shaking required for guaranteeing reliability, ordering, or data integrity. Most of these operations are handled by the application utilizing this protocol. Table 15 below shows the configurable options for this file.

Define	Values	Purpose
STACK_USE_UDP	N/A	Comment this if UDP module is not required. This module will be automatically enabled if there is at least one high-level module requiring UDP.
MAX_UDP_SOCKETS	1-254	To define total number of sockets supported (limited by available RAM). Compile-time check is done to make sure that enough sockets are available for selected

		UDP applications

Table 15 Configuration used by UDP.c

MAC.c handles the Media Access Control operations. This allows for the emulation of a full-duplex logical communication in a multi-point network. In Table 16 below are the configuration defines that MAC.c uses.

Define	Values	Purpose
MAX_TX_BUFFER_SIZE	201-1500	To define individual transmit buffer size
MAX_TX_BUFFER_COUNT	1-255	To define total number of transmit buffers. This number is limited by available MAC buffer size.
MY_IP_BYTE? MY_MASK_BYTE? MY_GATE_BYTE? MY_MAC_BYTE?	0-255	Actual IP, MAC, gateway and subnet mask values as saved/defined by application. If DHCP is enabled, these values reflect current DHCP server assigned configuration

Table 16 Configuration used by MAC.c

ARP.c runs the Address Resolution Protocol. This allows the host device to determine a hardware address from just knowing an IP address. Configuration values that are used by this module are described in Table 17 below.

Define	Values	Purpose
STACK_CLIENT_MODE	N/A	Client related code will be enabled
MY_IP_BYTE? MY_MASK_BYTE? MY_GATE_BYTE? MY_MAC_BYTE?	0-255	Actual IP, MAC, gateway and subnet mask values as saved/defined by application. If DHCP is enabled, these values reflect current DHCP server assigned configuration

Table 17 Configuration used by ARP.c

HTTP.c controls the webserver to run on the microchip. This module manages user connections and CGI GET operations. The GET command allows the webserver to fetch variables saved within the microprocessor and dynamically present them within a static web page. Table 18 below lists the configurable options that HTTP.c uses to implement the web server.

Define	Values	Purpose
MAX_HTTP_CONNECTIONS	1-255	To define maximum number of HTTP connections allowed at any time.

MAX_HTTP_ARGS (HTTP.c)	1-31	To define maximum number of HTML form fields including HTML form name
MAX_HTML_CMD_LEN (HTTP.c)	1-128	To define maximum length of HTML form URL string.

Table 18 Configuration used by HTTP.c

FTP.c implements a simple File Transfer Protocol application. The purpose of this is to allow an easy way to upload MPFS image files to the host device. Table 19 below shows the configurable values used by the FTP server.

Define	Values	Purpose
FTP_USER_NAME_LEN(FTP.h)	1-31	To define maximum length of FTP user name
STACK_USE_FTP_SERVER	N/A	Comment this if FTP Server is not required

Table 19 Configuration used by FTP.c

DHCP or Dynamic Host Configuration Protocol allows for the auto configuration of IP address settings. If enabled, this allows the host device to request network information from a DHCP server. The information received from the server allows the host device to configure its IP address, net mask, and gateway information. Table 20 below lists values utilized by DHCP.c**.**

Define	Values	Purpose
STACK_USE_DHCP	N/A	Comment this if DHCP is not required
MY_IP_BYTE? MY_MASK_BYTE? MY_GATE_BYTE? MY_MAC_BYTE?	0-255	Actual IP, MAC, gateway and subnet mask values as saved/defined by application. If DHCP is enabled, these values reflect current DHCP server assigned configuration

Table 20 Configuration used by DHCP.c

Serial Line Internet Protocol is an encapsulation of the Internet Protocol designed to work over serial ports. In order to use it within the TCP/IP stack, the module must be enabled. Table 21 below is a table of values utilized by this module.

Define	Values	Purpose
STACK_USE_SLIP	N/A	Comment this if SLIP is not required

Table 21 Configuration used by SLIP.c

Once a project is setup with the appropriate files included, the main application source file must be modified to include the programming sentences shown below in Figure 16.

```
// Declare this file as main application file

#define THIS_IS_STACK_APPLICATION
#include “StackTsk.h”
#include “Tick.h”
#include “dhcp.h” // Only if DHCP is used.
#include “http.h” // Only if HTTP is used.
#include “ftp.h” // Only if FTP is used.
// Other application specific include files
...
// Main entry point
void main(void)
{
// Perform application specific initialization
...

        // Initialize Stack components.
        // If StackApplication is used, initialize it too.
        TickInit();
        StackInit();
        HTTPInit(); // Only if HTTP is used.
        FTPInit(); // Only if FTP is used.
        // Enter into infinite program loop
        while(1)
        {
            // Update tick count. Can be done via interrupt.
            TickUpdate();
            // Let Stack Manager perform its task.
            StackTask();
            // Let any Stack application perform its task.
            HTTPServer(); // Only if HTTP is used.
            FTPServer(); // Only if FTP is used.
            // Application logic resides here.
            DoAppSpecificTask();
        }
}
```

Figure 16 Mandatory programming sentences

The provided TCP/IP stack is specifically written to utilize the Realtek RTL8019AS Network Interface Controller. Since the network controller being used is not that Realtek model, the MAC.c file will need to be modified.

The stack utilized the SRAM on the NIC as a holding buffer, until a higher level module reads it. It will also perform the IP checksum calculations in the SRAM of the NIC. This MAC layer also manages its own transmit queue. Using this queue, the caller can transmit a message and request the MAC to reserve it so that the same message can be retransmitted, if required. The size of this buffer can be specified.

2.7.9 Microchip HTTP Server

With Microchip's TCP/IP Stack comes a minimally implemented HTTP server. The overburdened HTTP is stripped down to the essential features. The end user is left to code their own features if more is needed. The HTTP server incorporates a set of useful features to the user. The list below discusses these features:

- Supports multiple HTTP connections
- Contains a simple file system (MPFS)
- Supports Web pages located in either internal program memory or external serial EEPROM
- Includes a PC-based program to create MPFS images from a given directory
- Supports the HTTP method "GET" (other methods can be easily added)
- Supports a modified Common Gateway Interface (CGI) to invoke predefined functions from within the remote browser
- Supports dynamic web page content generation

2.7.10 Implementation

In order to integrate the HTTP Server into a Suer application, the following must be done:

1. Uncomment STACK_USE_HTTP_SERVER in the header file "StackTsk.h" to enable HTTP Server related Code.
2. Set the desired MAX_HTTP_CONNECTIONS value in the "StackTsk.h" header file
3. Include the files "http.c" and "mpfs.c" in the project
4. Depending where web pages are stored, uncomment either MPFS_USE_PGRM, or MPFS_USE_EEPROM. If external data EEPROM is used as a storage media, include the file "xeeprom.c" as well
5. Modify the main() function of the application to include the HTTP server.

The web pages needed to be stored on the server need to be generated in advance and need to be converted into a compatible format for storage. The page itself needs to be stored in a format that the server can readily read. Provided by Microchip is the "Microchip File System" (MPFS). If the storage space is being provided by EEPROM, the data can be uploaded via FTP. Figure 17 below shows an example of this.

```
c:\ ftp 10.10.5.15
220 ready
User (10.10.5.15: (none)): ftp
331 Password required
Password: microchip
230 Logged in
ftp> put mpfsimg.bin
200 ok
150 Transferring data...
226 Transfer Complete
ftp>  16212  bytes  transferred  in
0.01Seconds 16212000.00Kbytes/sec.
ftp> quit
221 Bye
```

Figure 17 Uploading an MPFS Image using FTP

To provide the user with a dynamic page in order to view current system data, the use of CGI will be needed. With the Microchip HTTP server, the HTTP GET option is already implemented. When the HTTP server encounters a string '%xx' in a CGI page that it is serving, it calls the function HTTPGetVar. The function is implemented by the main user application and is used to transfer application specific variable status to HTTP. Figure 18 shown below uses the HTTPGetVar function to update system data by a CGI.

Syntax
WORD HTTPGetVar(BYTE *var*, WORD *ref*, BYTE ***val**)
Parameters
var [in]
Variable identifier whose status is to be returned
ref [in]
Call Reference. This reference value indicates if this is a very first call. After first call, this value is strictly maintained by the main application. HTTP uses the return value of this function to determine whether to call this function again for more data. Given that only one byte is transferred at a time with this callback, the reference value allows the main application to keep track of its data transfer. If a variable status requires more than bytes, the main application can use *ref* as an index to data array to be returned. Every time a byte is sent, the updated value of *ref* is returned as a return value; the same value is passed on next callback. In the end, when the last byte is sent, the application must return HTTP_END_OF_VAR as a return value. HTTP will keep calling this function until it receives HTTP_END_OF_VAR as a return value.

Possible values for this parameter are:

Value	Meaning
HTTP_START_OF_VAR	This is the very first callback for given variable for the current instance. If a multi-byte data transfer is required, this value should be used to conditionally initialize index to the multi-byte array that will be transferred for current variable
For all others	Main application specific value.

val [out]
One byte of data that is to be transferred

Return Values

New reference value as determined by main application. If this value is other than HTTP_END_OF_VAR, HTTP will call this function again with return value from previous call.

If HTTP_END_OF_VAR is returned, HTTP will not call this function and assumes that variable value transfer is finished.

Possible values for this parameter are:

Value	**Meaning**
HTTP_END_OF_VAR	This is a last data byte for given variable. HTTP will not call this function until another variable value is needed.
For all Others	Main application specific value.

Pre-Condition
None

Figure 18 CGI Page Calling the HTTPGetVar Function

With the information provided by the previously introduced function, we are able to provide real time data from the microcontroller to the user via a dynamically updating web page. Figure 19 shown below is an example of one such implementation.

“status.cgi” contains following HTML line:
…
<td>S3**=%04**</td><td>D6=**%01**</td><td>D5=**%00**</td>
…

Figure 19 Dynamically Updated Web Page using HTML code

During processing of this file, HTTP encounters the ‘%04’ string. After parsing it, HTTP makes a callback. HTTPGetVar(4, HTTP_START_OF_VAR, &value). In Figure 20, the main user application implements HTTPGetVar function as follows:

```
WORD HTTPGetVar(BYTE var, WORD ref, BYTE *val)
{
    // Identify variable.
    // Is it RB5 ?
    if ( var == 4 )
    {
        // We will simply return ‘1’ if RB5 is high,
        // or ‘0’ if low.
        if ( PORTBbits.RB5 )
            *val = ‘1’;
        else
            *val = ‘0;
        // Tell HTTP that this is last byte of
        // variable value.
        return HTTP_END_OF_VAR;
    }
    else
        // Check for other variables...
    ...
}
```

Figure 20 HTTPGetVar Function

2.8 MPFS

The Microchip HTTP server uses a simple file system (MPFS) to store Webpages. The image of the file system can be stored in on-chip program memory, or on an external serial EEPROM. Below is Figure 21 which describes how the MPFS stores multiple files:

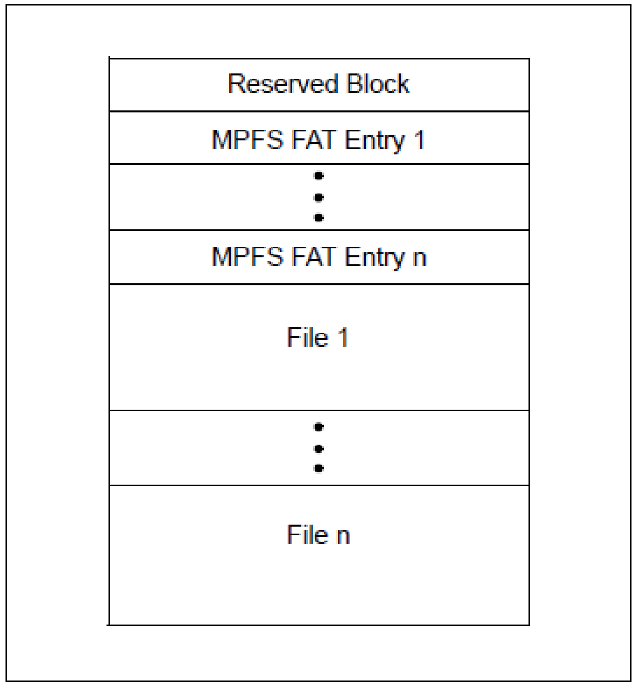

Figure 21 MPFS Image Format

The length of the Reserved Block is defined by MPFS_RESERVE_BLOCK. This block can be used by the main application to store simple configuration values. The storage begins with one or more MPFS FAT entries, followed by one or more file data. The FAT entry describes the file name, location and its status. Figure 22 below describes the format for the FAT entry.

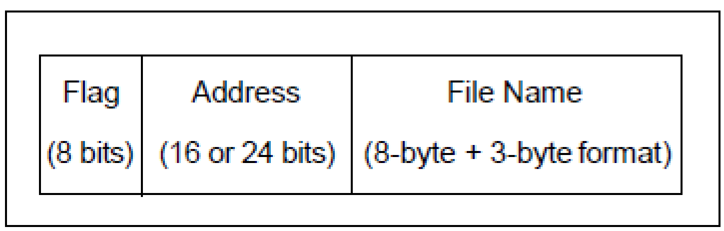

Figure 22 MPFS Fat Entry Format

The Flag indicates whether the current entry is in use, deleted, or at the end of the FAT. Each entry also contains either a 16 or 24-bit address value. The length is determined by the type of memory used, as well as the memory size model. If the internal program space is used, and the Microchip TCP/IP stack project is compiled with a small memory model, 16-bits are used. If the large memory model is selected, a 24-bit address is used. All EEPROM configurations use 16-bit addressing. This implies a maximum MPFS image size of 64 Kbytes for these devices.

MPFS uses a short naming scheme for file name of “8 + 3” (8 bytes for the name, 3 bytes for the extension). The 16-bit address gives the start of the first file data block. All file names are stored in upper case to make file name comparisons easier.

Each FAT entry points turn to a data block that contains the actual file data. The data block format is shown below. The block is terminated with a special 8-bit flag called EOF (End of File. Followed by FFFFh (for 16-bit), or FFFFFFh (24-bit addressing). If the data portion of the block contains an EOF character, it is stuffed with the special escape character, DLE. Any occurrence of DLE itself is also stuffed with DLE. Figure 23 shown below describes the MPFS data block format.

Data	EOF	FFFFh or FFFFFFh
(variable length)	(8 bits)	(16 or 24 bits)

Figure 23 MPFS Data Block Format

2.9 Mobile Web Site

Mobile web sites allow for specifically designed web pages to load templates specifically designed for mobile devices. The first access to the mobile web was offered in Finland in 1996. Since then the trend has caught on. As of October 2009, the International Telecommunication Union has stated that mobile web access today exceeds desktop computer-based access. Though originally limited to XHTML or Wireless Markup Language, many modern mobile devices are able to support a wider range of web formats.

2.10 iPhone App

iPhone applications are software that is native to the Apple iPhone. Apple provides developers with a Software Development Kit (SDK) who are running Mac OSX 10.5.4 or higher on an Intel Mac to create applications using Xcode. The iPhone Developer Program, which supplies the SDK, offers two distribution methods: Standard and Enterprise. Apps distributed through the standard program are sold exclusively in the Apple App Store. Published applications receive 70% of sales revenue, and no distribution costs are charged. Apple instead uses an annual subscription of $99/year to use the SDK and upload applications. To run the application, it must have a digital signature from apple. The certificate is only granted if the developed software is published under the standard or enterprise annual subscription.

2.11 Scripting Languages

2.11.1 PHP

PHP is a widely used, general-purpose scripting language. It was originally designed for web development to produce dynamic web pages. To accomplish this, PHP code is embedded into the HTML source document and interpreted by a web server with a PHP processor module, which then would generate the web content. The code is executed at runtime to generate the dynamic information. The primary use of PHP now focuses on server-side scripting, and is similar to other scripting languages that provide dynamic content from a web server to a client, such as Microsoft's Active Server Pages and Sun Microsystems' JavaServer Pages. It has also become popular for the development of frameworks that act as building blocks and a design structure to promote rapid application development. As of April 2007, over 20 million Internet domains had web services hosted on servers with PHP installed.

2.11.2 CGI

Common Gateway Interface is a standard that defines how web server software can delegate the generation of web pages to a text-based application. These applications are known as CGI scripts and can be written in any programming language. This allows the clients to have an interface with the web server.

2.11.3 JavaScript

Javascript is an implementation of the ECMA Script language standard and is typically used to enable programmatic access to computational objects within a host environment. The language was invented by Brendan Eich at Netscape and first appeared in Netscape Navigator 2.0. It was first adapted by Microsoft's Internet Explorer 3.0. Since the third edition of the EMCA Script standard, EMCA Script has become the programming language supported by essentially all web browsers.

2.11.4 HTML

Hypertext Markup Language, or HTML, is the predominant markup language for web pages. It provides a means to create structured documents by denoting structural semantics for text such as headings, paragraphs, lists, links, quotes and other items. Images and objects can be embedded and can create interactive forms. Nearly all of the HTML documents on the World Wide Web are delivered from Web servers to web browsers using HTTP.

2.12 Power

2.12.1 Main Control Unit / LCD Touch Screen User Interface

The main control unit and LCD touch screen user interface are to be a replacement unit for the existing HVAC control system thermostat or the main thermostat in the control system. In HVAC systems, the thermostat is usually powered by a 24V AC wire that is installed when the building is initially built and therefore 24V AC is what will be used to power our main control unit and LCD touch screen user interface. 24V AC is ideal for this application because the relays that are controlled by the main control unit are required to output 24V AC. The relay outputs will essentially be tied to the input power by putting them in a parallel configuration so that the voltage coming out of the wall in the building can power the 220V AC relays at the units. The 24V AC outputted by the main control unit can be thought of as "control voltages" because they are what is delivered to the components (for example AC1 and AC2) of the system and will control the power relays located at the units. The power relays are what control the power needed to run the units (usually 220V/240V AC).

Within the main control unit there are several components that each needs to be supplied with specific voltages. These components are the LCD touch screen, the main microprocessor, the ZigBee wireless chip, the 802.11b wireless internet chip, and the temperature and relative humidity sensor. Specifically, the LCD touch screen requires 5 – 12V DC, the main microprocessor requires 3 – 3.6V DC, the ZigBee wireless chip requires 3.3V DC, the 802.11b wireless Internet chip requires 3.3V DC, and the temperature and relative humidity sensor requires -0.3 to 5 V DC. To obtain these specific voltages, the printed circuit board must be designed to deliver the proper amount of voltage to the corresponding component using voltage regulators to ensure the correct voltage. Specifics on the printed circuit board design are discussed further in the PCB Design section of this paper.

2.12.2 Remote Sensing Unit

The remote sensing unit will be powered by a single battery source. The remote sensing unit is designed to be installed on the exterior of the building, and therefore no existing power supply will be present. In order to keep installation as simple as possible, and avoid running new wiring through an existing building, the remote sensing unit will be battery powered. This means that in order to install the remote sensing unit, it only needs to be secured to the building. The remote sensing unit will be enclosed in weather proof housing, and the housing will be one that is designed to be wall mounted. The details about using batteries to power the remote sensing unit will be discussed further in the PCB Design section of this paper.

2.13 Batteries

Batteries are going to be used to store capacitive charge in the secondary microcontroller for the HVAC control system. The two kinds of batteries that exist today are primary batteries and secondary batteries. For our project we will most likely use the secondary batteries which are also known as rechargeable batteries. This is good because once the microcontroller runs out of battery life it can be recharged up as many times as we want. We can figure out how much discharge time that the battery will have for the secondary microcontroller according to the relationship of t=Q/I, where I = current for the battery (in Amperes), Q = charge given out by the rechargeable battery (in Coulombs), and t = change in time (given in seconds).

Subcategories of rechargeable batteries:

1) Lead-Acid
2) Nickel-Cadmium
3) Nickel-Zinc
4) Nickel Metal Hydride
5) Lithium-Ion
6) Alkaline

Lead-acid batteries were the first rechargeable battery ever created. Some positive advantages of lead-acid batteries are that they are relatively low cost, very reliable, and have low internal impedance. They are also robust, tolerant to overcharging, and can deliver very high currents. The limitations of these batteries are there is a possible danger of them overheating during charging period as well as being very heavy and bulky in weight.

Nickel cadmium batteries have various applications that include emergency lighting, remote-controlled model airplanes and boats, wireless communications, and mobile computing. Despite their low resistance that can generate high currents. These batteries typically send out a voltage of 1.2 V. Nickel cadmium batteries have low internal resistance, tolerable discharge rate, and have a nominal cycle life of over 1,000 cycles. Many other features of the nickel cadmium batteries include its susceptibility to memory effect, being prone to damage by overcharging, as well as having an energy density double the amount of lead acid batteries. The batteries are reasonably priced and supply a wide temperature range to achieve adequate performance. Another concern with Nickel cadmium batteries is that the chemical composition of the battery is composed of the element cadmium which is a very lethal heavy metal.

Nickel metal hydride batteries are the powering force to start electric cars as well as other consumer electronics. Nickel-metal hydride batteries have a higher capacity and don’t suffer from memory effect when compared to nickel-cadmium batteries. One disadvantage for nickel metal hydride batteries is that they have a fast rate of discharge when the batteries are not used for a long period of time.

These batteries on average contain a voltage of 1.2 V, a specific energy of approximately 70 W*h/kg, and an energy density of 300 W*h/L.

Lithium-ion batteries are most commonly used in consumer electronics such as portable laptops, mobile cell phones, calculators, thermometers and many other devices. These batteries carry out a nominal value in voltage from 3.6 to 3.7 V. Also out of all the other available rechargeable batteries, these are the most powerful as well as the most expensive in cost. Other great features about this battery are that it requires little to no maintenance, battery cells can generate high current, and can provide relatively small amount of discharge. Despite all of its good advantages there are some limitations that it encounters. Lithium-ion batteries are very costly to manufacture, requires protection to maintain voltage and current limits, and it's capacity deteriorates after one year but eventually doesn't work in two or three years. If a lithium-ion battery is stored in a cool place 40% of the charge will decrease due to the deterioration process. Other aspects that describe the lithium-ion batteries are that they have transportation restrictions are not fully mature because the metals and chemicals inside the battery change on a regular basis.

Another battery type that is up for consideration for our Senior Design project is the rechargeable alkaline batteries. These are not the same as the regular alkaline batteries like Duracell and Energizer that come in different sizes such as AA, AAA, C, D, and 9 volts. The standard alkaline batteries are not the same as rechargeable alkaline batteries. The regular alkaline are basically a brand of primary batteries which means that they don't recharge and are therefore disposable after a certain amount of usage. Some of the benefits that the rechargeable alkaline batteries offer include affordability, being friendly to the environment, and provides a minimal self-discharge rate. It also provides the consumer with a high charge capacity. Applications for the rechargeable alkaline batteries encompass electronic devices used for radios, TV remote controls, flashlights, and other entertainment systems. This product also incorporates minor setbacks. These setbacks include only allowing a low amount of input current and limited battery life cycle. Limited battery life cycle for a normal rechargeable alkaline battery occurs when these batteries are discharged to approximately less than 50% of their entire capacity. When the battery is charged to less than 50% of its whole capacity, then it can operate at its maximum efficiency by supplying about 1.32V. A key point to notice with rechargeable alkaline batteries is that even though they are intended for continual recharges, the storage capacity that the cell of the battery can hold is decreased.

2.14 HVAC Environmental Factors

HVAC systems have many social and environmental drawbacks. Turning the ac conditioning on for a long period of time can cause such events such as blackouts and brownouts, climate change and smog, and social isolation. Blackouts are also known as power outages which result due to either a short in the wiring of the electrical network, damage to power lines, or the overloading of electricity mains. A brownout occurs when there is a decrease in voltage from an electrical power supply. Both of these conditions have serious causes for public health, safety, the economy, and the environment.

The next topic is climate change and smog which air conditioning is a primary contributor for. Air conditioners are one of the leading causes in climate change around the world. Energy given out by air conditioners will play a part in carbon-dioxide emissions that cause the current problem of global warming. The government every year tries to find out an efficient way to solve the energy crisis. Businesses demand that they be more energy efficient as well as make their air conditioners let out a minimal amount of carbon emissions. Europe has found a technological system for air conditioning to reduce carbons emissions and be more energy efficient. This system is called the Daikin's VRV and was just initiated to address all of these worldwide concerns.

Social isolation in this case happens when the temperatures are too hot outside and instead makes a person stay inside to get cooled by the air conditioner. Being inside all the time for air conditioning will cause a person to be isolated from his neighbors and communities, and as well contribute to social, emotional, and behavioral problems. Being alone all the time is not always a good thing even when it comes to deciding whether or not to have an HVAC system.

Schools across the country have a tough time trying to figure out how to distribute their resources as well as investing their money. The EPA in 1995 started the *Indoor Air Quality Tools for Schools* Program. School districts goals were to manage indoor air quality and also improve the health and academic performance of students.

Later on in 2007 the EPA wanted to see how if progress was being made in the *Indoor Air Quality Tools for Schools* Program. They visited and evaluated these three school districts which consist of elementary, middle, and high schools. These districts received positive results because of improved HVAC rules such as routine maintenance, cleaning, and construction and renovation management.

Contrastingly, before 1995 the EPA noticed that there were problems in the HVAC systems. As a consensus of all three school districts, the problems that happened are cleanliness issues, dangerous and hazardous storage of chemicals, dampness and mold occurring in the HVAC ducts, as well as pests and food storage violations.

2.15 Dampers

The Efficient HVAC Control and Feedback System controls the flow of air throughout the system with a series of dampers. These dampers are powered typically with low 24 V AC electric motors. The dampers are referred to as doors on the control process.

When using the manual air control timer mode: Door 1 (damper 1) is open, door 2 (damper 2) is closed and door 3 (damper 3) is open. When using the automatic energy-save mode: If the system calls for central air conditioning and the outside air meets conditions then door 1 (damper 1) is open, door 2 (damper 2) is closed and door 3 (damper 3) is open.

In the automatic fresh air mode: If the fresh air minimums have not been met: door 1 (damper 1) is open, door 2 (damper 2) is closed and door 3 (damper 3) is open. The central air AC air blower fan is turned on and door 4 (damper 4) is opened to blend in controlled amounts of fresh air between air exchanges.

Fresh air mode involves the main control unit making a decision to introduce new air into the building from outside. This has many advantages including removing stagnant air that has been inside the building along with any pollutants it has picked up while in the building. In typical HVAC systems, the air inside the building is repeatedly cooled and redistributed in the building. This means the only way to introduce fresh air into the building is to open windows. Opening and closing windows is a hassle for the occupants of the building because they must be closed when the building is unoccupied, and in larger buildings opening the windows is not always an option. Figure 24 pictured below is an air duct with a damper motor assembly. This particular duct was removed due to a defective damper.

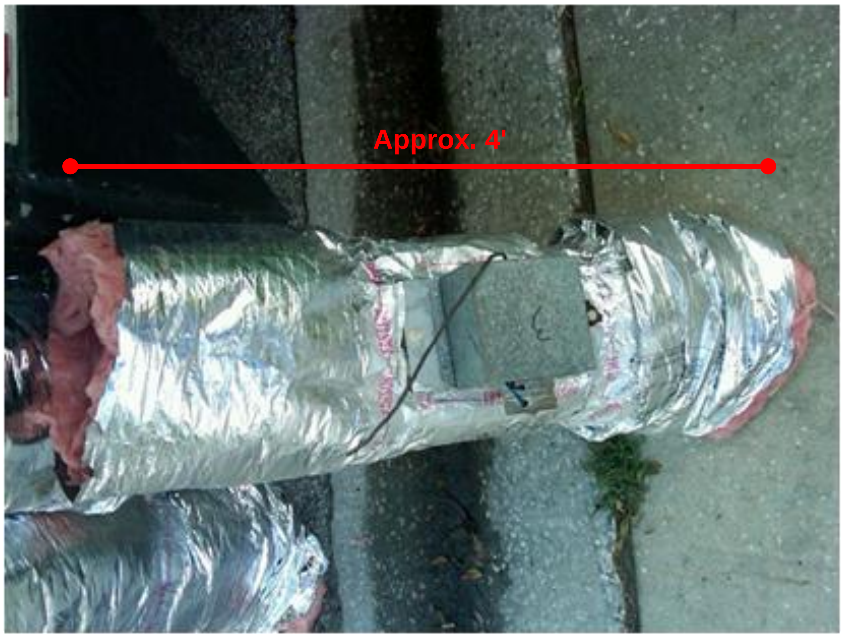

Figure 24 Air duct with damper motor assembly

Dampers can be operated by two different distinct modes either manual or automatic. These electronic zone dampers are often referred to as a Volume Control Damper (VCD). Automatic dampers are the type of dampers we are going to use in our design, whereas manual dampers function by turning a handle on the outside of a duct. Depicted below in Figure 25 is an example of what manual balancing damper looks like.

Figure 25 Manual balancing damper (Reprinting Permission Requested from Gran-Stratman Industries Inc.)

Figure 26 pictured below shows a volume control damper also known as an automated zone damper. Notice these differences in operations from these two dampers.

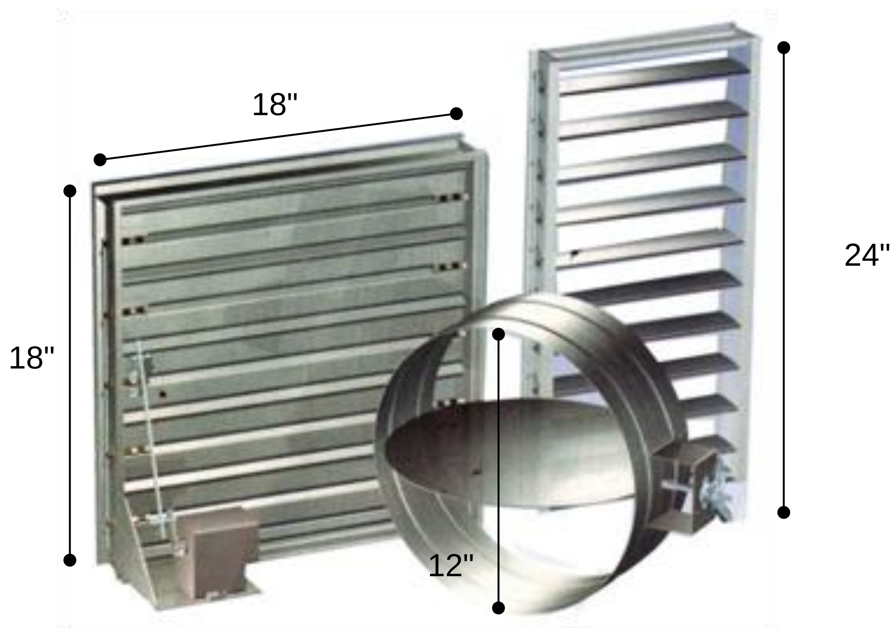

Figure 26 Volume control damper (Reprinting Permission Requested from Gran-Stratman Industries Inc.)

In order to purchase HVAC automated zone dampers there are some questions that must be considered before a purchase is made. Pick an accurate size in diameter for the damper that you will need. Some dampers come in lengths of 6 inches and 8 inches. Also determine the automated zone damper variety that you want, either normally open or normally closed. Subsequently you need to figure out how many dampers you will need and also make sure to purchase a 24 V AC power supply and electrical wire.

To select the best damper for a person's residential or commercial unit you need to compare and determine the function required for each damper. Damper varieties range from the balancing type or isolation type. An isolation type damper main purpose is to block air flow in the ducts once the AC unit is on. The balancing type damper regulates a certain amount of air flow through the ducts which is specified by the control panel from the users input. The configurations or shapes for balancing type dampers come in butterfly or louver shape. For the other damper type, the configuration basically comes as a guillotine shape. Once all these criteria's are determined, the mounting preferences need to be considered. When placing the dampers in a residential or commercial unit the mounting can either by a horizontal installation or vertical installation. Some other factors in damper placement are to calculate the velocity of airflow as well as check the size and shape of the damper.

Having automated zone dampers in the house is an asset to have because of its relatively inexpensive cost to install, they don't consume a lot of energy (low power consumption), and they are simple to maintain. Automated zone dampers also have disadvantages for HVAC systems. These dampers are not always reliable due to the normally open and normally closed conditions for the motors. Automated zone dampers control one zone or room in a house, whereas multiple zone dampers can control multiples zones of a building. Dampers of this type are very beneficial because one damper doesn't work, the other dampers operate without any deviation to air flow within the zone. A drawback of the multiple zone damper system is that they are less cost efficient and use up more power than the regular automated zone damper system.

2.16 Sensors

One of the main essential components for our HVAC system control that our group will be implementing in the design is sensors. The HVAC system control we are building is intended for residential units such as apartments and houses. A sensor that we will be utilizing in our HVAC design control measures a physical quantity such as temperature and humidity; and converts it into an electronic signal that will be read by an IC chip in the HVAC control system. These sensors will mainly be comprised of two types: a temperature sensor, and a humidity sensor. A temperature sensor is an integrated circuit chip that measures ambient temperature. These chips are usually placed on pre-designed circuit boards to accurately read and measure temperature for thermostats in residential and commercial units, vehicles as a digital or analog display, and thermometers (to read a person's internal temperature or for instance; to read the temperature of a swimming pool). These sensors are linearly proportional because as the temperature changes the resistance changes as well.

The different varieties of temperature sensors are resistance temperature detector, thermistor, and a thermocouple. A resistance temperature detector or RTD is a type of temperature sensor that has an electrical resistance change when the temperature changes as well. RTD's in today's industry are used in many household appliances because of their dependable, very good accuracy and precision, and maintainability. Most HVAC system controls use RTD's even though they are more expensive then thermistors and thermocouples.

Thermistor is a type of temperature sensor (which acts like a resistor) that is occasionally used in HVAC system controls whose resistance is directly altered with the initial temperature. A thermocouple is a type of thermometer that contains two wires of dissimilar metals. A junction exists between these metals and in return generates a voltage to a change in temperature. Thermocouples produce small current when heated and are not very precise or accurate in a standard HVAC system control. Figure 27 is a picture of thermocouple sensor used in electronic appliances around the house.

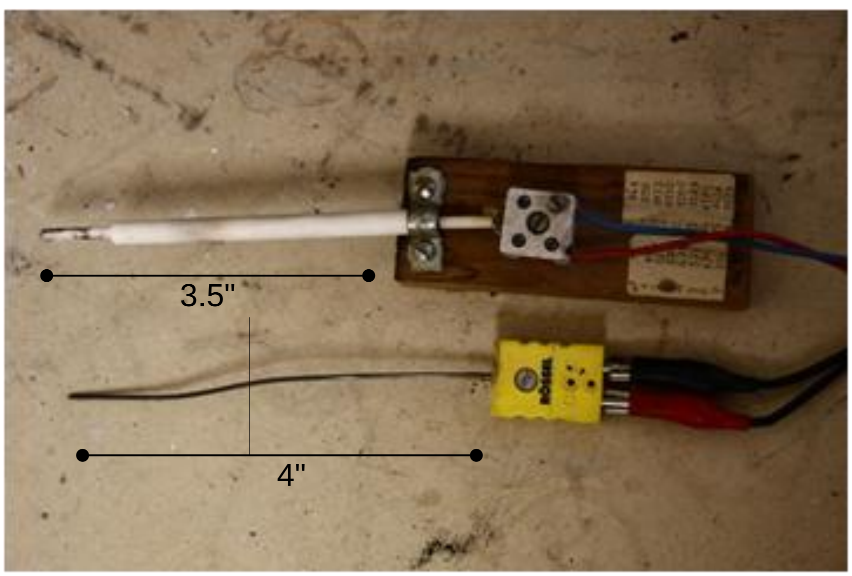

Figure 27 Thermocouple Sensor (Permission granted under the GNU Free Documentation License http://en.wikipedia.org)

Bead type thermistors are composed of two wires. The sensor is at the end of the wires denoted by the black area. The wire is approximately 2 inches in length. Figure 28 shows a bead type of thermistor which is a type of temperature sensor still being used today.

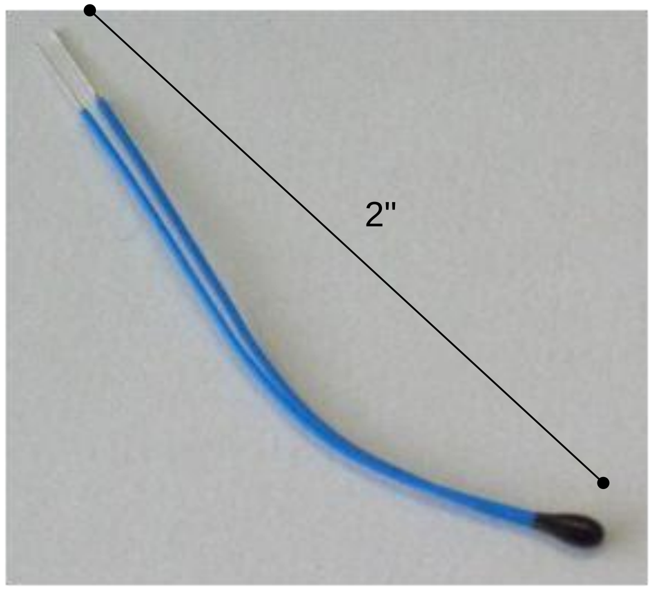

Figure 28 Bead type thermistor ((Permission is granted under the GNU Free Documentation License, http://en.wikipedia.org/)

Different temperature sensors have a wide range of temperatures pre-designed within each IC chip for manufacturing and functionality purposes. In Florida, we would generally want a temperature sensor to have a range of temperatures from 40 or 50 degrees F to probably 90 degrees F. That way we can preset the thermostat as to what temperature a user would want depending upon what season of the year it is. Most thermostats either use mercury or bimetallic strips to bend as the temperature changes. Bimetallic strips are two different metals that break or make electrical contact within a thermostat. These two metals expand by different amounts depending upon the material being used and eventually causing the strip to bend. This expansion is known as average coefficient of linear expansion. In order to find the average coefficient of linear expansion, the formula needed to derive this is as follows: $\Delta L = \alpha L_i \Delta T$. ΔL is the change in the initial and final lengths of the metals, α is the coefficient of linear expansion, and ΔT is the change or difference in the final and initial temperatures.

An air conditioner consists of the following categories: sensors, microcontrollers, and actuators. All three of these categories go through a control loop starting from a sensor where it reads/ interprets a signal and sends an electronic signal to the microcontroller. Then the microcontroller reads the sensor's signal and eventually converts it to the user's preferred setting on the controller. Finally the actuator responds to the microcontroller signal and performs an action to activate the sensors information.

In order to search for good sensors one needs to determine how reliable a sensor is, whether the sensor is weather proof in case of a wire short-circuiting, and its relative tolerance or resolution. The next step would be to search for how efficient or cost - effective the sensor is. If all these conditions are met, then the customer is on the right track in purchasing a sensor.

Another most commonly used sensor is the humidity sensor. In most electronic control systems, there are three different varieties of humidity sensors: the Dunmore element, Pope Cell, and finally the Polymer sensor. The Dunmore element also called resistive humidity sensors was built using a dual winding palladium wire on a metal substrate that is covered with lithium bromide solution. Altering the concentration of the solution will result in having high resolution sensors that cover a wide humidity range. This type of humidity sensor is normally used in HVAC system controls in residential and commercial units. The conductivity which is 1 / resistivity is calculated using an AC Wheatstone Bridge. The Dunmore element is characterized by low temperature coefficient, can work with relatively high temperatures, and able to recovery from moisture residue. Figure 29 illustrates the exponential relationship in voltage / current change between resistance (kΩ) and relative humidity (%).

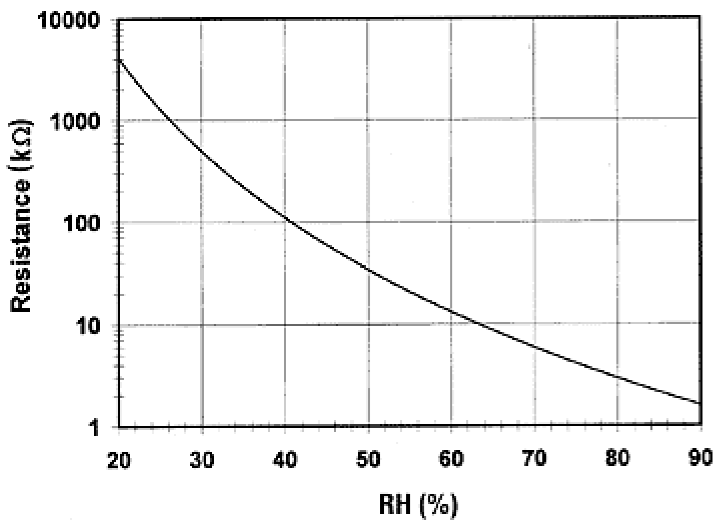

Figure 29 Resistive Humidity sensor graph with Resistance vs. Relative Humidity variables (Reprinting Permission Requested from Questex Media Group LLC)

The next type of humidity sensor is the Pope Cell which was designed using polystyrene coated with sulfuric acid on a metal base material. The Pope Cell has a wider humidity range than the Dunmore element. Thermal conductivity humidity sensors measure the absolute humidity from the conductivity of dry air.

Figure 30 is a Thermal Conductivity Humidity Sensor illustration that depicts temperatures in degrees Celsius with respect to their output signal in mV. Ranging from 40 degrees Celsius to 200 degrees Celsius, the output signal in mV decreases in higher temperature but as a result the absolute humidity generally increases in g/M^3.

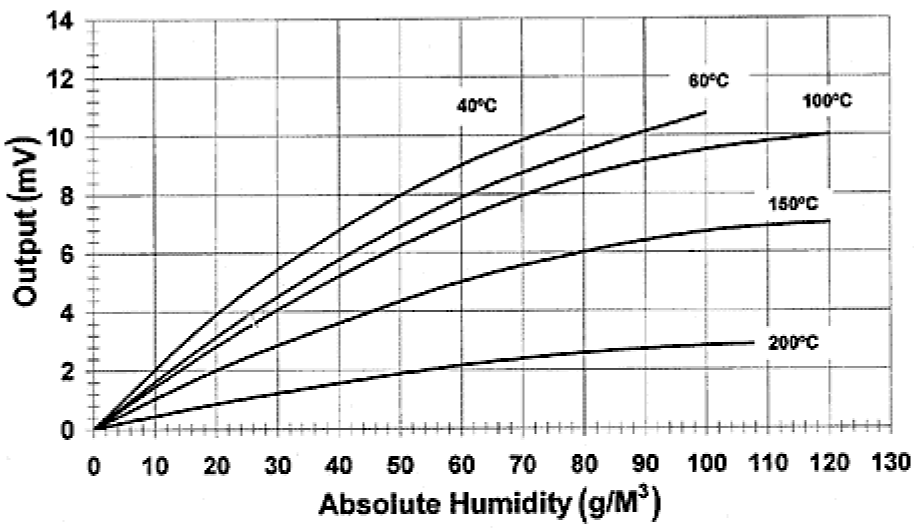

Figure 30 Output Signal in mV vs. Absolute Humidity in g/M^3 for Thermal Conductivity sensors (Reprinting Permission Requested from Questex Media Group LLC)

Another name for the Polymer sensor is a Capacitive Humidity sensor. These sensors calculate the change in the electrical impedance using an ammonium salt substrate. The resistance of a humidity sensor is directly proportional according to its relative humidity.

Figure 31 shows the linear correlation between capacitance and relative humidity for Capacitive Humidity sensors. This graph was taken with a reference measurement at 25 degrees Celsius.

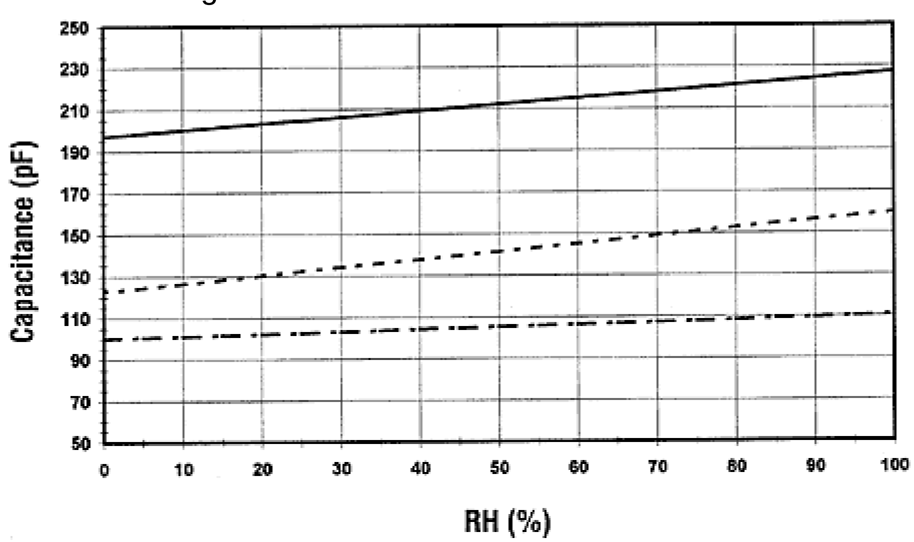

Figure 31 Capacitance of the capacitors in (pF) vs. Absolute Humidity for Thermal Conductivity sensors in (%) (Reprinting Permission Requested from Questex Media Group LLC)

In choosing the best humidity sensor some of the important concerns or questions that people come across are how accurate or precise the sensor is, whether the sensor is weather proof or resistant, cost - effectiveness, size, and maintainability.

Relative humidity is an important concept especially in the state of Florida because in the summer season it is extremely hot and humid above what the actual temperature outside is supposed to be. Sometimes when the actual temperature is 96 degrees F, the relative humidity (for example; 100% humidity) causes the temperature to feel like it is 102 degrees F outside. Basically high humidity will enable people to feel extremely hot because it makes the body sweat more and thus will succumb to a lot of perspiration from the skin.

Some essential concepts that come across when calculating relative humidity are dew point temperature, saturation vapor pressure of the air (Es), and the vapor pressure of the air (E). Dew point temperature, relative humidity, and absolute humidity are terms used in the everyday lives for meteorological forecasters in order to predict the weather for a certain areas or regions around the world. Dew point temperature is also a factor in the development of HVAC system controls. The dew point temperature is defined as the temperature for liquid water to evaporate at the same rate at which it condenses at a constant barometric pressure. Dew point temperature is very significant because of the various contributions in heat transfer, fossil fuels, printed goods, and plastics. It also has considerable roles in efficient use of energy in chemical manufacturing processes. When temperature is decreased, dew will appear as fog or change from a gas to liquid on a cooler surface more quickly than it does changing from a liquid to a vapor.

The most accurate dew point sensor is the chilled mirror hygrometer. In determining the accuracy of the chilled mirror dew point sensor one must account for measurement error from the calculation of relative humidity percentage due to dry bulb temperature and dew point temperature. A really good hygrometer out on the market that a customer can purchase now is the General Eastern M4 - RH system. This system can display and calculate dew point temperature and relative humidity. The hygrometer detects moisture buildup on a polished mirror that contains a chilled cooling system. The cooling system is a small thermoelectric heat pump. Light is reflected from a mirror to a photo cell which functions as feedback so it can check the dew point temperature of the mirror. In order to find and calculate the mirror temperature of this sensor, a platinum resistance temperature detector is utilized. The disadvantage of the chilled mirror dew point sensor is that it is relatively expensive.

Relative humidity is stated as the amount of water vapor which exists in a combined air and water vapor mixture. The following formula can compute the relative humidity: RH is equaled to E / Es * (100%).

The saturated vapor pressure of air is calculated according to the following formula:

$$Es = (6.11) * (10.0) * (\frac{7.50Tc}{237.7 + Tc})$$

where T_c = temperature in degrees Celsius.

The vapor pressure of the air is also found according to the following equation:

$$E = (6.11) * (10.0) * (\frac{7.50Tdc}{237.7+Tdc})$$

where T_{dc} = dew point temperature in degrees Celsius.

Absolute humidity is declared as the mass of water vapor that is contained in per unit volume of space. The formula is:

$$AH = \frac{m_w}{V_{net}}$$

where m_w = mass of water vapor, and V_{net} = total moisture of air (in m^3). Each measurement variable previously explained all represent the same water vapor in air condition.

Section 3: Design

3.1 Software Design

The main control unit's software design focus is based on simplicity. In order to meet our requirements, the unit needs to monitor a wire temperature, control multiple relays to power HVAC units and to control venting systems. In addition to the automated controls of the system, it must have a user interface for which a user can adjust system control settings.

The heart of the control system is a use case that handles all of the HVAC controls. Within this operation we will have our operational conditions checked, and based on adjustable user settings, this use case will pass information to power relays or adjust venting systems. In making a decision for which systems to enable, the control process must first receive readings from a wireless temperature and relative humidity sensor. With this current information, the system reads the settings that the user adjusted to suit their own comfort and power levels. Figure 32 shown below is the use case diagram for the main control unit.

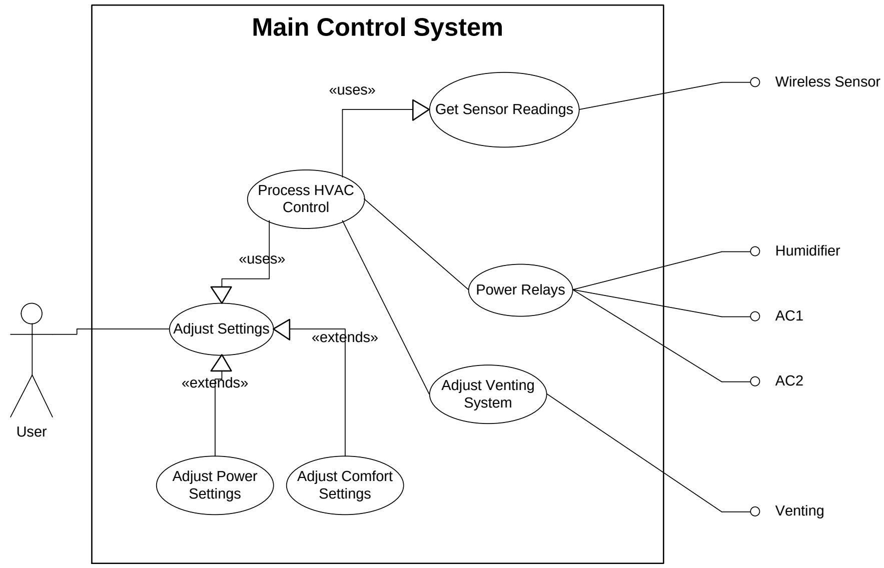

Figure 32 Use Case Diagram for MCU

For the wireless sensor, the software design is more basic. The main control unit will transmit a request for information. When this operation is received, the system will gather the current sensor reading. This information is then transmitted back to the MCU. Figure 33 illustrates the use case diagram for the wireless sensor.

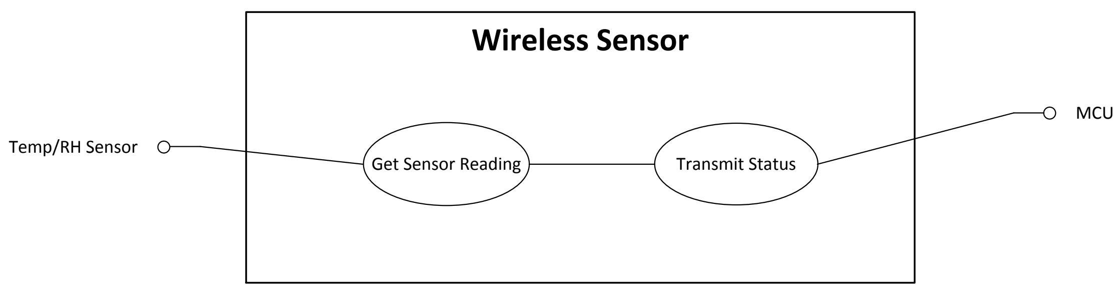

Figure 33 Use Case Diagram for the wireless sensor.

3.2 Wireless Communication

3.2.1 IEEE 802.15.4 2.4 GHz RF Transceiver Module (MRF24J40MB)

The sensors and microcontrollers that are collecting the data need to be able to communicate with the main microcontroller. We need a device with low power consumption, low data rate, and secure networking which can accomplish this. Microchip's® MRF24J40MB fit most of our requirements for a ZigBee device. Some of the applicable features of the MRF24J40MB are listed below in Table 22.

Key Features of the MRF24J40MB	
Operates on ISM Band 2.405 – 2.475 GHz freq.	Small size: 22.9 mm x 33.0 mm
Supports ZigBee®, MiWi and MiWi P2p wireless protocols	Surface mountable
Integrated PCB antenna	Up to 4000 ft. Range
Operating voltage 2.4V – 3.6 V (3.3V typical)	
Low current consumption	

Table 22 Features of MRF24J40MB

The MRF24J40MB module is compatible with Microchip's ® Microcontroller Families (Pic16F, PIC18F, PIC24F/H, dsPIC33). It is compatible with Microchip's® ZigBee software stacks, available free to download from Microchip's® website.

The main block diagram for the MRF24J40MB module is shown in Figure 34 below. This diagram depicts the main connections between the different components within the RF transceiver module. The arrow on the right show how it will connect with the microcontroller through the SPI wires.

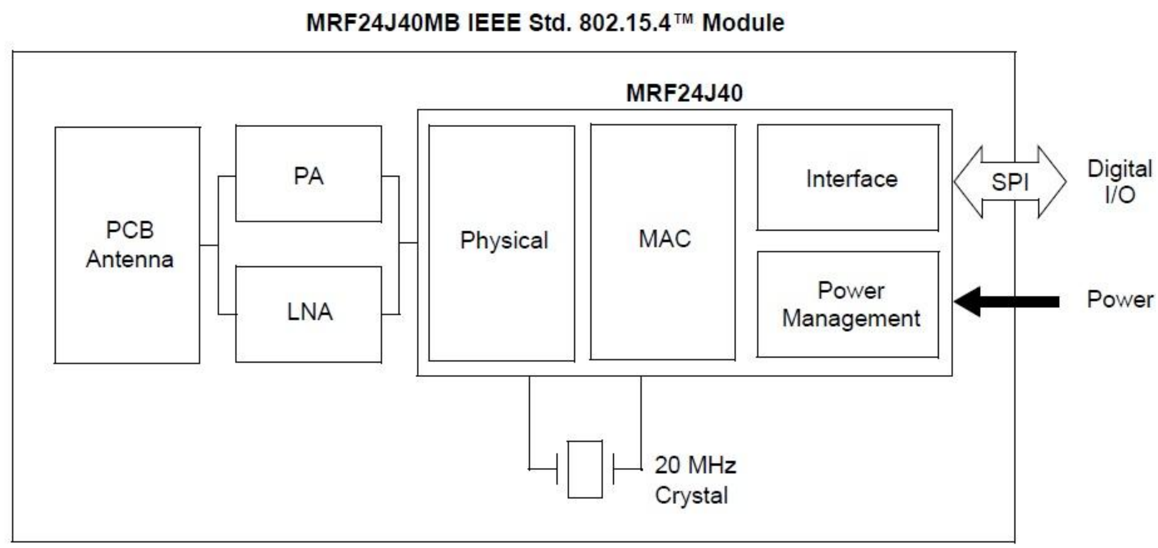

Figure 34 MRF24J40MB Block Diagram (Reprinted with permission from MicroChip®)

The MRF24J40MB module interfaces to the microcontroller via a four-wire serial slave SPI interface, as well as the interrupt, external wake-up trigger, reset, power and ground signals. In the Figure 35 below, we can see that input/ output from the microcontroller will connect with the SPI Chip Select (CS) input and clock (SCK), while the data will exchange through the SPI data in and out (SDI, SDO) pins. All data communications with the module are through the SPI interface.

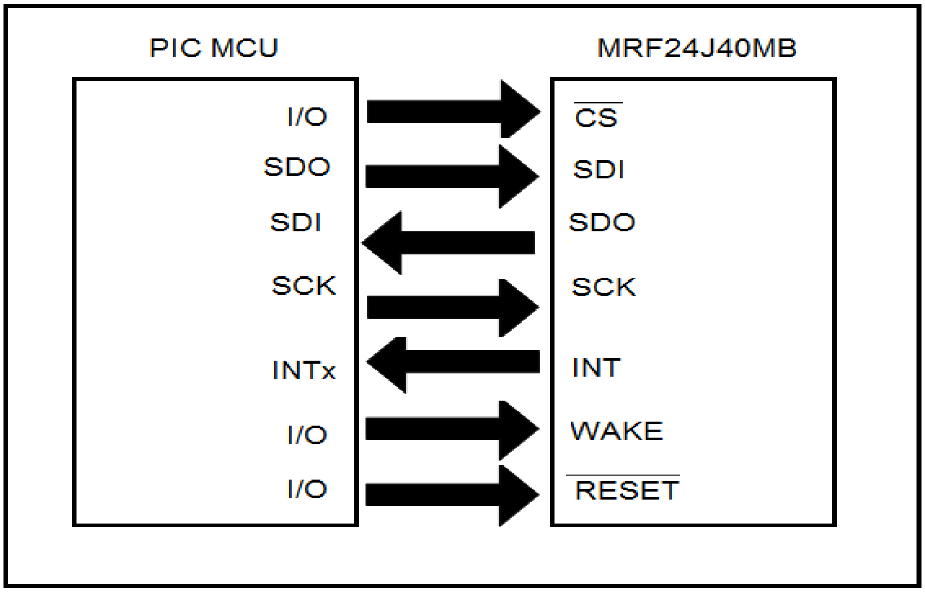

Figure 35 MRF24J40MB to Microcontroller Interface (Reprinted with permission from MicroChip®)

When operating the MRF24J40MB RF transceiver module, supplying power to the chip is one of our biggest challenges. Making sure that the voltage to the different parts on the chip is correct is essential. For the recommended operating conditions of the module, Table 23 below outlines the key areas. The supply voltage (VDD) for the RF, analog, and digital circuits, is the 2.4V – 3.6V range typical of standard industry RF transceiver modules. The one area to be concerned with when designing is the input high voltage, and input low voltage. Too much or too little voltage can affect the operation of the module and ultimately lead to failure if not properly addressed in the design phase and build of the system.

Parameters	Min	Typ	Max	Units
Ambient Operating Temperature	-40	______	+ 85	ºC
Supply Voltage for RF, Analog and Digital Circuits	2.4	3.3	3.6	V
Supply Voltage for	2.4	______	3.6	V

Digital I/O				
Input High Voltage (V_{IH})	0.5 x V_{DD}	______	V_{DD} + 0.3	V
Input Low Voltage (V_{IL})	-0.3	______	0.22 x V_{DD}	V

Table 23 MRF24J40MB Recommended Operating Conditions (Reprinted with permission from MicroChip®)

One of the great features of the MRF24J40MB is the low current consumption that allows the RF transceiver module to ultimately consume less power. The module has three modes: Sleep, Transmit (TX), and Receive (RX). For the sleep mode when the sleep clock is disabled, the MRF24J40MB uses 5 uA of current. At the maximum output power, in the transmit state, it uses 130 mA of current, while in the receive mode, only 25 mA is consumed.

3.2.2 IEEE 802.11b™ RF Transceiver Module (MRF24WB0MA)

The main microcontroller for our system needs to be able to connect to the internet. One solution that we researched was having a RF transceiver that was compatible with IEEE 802.11 protocols. Looking at Microchip's ® wireless solutions, the MRF24WB0MA Wi-Fi radio transceiver module fit many of our requirements.

The MRF24WB0MA has many features that work well with our system. The MRF24WB0MA is a 36 pin surface mountable module that's dimensions are 21 mm x 31 mm. It operates on the ISM 2.400 – 2.483.5 GHz band, which is in the 802.11 b protocol. The module requires a low supply voltage, 2.7V – 3.6V (3.3V typical), the standard operating voltage range of a RF transceiver module. This will be beneficial, as other components also operate off of a similar range, with 3.3V being the usual measurement.

With balanced receiver and transmitter characteristics, the MRF24WB0MA can offer different modes of low current consumption depending on what is called for by the user. In Receive (RX) mode, only 85 mA is used, while in the Transmit (TX) mode, only 154 mA. In Hibernate, less than 01 uA is used, while the Sleep mode uses 250 uA.

The MRF24WB0MA module is designed to be used with Microchip's ® TCIP/IP software stack, as well many Microchip® microcontroller families (PIC18, PIC24, dsPIC33, and the PIC32). The TCIP/IP software stack is available free to download from Microchip® website. The combination of this module and a PIC microcontroller operating the TCP/IP stack will result in supporting the IEEE 802.11 and IP services, which allows for an immediate implementation of a wireless web server. The microcontroller communicates through the application programming interface (API) command which is within the TCP/IP stack.

The main block diagram for the MRF24WB0MA module is shown in Figure 36 below. This diagram depicts the main connections between the different components within the RF transceiver module. The arrows on the right show how it will connect with the microcontroller.

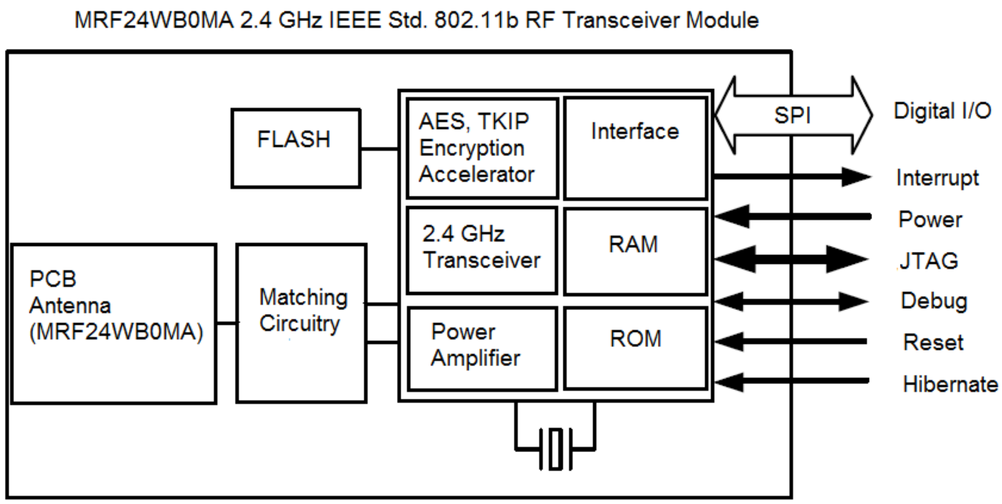

Figure 36 Block Diagram for MRF24WB0MA (Reprinted with permission from MicroChip®)

The MRF24WB0MA module interfaces to the microcontroller via a four-wire serial slave SPI interface, as well as the interrupt, hibernate, reset, power and ground signals. In the Figure 37 below, we can see that input/ output from the microcontroller will connect with the SPI Chip Select (CS) input and clock (SCK), while the data will exchange through the SPI data in and out (SDI, SDO) pins. All data communications with the module are through the SPI interface.

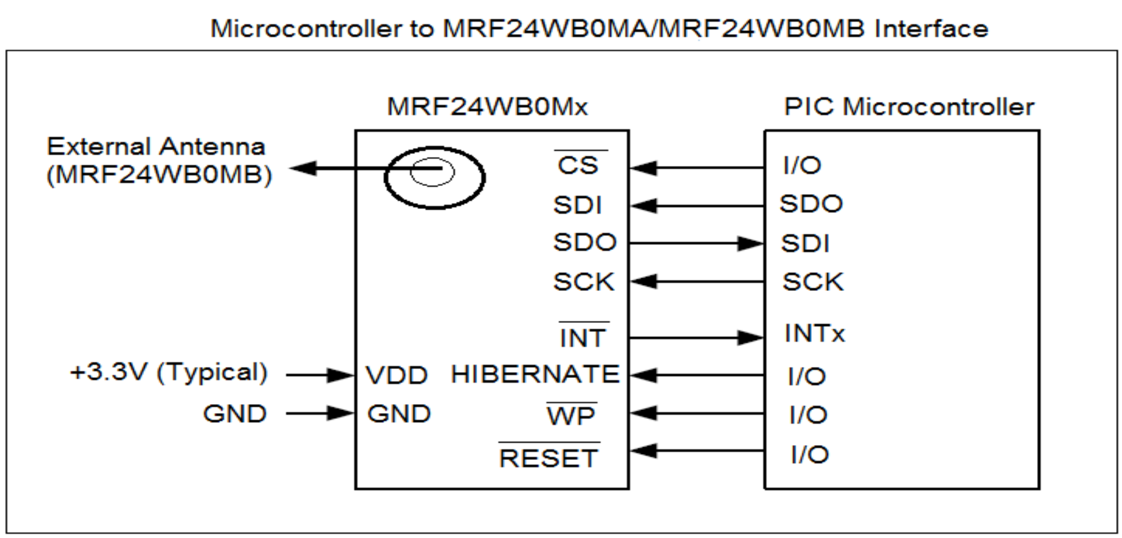

Figure 37 MRF24WB0MA interface to microcontroller (Reprinted with permission from MicroChip®)

The MRF24WB0MA has several power states. These are Hibernate, Sleep, and Active, which has two sub-states. The power state diagram in table 24 below show how the 3.3V power (VDD) is supplied during the different states of MRF24WB0MA. The overall power consumption of the system depends on which state is referenced during operation.

State	V_{DD}	$\overline{CS}$	Description
Off	0V	0V	Power is completely disconnected
Hibernate	3.3V	3.3V	All internal power regulators are OFF – enabled by HIBERNATE pin
Sleep	3.3V	0V	Enabled by TCPIP driver
RX On	3.3V	0V	Receive circuits are on and receiving
TX On	3.3V	0V	Transmit circuits are on and transmitting
Standby	3.3V	0V	State machine transition state only – not user controlled

Table 24 MRF24WB0MA Power State definition (Reprinted with permission from MicroChip®)

Hibernate is the closest state to an “off” state. The Hibernate state has to be fully controlled and programmed by the microcontroller and requires the TCP/IP stack to restart on an awake. The Sleep state is a low power dynamic state that will enter the 802.11 power save mode when all activity is complete. The module will wake autonomously to any microcontroller intervention to check Delivery Traffic Indication Messages (DTIM) from the Access Point, and deliver data appropriately. DTIM checks can be programmed and set for intervals. The Active state is identified as one of two states where the radio circuitry is fully on. There is the Receive state (Rx) and the Transmit state (TX). The Standby state is used to help identify and track operations during power tracking. Figure 38 below helps display how all the different states interact with each other.

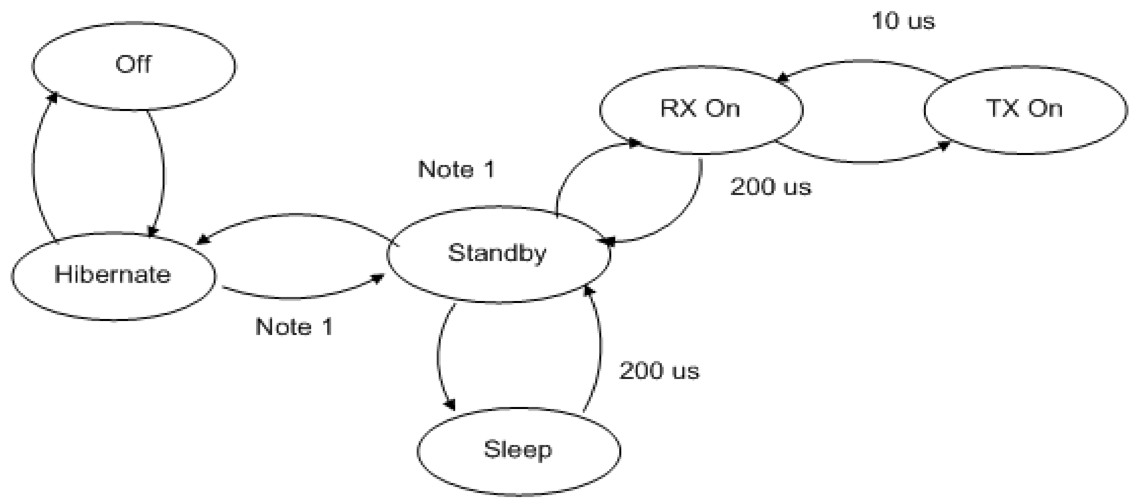

Figure 38 MRF24WB0MA Power State diagram (Reprinted with permission from MicroChip®)

3.3 Temperature and Relative Humidity Sensor

In order to measure temperature and relative humidity, we have chosen to implement the SHT21 temperature / relative humidity sensor made by Sensirion. This was chosen because it measures both the temperature and humidity, thus simplifying our design by eliminating the necessity for two sensors. The SHT21 is one of the newest sensors on the market and was initially released in a complete version on January 21, 2010. At this time, the manufacturer is offering free samples of this product. At a size of 3x3x1.1mm, the SHT21 is currently the world's smallest temperature and relative humidity sensor. This is advantageous to us since the sensor will be surface mounted onto a printed circuit board and space will be at a premium. Sensirion has samples of the SHT21 available to the public. We requested ten of these samples from the company.

3.3.1 Sensirion SHT21

The Sensirion SHT21 Humidity and Temperature Sensor is the latest humidity and temperature sensor that Sensirion has added to its line. It has a 3x3mm foot print, comes pre calibrated, and uses I^2C protocol to communicate to a microcontroller. The SHT21 has a normal operating range that varies from 20˚C to 100˚C (68˚F to 212˚F) at about 8% relative humidity and from -20˚C to 60˚C (-4˚F to 140˚F) at 90% relative humidity as shown in Figure 39. The range that our device is designed to operate in is well within these parameters.

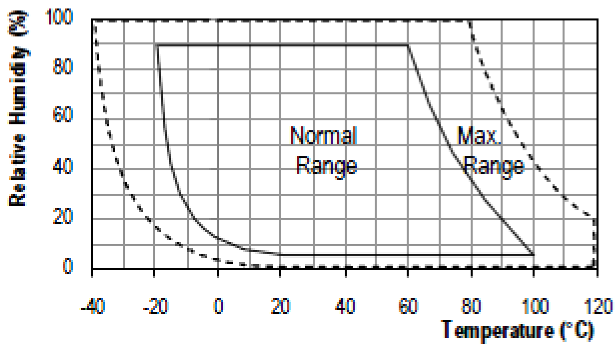

Figure 39 SHT21 Normal operating range (Reprinted with permission from Sensirion)

The SHT21 has a default resolution of 12 bits for relative humidity and 14 bits for temperature. At this resolution, with a V_{DD} of 3.0V and at 25˚C, the sensor has accuracy for relative humidity and temperature of +-2.0%RH and +-0.3˚C respectively.

The chip has six pins, that include SDA (Bidirectional Serial Data), VSS (Ground), VDD (Supply Voltage), SCL (Bidirectional Serial Clock), and two floating pins that do not connect to anything. The pin layout can be seen below in Figure 40.

Pin	Name	Comment
1	SDA	Serial Data, bidirectional
2	VSS	Ground
5	V_{DD}	Supply Voltage
6	SCL	Serial Clock, bidirectional
3, 4	NC	Not Connected

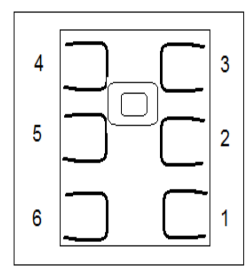

Figure 40 SHT21 pin layout (Reprinted with permission from Sensirion)

The supply voltage, V_{DD} can range from 2.1V – 3.6V with a typical value of 3V. With this supply voltage the chip will typically draw 0.15 µA when in sleep mode (not measuring temperature/humidity) and 300 µA while measuring.

3.3.2 Sensirion SHT21 and the I^2C Protocol

The SHT21 utilizes the I^2C, or Inter-Integrated Circuit protocol. The I^2C format uses two bidirectional lines. They are the Serial Data Line (SDA) and the Serial Clock (SCL). I^2C is appropriate for our design because we are sending a small amount of data between the sensor and the microcontroller which the I^2C interface is able to handle while being extremely cost efficient. Only having two connections between the sensor and the microcontroller is also a plus since space on printed circuit boards is usually scarce.

Data can be transmitted across the SDA line only after a "start condition" has been met. The start condition entails the SDA line going from high to low while the SCL is high. Once data transmission is complete, a "stop condition" of the SDA going from low to high while SCL is high. Once the start condition has been acknowledged, the data bits are set while SCL is low (blue sections) and the data is transmitted and received while the SCL is high (green sections). An example of this process is described in Figure 41 below.

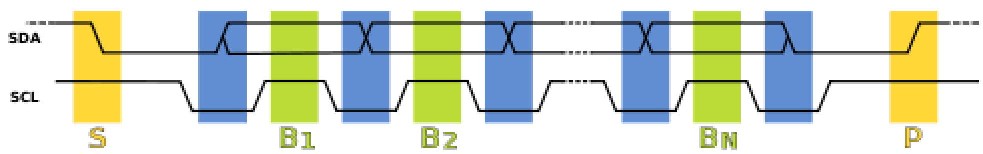

Figure 41 Start Conditions for I²C protocol (Reprinted with permission from Sensirion)

The I²C protocol begins by sending the start condition from the microcontroller as mentioned above, followed by a header that is made up of a 7-bit device address and an SDA directional bit. The directional bit is set up to be a '1' for Read and a '0' for write. After the falling edge of the eighth clock cycle, the sensor will acknowledge the command by pulling the SDA pin low.

The sensor now is ready to accept a command. The commands that the SHT21 accepts are trigger temperature measurement (hold master and no hold master), trigger relative humidity measurement (hold master and no hold master), and write user register, read user register, and soft reset. The corresponding codes for these commands are summarized in Figure 42 below.

Command	Comment	Code
Trigger T measurement	hold master	1110'0011
Trigger RH measurement	hold master	1110'0101
Trigger T measurement	no hold master	1111'0011
Trigger RH measurement	no hold master	1111'0101
Write user register		1110'0110
Read user register		1110'0111
Soft reset		1111'1110

Figure 42 Commands accepted by SHT21 (Reprinted with permission from Sensirion)

The difference between hold master mode and no hold master mode is as follows. In hold master mode the clock line is blocked by the sensor while the measurement is taking place. In no hold master mode the clock line is left open so that other communication can take place while the sensor is making a measurement. Whichever mode is chosen, the maximum resolution for either relative humidity or temperature is 14 bits. This leaves the two LSB's to describe the type of measurement. The most LSB is not assigned to anything, but the second most LSB describes a temperature reading with a '0' and a relative humidity reading with a '1'. The soft reset command essentially reboots the sensor without having to turn off the power. The soft reset function takes less than 15ms.

The user register is an eight bit register that comes from the factory with default settings. It initially sets the resolution of relative humidity to 12 bits and temperature to 14 bits. The default register settings are shown in Figure 43.

Bit	# Bits	Description / Coding	Default
7, 0	2	Measurement resolution (RH / T) '00': 12 bit / 14 bit '01': 8 bit / 12 bit '10': 10 bit / 13 bit '11': 11 bit / 11 bit	'00'
6	1	Status: End of battery[15] '0': V_{DD} > 2.25 V '1': V_{DD} < 2.25 V	'0'
3, 4, 5	3	Reserved	
2	1	Enable on-chip heater	'0'
1	1	Disable OTP Reload	'1'

Figure 43 SHT21 Default register settings (Reprinted with permission from Sensirion)

Once the bits measurement is taken and the bits are transferred, it must be converted into a number that makes sense to the user. The binary number must be converted to a decimal number (called S_{RH} or S_T for relative humidity, or temperature, respectively). Once converted into decimal, the value must be plugged into a formula to get the final output. The formulas for relative humidity and temperature conversion are shown below. The units for relative humidity are %RH and the units for temperature are ˚C.

$$RH = -6 + 125 * (S_{RH} / 2^{16})$$

$$T = -46.85 + 175.72 * (S_T / 2^{16})$$

3.4 Evervision LCD Panel

This LCD touch screen panel from the Reach Technologies Inc website is what has been chosen to be implemented into our design as the user interface for the efficient HVAC control and feedback system. Since this is one of the most expensive components of the design, we presented the sponsors with a list of similar options and they picked the one they thought was the best compromise. They want to have a large, touch screen user interface while keeping the cost down to both stay within our budget and keep the overall cost of the system low. We have chosen to purchase the development kit which is composed of a 7 inch

TFT-LCD panel, and the SLCD5 controller (SLCD5 controller will be discussed in detail in a later section). To activate the LCD touch screen we can either use the user's finger or a pen to input various states for our HVAC control system. On the home screen of the LCD panel the user will be able to, among other things, set the desired temperature and relative humidity for when the system is in cooling mode, set the temperature and relative humidity for when the system is in heating mode, view the current temperature and relative humidity inside the building, view the current temperature and relative humidity outside the building, and choose between several settings that range from maximum savings to maximum comfort (specifies to the system the tolerance for temperature and relative humidity variation from set points). The model number of the Evervision screen we have chosen is VGG804805-6UFLWE. Each letter and number is a descriptor of a part of the panel. The descriptors that are important to our implementation of the design are outlined in Table 25.

LCD Type	LCD Model	Backlight Type	Backlight Color
U: Transmissive/Positive	F: TFT	L: General LED	W: White

Table 25 Important descriptors of the Evervision 7" LCD panel from the model number (Reprinting Permission Granted from Evervision)

The physical specifications of the LCD panel are what must meet the basic requirements presented to us by the sponsors. Originally the sponsors informed us they wanted something in the 7 to 8 inch range that was touch sensitive that would be aesthetically pleasing (bright, colorful display). Again, since this is the only portion of the system that a potential customer would interact with, the LCD panel must be very attractive. The physical specifications for the Evervision 7" LCD are shown in Table 26 below.

Item	Specifications	Unit
Size of Screen	7	inches
Active Area	152.4(H) x 91.44 (V)	millimeters
Dot Size	0.0635(H) x 0.1905(V)	millimeters
Pixel Configuration	RGB Vertical Stripe	-
Weight	215	grams
Display Mode	Transmissive Mode Normally White TN Type	-
Display Format	800RGB(H)x480(V)	Dot
Surface Treatment	Anti-Glare and Hard Coating (3H)	-
Outline Dimension	166.6(W)x107.0(H)x11.5(D)	millimeters
Viewing Direction	6 O'clock	-

Table 26 Specifications for 7 inch Evervision LCD Panel

3.4.1 Environmental Conditions for Evervision LCD Panel

Our resistive touch screen device we purchased has many environmental conditions to consider. They include storage temperature and operating ambient temperature. Storage temperature has a min value of -30º Celsius and a max value of 80º Celsius. For the operating ambient temperature parameter it functions by having a min value of -20º Celsius and a max value of 70º Celsius. Some primary states that involve temperature and relative humidity range from 90% max RH when the ambient temp is ≤ to 40º Celsius. Table 27 describes the environmental conditions that must be followed when dealing with the Evervision 7” LCD with touch screen interface.

Item	Symbol	Minimum	Maximum	Unit
Storage Temp	T_{ST}	-30	+80	˚C
Operating Ambient Temp	T_{OP}	-20	+70	˚C

Table 27 Environmental conditions that must be followed when dealing with the Evervision 7” LCD with touch screen interface.

3.4.2 Electrical Characteristics

The most important specifications that we must follow when dealing with the Evervision 7” LCD screen are the electrical characteristics. These characteristics include but are not limited to, digital power supply voltage, power supply current, input high threshold voltage, input low threshold voltage, and power consumption. Table 28 shown below describes how much power, voltage, and frequency will be needed to operate our 7” Evervision LCD Panel.

Item	Minimum Value	Maximum Value	Unit
Power Supply Voltage	3.0	3.6	V
Power Supply Current	-	585	mA
Power Consumption	-	1.931	W
VSYNC Frequency	-	75	Hz
HSYNC Frequency	-	39.2	KHz
DCLK Frequency	-	40	MHz
Input High Threshold Voltage	0.7VCC	VCC	V

Table 28 This figure tells us how much power, voltage, and frequency will be needed to operate our 7 inch Evervision LCD Panel.

3.5 SLCD5 Controller

The SLCD5 controller is what provides the GUI for the LCD interface. It is meant to give the developer a simple way to generate a user interface on the screen to fit his or her needs without having to do a lot of low level graphical programming. The controller board is essentially the connector piece between the microcontroller and the LCD interface. The microcontroller would not be capable of producing the necessary images on the LCD screen as it does not have enough processing power.

The controller board is able to load Bitmap images onto the screen, place them where the developer instructs it to and move or remove them as necessary. The controller board is required to be programmed separately from the microcontroller and uses a separate interface to accomplish this portion of the programming. The SLCD5 controller is even more essential to the overall system than the LCD screen itself. Although the LCD screen is what the user interacts with and is the only part of the system to be seen by the user, the controller board is responsible for making sure the LCD screen performs the tasks expected of it by the user and responds accurately to the user input. Figure 44 is a picture of the SLCD5 controller.

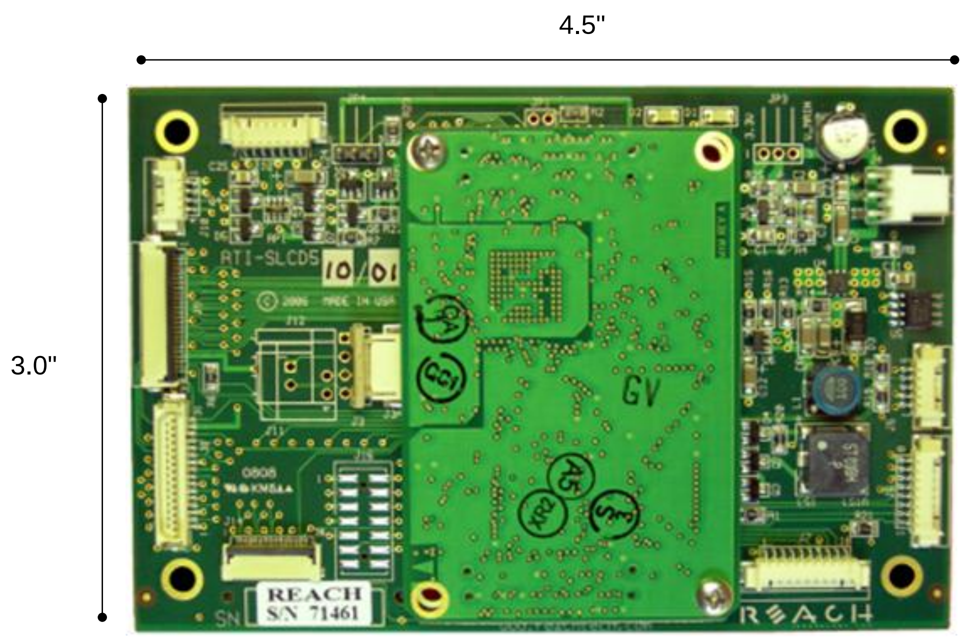

Figure 44 The SLCD5 controller board (Reprinted with permission from Reach Technologies Inc)

The LCD touch screen should contain VGA resolution and have at least 16 bit color. The SLCD5 controller has many features that will satisfy the design requirements of our group. The features of the SLCD5 are listed below in Table 29:

Features of SLCD5	
Drives digital TFT displays at QVGA and VGA resolution	Beeper for audible touch feedback and alarms
16 bit color	3" by 4.5" size, 0.55" thick
Touch controller (4 wire resistive) on board	High speed ARM9 proccessor 200MHz
On-board RS232 and TTL level interfaces	4MB data flash for user downloadable bitmaps with RLE compression
Blacklight enable and brightness control	SD card slot for firmware upgrades and bitmap / macro storage

Table 29 SLCD5 features

3.5.1 Electrical Characteristics

The electrical characteristics of the SLCD5 are important for the group and must be taken into consideration for the overall design of the Efficient HVAC Monitoring and Feedback System. We are required to follow these specifications during development of the system and in the final design of the system. The SLCD5 accepts between 5 and 12V DC +/- 10% as a power source and has an on-board switching regulator to generate the 3.3V needed by the LCD panel. Table 30 shows some of the electrical characteristics associated with the SLCD5 controller board.

Voltage:	Typical Current (beeper off):	Typical Current (beeper on full):
5V	230mA (typ.)	300mA (typ.)
12V	150mA (typ.)	220mA (typ.)

Table 30 Electrical Characteristics of the SLCD5 Controller Board (Permission to use this information is pending)

In order for the SLCD5 to operate it requires connections for power, communications, panel, and inverter. For power the J6 or J4 connector can be used. The difference between these two implementations is the J6 uses one cable for both communications and power, while the J4 has separate cables for power and communications. The J4 connector must be used if the inverter demands more than 1A of current. For communications the COM0 port can be used in conjunction with the J6 connector (typically RS-232) or the J7 COM1 port can be used (RS-232 or CMOS 3.3V). For panel, the J8 connector is used for most VGA panels, while the J9 connector is used for most QVGA panels. For the inverter the J13 connector is used for high power for VGA panel inverters, while the J10 connector is compatible with SLCD5 inverter cabling for QVGA panels. The following Figure 45 shows the connectors and jumpers for the

SLCD5.

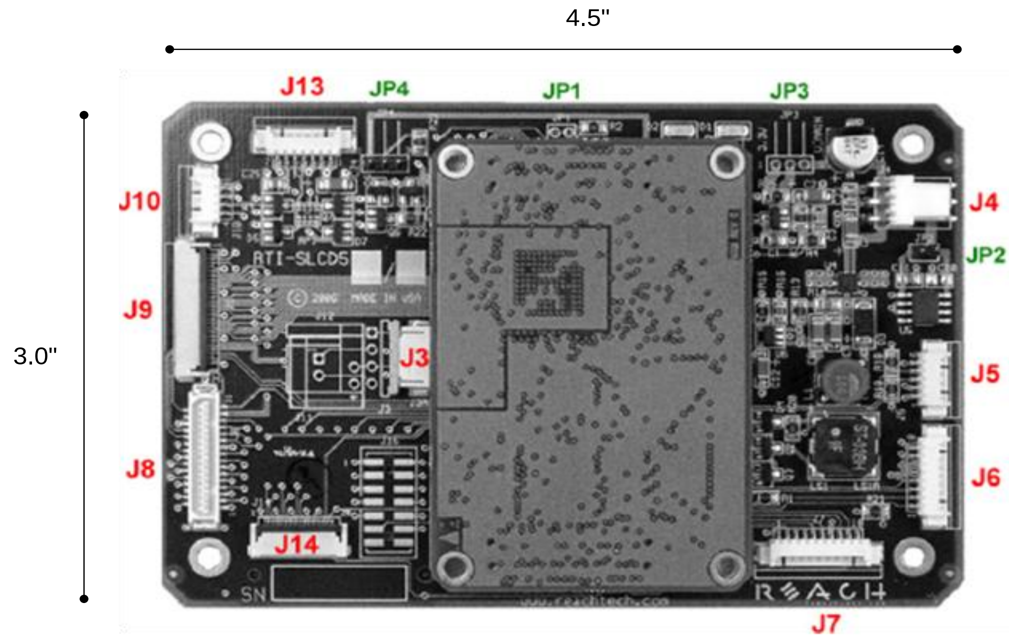

Figure 45 Connectors and Jumpers Layout of the SLCD5

(Reprinted with permission from Reach Technologies Inc)

The SLCD5 can utilize either RS-232 or CMOS logic levels for serial communication. By default the COM0 serial port is configured for RS-232. The COM0 port is usually deemed the “Main” port and is connected to the embedded processor to control the display. The COM1 port is usually deemed the “Aux” port and is typically used to update the display bitmaps and macros. The default settings for serial communications is 115200 baud, 8 data bits , no parity, with 1 stop bit, and software (XON/XOFF) flow control. The baud rate is changeable. Figure 46 that is shown below illustrates a typical communication setup for the SLCD5.

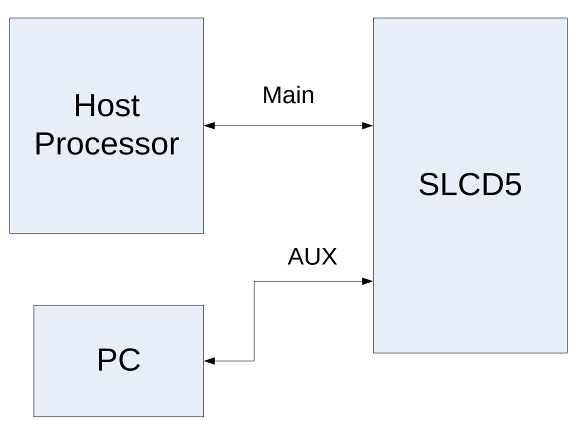

Figure 46 SCLD5 Communication Setup

3.5.2 Touch Interface

The touch controller of the SLCD5 is meant to interface to a four wire resistive touchscreen. Touch sensitive areas on the display are defined as either “hotspots” or “buttons”. When either of these is pressed or released, the SLCD5 has the ability to either notify the host directly or execute a “macro” which is a predetermined sequence of SLCD5 commands.

A hotspot is an area of the display that is touch-sensitive. The two types of hotspots are visible and invisible hotspots. A visible hotspot is the standard type of hotspot and when it is touched, the display area of the hotspot is color inverted in order to provide a visual indication that a hotspot has been activated. On the other hand, an invisible hotspot does not provide any visual indication when it has been touched. When a touch control is used to switch display screens, an invisible hotspot is the best option because the host redraws the screen when the hotspot is pressed and sometimes the hotspot area can become inverted when the user removes their finger from the screen.

A button is the other type of touch sensitive area on the display is a button. A button is a touch sensitive area with two bitmaps associated with it. These bitmaps correspond to the two states of the button (normal/not pressed and active/pressed). This allows the button to take on the form of any GUI object including pushbuttons, toggle switches, radio buttons, check boxes, and so forth. There are normal (momentary) and latching buttons. A momentary button only changes its visual state when pressed (such as a keyboard key) while a latching button is like a checkbox where the button is pressed and released and the checkbox is filled and another press and release is required to clear the box.

3.5.3 Bitmap Images and the BMPload Program

Many areas on the touch screen, whether touchable or not touchable are actually bitmap images that must be loaded onto the controller from a computer. Examples of bitmaps that will be loaded onto the screen via the controller are logos, all buttons, or any pictures that the sponsor specifies must be on the LCD display. The SLCD5 has 4 Megabytes of on-board data flash memory for storing bitmaps and macros. Since bitmaps are used to create most of the visual elements of the user interface, the programmer may find the need to create certain bitmap images to be loaded onto the controller board. Some popular programs used to create bitmaps are Adobe Photoshop, and the open source program, GIMP. The programmer can simply use the “PrintScreen” function of the PC to capture the desired element and then paste the screen to either Photoshop or GIMP. Bitmaps must be saved in 24 bit RGB color mode.

In order to load a bitmap image onto the controller, it must be hooked up to a computer that is running the BMPload program (.bmp is the Windows file extension for a bitmap file. The BMPload program is included with the development kit we have purchased. The BMPload program requires bitmaps to be in 24 bit RGB color. The SLCD5 uses 16 bit color in 565 formatting, but the BMPload program does the required translation. The BMPload program is designed to run on Windows XP. The computer that is running the BMPload program needs to be connected to the SLCD5 board using either the Main or Aux serial port.

The first screen that appears when the BMPload program is booted allows the user to use an "Add BMP" button to add BMP files to the list. Once loaded, the BMP files are indexed by the order in which they are added. This is important because when using the DISPLAY BITMAP IMAGE command you use the index number to refer to the specific bitmap you are trying to place. The best way to add the BMP files to the list is to start all bmp file names with their index number, for example "01_first_bitmap.bmp". Then insert all of the .bmp files into one list file (.lst) which is a standard text file and add this file to the BMPload program. Once all desired bitmaps have been loaded, you can use either the "Save to File" button or the "Store into SLCD" button to save the bitmaps. The "Save to File" button saves all the bitmaps to the SD card (file name must be 8 characters, start with "slcd" and have the extension ".bin"). The "Store into SLCD" button stores the images to the SLCD5 flash memory via the serial port. The BMPload program is only designed to get the .bmp files from the PC connected to the SLCD5 to either the Flash memory or the SD card on the SLCD5.

Once the .bmp files are loaded onto the SLCD5, they still need to be implemented into the code that will produce the images on the LCD touch screen. Table 31 describes several of the commands for the SLCD5 that will be used during programming in order to place .bmp files to be used for items such as buttons and hotspots on the LCD screen.

Name	Description	Command	Arguments
Display Bitmap Image	Copies previously stored bitmap onto screen at x y	xi <number> x y	<number>: Bitmap number
Button Define - Momentary	Defines a momentary touch button on the screen	bd <n> <x> <y> <type> "text" <dx> <dy> <bmp0> <bmp1>	<n>:Button number <x><y>:Upper left hand corner of button <type>: Button type "text": Text to display <dx>/<dy> : x/y dir. text offset <bmp0>/<bmp1>: Index of bitmap displayed in unpressed/pressed

			state
Button Define – Latching State	Defines a touch button with two distinct states	bd <n> <x> <y> <type> "text0" "text1" <dx0> <dy0> <dx1> <dy1> <bmp0> <bmp1>	<n>: Button number <x><y>:Upper left hand corner of button <type>: Button Type "text0":String to be displayed on button state 0 "text1":String to be displayed on button state 1 <dx0>/<dy0>: Text to be offset in x/y dir for "text0" <dx1>/<dy1>:Same as above for "text1" <bmp0>/<bmp1>:Index of bitmap in state 0/1
Define Hotspot (visible touch area)	Defines a touch area on the screen. When touched, this area's number will be returned on the serial control line. Defined area will be set to reverse video while touched.	x <n> x0 y0 x1 y1	<n>: touch button (x0,y0)/(x1,y1): specify touch area for this spot
Define Special Hotspot (invisible touch area)	Same as Define Hotspot except the touch area is not reverse video highlighted when touched.	xs <n> x0 y0 x1 y1	Same as Define Hotspot command

Table 31 Commands expected to be used in order to place buttons and hotspots on the LCD screen

3.5.4 Macro Commands and File Format

As well as bitmaps, macros may be loaded to the SLCD5 controller board using the BMPload program. Macros generally serve two main purposes. First, they allow a series of commands to be invoked by a single command. The two main advantages of this are to speed up the display and to reduce the space needed in the host processor to store the commands. Macros can have parameters associated with them so that a general purpose macro can be used in different ways on several screens. For example if we created a macro to have buttons for the user to raise and lower temperature and relative humidity with a display of current temperature and relative humidity conditions between the buttons, we could associate parameters as to where to draw this on the screen. This would save us time when programming because we could reuse the drawing on every screen simply by calling the macro and specifying where to place it on that particular screen. Macros can also be linked to specific buttons so that when the button is pressed a single macro can be called that creates the new screen that the user expects. The macro files can be created by using applications such as notepad and can be saved as an ASCII text file. The use of this file format allows the macro definition file to be used to both load the macros into the SLCD5 flash memory and to be used as a "C" include file in the program that runs the microcontroller. This allows the one macro file to be used on both ends and therefore avoids any potential confusion with macro index numbers. The following example shows the general format for a macro file.

#define <text_name><number>

(one or more command lines)

.

.

#end

The only use of the <text_name> identifier is to provide the C program with a reference to include the macro file in the library. The <number> argument is 1 for the first macro, 2 for the second, and so on. The macros must be listed in increasing index order.

There are some limitations associated with the use of macros. The limitations on macro commands associated with firmware version 2.3.0 and above are as follows:

- Macros have the ability to call other macros, but the maximum call depth is 4.
- The maximum number of arguments allowed per macro is 4.
- The maximum characters per argument are 8.
- The maximum number of stored arguments is 50.

In order to parameterize macros, the escape sequences '0', '1', '2', '3' in the command lines. When the programmer invokes the macro, they supply arguments to replace the escape sequences. For example the following is a macro definition:

#define example 1

t "'0'" '1' '2'

#end

The following command will use the above macro to display the text "Hello" at location x=40, y=50

>m 1 Hello 40 50

3.6 Design Summary

The Efficient HVAC Control and Feedback System is composed of three major components. These components are the LCD Touch Screen User Interface, Remote Sensing Unit, and the Main Control Unit. Other design components being used in this project are the web server and the control and power relays. The Main Control Unit is the part of the system where the central or main control and feedback takes place. Our system will feature the User Interface, Remote Sensing Unit, and the Main Control Unit. High - Level System block diagram shown below in Figure 47 describes the interaction between these three main components. Instead of having a detailed description and requirements of each device, this diagram illustrates a general description of their overall functions. Our last component is the Remote Sensing Unit that is the part of the system that communicates with the Main Control Unit from a location outside the building.

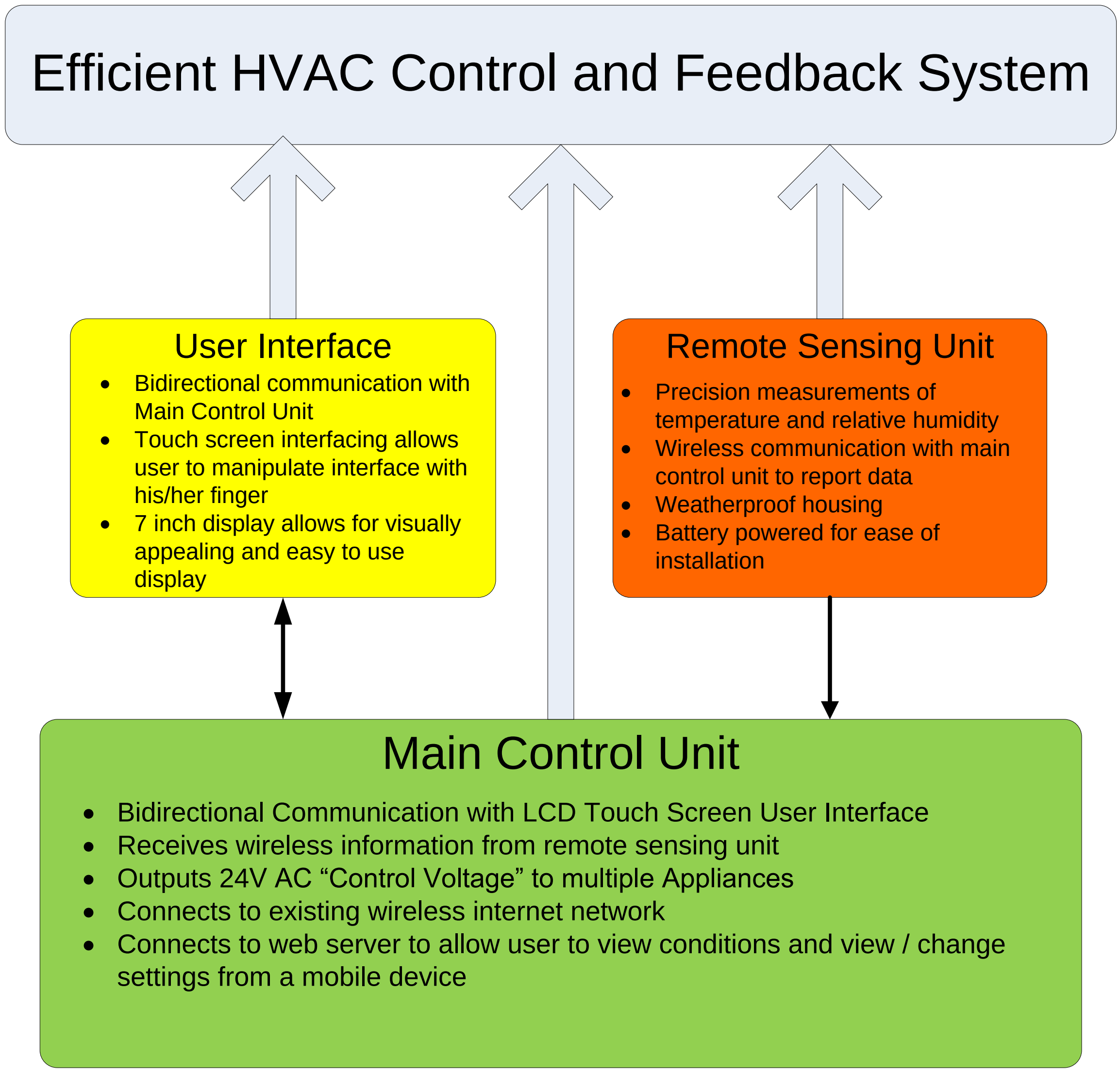

Figure 47 - High - Level System Block Diagram

The LCD touch screen is the main user interface of our system which primarily consists of a 7" display that is visually appealing to the user, allows for bidirectional communication with the Main Control Unit and as well as let the user to manipulate the touch screen interface by means of his/her finger. The web server will allow for remote manipulation of the system settings using any web - enabled mobile device.

The Remote Sensing Unit is the least complex of the four main components. The components housed inside the Remote Sensing Unit are, a temperature and relative humidity sensor, a microcontroller, and a ZigBee wireless chip. The sensor takes both temperature and relative humidity readings and reports these values to the microcontroller also located in the remote sensing unit. The microcontroller intakes the readings and if necessary; manipulates the data so that it can be sent to the ZigBee chip in a form that is acceptable for wireless transmission. The ZigBee chip then transmits the information to the ZigBee chip on the Main Control Unit.

The Main Control Unit is the most complex part of the Efficient HVAC Control and Feedback System. The Main Control Unit is composed of a main microcontroller, a ZigBee wireless transceiver, an 802.11b RF transceiver, control relays and a temperature and relative humidity sensor. Our main control unit deals with two types of interfacing conditions that communicate with the main microcontroller and two types of connections. They are SPI (Serial - Peripheral) and I^2C (Inter-Integrated) interfacing as well as the serial connection between the main microcontroller and the LCD Touch Screen Display. This serial interface will consume one of the two UART connections. Figure 48 shown below illustrates the main control unit's interfacing structure for the Efficient HVAC Control System.

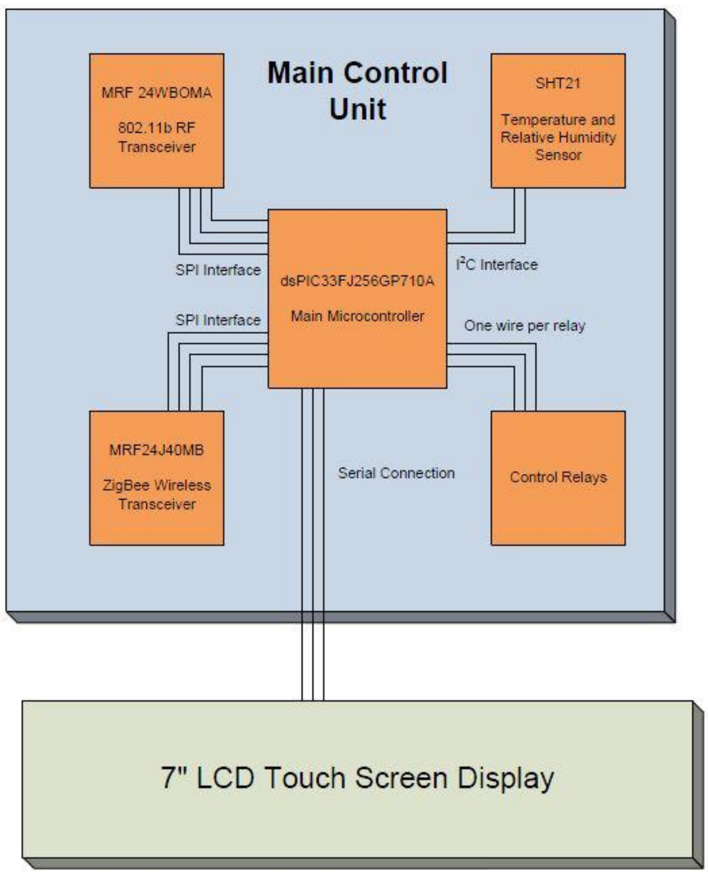

Figure 48 - Main Control Unit Interfacing

The main microcontroller is then required to accept inputs from multiple sources. First, it must accept the information that has been transferred from the Remote Sensing Unit using the Zigbee chips. Second, it must accept another temperature and relative humidity reading from the on - board sensor. Third, it must accept user inputted settings from the LCD touch screen interface controller board. Fourth, it must accept inputs from the web server through the 802.11b wireless chip. After considering readings from the sensors, the web server, and LCD user interface; the Main Control Unit must come to a decision as to what course of action to take.

The Main Control Unit then controls the appropriate components of the HVAC system such as the compressors, air handlers, and dehumidifiers. The Main Control Unit is designed and programmed to use the least energy possible while satisfying the conditions set by the user. The Main Control Unit is responsible for updating the LCD controller with current conditions as well as connecting to the internet to update the web server with current interior and exterior conditions associated with the building. Figure 49 shows a basic outline of the user case processes that happens in the main control system of the Efficient HVAC Control and Feedback System that we have designed.

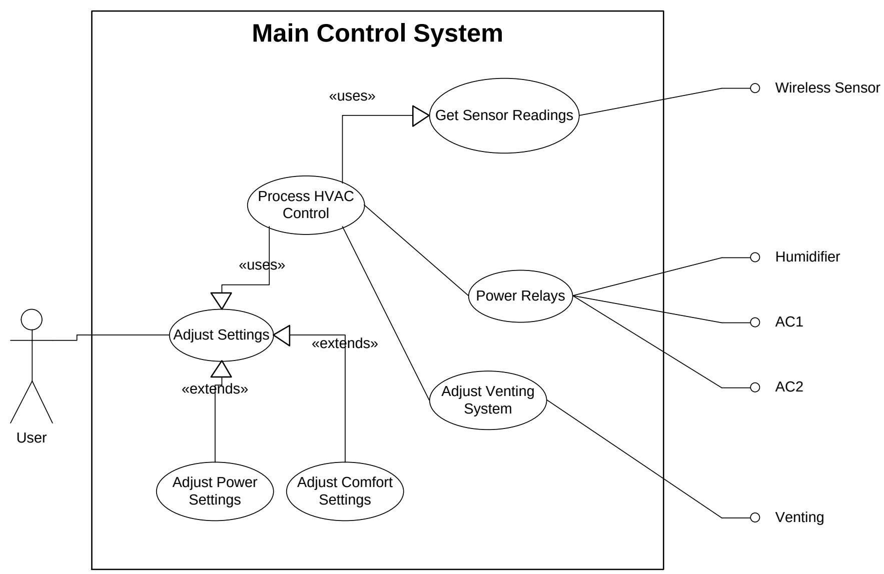

Figure 49 - Outline of the User - Case Processes for the Main Control Unit

Our secondary microcontroller incorporates three serial communication peripherals such as an SPI, I^2C, and UART modules. The secondary microcontroller primary task is to take in the data from the SHT21 sensor. Another component of the secondary microcontroller is the remote battery to power it. We decided on using the alkaline (AA) battery because compared to most other batteries it had significant battery life, capacity (in mA/h), and low - self discharge rate. Also to store the battery we are going to use some type of box that is weather-proof so that it won't short circuit the power connection from the battery to the secondary microcontroller. The secondary microcontroller uses a C compiler with a 16 – bit wide data path, and 512 bytes of RAM data memory. It also incorporates 18 I/O pins that are designed to be programmed to work with the SHT 21 sensor and the Zigbee RF transceiver. Lastly, it also has Analog to Digital Converters that are intended to transfer input analog voltages into a digital number that are directly proportional to the input voltage or current. In Figure 50 shown below, illustrates the block diagram of the secondary microcontroller which contains the peripheral connection with the different components.

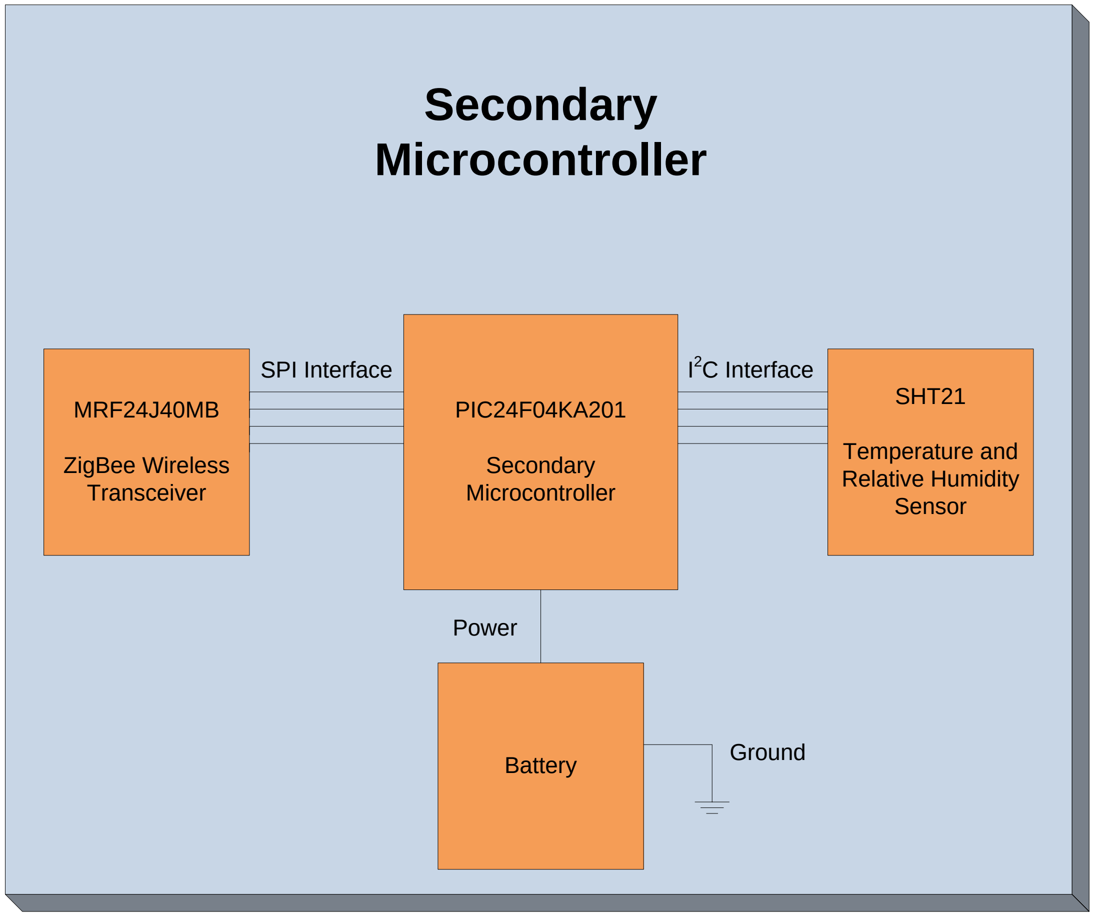

Figure 50 - Secondary Microcontroller Interfacing

In designing the Efficient HVAC Feedback and Control System there are two types of relays that are involved with the main control unit. The 24 V AC Control Relays and the 220/240 V AC Power Relays. Control relays are switches that can be turned on or off when a decision is made. For the main control unit, when the control relays are switched on and the decision to turn their specific component on has been made. The output of each control relay is 24 V AC. Next is the 220/240 V AC Power Relays which are located outside at the compressor and at the inside air handler. When the power relay is turned to the on - position, the 220/240 V AC is connection to the compressor or the air handler. It will run until the main control unit decides when it is time to stop and the relay in return is turned back to the off - position. The power relays will be used for the air conditioners (1 ton, 2 ton and 3 ton) as well as the ventilation and the dehumidifier. Figure 51 shows the typical HVAC relay setup that will be utilized.

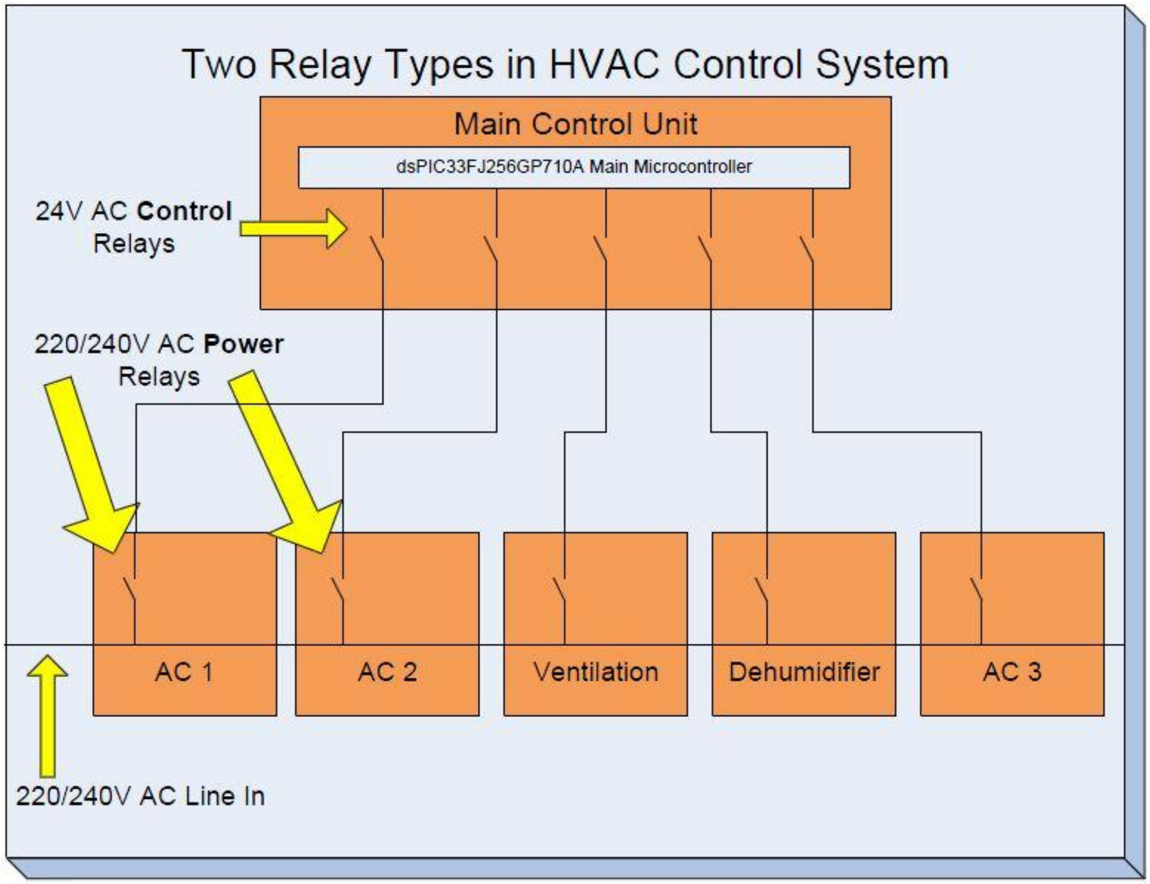

Figure 51 - Typical Relay setup for HVAC Control Systems

The LCD touch screen user interface is one of two ways the user can interact with the system. The LCD touch screen user interface is mounted inside the building on the wall and is a replacement for a conventional thermostat. The LCD touch screen communicates with the main microcontroller through an attached controller board. The controller board reports to the main microcontroller what has been touched on the screen, and uses information provided to it from the main microcontroller to update appropriate fields on the LCD screen.

The web server is another means of manipulating the system. The web server is designed to be viewed on a mobile device from a remote location. This allows the user to change the system settings for when the building is not occupied. The web server communicates with the main control unit so the appropriate fields are kept current and changes to settings are saved. The web server is set up to use Wi-Fi technology to connect to the internet for complete remote access to the system.

Section 4: Prototype

4.1 Vendors

These vendors serve a special role and purpose in the development of the HVAC control system as well as have a direct association to our sponsors. All of these companies provided us essential components for our wireless microcontrollers, development board, LCD touch screen display, and wireless interfacing to communicate between the microchip and the router and vice versa. We researched these companies thoroughly and we thought that they would provide us a great opportunity to get excellent products that focus on low power consumption (in BTUs), energy efficiency, and eco-friendly air quality. They also allowed for satisfactory comfort to the consumer, and to supply heating and cooling for the commercial or residential unit according to their consumers preferred temperature and humidity settings. Our Senior Design group as well as our sponsors wanted to account for each vendor's expertise in the area of microelectronics

4.1.1 Reach Technology Inc.

Reach Technology Incorporated is a corporation based in Fremont, California that specializes in LCD touch screen displays. Since 1988 they have helped customers looking for touch displays ranging from hotel room kiosks, medical control systems, and tugboat engines. Some qualities that Reach Technology Inc offers are product durability, great display quality, and adequate battery operation. This company was appealing to us to use because we ordered a 7 inch LCD Display Module for our HVAC control system. This LCD color touch screen display development kit package incorporates an LCD, SLCD5 microcontroller, software driver, and touch screen. This development kit features Evervision's panel for electronic applications that demand easy access.

4.1.2 Microchip

Microchip Technology is a company whose primary concentration is in the semiconductor industry. The company's base of operations is located in Chandler, Arizona consisting of approximately 5,000 employees where they produce electronic appliances such as microcontrollers, memory and analog semiconductors. Memory products include serial EEPROMS and serial SRAM as well as other analog devices. The company was basically founded by Steve Sanghi, J Bjornholt, and Ganesh Moorthyin 1989. Even though it was originally founded in 1989, they actually existed in 1987 when General Instrument split off their microelectronic department into their privately owned company. We were interested in their products because of the wireless interfacing being involved between the control panel and the router. Our group ordered wireless network devices on their main website for the integrated circuit chip such as the Zigbee MRF24WBOMA and the Wi-Fi for the development board inside the HVAC control panel.

4.1.3 Sensirion

Sensirion is an engineering firm that is located in the municipality in the Canton of Zürich, Switzerland. This company consists of more than 180 employees that manufacturer sensor parts primarily for OEM applications. Sensirion was created in 1998 by Felix Mayer and Moritz Lechner. The products developed at Sensirion are applied in the medical field, automotive industry, and HVAC systems. The technology for the sensors integrates CMOS circuitry. Noticing that these products are used in the HVAC systems, we ordered humidity and temperature sensors from their company's website. This company played a big role for our project because of the need for our HVAC control panel to read the inside and outside temperature and humidity settings. When looking at which part would best work in our system, we had to make sure that these sensors would meet the conditions that the sponsors wanted. In order to meet the conditions, the component that would do that is the SHT21 temperature / relative humidity sensor.

4.2 Printed Circuit Board

The most important issue that comes into constructing our HVAC control system is the printed circuit board design. Printed circuit boards are necessary because it allows all of our IC chips (for Temperature and Humidity) as well as the LED's, resistors, capacitors, memory devices and other electronic circuits to be soldered by surface mount technology directly to the PCB. Without the surface mounting process, we would have to manually connect everything to the board by a soldering iron and the process would take too much time. Nowadays PCB's are assembled step by step using computer based programs. The software used for these computer programs are nice to utilize because they allow for flexibility in board design layout as well as editing in case you make a mistake.

To start the printed circuit board process, our group went onto the website: <http://www.pcb123.com/>. From there, we downloaded the free PCB Design Software. When comparing this software to other existing software available out there, this one best suited our needs. The software acts as a prototype for our HVAC control system so we can refer to it often in case for help. Once we fill in all of the detailed design specifications for our PCB we can directly order it from the PCB software.

Procedure for designing a new printed circuit board using the PCB123 software for our HVAC control system:

1) Call the board any name that you want.
2) Make a netlist file for your printed circuit board. A netlist file will tell the manufacturer in an organized fashion all of the listed individual components, their numbered terminal ports, and where they should be placed on the board.
3) Next step is to define your board size in terms of width and height of the printed circuit board. Make sure to choose a good width and height so that

you give yourself enough workspace to add more electronic components if necessary.

4) After that the PCB designer must select the number of layers that he wants for his design. The designer can choose from 2 layers, 4 layers, or 6 layers. 2 layers are mostly used for simple designs, 4 layers is preferably applied for medium-density designs, and 6 layers mainly works for high density or complex designs.
5) If the user/designer determines that he would like to select either 4 layers or 6 layer PCB board then they have option for adding additional plane layers. Plane layers are sheets of copper material.
6) Subsequently the board has additional features such as coating for the PCB. The designer can decide whether he would want a soldermask or a silkscreen. Our best bet when designing our PCB is to use soldermask, which is a green coating on the circuit board.
7) Then we have an option of choosing which thickness you would like to use. On the PCB123 software, you can select either 0.031 inches or 0.062 inches. For our design which should use 0.062 inches as it is most recommended.
8) Last of all, the copper weight is the next factor in the development of the printed circuit board. There are two alternatives to select from for the type of copper weight that you want: the 1 – oz or the 2.5 oz. The HVAC control system will want a 1-oz to make the finished product for our PCB.

The common standard that is referred to for the design of PCB's is IPC-2221A. IPC stands for the Institute for Interconnecting and Packaging Electronic Circuits which is the authoritative figure that controls every aspect of PCB design, manufacturing, and testing. The key document that describes PCB design is IPC - 2221 which is specifically titled "Generic Standard on Printed Board Design."

When fabricating the PCB, the rules that must be considered when making the foundation for every component being surface mounted on entails board size (tracks), trace width and spacing, pad sizes, holes sizes, and hole spacing.

You may ask yourself, what are the factors that involve picking an accurate board size (track) for your PCB? These parameters depend upon the electrical requirements of the HVAC design, the routing clearance and space available, and your own preference. Standard board spacing for routing is 0.3 inches with an additional 1 to 2 inch border on the board for processing. Larger track width is preferred more because they have low direct current resistance and relatively small inductance. Lower limit of the track width will depend upon the track resolution that the manufacturer for the printed circuit board is capable of producing. Also the size of the board will have a particular amount of resistance given off. Finally, the thickness of the copper substrate will have a huge effect on the printed circuit board when soldered upon.

Pads are defined as a portion of a pattern on PCB's that are selected for the purpose of surface mounting electrical components. The important topics concerning pads involve their sizes, shapes, and dimensions. Pads heavily rely upon the manufacturing process used to make the printed circuit board as well as a person's solder ability. Another factor that is used to evaluate pads on a PCB is known as the pad or hole ratio. More generally the pad or hole ratio is referring to the pad size to hole size. The rule of thumb for the pad on the PCB should be 1.8 times the diameter of the hole because it will let the alignment tolerances on the drill.

Using the PCB 123 software, the manufacturer has the option of choosing which hole sizes he prefers best to implement on the printed circuit board. Make sure to notice that when picking a hole size the plate-through will directly result in making a hole narrow. These plate-through thickness of the holes range from 0.001 inches to 0.003 inches.

Another design rule to consider when making a PCB is trace width and spacing. The trace width of the PCB depends upon the maximum temperature rise of current and as well as the impedance tolerance. The least width of trace and spacing are factored upon the x/y rules. X stands for the least trace width and y is the least trace spacing.

Tracing spacing is an important parameter to discuss when trying to make a PCB. It will tell the designer how to layout the traces width and spacing between the holes. When a manufacturer makes a PCB he has to make sure that you are given adequate spacing, so if the traces are adjacent to the holes there is a possibility that they will be shorted and therefore the board will be no longer good to use. To calculate the spacing requirements one must determine the peak voltage and then plug it into the formula described below.

Trace Spacing
$Spacing(in\ mm) = 0.6 + V_{peak} * (0.005)$
V_{peak} = peak voltage (in Volts)
To find peak voltage in terms of Root - Mean Square Voltage:
$V_{peak} = \sqrt{2} * V_{rms}$

Often when setting a workspace for the development of the PCB, people must lay your board on a fixed grid, called a "snap grid."This will function in order to make all the components on the PCB snap into their permanent positions on the grid. Another grid to question whether a developer would want to use is a visible grid. A visible grid consist of an on-screen grid of solid lines or dots. Here are some facts to bear in mind when working on grids for the design of PCB's.

- A snap grid is crucial because the workspace for the PCB will allow the parts being placed on the board to be neat and well organized.

- Another aspect about a snap grid is that it will make editing, movement of tracks, and components easier to do because the board will eventually expand in size.
- There are two types of grids in a PCB package that a developer in electronics can choose from: a visible grid or a snap grid.

Design Equations for Printed Circuit Boards

The first design factor for printed circuit boards to discuss about is the conductor capacitance. The conductor capacitance is necessary because it will tell the designer how much electrical energy is stored for a given potential. Finding the capacitance is easy to figure out once you are given the thickness of the conductor, the conductor width, and the distance between conductors. To attain the value of the dielectric constant for the substrate that can be looked up in a table with other materials.

Conductor Capacitance

$$C = 0.31 * \left(\frac{a}{b}\right) + 0.23 * (1 + k) * log10 * [1 + \left(\frac{2b}{d}\right) + 2b + (\frac{b^2}{d^2})]$$

k = substrate dielectric constant
a = thickness of the conductor
b = conductor width (given in inches)
d = distance between conductors (given in inches)

Another concept that is prevalent in printed circuit board design for manufacturers is conductor resistance. Conductor resistance is affected by the thickness of a wire, length, temperature, and the conductivity of the base material being used. The thickness of the wire is basically the cross sectional area of the substance being fabricated. Area in this case is length of the material times the width of the material. In order to determine the conductor resistance the only specification that a designer needs to take into consideration is the conductor width.

Conductor Resistance

$$R = 0.000227 * W$$

W = conductor width (given in inches)

The characteristic impedance of an electric structure is the ratio of amplitudes of voltage and current waves moving along an infinitely long line. Characteristic impedance comes into view as resistance due to them having the same SI units. The power of the infinitely long line is accounted for since it is being generated on one end of the line and transmitted through the line as well. For a printed circuit board this is the formula used to determine the characteristic impedance of an infinitely long line.

Characteristic Impedance

$$Zo = R + \frac{j\omega L}{G} + k\omega C$$

Z_o = impedance of an infinitely long line (in ohms)
R = resistance (in ohms)
L = inductance (in H)
G = conductivity per unit length of line (in mhos)
C = capacitance (in F)

A microstrip is an electric medium that can be made using a PCB. The cross sectional surface representation of a microstrip can be divided up into 4 components. These components are the conductor, the upper dielectric, dielectric substrate, and the ground plane. Some drawbacks to the microstrip are that they have minimal power handling capacity and high losses. Figure 52 is an illustration of the linear geometric depiction of a microstrip being fabricated on a PCB.

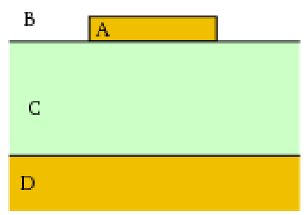

Figure 52 Microstrip Layout on a PCB

A is known as the top conductor, B is the upper dielectric medium, C is defined as the dielectric substrate or level between the dielectric and the conductor, D is referred to as the ground plane

Illustrated below is the method to calculate the characteristic impedance of a microstrip line. The impedance of the microstrip line is altered with the frequency of the material being used. The quasi-static characteristic impedance can affect how the frequency rises or falls for the substrate.

Characteristic Impedance for a Microstrip

$$Zo = \left(\frac{h}{W}\right) * \left(\frac{377}{\sqrt{e_r}}\right) * [1 + \left(\frac{2h}{\pi W}\right) * \left[1 + \ln\left(\frac{\pi W}{h}\right)\right]]$$

h = dielectric thickness
W = microstrip width
E_r = substrates dielectric constant

4.3 Main Control Unit

Our design calls for the main control unit to be powered by a 24V AC common wire that is installed in the building during the initial construction project. The advantage of this design is that the main control unit will run as long as there is power being delivered to the building. The alternative method of powering the main control unit was batteries but our group decided to implement the 24V AC wire into our design, saving the user the hassle of ever having to change batteries. In the future, a redesign may incorporate a backup battery system into the main control unit so that in the event that the building loses power, the backup batteries are able to power the system and the user's settings will not be lost.

The main control unit houses several components of the overall design. The components located in the main control unit are the SHT21 Sensor, the dsPIC33FJ256GP710A main microcontroller, the Zigbee MRF24J40MB wireless chip, and the MRF24WB0MA 802.11b wireless chip. Also associated with the main control unit and therefore powered by the 24V AC wire will be the 7" Evervision LCD touch screen and SLCD5 LCD controller. The 802.11b wireless chip has an operating voltage range of 2.7V – 3.6V with a typical voltage of 3.3V, the Zigbee chip has an operating voltage range of 2.4V -3.6V with a typical voltage of 3.3V, the main microcontroller has an operating voltage range of 3V – 3.6V, and the LCD touch screen and SLCD5 controller require 5V – 12V, and the temperature and relative humidity sensor has an operating voltage range of 2.1V – 3.6V with a typical value of 3V. The SLCD5 controller has an on board switching regulator that generates the 3.3V necessary for the panel to operate. These voltages are shown in Table 32 shown below.

Component	Min Operating Voltage (V)	Typical Operating Voltage (V)	Max Operating Voltage (V)
Main Microcontroller	3	N/A	3.6
Zigbee wireless chip	2.4	3.3	3.6
802.11b wireless chip	2.7	3.3	3.6
Temperature and Relative Humidity sensor	2.1	3	3.6
LCD Touch Screen and Controller	5	N/A	12

Table 32 Minimum, maximum, and typical operating voltages for components associated with the Main Control Unit

In order to power the parts with the voltages mentioned above, there must be circuitry placed on the PCB to convert the 24V AC leaving the wall into a smaller, useable voltage. Another aspect of the circuit is that it must convert the voltage from AC to DC because the input voltages to the components are all DC voltages. Since the main microcontroller, Zigbee wireless chip, 802.11b wireless chip, and temperature and relative humidity sensor all have the ability to operate off 3.3V they will all be connected in parallel.

In order to transform the input voltage from 24V AC to 3.3V DC several steps must be taken. First, the signal needs to be converted from AC to DC. To accomplish this we have decided to use full wave rectification. This is also called bridge rectification and is accomplished through the implementation of four diodes. The bridge diode is an arrangement of four diodes in a diamond configuration so that no matter the polarity of the input, the polarity of output is the same no matter the polarity of the input. In other words, whenever the AC signal would go below the x-axis, the signal is reflected about the x-axis so that the entire signal is above the x-axis. A bridge rectifier that would be applicable to our design is a KBPC8005.

At this point, the entire signal is of the same polarity, but the magnitude of the signal is still not constant enough to be considered DC. The signal is still continuously varying, or "pulsating" in magnitude, which is commonly referred to as "ripple". In order to smooth out the ripple a capacitor, known as the reservoir, or smoothing capacitor is used. The value of the smoothing capacitor is dependent upon the voltage regulator implemented.

Once the signal is smoothed, it is considered close enough to a true DC signal to be sent through a voltage regulator. A voltage regulator is designed to take a DC input voltage and output a specified DC voltage. For our design the desired DC output voltage is 3.3V. This will allow us to use one voltage regulator to deliver the necessary power to the main microcontroller, the temperature and humidity sensor, the Zigbee wireless chip, and the 802.11b wireless chip.

The voltage regulator we have decided to implement into our design is the LM2937-3.3 from National Semiconductor. It has a maximum input voltage of 26V, which makes it eligible for our design because our input voltage will be 24V. The output of the LM2937 is 3.3V DC. When placing this voltage regulator in a circuit, a 0.1uF capacitor should be placed between the regulator and the input, and a 10uF capacitor should be placed between the regulator and the load. The placement of these capacitors is shown in Figure 53 shown below.

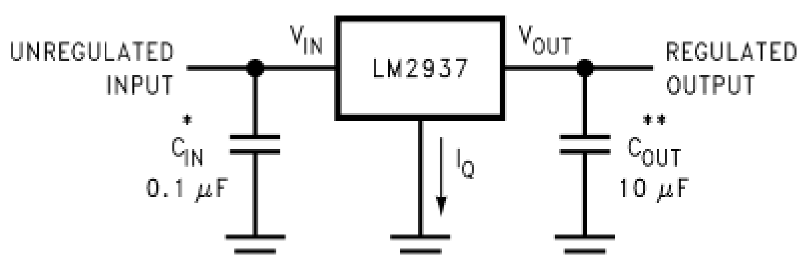

Figure 53 Capacitors Associated with LM2937-3.3 Voltage Regulator (Permission Requested)

Overall, the 24V AC signal must be manipulated in two stages. First, it must be changed from AC to DC. To accomplish AC to DC transformation, bridge rectification is used. The bridge rectifier does not completely smooth out the signal, so a capacitor is placed between the rectifier and the regulator in order to further smooth the signal. Once smooth, the signal is now ready to be dropped to the necessary voltage by passing through a voltage regulator. This process is described in Figure 54 shown below.

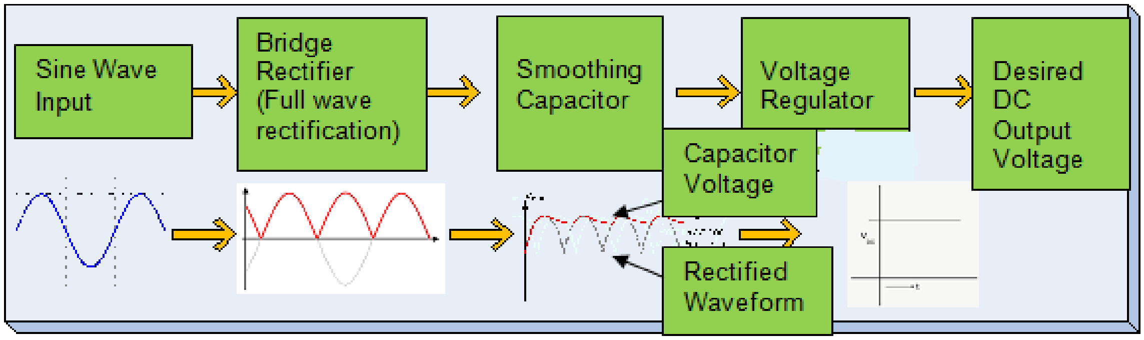

Figure 54 24V AC to 3.3V DC conversion

4.4 Remote Sensing Unit

The remote sensing unit is designed to be mounted on the exterior of a building, where there will not be a power source available. The remote sensing will therefore be battery powered. The components inside the remote sensing are the temperature and relative humidity sensor, the Zigbee wireless chip, and the secondary microcontroller. The temperature and relative humidity sensor has a typical operating voltage of 3V; the Zigbee wireless chip has a typical operating voltage of 3.3V; and the secondary microcontroller has a typical operating voltage of 3.3V. Table 33 shows a typical operating range for the components in the remote sensing unit.

Component	Min Operating Voltage (V)	Typical Operating Voltage (V)	Max Operating Voltage (V)
Secondary Microcontroller	1.8	3.3	3.6
Zigbee Wireless Chip	2.4	3.3	3.6
Temperature and Relative Humidity Sensor	2.1	3	3.6

Table 33 Operating Voltage Range for Components of Remote Sensing Unit

Since the battery will be powering these three voltages, the amount of current being drawn by each component needs to be considered. This is important because a battery must be chosen that will be capable of providing the required amount of current for an acceptable period of time. For our application the batteries should not have to be changed on a regular basis, so a battery must be capable of providing current for an extended period of time. The secondary microcontroller draws 200mA max, the Zigbee chip draws 5mA max, and the temperature and relative humidity sensor draws 100mA max.

The battery we have chosen is a 3.6V lithium battery to power the remote sensing unit. The nominal capacity of the battery is 2.1Ah which should be enough to power our unit for a sufficient amount of time. The temperature and relative humidity sensor, secondary microcontroller, and the Zigbee wireless chip all have "sleep" modes which are designed to reduce power consumption when they are not being used. The remote sensing unit will not be continually reading temperature and relative humidity, but rather will take readings at a time interval set by the programmers (for example, once a minute), send that information to the main control unit, then return to sleep mode until it is time to make another reading. Implementing this method allows the remote sensing unit to consume much less power over time. In order to connect the battery to the PCB, a surface mount battery holder must be implemented. The battery holder has contacts that will connect with the battery as well as contacts that will touch the PCB. This will allow for power transfer from the battery to the PCB. The 3.6V of the battery must be converted to 3.3V to be used by the components and this will be done by a voltage regulator such as the one used in the main control unit. Since the output of the battery is DC, no rectification will be necessary, and the output of the battery can be inputted directly into the regulator.

4.5 Relays

Relays are what will turn on and off the high voltage and high current circuits that power the compressors, air handlers, and dehumidifiers of the HVAC system that our project will be controlling. The point of the relays is to be able to make the decisions using our microcontroller which has very small voltage and current outputs to control a circuit with higher voltage and current characteristics.

For the HVAC control system we have chosen to use an SRS-03VDC-SL relay by Songle. The model is the SRS relay, the 03VDC represents the coil voltage, S represents a sealed structure type, and the L represents a coil sensitivity of 0.36W. This relay could potentially be connected directly to the output of the main microcontroller because the coil voltage of the relay is 3V. The coil voltage is the amount of voltage required by the relay by the controlling circuit. When the coil voltage requirement is met, the EMF created by the coil of wire is sufficient to make the switch change from the "off" contact to the "on" contact. Therefore, because the output voltage from the I/O pins on the main microcontroller is between 3 and 3.5V the relay and the microcontroller could be connected directly to one another. Table 34 shown below describes the key characteristics of the SRS - 03VDC-SL Relay.

SRS/SRSZ	XX VDC	S	L
Model of relay	Nominal Coil Voltage	Structure	Coil sensitivity
SRS	03	Sealed type	L: 0.36W

Table 34 Key Characteristics SRS - 03VDC - SL Relay

For our system, we have decided to not connect the main microcontroller directly. Instead, we have chosen to implement a Darlington array driver. The Darlington array driver is basically multiple transistor circuits built into one chip. The reason for the implementation of the Darlington array driver is because when considering the logic for our system there is potential for multiple outputs to be running at the same time. For example, there will be times when multiple compressors and multiple air handlers will need to be running simultaneously. Powering all of these relays at the same time straight from the I/O pins of the microcontroller would put unnecessary stress on the microcontroller. The Darlington array driver also has built in “clamp diodes” which helps to suppress the inductive kick of the relays. The array driver we have chosen is a chip that contains eight Darlington transistors with common emitters and integral suppression diodes for inductive loads. In specific we have chosen the ULN2803A. This specific array has a 2.7kΩ input resistor. According to the datasheet, in order to turn on each transistor an input current of between 0.93 and 1.35mA is required. The following equations describe how the output from the main microcontroller will meet these requirements.

Minimum output of I/O pin: 3V, Input resistor: 2.7kΩ

$$V = i * R$$

$$i = \frac{V}{R}$$

$$i = \frac{3V}{2700\Omega} = 1.11\text{mA}$$

Maximum output of I/O pin: 3.5V, Input resistor: 2.7kΩ

$$V = i * R$$

$$i = \frac{V}{R}$$

$$i = \frac{3.5V}{2700\Omega} = 1.29\text{mA}$$

These equations show that with the main microcontroller providing between 3 and 3.5V output from the I/O pins, there will be between 1.11mA and 1.29mA delivered to the array driver when the I/O pin goes to its “high” state. This range of current is within the range accepted by the array driver to switch the corresponding internal transistor to the “on” state. The pin will hold its “high” state while the corresponding HVAC component needs to be running and the transistor will stay in its “on” state, keeping the corresponding resistor’s contacts touching providing the control voltage (24V AC) to the power relay that will allow the HVAC system component to run.

4.6 Demonstration

The final step in the prototyping process is the demonstration of the HVAC control system. We will be required to make the system portable so that it can fit into a room to be tested in front of a panel of professors. Because the system is designed to be installed into an existing building, there are obvious modifications that must be made in order to demonstrate the system works to a group of people in a room. Actually installing the system into the building where the demonstration will take place is not an option as there is already and HVAC control system in place. Also, installing it into one of the homes of the group members is not possible because the group is required to have the LCD touch screen interface in the room where the presentation will take place.

Main Control Unit and User Interface

The main control unit and the user interface will be mounted to a surface, such as a sheet of plywood that will allow them to be fastened as if they were installed on a wall in a building, but at the same time be portable enough for the group to carry the system into the room where the demonstration will take place. The main control unit and user interface will be well secured to the backing surface using a method such as screws. The group will wait on the arrival of the LCD screen to see if it comes with any mounting hardware and if it does not they will shop for hardware suitable for mounting a 7” LCD to the wall of a building. During the demonstration all functions of the LCD touch screen will be shown and the group plans on letting a person not in the group operate the touch screen to show that it is easy to use.

Remote Sensing Unit

The remote sensing unit is designed to be mounted on the outside of a building. It is designed to be powered by a battery, and therefore will require no external power supply. This unit will be small in size and easily transportable. It is also designed to communicate with the main control unit wirelessly. Since it does not require external wires for power or for communication, the remote sensing unit is completely self contained. The internal components of the remote sensing unit will all be mounted on a printed circuit board. There will be a sensor, a microcontroller, a wireless chip, and a battery mounted to the board. Since this unit is designed to be placed outdoors, the printed circuit board will be mounted inside of a housing to protect from the harsh elements that outdoor electronic devices are subjected to. Figure 55 below shows an example of a possible weatherproof housing for the remote sensing unit.

Figure 55 An example of a weatherproof wall mount housing for small electronic devices such as a remote sensing unit.

(Permission to use photo pending)

Since there will be a temperature and relative humidity sensor inside the weatherproof box we will need airflow into the box in order to get accurate temperature and relative humidity readings. In order to achieve this we plan on obtaining a weatherproof box and fabricating our own ventilation system for the box. The vents must allow a sufficient amount of air into the box, but still protect the circuitry inside from elements such as rain, snow, and hail. After multiple discussions we have come to the conclusion that the most appropriate place for the vents would be on the bottom of the box. Putting vents on the bottom of the box would allow for sufficient air flow while not allowing any liquid that falls from the sky to get into the internal circuitry.

For the demonstration we cannot bring multiple air compressors, air handlers and dehumidifiers with us into the room. We must be able to demonstrate that our system is providing the correct outputs with power. For the demonstration we will use the LCD user interface to set a temperature for the system to maintain. Once the temperature is set we will then use either a heat gun or a source of cold air to raise or lower the temperature at the main control unit. This process will represent the temperature inside the building either raising or lowering. We will also be manipulating the temperature at the remote sensing unit to simulate the outdoor temperature. Depending on the temperature change at both locations along with user settings the system will come up with the correct course of action to maintain the user set points and take the appropriate course of action.

We will set up several different scenarios to demonstrate the wide range of situations the system can handle. For example for one scenario we may have the user interface set to "maximum energy savings". For this scenario we may raise the indoor temperature by only one degree. The system will recognize this is the situation and will not turn anything on because the user has told the system that there must be more than a one degree discrepancy in the set value and the actual value before it is necessary to begin cooling the building. Another scenario is that we may have the user setting to "maximum comfort" and raise the inside temperature one or more degrees above the set point. Also, we may manipulate the outdoor temperature to be desirable for cooling the building. In this scenario the system will recognize the outdoor air is applicable for cooling the building and instead of using the compressor, it will simply bring the outside air into the building to bring the temperature back to the desired set point.

These scenarios will demonstrate the decision making capabilities of the main control unit along with the wireless / remote sensing capabilities of the remote sensing unit. In addition to demonstrating the functionality of these two aspects of the control system, we must also demonstrate the wireless control capabilities. To demonstrate this we will use one of the group member's smart phones to log onto the web server and manipulate the set points of the system over the internet instead of by using the LCD touch screen in the room.

Since we cannot bring AC units into the demonstration room, and cannot integrate this system to the HVAC system already in place in the room we must find some other way to show that the 24V AC control voltage is being delivered to the appropriate appliances. In order to accomplish this we will replace the AC units and dehumidifier with LED lights. Instead of the actual HVAC components running for a specified amount of time, the LED lights will be illuminated for the same duration of time and a voltmeter will be used by the group to show the correct amount of voltage is being delivered. Overall this form of demonstration is different from the practical application of the HVAC control system but will be sufficient to demonstrate the system is fully functional and has met all requirements.

Section 5: Testing

With the majority of our components for the system coming from the Microchip® Company, one avenue that we pursued was finding development and testing kits made by Microchip for their parts. We need a development system that could accommodate all of our subsystems and components. After checking we were able to find the versatile Explorer 16 Development Board which was just what we were looking for.

5.1 Explorer 16 Development Board

Microchip's® Explorer 16 Development board provides a low cost, modular development system for 16-bit microcontroller families. This board supports both the PIC24 and dsPIC33F microcontroller families which we will be using in the system. This will be the main testing device for our system.

The Explorer Development board offers so many great features and capabilities that will be beneficial to our system for testing, prototyping and building. The development board operates with a direct 9VDC power input, which it then powers down to the +3.3 V and +5 V needed to run our devices being tested. An LCD display on the board lets the tester see real time results when programming the different modules. The board also has a push button switches for user defined inputs and for resets. There are also LED lights for various testing uses as well, which will come in handy when running most of our debugging and testing. On the Explorer board are socket and edge connector for PICtail card compatibility. With both wireless modules we are using in the system having PICtail daughter boards outlined in the sections below, this feature was a key selling point in choosing this development board. The high level block diagram in Figure 56 below outlines the main connections between the integral parts and components.

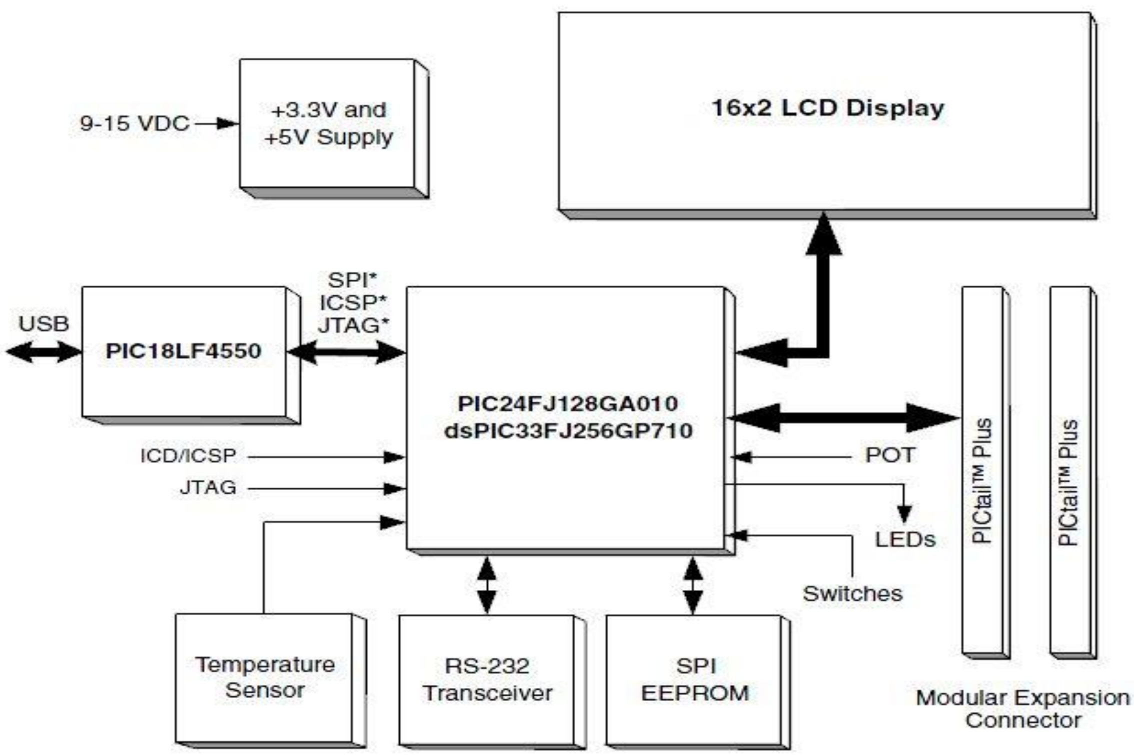

Figure 56 High-Level Explorer 16 Development Board Block Diagram (Reprinted with permission from MicroChip®)

Debugging and testing is going to be the Explorer 16 Development board's primary function. The 6-wire In-Circuit Debugger (ICD) connector included on the board connects to MPLAB ICD 3 software including in the development kit. The MPLAB ICD 3 is a programming/ debugging module made for beginning users for real time debugging, high speed programming and a ruggedized probe interface, perfect for protection against over voltage and current situations.

Included with the Explorer 16 Development Board are two preprogrammed 16-bit sample devices: a dsPIC33FJ256GP710 and a PIC24FJ128GA010. This is great for our system as our main microcontroller unit is under the dsPIC33FJ256GP710 family. One of the great features that accompany the development board is the Plug-in Modules (PIM) options. The secondary microcontroller is not included with the development kit, so having Microchip's® PIM options for the other PIC families are essential for our project. For the secondary microcontroller, we need the 100-pin Plug-in Module (PIM) for our PIC24F04KA201 to test. Microchip® has a PIM with a 28-pin PIC24F16KA102 sample device which can be used with the Explorer 16 Development board. This sample PIM is in the same related family as the PIC24F04KA201, the module we are going with in our design.

5.2 MRF24J40MB PICtail™/ PICtail Plus Daughter Board

To test Microchip's® MRF24J40MB IEEE 802.15.4 RF transceiver module, a PICtail™ daughter board is a perfect solution for developing, testing. This daughter board is compatible with Microchip's® 16-bit microcontroller Explorer 16 Development Board that we are also using. The MRF24J40MB wireless chip module will be placed at the top in the designated slot on the upper portion of the PICtail™ daughter board like the one shown in Figure 57 below.

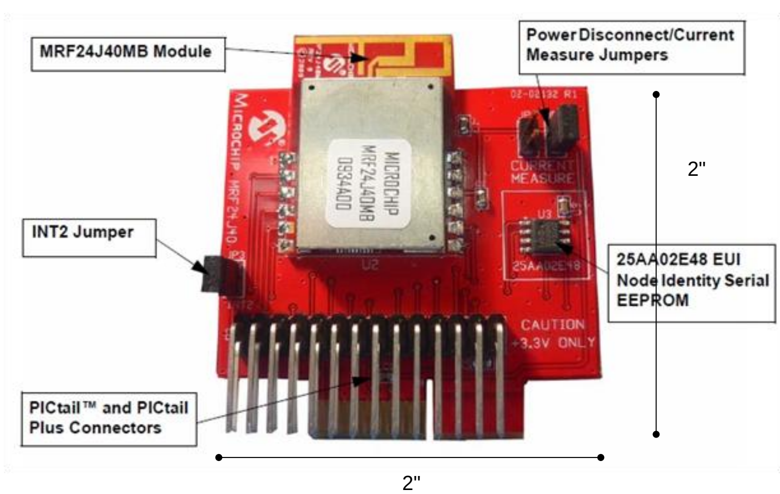

Figure 57 MRF24J40MB PICtail™/ PICtail Plus Daughter Board

(Reprinted with permission from Microchip®)

The MRF24J40MB PICtail/ PICtail Plus Daughter Board can be plugged into the Explorer 16 Development Board. The 30-pin card edge connector can be plugged into the PICtail Plus connector on the development board. Depending on if the card connects to the top section, or the mid-section of the board, it will connect to the SPI Port 1 and SPI Port 2 respectively, on the PIC® microcontroller plugged into the PIM socket, located at the center of the development board. Figure 58 below shows how the daughter board can be easily implemented onto the development board.

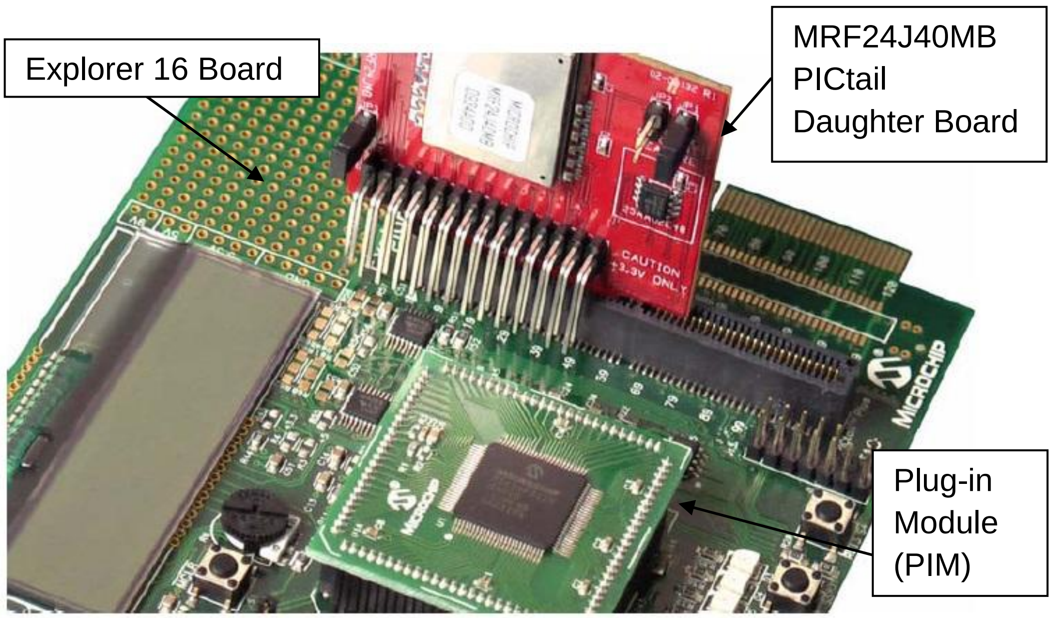

Figure 58 MRF24J40MB PICtail™ Daughter Board plugged into Explorer 16 Development Board

(Reprinted with permission from Microchip®)

5.3 MRF24WB0MA Wi-Fi PICtail/ PICtail Plus Daughter Board

To test Microchip's® MRF24WB0MA IEEE 802.11 Wi-Fi RF transceiver module, a PICtail™ daughter board is a perfect solution for developing, testing. This daughter board is compatible with Microchip's® 16-bit microcontroller Explorer 16 Development Board that we are also using. This demonstration board will evaluate the Wi-Fi® connectivity of the microcontroller using the MRF24WB0MA module.

The MRF24WB0MA PICtail™ daughter board is very simple to program and to use. The Input/ Output pins on the daughter board are very similar to the connections on other Microchip products. The SPI Chip Select (CS), SPI clock (SCK) and the SPI data in and out (SDI, SDO) are the basic 4 connections between the two devices, and the daughter board handles all of those connections as seen the Figure 59 below.

Function	I/O	PICtail™ Pin	PICtail Plus Pin	Description
$\overline{\text{CS}}$	I	RC2	RB2	SPI Chip Select
SCK	I	RC3/SCK	RF6/SCK1	SPI Clock
SDO	O	RC4/SDI	RF7/SDI1	SPI Data Out from MRF24WB0MA
SDI	I	RC5/SDO	RF8/SDO1	SPI Data In to MRF24WB0MA
$\overline{\text{INT}}$	O	RB0INT0	RE8/INT1	Open Drain Interrupt Signal to Microcontroller
$\overline{\text{RESET}}$	I	RB1	RF0	Reset Signal to MRF24WB0MA
HIBERNATE	I	RB2	RF1	Hibernate Signal to MRF24WB0MA

Figure 59 MRF24WB0MA Signal Interface

(Reprinted with permission from Microchip®)

Once the PICtail daughter board in plugged into the Explorer development board, we will then have to download the correct Microchip® TCP/IP stack from Microchip's® Application Libraries at http://www.microchip.com/mal. The daughter board is compatible with the TCP/IP Stack version 5.25 or later. This stack is preconfigured to use the preprogrammed MAC address in the MRF24WB0MA module. This configuration can be changed by modifying the file *WF_Config.h*. The Microchip TCP/IP stack examples are written to interface with an existing wireless router using this information:

- SSID: MicrochipDemoAP
- Channel: 1, 6 or 11
- Security: Disabled

5.4 Safety Considerations

One issue that we have to take precautions for while design and building our system is electrostatic discharge (ESD). ESD happens when electric current flows between two objects at different electrical potentials. These unwanted currents of ESD are the main culprit to electronic equipment damage. To prevent ESD from affecting all of our electrical parts and components, we will be implementing some policies to protect ourselves and the project. Grounding all conductive materials, objects and personnel directly interfacing with the electronic equipment during the prototyping, developing and testing phases of the project is the best way to prevent ESD. Anti-static wrist straps are the most cost effective method to prevent ESD.

5.5 Equipment

To observe and test the behavior of our HVAC control system we are going to use the available devices that are presently in the Senior Design Lab. If some of the instruments are not there for us, we can always buy them from an independent vendor.

- Oscilloscope
  This device will allows us to view signal voltages on an x-y coordinate system. Even though the oscilloscope shows voltages on the y-axis any other quantity can be change to represent voltage such as current. Oscilloscopes are useful because it can display the shape of a particular wave. Each waveform can measure and present various characteristics such as amplitude, period, and frequency. Other features that the oscilloscope can show are the pulse width and rise time of two distinct occurrences.
- Function Generator
  A function generator is electronic software that is used to make electrical signals or waveforms. These function generators generate waveforms such as a sine wave, square wave, triangle wave, and saw tooth wave.
- High Current Ammeter
  An ammeter will be necessary for our HVAC control system because it will measure electrical current in a circuit. The device uses a moving coil with a needle which reads the amount of current being generated by the circuit. As the needle points more to the right the current will start to increase in amperage.
- Breadboard
  A breadboard is used as a construction setup or base for where we place integrated circuit chips in order to connect wires to different I/O ports. We do this so we can test them so that they are working according to our data sheet specifications. A solderless breadboard will be applied as a prototype to test and observe the behavior of components such as LED’s, diodes, resistors, capacitors, and inductors.
- Multimeter
  A multimeter is an excellent device to use for our project because it can measure voltages, currents, and resistances. This electronic tool can be measured either with analog or digital circuits. Another useful method for a multimeter is that it can figure out electrical problems in wiring systems and power supplies.
- Computer Simulation
  Computer simulation is used as a preliminary basis for schematic layout design and printed circuit boards. It will tell us as designers where every components should be placed and how much current and voltage is necessary for these particular parts.
- R, L, and C values
  Resistor, inductor, and capacitor values will be included in our HVAC control system design to accommodate changes when necessary.

- Soldering Gun
  This electric tool is used to solder loose wire connections in a circuit or network. To accompany the gun we must have solder thread to tap out or heat solder filament.

5.6 Environment

The testing environment for the bulk of the time will be spent inside the Senior Design II lab. If other components that we purchase require more workspace to work then our group will go to selected off campus locations in order to construct our HVAC control system. In coordination with our sponsors traveling to different sites to test out their different systems might be necessary. When placing our HVAC control system outside it must have a cover to protect its electrical components in case of bad weather due to heavy amounts of precipitation. Wherever we choose a place to work at it must have a high standard of safety and procedures in case of electrical fire due to a wire being shorted or overrun with too much input current as well as having an electrostatic discharge.

5.7 Final Specifications and Requirements

5.7.1 Final Specifications

Through collaboration with our sponsors, we have been able to produce a set of specifications to go with our Efficient HVAC Control and Feedback System. The final specifications we have been able to produce through our research and design work have come out very similar to our initial specifications. We found that the amount of parts available for electronics based projects such as ours is so large that with enough searching almost any realistic specification can be met. The final specifications we have come up with for the Efficient HVAC Control and Feedback system are shown below in list and table form.

- Total cost of the system materials is below $1500 (including development kits)
- Intersystem wireless data transmission (temperature and relative humidity values) over a distance of 100 feet or more
- 802.11b wireless connection to allow for remote control of system via mobile device
- Delivery of 24V AC control voltage to all HVAC components
- Realistic temperature (0 ˚F - 110˚F) and relative humidity (0% - 100%) measurements for exterior of building
- Measurements of interior temperature with an accuracy of +- 0.5 ˚C
- Measurements of exterior temperature with an accuracy of +- 0.5 ˚C
- Measurements of interior relative humidity with an accuracy of +- 5%
- Measurements of exterior relative humidity with an accuracy of +- 5%
- LCD touch screen interface with diagonal screen size of 7”

Table 35 shown below describes about the specifications between the main and secondary microcontrollers for the HVAC control system.

Main Microcontroller	Secondary Microcontroller
Supply Voltage: 3 – 3.6V	Supply Voltage: 1.8 – 3.6V
Up to 40 MIPS	4 Kbytes program memory
Two 40 – bit accumulators	1 SPI port
32/16 and 16/16 divide operations	1 I^2C port
16 x 16 fractional/integer multiply operations	1 UART port
256 Kbytes Flash memory	C Language compatible
30 Kbytes RAM	18 programmable I/O pins
85 programmable I/O pins	10 – Bit A/D converter
2 SPI ports	3 timers
2 I^2C ports	512 bytes RAM
2 UART ports	

Table 35 Final microcontroller specs

The main microcontroller that is used in the design requires a supply voltage of 3 – 3.6 V in order to be powered on. It has 85 programmable I/O pins that will be used as outputs to control relays. It has 2 SPI ports, 2 I^2C ports, and 2 UART ports that will be used for interfacing with other components in the main control units. The 256k bytes of on-board flash memory will be used to store the programming for the decision making logic and the 512 bytes RAM will run the program. All programming for the main microcontroller will be done using the C language.

The secondary microcontroller that is used in the design requires a supply voltage of 1.8 – 3.6V in order to be powered on. It has 1 SPI port and 1 I^2C port that will be used to communicate with the sensor and the ZigBee chip. The programming will be stored in the 4K bytes program memory and the 512 bytes RAM will run the program. All programming for the secondary microcontroller will be done using the C language.

5.7.2 Final Requirements

The sponsor for our project, AC3 Development Group, LLC provided the requirements for our project. The high level requirements of the system are as follows. The system is required to sense temperature and relative humidity from inside and outside a building (residential or commercial), read the settings determined by the user (inputted via LCD touch screen interface), and make an intelligent decision to satisfy the preset temperature and relative humidity levels in the most effective and energy efficient manner.

The system is intended to either be retrofitted to an existing HVAC system, or to be installed in a new building but only require essentially the normal wiring that would be installed for a normal HVAC system. In order to avoid running additional wire not normally associated with an HVAC system inside either an existing structure, or a newly constructed building the temperature and relative humidity measurements taken outside must be transmitted to the Main Control Unit wirelessly. In order to achieve wireless data transmission, the sensor must make its readings; pass the data to a microcontroller which, in turn, must pass the data to a wireless chip that will communicate with another wireless chip on the Main Control Unit.

The wiring for the air conditioning units to be controlled is already installed in the building, and therefore controlling the power relays to turn the air conditioning units on and off can be done via wire. AC units typically run on 240 Volts AC. To get this voltage to the units, a power relay must be switched to essentially complete a circuit connecting the units to the main 240V power supply from the building. Out control system is required to switch appropriate relays to send 24 V to the 240 V power relays which turn on the AC units. To control each unit, a signal must be used for each of the following functions of the unit. The HVAC components of an air conditioning system are, 1st Stage Heating, 2nd Stage Heating, Blower / Fan, Compressor, Reversing Valve, and 24V Common. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers set standard naming and color coding standards for these functions that we plan to follow in both our system design and the planned demonstration. Table 36 shows each HVAC Component along with its ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Naming and Color Coding Standard.

HVAC Component	ASHRAE Naming & Color
1st Stage Heating	W1
2nd Stage Heating	W2
Blower / Fan	G
Compressor	Y1
Reversing Valve	O
24V Common	R

Table 36 HVAC Components and the Corresponding ASHRAE Naming and Color Standards

The subsystem that controls new air flow into the building is required to control four dampers in the ducts of the HVAC system, and is required to be controlled wirelessly. These four dampers will control airflow through the ducts depending on user controlled settings via the touch screen. If a dehumidification unit is not integrated into the existing HVAC system at the time the Efficient HVAC Control and Feedback System is installed, it must also be controlled wirelessly.

Section 6: Conclusion and Summary

The overall writing procedure included research of all topics of the system, designing schematics and block diagrams, and describing how to accomplish all required software and hardware features for our Efficient HVAC Control and Feedback System. The first task was gaining an understanding of conventional HVAC systems and once we acquired this knowledge we were able to implement those fundamental concepts into the design, build, and testing procedures associated with the Efficient HVAC Control and Feedback System. Our group's primary focus was to take an existing HVAC system that is installed in every residential and commercial building and creatively expand on it in a way that would make the system more functional and efficient for both residential and commercial applications.

The Efficient HVAC Control and Feedback System allows the user to control both temperature and relative humidity levels inside a building. The user has the ability to control the system through an LCD touch screen inside the building, or remotely by accessing a web server through any Internet capable mobile device. The web server and LCD touch screen are also updated with real time temperature and relative humidity levels so the user can monitor current conditions inside their building either from inside the building or at a remote location.

Along with the ability to control temperature and relative humidity levels, the Efficient HVAC Control and Feedback System has a function for introducing fresh air into the building. This function is unique to our system and has never been implemented into an HVAC control system. Traditional HVAC systems recirculate the inside air when cooling or heating the building. Bringing in outside air using the HVAC system has several benefits such as better health, more comfort, less housework, money savings, and better security. An air exchange provides a cleaner interior by removing indoor air contaminants such as smoke, dust, germs, gases, mold spores and odors and replacing it with filtered, outdoor air. The air exchange part of the system can be set to run either on a schedule, or only when the outdoor air conditions are favorable to cool or heat the building in order to save energy.

Energy savings is another key feature of the Efficient HVAC Control and Feedback System. By allowing the user to set the relative humidity level along with temperature, the air conditioner is not always required to be started when the inside conditions are not ideal. The system has multiple settings to allow the user to select between "max comfort" and "max savings". Choosing a level between the two settings allows the user to specify to the system how much the conditions must differ from the set conditions before action will be taken. This difference is known as the “comfort band.” The setting that has been selected will be shown to the user on an “energy usage bar” located on the home screen of the LCD display.

In a standard 3-Ton air conditioning system, any time the inside conditions are not ideal the entire system is powered on, using about 4000 Watts of power. With the Efficient HVAC Control and Feedback system, there are multiple methods available to cool or heat the building. First, if the air temperature is within the comfort band setting, but the humidity is above the comfort range, the dehumidifier will be powered on until the humidity is back at a comfortable level. Typical dehumidifiers use about 500 Watts of power and therefore this option uses 1/8 of the power that a typical 3-Ton air conditioning system would be using for this scenario. If the temperature is mildly above the comfort band settings, the system will use only the 1-Ton air conditioner to cool the building which typically uses 1500 Watts, or 3/8 of the power that would have been used in this scenario. If the temperature and humidity are mildly higher than the comfort band setting, the 1-Ton air conditioner and the dehumidifier will both work to bring the conditions back to within acceptable range. This will use 2000 Watts which is ½ of the power that would normally be used. With the temperature moderately above comfort settings, the 2-Ton air conditioner will be activated, consuming 2500 Watts, which is 5/8 the power that would normally be used. With both temperature and humidity moderately above the comfort settings, the 2-Ton air conditioner and the dehumidifier will be activated, using 3000 Watts, or ¾ of the energy of running the entire system. Only on the hottest days of summer, with the max comfort setting selected will both air conditioners and the dehumidifier be activated, and the full 4000 Watts of power be used. Breaking down the HVAC system controls in this way allows the system to consume significantly less power than a traditional system, hence save the owner money on the electric bill.

In order to complete the system, we had to do research, shop for parts, and create a design to implement all of the necessary components. The components that make up the system include, relays, relay drivers, power supplies, main and secondary microcontrollers, printed circuit boards, LCD screen, temperature and relative humidity sensors, and wireless communication chips. The hardware components of the system will be what make up the total cost to build the system, as we will be doing all of the software design and coding ourselves. Our, sponsors, AC3 Development group LLC have specified a budget of $1500 for the overall design and build of the system, and therefore we had to take cost into consideration during the hardware design process.

The Efficient HVAC Control and Feedback System has two main components. The less complex of the two components is the Remote Sensing Unit. The Remote Sensing Unit has the responsibility of measuring the outdoor temperature and relative humidity and reporting these values to the other component, the Main Control Unit. The Remote Sensing Unit uses a single sensor that is capable of making the temperature and the relative humidity reading. The sensor reports to the secondary microcontroller. The secondary microcontroller is the central component of the Remote Sensing Unit and is interfaced to the sensor and the wireless communication chip. The secondary microcontroller receives the temperature and relative humidity information from the sensor and takes care of any manipulation that must be done to put the information into a form accepted by the wireless chip. The wireless chip is then given the information by the secondary microcontroller, and the information is reported to another wireless chip in the Main Control Unit.

The Remote Sensing Unit is located on the exterior of the building. Throughout the design process we have kept in mind that installation of the system needs to be kept as simple as possible. The purpose of a simple install is so that the system will be able to be installed in a new building in the same manner that a typical HVAC system would be installed or it can be retrofitted to an existing structure without having to run new wire through an existing building. Since the Remote Sensing Unit is intended to be installed on the exterior of the building, three issues must be taken into consideration. First, there is no power supply where the Remote Sensing Unit will be installed, therefore battery power is needed. The battery needs to power the Remote Sensing Unit for a sufficient period of time because changing the batteries on a regular basis is not realistic. Secondly, the Remote Sensing Unit must be protected from the elements such as rain, and snow. In order to protect the Remote Sensing Unit it will be placed in a weather proof box. Although the box is weatherproof, it needs to allow air flow so that temperature and relative humidity readings are accurate. The third issue is installation. The Remote Sensing Unit needs to be housed in an enclosure that is made to be mounted onto a wall using screws.

The Main Control Unit is the other main component of the system. The Main Control Unit consists of the main microcontroller, a temperature and relative humidity sensor, two wireless chips and, the LCD touch screen user interface. This is the part of the system where the decision will be made about which components of the HVAC system will be turned on. The main microcontroller is interfaced with a temperature and relative humidity sensor, an 802.11b wireless chip, a ZigBee wireless chip, control relays, and the LCD touch screen user interface. The Main Control Unit Uses the current indoor and outdoor temperature and relative humidity values, and the user selected settings as input and determines what is necessary to heat or cool the building. The signals from the main microcontroller goes to 24V relays which then send a 24V control voltage to the appropriate component. The Main Control Unit updates the touch screen display and the web server so that current and accurate information is displayed at the two user interfaces.

The LCD Touch Screen display is the main user interface for the system. It is composed of a display and a controller. The controller is what is programmed and interfaces with the main microcontroller. The controller produces the image on the display and also reports to the main microcontroller what has been touched on the screen. The display is composed of a home screen and several sub screens. The home screen displays the logos of the sponsors, the current indoor conditions, the set points for temperature and relative humidity, the max comfort / max savings settings, and the energy usage bar.

The software design process is another obstacle to overcome. The programming involves the "brains" of the system. The programming allows all of the components to interact with each other and allows the system to respond to the user exactly how it is expected to. There are three main programming tasks that must be accomplished in order for the system to meet our expectations.

First, the microcontrollers need to be programmed. The secondary microcontroller does not require extensive programming as it is only responsible for passing information from the sensor to the ZigBee wireless chip. The main microcontroller requires extensive programming. It takes input from the LCD touch screen, the temperature and relative humidity sensor, the ZigBee wireless chip, and the 802.11b wireless chip. Ultimately the main microcontroller is what turns on an input / output pin to send the correct voltage to the control relays and keeps that pin "high", or on, until the HVAC component being controlled needs to be turned off. The microcontrollers will be programmed using the Explorer 16 Development Kit from Microchip. The Explorer 16 allows the programming to be done in C which is the programming language our group is most familiar with. The ability to program in a high level language such as C or C++ make the programming take significantly less time than if we were forced to program in a low level language such as an assembly language.

Next, the LCD touch screen needs to be programmed. The LCD screen communicates with the main microcontroller through a controller board. The controller board connects to a PC through either serial connection or USB connection. The controller board is then loaded with bitmaps and macros through the BMPload program. The programming for the LCD touch screen will consist of setting up a home screen and several other sub screens. The home screen is what will be displayed when the unit is initially powered on and will have the main options for the user to manipulate. If a button is pressed that requires more options to be displayed, the LCD will then bring up another screen depending on which button was pressed. The controller board reports back to the main control unit which button has been pressed as the user is manipulating the screen. The LCD is the main user interface for the system so the programming is essential to the overall success of the system.

Lastly, the web server needs to be programmed. The web server is what gives the user remote access of the system using an Internet ready mobile device. The web server needs to communicate with the main microcontroller so that the web server can be updated along with the rest of the system. The web server will be set up to be display current indoor and outdoor temperature and relative humidity and allow the user to set new values for temperature and relative humidity as well as manipulate all other options that are available on the LCD touch screen.

Considerations have been made to allow features to be added to the system in the future. All aspects of the system are able to be reprogrammed in the future. Features such as air purification components, CO2 sensors, airflow sensors, and severe weather alerts are all possibilities of additions to the system in the future. Air purification would allow filters to be installed to clean the air being circulated in the building, CO2 sensors would alert the user if dangerous levels exist in the building, airflow sensors would alert the user that a filter needs to be changed, and severe weather alerts would alert the user of storms that will be effecting the building in the near future. These features and alerts would be added to expand the functionality and capability of the system as a whole.

With the increased capabilities of cost effective technologies and the growing demand for energy efficient systems, the need for intelligent control systems is higher than it has ever been. In specific, efficient HVAC control systems are in high demand. Because virtually every building has an HVAC system associated with it, and the fact that the HVAC system is usually the leading energy consumer in the building the need for an efficient HVAC control system is particularly high. The system to be constructed is designed to reduce the energy consumption of the traditional HVAC system by making smart decisions as to which components to run, by adding a dehumidification element to the process, and by using outside air to help heat or cool the building when applicable. In addition to outside air being used to heat or cool the building, outside air helps to filter unwanted contaminants out of the building along with the old stagnant air. By combining the user interfaces of an LCD touch screen and a mobile web server, the user is able to interact with the system using technologies of wireless Internet connectivity and touch screen sensing that have only recently become inexpensive enough to be utilized for this application, making this system a cutting edge technological system. Smart control and feedback systems will become more common as technology becomes less expensive and as demand continues to rise, and therefore the Efficient HVAC Control and Feedback System is a product that is on the leading edge of products intended to save energy and money.

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- Bruno, Frank. “Wireless Pulse-Oximeter.” Senior Design Group 7 Spring 2010. <http://eecs.ucf.edu/seniordesign/fa2009sp2010/g07/>
- Daigneault, Marc. “HVAC Monitor.” MGD Engineering. <http://www.mgdengineering.com/hvac.htm>
- Graffagnino, Frank. “House Temperature Data Logging.” <http://www.graffagnino.net/frankie/projects/house_temperatures/>

Appendix A: Datasheets

Explorer 16 Development Board User's Guide by Microchip

dsPIC33FJXXXGPX06A/X08A/X10A Data Sheet by Microchip

PIC24F04KA201 Family Data Sheet by Microchip

PIC24FXXKAXXX Flash Programming Specs

MRF24WB0MA/MRF24WB0MB Datasheet by Microchip

MRF24J40 Datasheet by Microchip

SHT21 Datasheet by Sensirion

SRS-03VDC-SL Datasheet by Songle Relay

LM2937-3.3 Datasheet by National Semiconductor

ULN2803A Datasheet by SGS-Thomson

51-0102-21 7" Evervision LCD Module Datasheet by Reach Technology

SLCD5 Reference Manual Version 1.34 by Reach Technology

Appendix B: Copyright / Permissions

Derick

We would be glad to let you use 3M images with the proper "Provided courtesy of 3M Touch Systems" acknowledgement. Not all the images on that site were our images. Which ones are you specifically interested in?

Regards,

Tim.

3M

Tim Holt | Communications Manager
3M Touch Systems
3M Electro & Communications Business
501 Griffin Brook Park | Methuen, MA 01844
O: 978 659 9379
tholt@mmm.com | www.3M.com/touch

Check out the new touch industry reference site: www.touchtopics.com

3M Touch videos are now available at www.youtube.com/3mtouchsystems

Start receiving 3M Touch News by signing up at www.3m.com/enews

Contact 3M

Send an e-mail to 3M. Do you have a question or comment about a 3M product or service? Please complete the form below.

Required fields are indicated by an asterisk (*).

Top of Form

*Subject of your message: Asking permission to use pictures on website

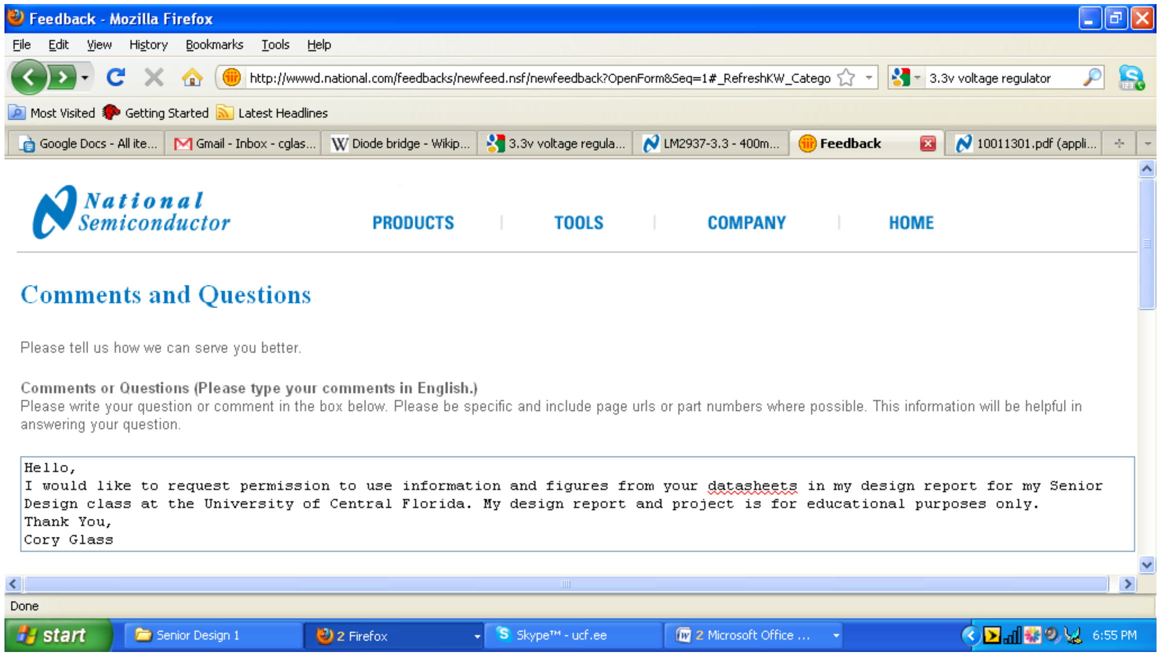
Please provide the information that will help us respond to your request.

I am a Senior at the University of Central Florida in Orlando, Florida. I am in my Senior Design class and our group is building an HVAC control system. I would like to ask permissions to use the touch screen pictures on the website:
http://wiki.fluidproject.org/display/fluid/Benchmarking+-+Touch+Screen+Options
I was told to contact you by the webpage publisher/author for permissions privileges.

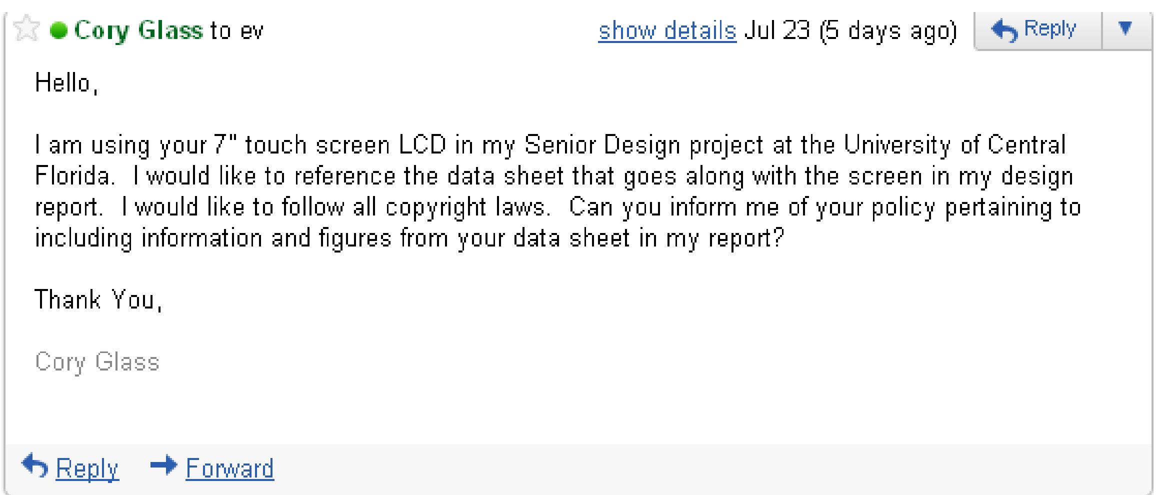
Thanks very much,

Derick Holzmacher
Phone Number: 727-580-6767

National Semiconductor Permission:



Evervision LCD Permission:



kelly_chen to me show details Jul 27 (1 day ago) Reply

Dear Sir,

Thanks for your notice. Basically, we don't have any special copyright rules for our product, it depends on what the purpose you need for. Could you please also let me know where you get our sample and data sheet?

Thank you.
Best regards,
Kelly Chen

EVERVISION Electronics Co., Ltd.
EU/US Sales & Marketing Division
Tel : 886-2-8227-2788 ext 316
Fax : 886-2-8227-2799
Web : www.evervisionlcd.com

Reach Technology Permission:

datestamp: 2010-07-24 2:05 pm
Full Name: Cory Glass
Company: UCF
Email: CGlass08@gmail.com
Comments: Hello,

I would like to request permission to use information and figures from your data sheets in my design report for my Senior Design class at the University of Central Florida. Thank You

Jonathan More to me, Audrey show details Jul 26 (2 days ago) Reply

Dear Cory -

You have permission to use information and figures from our data sheets in your design report.

Thanks for asking - very professional.

Regards,

Jonathan More
President
Reach Technology Inc.
155 B Avenue Suite 200
Lake Oswego OR 97034
PH: 503-675-6464 ext.111
FX: 503-675-7554
www.reachtech.com

Microchip Permssion:

-----Original Message-----
From: Cory Glass [mailto:cglass08@yahoo.com]
Sent: Thursday, July 01, 2010 1:21 PM
To: Eric Lawson - C11906
Subject: Permission to use Data and Figures

To whom it may concern,

I am seeking permission to use figures and information from your data sheets in a design report I am writing for Electrical Engineering Senior Design class at The University of Central Florida. I am using MicroChip parts almost exclusively for my project and the information and figures from your data sheets would be useful content to include in my design report.

RE: Permission to use Data and Figures

Mon, July 12, 2010 12:42:15 PM

From: "Eric.Lawson@microchip.com" <Eric.Lawson@microchip.com> Add to Contacts
To: cglass08@yahoo.com

Hi Cory,

Please follow the guidelines from Microchip's Legal Department, which are on the following Web page:
http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=487&param=en023282

Thanks,
Eric Lawson, Public Relations Manager
Microchip Technology Inc.
480-792-7182, Fax: 480-792-4150
eric.lawson@microchip.com
2355 W. Chandler BLVD.
Chandler, AZ 85224

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From: djho@tampabay.rr.com

To: granstratman@yahoo.com

Cc:

Subject: Asking permission to use pictures on website

Priority: Normal **Date:** Sunday, July 25, 2010 10:16 PM **Size:** 967 Bytes

Hello,

My name is Derick Holzmacher and I am part of a Senior Design group at the Unversity of Central Florida in Orlando, Florida. We are designing a HVAC control system as our Senior Design project. While researching, I have come across Volume Control Damper picture and the Manual Balancing Damper picture. I would like to request your permission to reuse these pictures from your website in our initial design documentation.

Thank you very much.

Sincerely,

Derick Holzmacher

Home > Contact Info

Contact Us

First Name *	Derick
Last Name *	Holzmacher
Title	Electrical Engineer
Company *	University of Central
Website	
Email *	djho@tampabay.rr.cc
Phone *	727-580-6767
Fax	
Address	

Your details will remain secure with us and will not be passed on to any third party.

You can also contact us at:

Densitron Europe	Email sales@densitron.co.uk Phone: +44 (0)207 648 4200
Densitron America	Email DCAWebSales@densitron.com Phone: +1 951-284-7600 x 252
Densitron Asia	Email sales@densitron.com.tw Phone: +886 2 2698 1266
Densitron Japan	Phone: +81 3 3767-9701
Densitron France	Email france.sales@densitron.fr Phone: +33 251 710 158
Densitron Germany	Email info@densitron.de Phone: +49 (0) 811 55 05 949
Densitron Nordic	Email sales@densitron.fi Phone: +358 9 270 93010

Country *	United States	Or view our comprehensive offices and representatives section.
Postal Code/Zip *	32765	* indicates a required field
Comments	I am a Senior at the University o I am building an HVAC control s Thanks very much.	

Contact Us

Customer Care

Elo takes all customer input seriously as part of our ongoing continuous improvement efforts. If we fail to meet your expectations, please let us know by submitting this form or calling 1-800-557-1458 (option 2).

Required fields

Requestor Name	Derick Holzmacher
Company	University of Central Florida
Contact (if different from Requestor)	
Address1	
Address2	
City	Orlando
State/Province	Florida
Zip/Postal Code	32765
Country	United States

Phone	727-580-6767
Fax	
E-mail Address	djho@tampabay.rr.com
Sales Manager	
Action (Select one)	Response Required Commentary Only
Part Number (where applicable)	
Model/Description	
Serial Number(s)	
Describe Issue (max 3990 characters)	Titled: Asking permission to use pictures on we I am a Senior at the University of Central Florida http://wiki.fluidproject.org/display/fluid/Benchm

Submit Reset

From:	djho@tampabay.rr.com
To:	permissions@questex.com
Cc:	

Subject: Asking Permission to use pictures on website

Priority: Normal **Date:** Sunday, July 25, 2010 9:44 PM **Size:** 1 KB

Hello,

My name is Derick Holzmacher and I am part of a Senior Design group at the Unversity of Central Florida in Orlando, Florida. We are designing a HVAC control system as our Senior Design project. While researching, I have come across the Choosing a Humidity Sensor: A Review of Three Technologies article. I would like to request your permission to reuse these pictures from your website in our initial design documentation.

Thank you very much.

Sincerely,

Derick Holzmacher

I previously went to your contact us link on your website and faxed a copy explaining myself that I was going to use these pictures on the website and I was asking for permission to use them. I faxed it to your Permissions Department in Newton Massachusetts and it has been a month and they never have responded to my request. Can you help me out with this predicament?

Phone Number: 727-580-6767
Email: djho@tampabay.rr.com

Abbreviations and Acronyms

AC – Alternating Current
ACK – Acknowledgement Frame
ADC – Analog to Digital Converter
CpE – Computer Engineering
CPU – Central Processing Unit
CR – Contrast Ratio
EE – Electrical Engineering
EEPROM – Electrically-Erasable Programmable Read-Only Memory
GHz – Gigahertz
GM – Group Meetings
HVAC – Heating, Ventilation, and Air Conditioning
I/O – Input/Output
I^2C – Inter – Integrated Circuit
IC – Integrated Circuit / Integrated Chip
IDE – Integrated Development Environment
ISA – Industry Standard Architecture
ISM – Industrial, Scientific and Medical
LCD – Liquid Crystal Display
MAC – Media Access Control
Mbps – Megabits per second
MCU – Main Control Unit
MIPS – Millions of Instructions Per Second
NC – Normally Closed
PAN – Personal Area Network
PC – Personal Computer
PCB – Printed Circuit Board
RAM – Random Accessing Memory
RF – Radio Frequency
ROM – Read Only Memory
SPI – Serial Peripheral Interface
SRAM – Static Random Access Memory
UART - Universal Asynchronous Receiver/Transmitter
USB – Universal Serial Bus
WPAN – Wireless Personal Area Network
XLP – Extreme Low Power