Department of Electrical and Computer Engineering
University of Windsor

Capstone Project Proposal (88-400)
Form 2: Proposal Form

This form is to show how you lay out the direction for your project. Please have a thorough research about your project and then fill out this form with consulting with your supervisor/co-supervisor. The form will be used as a part of the marking scheme in this course and is worth 10 points (out of 100).

After completion, email this form to the Capstone Design Project Coordinator Dr. B. Shahrrava at shahrrav@uwindsor.ca before the deadline (Monday Feb. 26th, at 4:00 pm).

Project Title:

Intelligent HVAC IoT Control System

Project Description:

Summary:

The "Intelligent HVAC IoT Control System" is a series of easy-installation products that allow residential home owners to upgrade their existing home heating, ventilation and air conditioning (HVAC) systems to a “zoned” HVAC system. This would allow customers to achieve room-level temperature control and be able to add an unlimited number of temperature-controlled zones to any home HVAC system.

The Capstone project involves creating three separate communication products, a “main hub” thermostat that replaces the traditional HVAC thermostat in houses, “room temperature sensors” that are placed in rooms/areas around the house, and “smart vents” that replace the traditional vent covers in houses. An overview of the system is given in Figure 1.

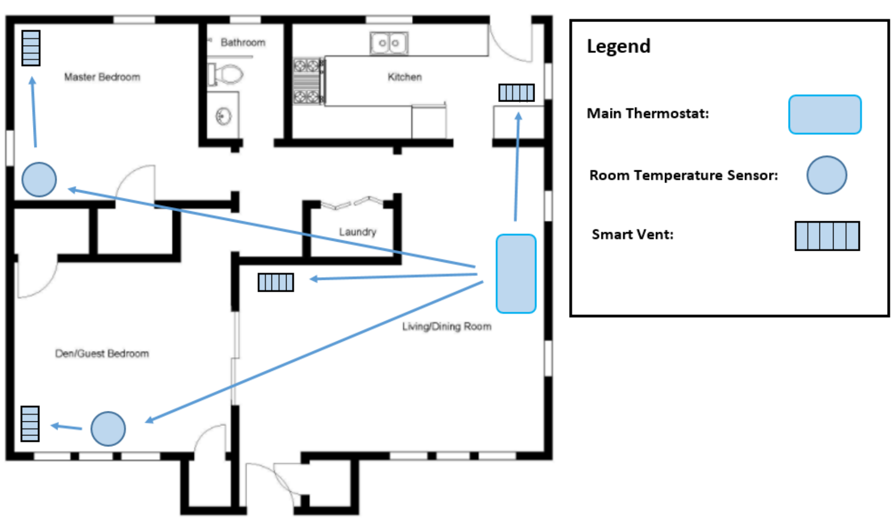

Figure 1 – Overview of Design

The vents, room temperature sensors and main thermostat shown in Figure 1 are enlarged for illustration purposes.

The concept illustrated in Figure 1 provides a high level overview of the final product system. It involves a main hub thermostat communicating with both room sensors and smart vents over an RF communication protocol to dynamically adjust the output of the heating and air conditioning units of the house. The room temperature sensors communicate with the smart vents to tell them how open or closed they should be. By controlling the amount to which the vent is open or closed a room temperature sensor can make the temperature of a specific room or zone any desired temperature by simplify increasing or decreasing the openness of the vents it controls. It is important to note that the room sensors are optional as depicted in Figure 1, however room-level temperature control is not possible in rooms/areas without a room temperature sensor. The main hub can communicate directly with the smart vents if room temperature sensors are not yet installed. This makes the system scalable and customizable. As room temperature sensors are added over time and paired with smart vents the main hub communicates with the room sensors rather than the smart vents. This clever design choice allows customers to add and remove room sensors and smart vents at any time in the lifecycle of the system to provide any level of temperature control desired.

Each product has the following functionality and components:

- **Main Hub Thermostat:** This is an internet-connected thermostat as well as an RF transceiver. This thermostat is hardwired to the heating and air conditioning unit in the house such as a furnace or outdoor air conditioner unit just as a conventional house thermostat is connected. The main hub talks to the room temperature sensors and smart vents using a low power, RF transceiver module. The main hub communicates with the room sensors to determine the temperature of the rooms or zones equipped with room sensors (as stated above, room sensors are not required in every room and can be added at any time to expand the system).
- **Room Temperature Sensor:** The room temperature sensors are equipped with a temperature sensor as well as a low power RF transceiver to receiver commands from the main hub while also instructing the smart vents to open or close. The sensor is set to a desired temperature by the consumer using the simple interface. The sensor then compares the desired temperature with the temperature reading of its temperature sensor and instructs the smart vents wirelessly connected to it to open more or less based on the difference between the two temperature readings. It is important to note that the name “room temperature sensor” is a bit of a misnomer. This is because a room sensor could control many rooms (referred to as a “zone”) not just a single room. Thus with two room sensors customers could effectively divide their house into two “zones” each with a different temperature rather than just controlling two rooms. This means that customers do not need to buy a room temperature sensor for every room, they can group multiple rooms together to create customizable zones. A room temperature sensor can control many smart vents enabling entire sections of a house to be controlled by a single room temperature sensor.
- **Smart Vent:** The smart vents are battery powered vent covers with an on board RF receiver and servo motor. The RF receiver receives instructions from the room sensor or main hub thermostat to adjust how open or closed it is. These instructions are then translated to PWM commands to control the servo motor that opens or closes the vent.

The communication system architecture is shown in Figure 2.

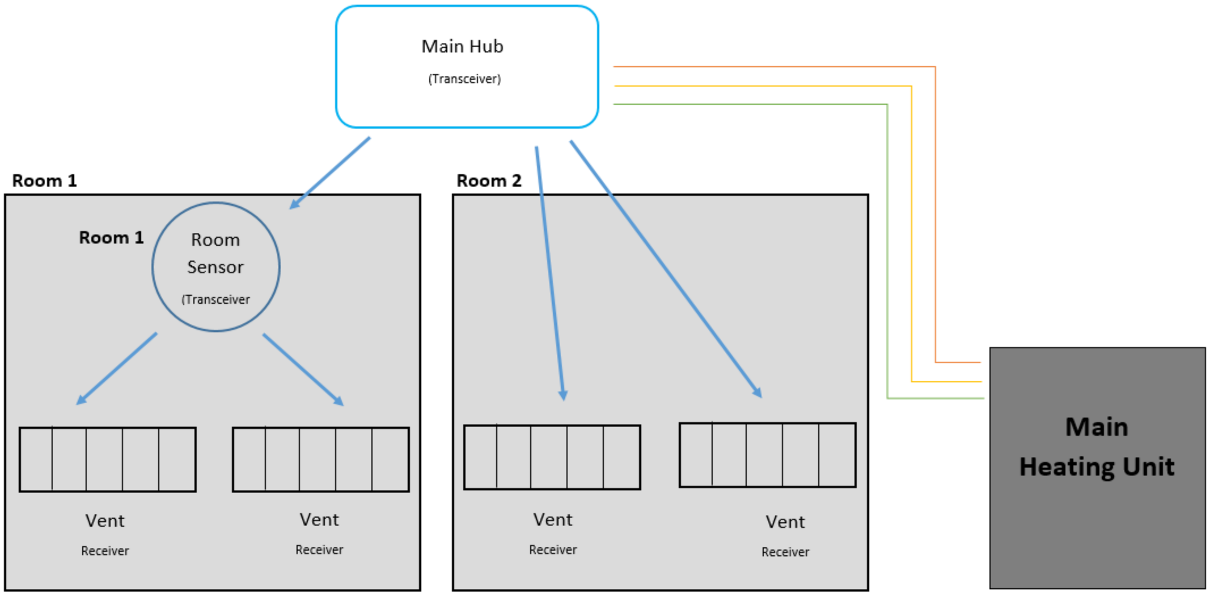

Figure 2 – High Level Overview of the Communication Architecture

The image in Figure 2 is an example of a typical setup, the blue arrows indicating wireless RF communication while the orange, yellow and green lines represent wires connecting the main hub thermostat to a central heating/cooling unit.

Goals and Objectives:

The most important goals and objectives are:

- Room level temperature control
- Demonstrate it working
    - Physical model or other means
- Wireless/Non-invasive installation
    - between devices and battery
    - device association (main thermostat to vent, zoning thermostat to vent, zoning thermostat to main thermostat)
- Wi-Fi connected (IoT)
- Very low power consumption (long battery life) for peripherals
- Low Maintenance – once installed and setup there is very little customer interaction
- Improve efficiency (save money)
- Low liability
- Error handling - when it breaks, it is in a stable state

The goals and features that the team is still considering are:

- Learning your houses heat signature (more than just a control system)
- Low cost
- User defined time changes to temperature
- Approx. time to get to desired temperature

These features and goals need further research in order to determine the value they add to the product versus the added cost and power consumption they introduce to the product as well as the feasibility of the proposed feature/goal.

Brief background:

Motivation for the Product

The idea for the project came from a team with a research and market demand minded viewpoint. The team setout to develop a product that fills a hole in the modern day market while also maintaining an environmentally progressive mentality. The pursuit of home comfort has been endlessly chased by mankind for centuries. With the exponential advancement of electronics in the last two decades many systems in modern homes improved but one in particular has lagged behind the curve. Modern HVAC systems are being built and designed in almost an identical fashion since the first central air conditioning systems in the 1970s. While the concept of treating a house as one large thermal resistive network with one heating and cooling source is well founded in thermodynamics the idea of setting one temperature for an entire house seems like a prehistoric one. With the shift to an "Internet of Things" (IOT) modern society and the increasing demand to have networks and fully controllable systems it is about time the ancient residential HVAC systems of the past get refreshed.

The "Intelligent HVAC IoT Control System" enables homeowners to fully utilize the power of the IoT and embedded systems to have full control of the temperature in their homes and pay for heating and cooling that they actually use. By adding a low cost, easily installable, and intelligent overlay on top of existing HVAC systems customer can not only have more control of their home but also save on energy consumption and money.

After extensive research into the current technology making up the foundation of modern day residential HVAC systems the team began preliminary research into the average cost of heating a home in Ontario, Canada.

The model shown in Figure 3 is a thermal model of a house simulated in Simulink. The system models the outdoor environment, the thermal characteristics of the house, and the house heating system. Without going to far into the technical aspects the model calculates the heating cost for a house by integrating the total heat flow of the system and multiplying it by the energy cost.

The set point of the thermostat (the temperature that must be maintained indoors) is 69°F which is the national average for 2017 based on the Canada Mortgage and Housing Corporation[1]. The thermostat allows for fluctuations of 5°F above or below the desired house temperature. If the temperature drops below 64°F then the thermostat turns the heater on. The outdoor temperature is based on the data from Government of Canada for Toronto, Ontario in the month of February 2018[2] where the mean temperature was -3.4°C (25.8°C) while the mean minimum daily temperature was -7.6°C (18.3°F) and the mean maximum daily temperature was 0.8°C (33.4°F). The average weight of air in a 2,000 square-foot house is 1200 lbs[3] (544.3kg) which is what is being used in the model. The house has two floors with 8 4ft x 2ft windows. The heater is blowing air at a temperature of 122°F at a constant flow rate of 3600kg/hr. The cost of electricity per kilowatt hour is 9 cents which is the average cost per kilowatt hour during the mid-peak time based on the data provided by the Ontario Energy Board[4].

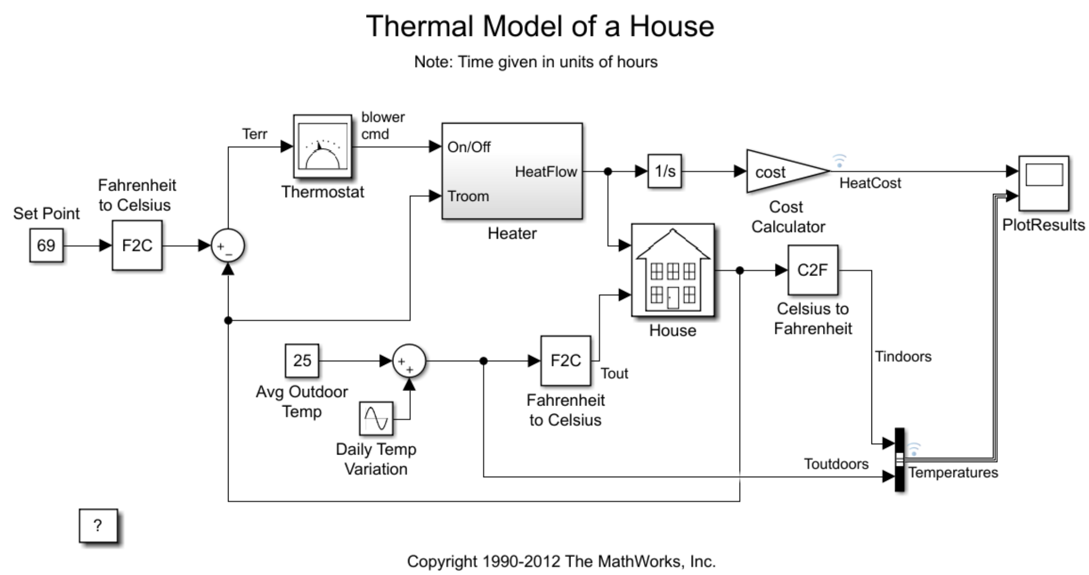

Figure 3 – Thermal Model of a House in Simulink

The simulation results for a period of one month (approx. 733 hours) are shown in Figure 4.

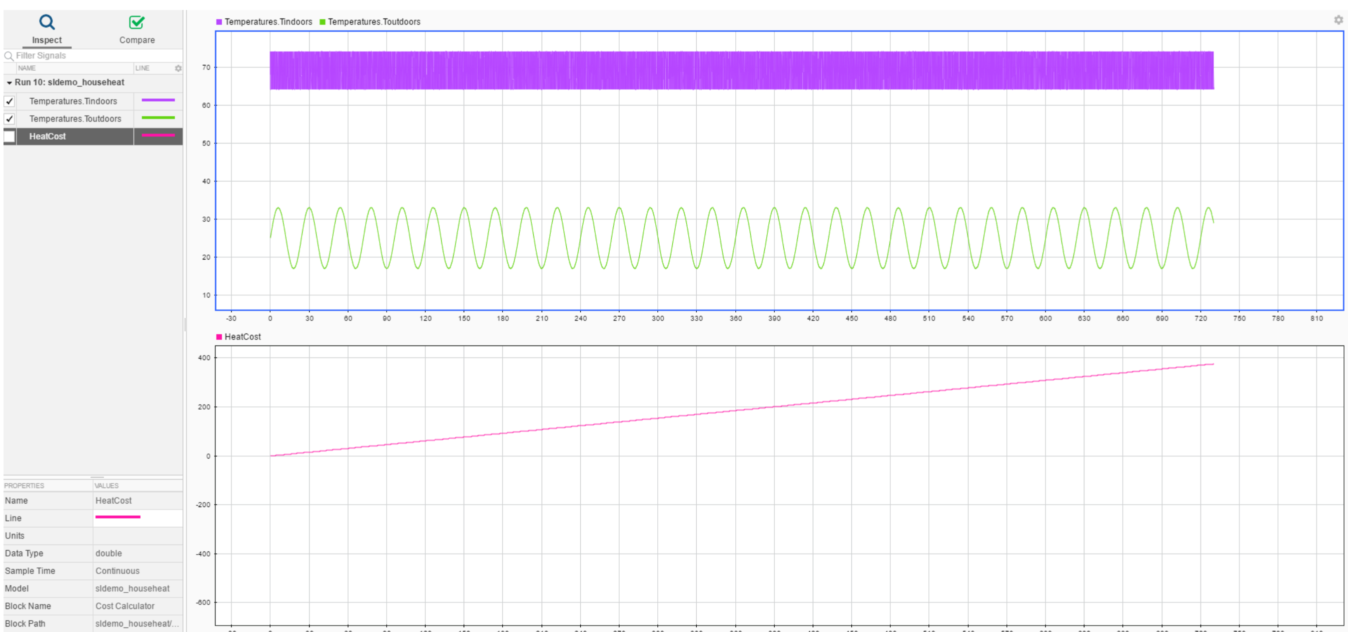

Figure 4 – Simulation Results from Thermal Model of House

As can be seen in the first plot in Figure 4 the indoor temperature of the house (The purple ramp signal) fluctuates 5°F around 69°F as the temperature of the outdoor temperature (The green sinusoid) increases and decreases from 18°F to 33°F as specified. The total cost to heat the house is shown in the second plot of Figure 4 where the total heat flow from the heater is multiplied by 0.09$/kWh and then integrated over 733 hours. The cost to heat the 2,000 square foot house for the month is almost $400.

By modifying the model in Figure 3 to represent a room by room thermal resistance rather than treating the house as one Thevenin equivalent resistance as shown in Figure 5, much lower costs per month were achieved.

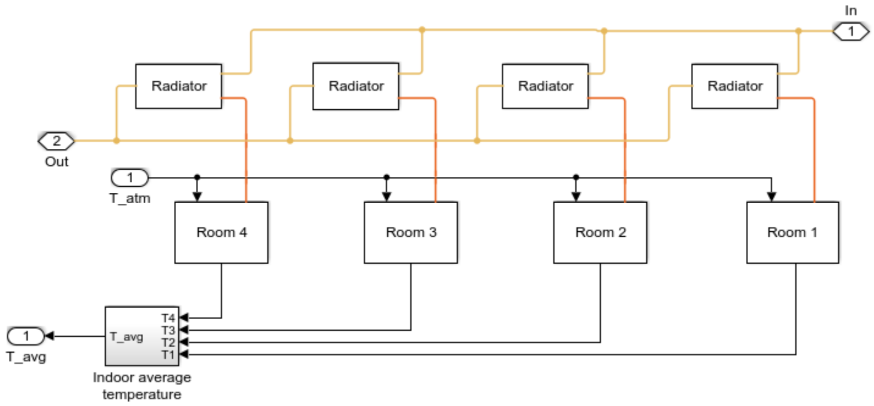

Figure 5 – Room Level Thermal Model of the House

Note that the model in Figure 5 replaces the "House" block in Figure 3 however to emphasize the model of the house only it was shown not the entire model.

Using this new house model while keeping the outdoor temperature model and thermostat model the same a monthly cost as low as $130 was achieved by ensuring that two rooms were at 69°F within 5°F while the other unused rooms at 65°F.

From the simulations and thermal models, it became apparent that there were huge cost saving benefits in addition to enabling customers to have room level temperature control.

Zoning

The concept of zoning in HVAC systems is the dividing of rooms and areas of a building into separately controlled temperature "zones". A traditional zoned HVAC system is shown in Figure 6.

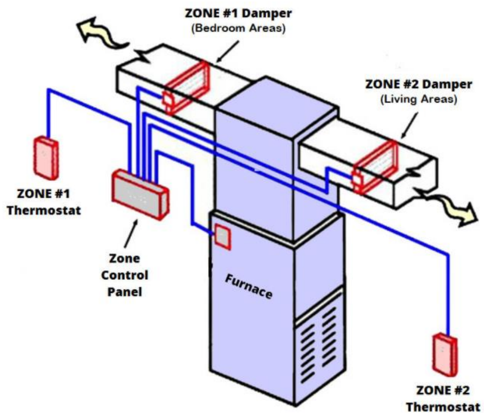

Figure 6 – Traditional Zoning HVAC System

These type of zoning systems involve the opening and closing of dampeners inside the ducts of the HVAC system to control airflow to zones in a building. This type of design involves an expensive installation of dampeners inside the ducts of HVAC systems and is very costly to install on new buildings let alone upgrading existing HVAC infrastructure. It is very common in commercial buildings (such as CEI for example) to implement this type of HVAC system but not in residential homes.

Our product seeks to solve this gap in the market and overcome the large cost in installing upgrading to a zoned system.

Methodology: (Formulate a solution plan (methodology) and explain how to execute a solution process for the engineering problem in your project.)

Challenges to Overcome

The solution process for completing the project starts with identify the challenges and problems that need to be accomplished and identifying what the team will do to overcome them. The development process for the product will follow a linear approach to learning the skills required to accomplish a challenge then completing that challenge and moving on to the next. Upon completing the development process, the team streamlines into an iterative testing process to validate the design and the robustness of the product.

This methodology is predicated on a well thought out list of sequential challenges/objectives that progressively build the products in a logical order. The products can be built concurrently as long as it facilitates the design process and makes sense based on the skills and knowledge of the team at that time.

The high level list of objectives and challenges that the team will need to overcome to meet the goals outlined earlier in this proposal are:

1.) Decide on what the system features will be and what the system will accomplish.
2.) Research the most common modern residential HVAC systems and understand how they work on a technical
3.) Decided on a Communication Architecture and hierarchy for the system to enable the devices to talk to each other
4.) Determine what functions each product will do as well as estimate how much power each one require
5.) Decide on the communication protocol to be used in communication including the modulation scheme, baud rate, frequency band/range, transmit power and range.
6.) Research the current industry solutions for implementing the decided upon communication protocol as well as the functions outlined for each product in objective four.
7.) Pick the hardware to implement the communication protocol for each device as well as the hardware required to implement the functions for each product as outlined in objective four.
8.) Research and learn how each hardware component chosen is programmed and used by reading textbooks on the material as well as the datasheets of each component.
9.) Begin the preliminary assembly of each component building and testing each function separately in a modular-like assembly process.
10.) Bring together the components of each product to form the prototype of each of the three products.
11.) Test each product and the entire system in real world environments and perform analysis of the performance as necessary.
12.) Adjust the design and components of each product and repeat objectives 6 through 10 iteratively until the system performs to specification and meets all goals outlined in the Goals and Objectives section of this report.
13.) Document each product, it specifications and how it works once a final design has been decided on.
14.) Prepare a presentation and proof of design for the system to demonstrate its usefulness, robustness and marketability.

How to Model a House (Thermal Resistance Network)

The most daunting challenge of the project is determining the algorithm and logic of the microcontrollers and thermostats to accurately and efficiently distribute heat and cold air. This challenged will be approached from an electrical engineering perspective. The principle concept used to model the thermal system of a house is rooted in circuit design. Shown in Figure 7 is the analogy between modelling thermal resistance systems and electrical systems:

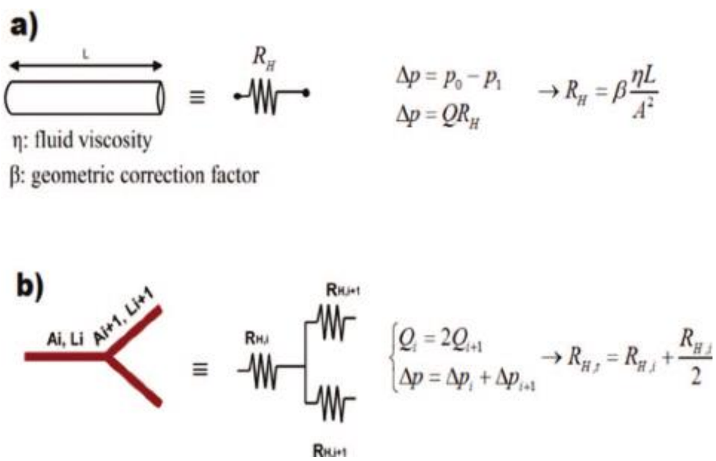

Figure 7 – Analogy Between Thermal Systems and Electrical Systems

By automatically controlling how easily each air vent in a zone allows air to pass through, which effectively controls the "resistance" to air flow seen by that zone in order to enhance air flow to areas with higher demands (air vents are controlled to be variably open) and prevent flow of heat to zones with lower demands (air vents are controlled to be variably closed). Utilizing the well established electrical circuit analysis skills of the team allows us more quickly and accurately model thermal networks as well as design algorithms and logic to implement solutions to them.

Final Product/Result: (*This section will also detail the final format of the project and how it will be presented*.)

The final project solution will consist of three products:

1.) Main Hub Thermostat
2.) Room Temperature Sensor
3.) Smart Vents

Each of these products will have the functionality specified in the Summary section of this report while the entire system will perform and accomplish the goals and objectives outlined in the Goals and Objectives section of this report.

The demonstration and proof of design of the system will involve a real-time, physical, table-top demonstration of the system. Demonstrating the project on a real-time house-level scale is not practical as it would require a house and central air system. The table-top model will simulate the conditions of a full scale house with real-time temperature readings of contained and isolated models representing zones.

Application of the End Result/Product:

The end result product will be a suite of products that can easily be installed in a residential home to allow room-level temperature control as shown in Figure 8. Each product in the suite can be bought individually and more devices can be added gradually over time or tens of devices can be bought and setup simultaneously. The three products are the main hub thermostat, the room temperature sensors and the smart vents.

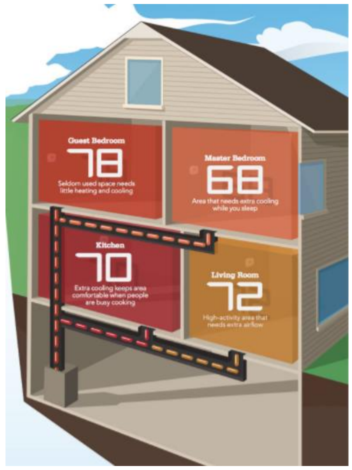

Figure 8 – Final Result of the Product

The main hub thermostat must be purchased before any other product is purchased as the other products require it to function. This main thermostat is hard wired into the home's central heating and cooling system so that is can turn the heating unit and cooling unit on and off as necessary. The room temperature sensors are an optional product that are placed in rooms and zones around the house to monitor and control the temperature of rooms/zones by controlling smart vents. The smart vents are installed in place of regular vent covers and connect to room temperature sensors or the main thermostat hub. They are equipped with motors that open and close the vent to varying degrees based on commands from either room temperature sensors or the main thermostat hub. The room temperature sensor and main hub instruct the vent how open or closed it should be based on the current temperature of the room/zone and the desired temperature of the room/zone. It is important to note that although the main thermostat can communicate with smart vents directly if a room temperature sensor is not present, without any room sensors the system will act like a normal HVAC system. As room sensors are added and zones are created the main hub can act as an extra room temperature sensor for zones without room temperature sensors.

Timeframe: (*outline the timetable for the project*)

Shown in Figure 9 is the proposed timeline for the project, the orange bars represent days completed as of February 21st 2018 while the grey bars represent days remaining for the task.

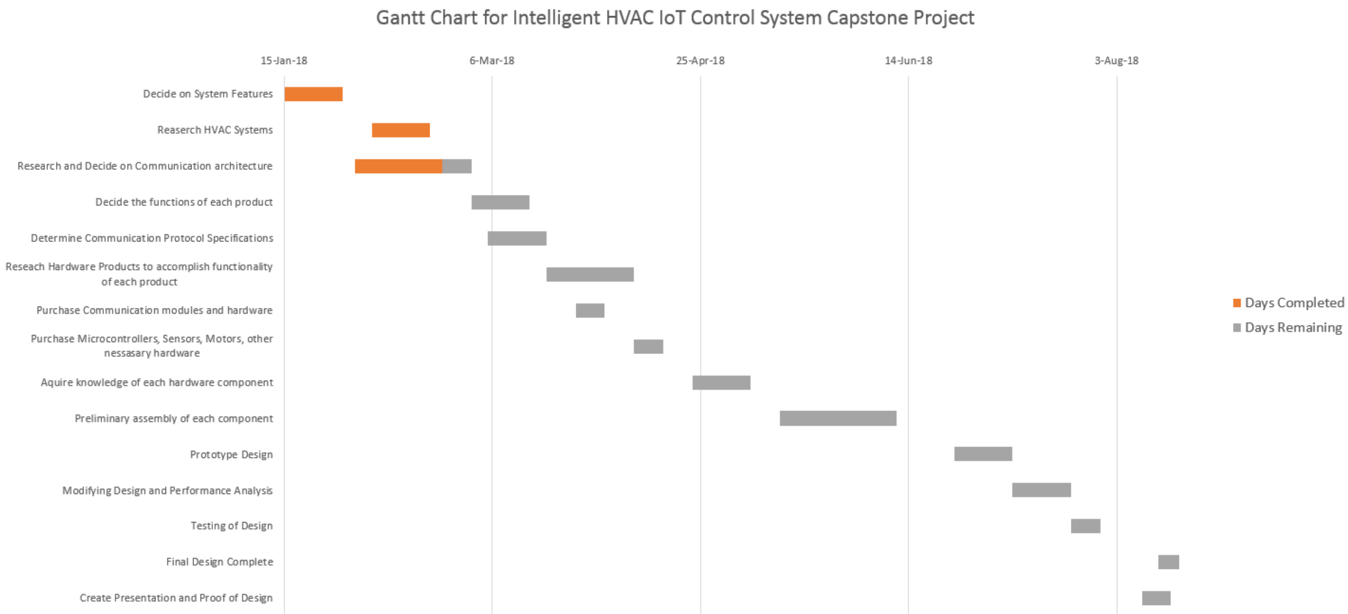

Figure 9 – Gantt Chart for Capstone Project

This timeline is subject to change as the team responds and encounters new challenges and obstacles.

Students tasks: (*The Capstone design process requires contribution from the team members both as individuals and at the team level. Specify the detailed responsibility and expected contribution of each student (with student's name) in this project.*)

Task	Team Member Responsible
Design of Communication Protocol	Sean Santarossa
Programming of Microcontrollers	Eric Parker
3D Modelling of Chassis for Each Product	Sean Santarossa
Design and Implementation of HMIs	Eric Parker
Heat Transfer Calculations and Thermal Modelling	Sean Santarossa
Internet Capable Features of Main Thermostat	Eric Parker
Physical Construction of Each Hardware Circuit	Eric Parker
Testing and Troubleshooting of Physical Hardware	Eric Parker, Sean Santarossa
Research and Deciding on Hardware Components	Eric Parker, Sean Santarossa
Research of HVAC System Designs	Eric Parker, Sean Santarossa

Project Budget: (*Provide a summary of the project budget.*)

The estimated budget for the project is shown in Figure 10. This budget will greatly depend on the decided upon hardware for the Human Machine Interfaces (HMIs) as well as which optional goals and objectives are implemented in the final design. Note that 3D modelling was overestimated in order to take into account multiple iterations of chassis designs for each product.

Estimated Budget 2018

Project: Intelligent HVAC IoT Control System

Name of Item	Estimated Cost	Notes
Main Hub Thermostat		
IoT Hardware Developer Kit (ex. Particle Photon, Rasberry Pi etc.)	$ 60.00	Between $20 to $100
Human Machine Interface (HMI)	$ 120.00	
Microcontroller	$ 15.00	
RF Transceiver Module	$ 10.00	
Plastic Custom 3D Printed Chasis	$ 65.00	at $10 per cubic inch of material
Room Temperature Sensors		
Microcontroller	$ 15.00	
Human Machine Interface (HMI) Or Physical Buttons	$ 100.00	If buttons are used instead the price will reduce significantly
RF Transceiver Module	$ 10.00	
Voltage Regulator (Optional)	$ 5.00	
Temperature Sensor	$ 5.00	
Plastic Custom 3D Printed Chasis	$ 40.00	at $10 per cubic inch of material
Smart Vents		
Microcontroller	$ 15.00	
RF Reciver Module	$ 10.00	
Voltage Regular (Optional)	$ 5.00	
Plastic Custom 3D Printed Chasis	$ 70.00	
Servo Motor	$ 5.00	at $10 per cubic inch of material
General		
Batteries	$ 30.00	
Battery Holders	$ 5.00	
Total:	**$ 550.00**	

Figure 10 – Estimated Budget for Capstone Project

Skill Requirements: (*List the skills/knowledge/courses that students need to have prior to getting started on the project. Also, list the skills/knowledge students need to master for successful completion of the project.*)

Skills/Knowledge Needed	Courses/Textbooks/Resources Needed to Gain Skills/Knowledge
Programming for IoT enabled Thermostat	Read "Programming for the Internet of Things" - Dawid Borycki
Signal Processing of Wireless Communication Data	Currently Taking Digital Signal Processing Course
Programming the Microcontrollers	Review Computer Aided Analysis Course, discussions with supervisor Dr. A Ahmadi
Reading and Understanding Hardware Datasheets	Review Microprocessors Course
Implementing and Designing the Communication Protocol	Currently Taking Embedded Systems Course, discussion with Dr. Tepe
Understand HVAC Systems	Read "Fundamentals of HVAC Systems" – Robert McDowall
Building Digital Logic Circuits	Review Digital Logic Design Course
Building and Programming RF Modules	Review Analog Communications Course

References: (*Please include references showing the applicability of the project and research method.*)

[1] “Setback Thermostats,” cmhc-schl.gc.ca, 14 August 2017. [Online]. Available: https://www.cmhc-schl.gc.ca/en/co/grho/grho_002.cfm. [Accessed 8 February 2018].
[2] “Daily Data Report for February 2018,” climate.weather.gc.ca, 22 February 2017. [Online]. Available: http://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=51459. [Accessed 22 February 2018].
[3] “Airflow,” homepower.com. [Online]. Available: https://www.homepower.com/airflow. [Accessed 21 February 2018].
[4] “Electricity rates,” Ontario Energy Board, 1 November 2017. [Online]. Available: https://www.oeb.ca/rates-and-your-bill/electricity-rates. [Accessed 19 February 2018].