February 20, 2017

Andrew H. Rawicz

School of Engineering Science

Simon Fraser University

V5A 1S6

Re: ENSC405W Requirements Specification – VentNet Home Heating Control System

Dear Dr. Rawicz,

Please find attached Aeolus System's requirements specification document for the VentNet Home Heating Control System. We at Aeolus Systems aim to create the VentNet system, a cost-effective and easy to install home heating control system that can accurately control the temperature in each room for a furnace heated home. The VentNet system will control the temperature in rooms by regulating the airflow from a home's heating ducts with motorized vents controlled by a smart thermostat and web interface.

In the requirements specification document, we provide details regarding the functional requirements that will go into the VentNet system as well as providing an overview of the system and its modules. The document will also explore product sustainability, safety considerations, and engineering standards that pertain to our project. We believe that by thoroughly specifying the requirements to be designed into the VentNet system, we will have a clear guide during its development.

Aeolus Systems consists of 4 experienced senior computer engineering students each with industry experience and a hobby in embedded systems development. The founding members of Aeolus Systems are Paul Khuu, Jeremy Leung, James Voong, and Steven Zhou.

Thank you for reviewing our requirements specifications for the VentNet Home Heating Control System. If you have any further questions, please feel free to contact me by phone (778-708-8679) or email (rza32@sfu.ca).

Sincerely,

Steven Zhou

Chief Executive Officer

Aeolus Systems

Requirements Specification

VentNet

Home Heating Control System

by

Aeolus Systems

James Voong

Jeremy Leung

Paul Khuu

Steven Zhou

FEBRUARY 20, 2017

Version 1.18

Abstract

VentNet is a combination of multiple individual smart modules formed into a cohesive system to allow multiple heating zone temperature control in a furnace heated home which normally only has one heating zone covering the entire house. To this end VentNet will provide four main features: individual temperature control in each zone, web application interface for advanced features, a master thermostat module for system control, and a low-power wireless communications protocol. To implement these features, four major components will be developed: the smart thermostat, the router module, the room sensors, and the motorized vent covers. The room sensors are integral because it provides important ambient temperature information to the rest of the system. The smart thermostat then reads this information and then decides whether or not the main furnace or vents need to be turned on/off or open/closed. The information is then fed to the router module where the commands are handled and read by the web application so that the user is able to determine the state of the heat distribution in the building and then update accordingly to their new desired temperature. Additionally, the application will provide users the ability to monitor their heat usage and schedule customized heating patterns and the VentNet thermostat will provide the user with a physical medium for changing the temperature as a backup to the web application. By providing these functionalities, VentNet promotes comfort through optimal heating by minimizing the previous carelessly wasted heat.

The proof-of-concept model will consist of the following features:

- Vent Cover
- Temperature Sensor
- Master Thermostat
- Router Module
- Web Application
- Wireless Protocol and Radio

This document describes the requirements specification of VentNet, providing high-level details on the desired functionality for the project and the justification. The requirements span a variety of categories such as system, physical, mechanical, standards, and documentation requirements. In addition, a final section provides a description of the safety and sustainability of VentNet.

Table of Contents

List of Figures

Glossary

ABS	Acrylonitrile Butadiene Styrene is a plastic that is commonly used as a material in 3D printing
Air Vents	An opening in the home's duct network from where hot air is released into the house.
Duct	A channel allowing for the passage of air. In the context of this document, used to refer to home heating ducts that transport hot air from the furnace.
Data Collisions	The result of data being sent at the same time from different parts of the network, causing unexpected results such as data loss.
Furnace	A common home appliance for heating the house. It is connected to a blower and duct network to distribute the hot air.
Heating Zone	Defines a specific space (set of rooms, etc.) capable of independent control over its temperature. Furnace homes often have one heating zone whilst electric and boiler homes have multiple.
Home Automation	The use of computers to control basic home functions such as heating, lighting, security, etc.
IoT	Internet of Things, the internetworking of physical devices to allow for the exchange of data.
Microcontroller	An integrated circuit dedicated to performing one specific task.
Paired Devices	Two devices that are wirelessly connected to one another and mainly communicate to one another.
PCB	Printed Circuit Board
Smart Devices	An electronic device capable of communicating with other devices that is able to operate interactively and autonomously to some degree.
SPI Bus	A serial peripheral interface bus that is typically used for communications between a microcontroller and small peripherals. [1]
Thermostat	A device capable of reading ambient air temperatures and connected to the furnace to control furnace output based on temperature setting.
WebApp	A typical client-server software application where the client interface runs in a web browser.

1 Introduction

When talking about home heating in Canada, "[furnaces are] the main type of heating system used by Canadian households in 2011" with a reported 57% of the population of Canada utilizing one as shown below in figure 1 [2]. "A furnace works by blowing heated air through ducts that deliver warm air to rooms throughout the house via air registers or grills" [3] and this is controlled by thermostats which contain sensors that measure the ambient temperature of the room. Typically speaking, thermostats are placed in convenient and frequently-accessed locations of the house so that the heating is most precise within these zones. A costly and problematic issue arises due to the limited quantity of thermostats as areas without sensors have poor information on the temperature of the room. Heating inconsistencies, such as cold and hot spots, derive from this issue and as such, furnaces "will have to work harder than it should in order to heat [homes] evenly" [4] leading to higher energy bills and heating inefficiency. To address this concern, we devised the VentNet system.

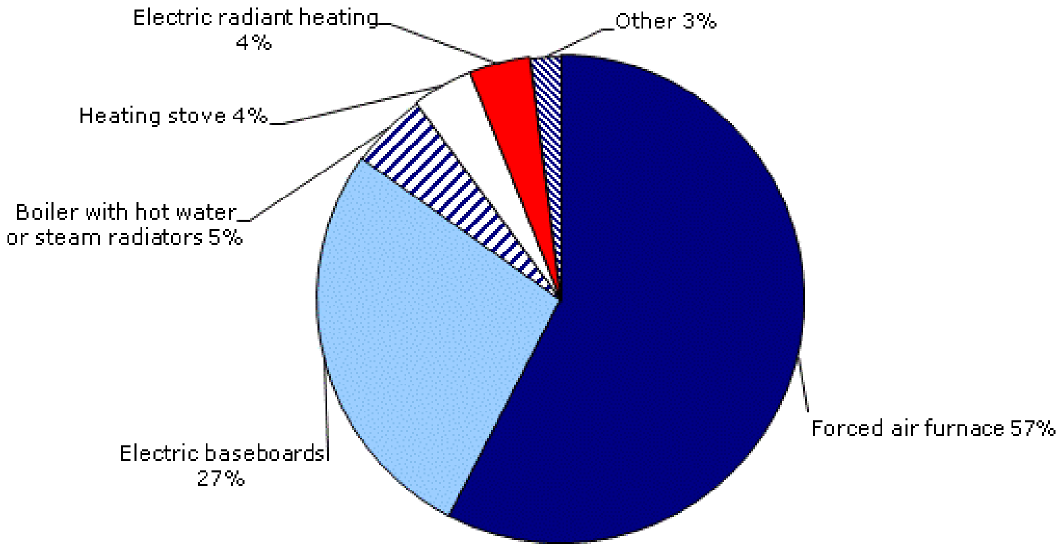

FIGURE 1: CANADIAN HOME HEATING SYSTEMS IN 2011

VentNet is a robust solution for solving heating inconsistencies using a combination of sensors and smart vents. The VentNet system offers wireless vents, to induce variable heating, and smart thermostats seamlessly controlled through the VentNet web application. Our smart vents open and close according to the accurate information provided by the system's sensors and thermostats, indicating precise controls for flexibility and comfort. Through the web application, users shall have the convenience of scheduling heating habits while also being able to monitor the temperature and their usage such that their home heating experience can be further optimized. With optimized coverage of the VentNet system throughout the house, VentNet is meant to give users the freedom of not having to worry about heating inconsistencies and the ability of customizing their own heating preferences to elevate both comfort and savings.

This requirements specification document will outline the following:

- The VentNet system and its comprising modules
- An overview of the planned proof of concept model to be built by Apr. 10
- The functional requirements for the model and possible stretch goal requirements
- Safety, sustainability, and engineering standards considerations

1.1 Scope

This document describes the specifications necessary for the VentNet system. It will include a requirements list sorting between the requirements necessary for minimal functionality of the proof-of-concept model, certain additional features planned for the Apr. 10 demo device, and preliminary requirements for a production prototype. These requirements will be used to guide the design and development process for the VentNet system.

1.2 Intended Audience

This requirements specification document is intended for use by all members of Aeolus Systems for multiple purposes. Firstly, the ability of Aeolus Systems to integrate functional requirements into the prototype model will be used to track completion and progress. Secondly, the design requirements list will guide the development schedule and serve as a reference for the design goals of the VentNet system.

2 System Overview

The VentNet system consists of four major components: the thermostat, router module, room sensors, and motorized vent covers. Figure 2 shows the basic overview of our system and the communications that the modules will make to one another. The four modules that will be created by Aeolus Systems are denoted with the logo next to the module.

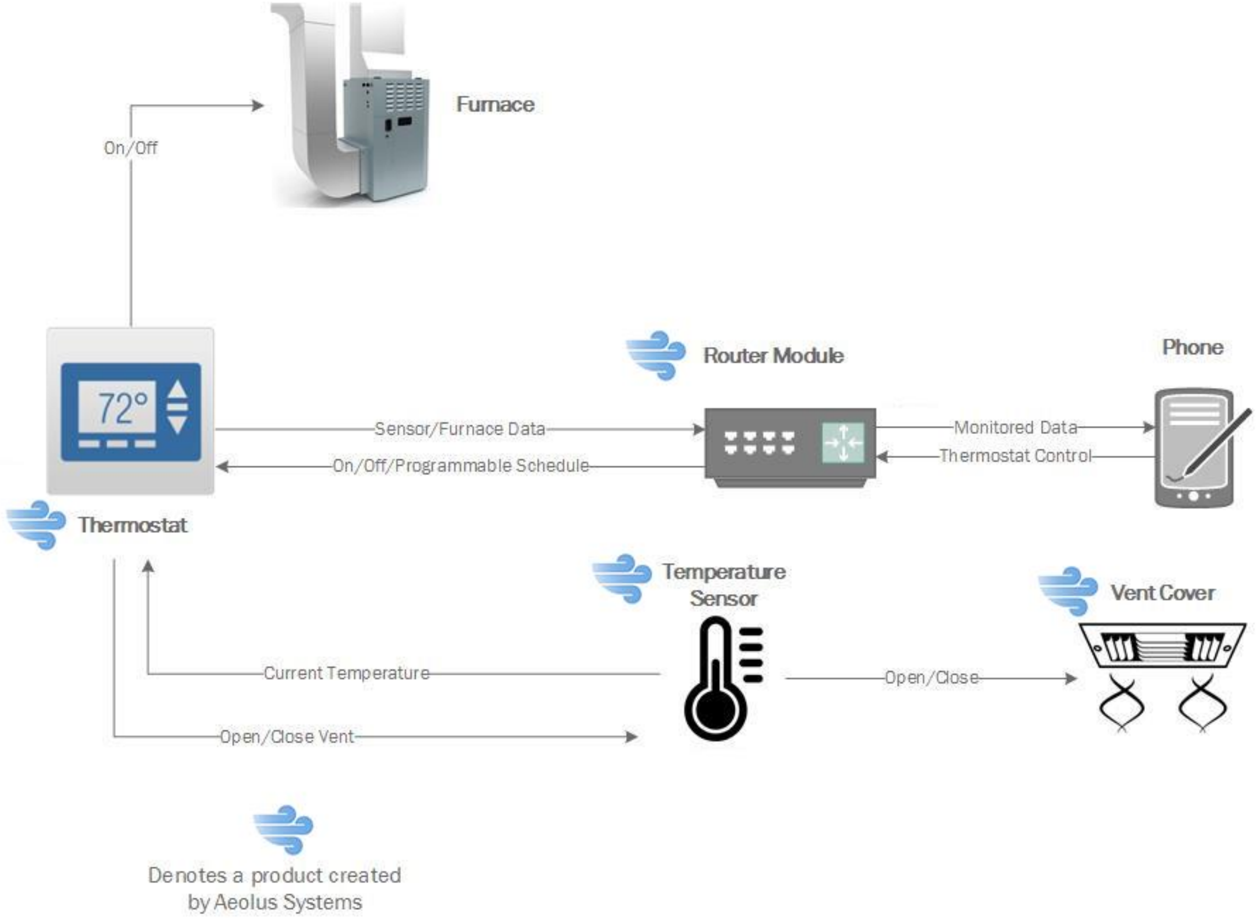

FIGURE 2: SYSTEM DIAGRAM OF THE VENTNET SYSTEM

In the VentNet system, our four modules communicate through our custom radio module to send data and commands to one another.

To begin, our thermostat is the heart of our system, sending on and off signals to the furnace based on the various room temperatures. It will also send sensor and furnace data to our router module for processing and signals to the temperature sensors to close or open the vent covers. The thermostat will require a microcontroller, a radio, a LCD to show the temperature data and settings, and a battery.

The temperature sensor measures ambient temperature in a room and will signal the paired vent cover(s) to open or close when the room temperature moves away from the set temperature. If the room temperature dictates that the vent(s) are to be opened for heating, then the temperature sensor will also signal the master thermostat to turn on the furnace. The temperature sensor will require an outlet power source, a simple microcontroller and a radio.

Our vent covers are each paired with a temperature sensor and open and close through signals sent by its paired temperature sensor. The vent covers will also utilize a simple microcontroller to open/close the baffles, a radio to communicate with the temperature sensor, and a battery power source.

On the advanced settings side of the system, the Router Module, connects to the local home network to host a web application for adjusting the temperature setting in each room, in addition to offering other advanced settings and monitoring features. It receives data for display from the thermostat and sends out programmed schedules to the thermostat through our radio protocol. The router module will require a microcontroller, a radio, a power supply and a connection to the home router to function.

3 Requirements Justification

To illustrate the reasoning of the requirements we chose, it is important to consider the purpose and goals of the VentNet. We would like to create four unique modules capable of wirelessly communicating while being low in power consumption and convenient for the average user to set up. To achieve this, we will be using the simplest methods of user interaction to require little user training. Examples of such measures include our LCD screen with buttons for temperature settings as well as a plain button and LED for the vent cover and temperature sensor pairing. All four modules will also feature a simple pairing process akin to the Bluetooth pairing process with a button and LED.

For our wireless protocol, we pinpointed the governing rules we will require our standard to have. We want our devices to be able to have good range and penetration in the case for large homes, robustly handle loss of power and use little energy to help homeowners avoid constantly replacing batteries. Thus, the chosen requirements will help form a set of regulations for our protocol to force us at Aeolus Systems to develop a dependable and power-conservative wireless protocol with strong signal quality.

In terms of priority organization, we carefully considered our remaining time, resources, and expertise in our allocation of requirement priorities to allow us to demonstrate the functionality of the VentNet by April while granting us a feasible workload for the refinement phase. Most notably, shifting of various requirements to stretch goal and production priorities will give us more leeway and insight upon finishing up the prototype tasks.

4 Requirements Classification

Throughout this document, requirements will be classified by a numbering convention that denotes the type of requirement they cover, the item affected by the requirement, a unique identification number within their type and item grouping, and the priority of completion for the requirement. The format of the number convention is:

[R**a**.**b**.**c**-P**d**]

where the **bold** letters are each a number denoting certain properties.

The first number, **a**, denotes requirement type:

Requirement Types

1. System Requirements
2. Physical Requirements
3. Mechanical Requirements
4. Standards Requirements
5. Documentation Requirements

The second number, **b**, denotes which item the requirement affects:

Project Items

1. Vent Cover
2. Temperature Sensor
3. Master Thermostat
4. Router Module and WebApp
5. Wireless Protocol and Radio
6. Multiple Modules/Whole System

The third number, **c**, is a unique number used to identify requirements in their type and item grouping.

The fourth number, **d**, denotes the priority of completion for the requirement:

Priority of Requirement Completion

1. Minimum functionality for prototype
2. Listed on proposal
3. Stretch Goals
4. Production Quality

5 Requirements

This section describes the functional requirements of the VentNet system and is split into five main categories: system requirements, physical requirements, mechanical requirements, standards requirements and documentation requirements.

The system requirements include the required functionality, anything needed for the module to function and communications required of each component for the VentNet system to function. In contrast the physical requirements will list the sizes and appearances of our individual modules. To make these estimates, we considered the size of the components being enclosed and gave ourselves additional space in the case there are unaccounted factors.

As our system only contains one major mechanism in the vent module, our list of mechanical requirements is low. Furthermore, as we will be using an existing vent mechanism for the proof-of-concept, creation of the vent mechanism has been pushed to the production phase. On the standards requirements, we have listed professional standards we believe will apply to the VentNet and help guide us toward a safer and quicker development path. Lastly, our documentation requirements list the requirements that will be needed in a user manual for a consumer.

5.1 System Requirements

Vent Cover

R1.1.1–P1 The vents shall be able to close in order to restrict airflow
R1.1.2–P1 The vents shall have wireless capabilities
R1.1.3–P1 The vents shall be able to open and close on command from the internal microcontroller
R1.1.4–P1 The vent's microcontroller shall be able to receive commands to open and close through a wireless protocol from the thermo-sensor
R1.1.5–P1 The vents shall be able to be paired and unpaired with a temperature sensor
R1.1.6–P2 The vents shall be powered by AAA batteries
R1.1.7–P4 The vents shall last a minimum of 2 years on a new pair of batteries

Temperature Sensor

R1.2.1–P1 The temperature sensor shall have wireless capabilities
R1.2.2–P1 The temperature sensor shall be able to send open and close commands wirelessly to a paired vent cover
R1.2.3–P1 The temperature sensor shall send the current room temperature to the main thermostat every minute
R1.2.4–P1 The temperature sensor shall be able to be wirelessly paired and unpaired with a vent cover
R1.2.5–P2 The temperature sensor shall be powered using an electrical outlet

R1.2.6-P4 The temperature sensor shall have a USB port capable of providing power

Master Thermostat

R1.3.1–P1 The thermostat shall be able to turn the furnace on and off
R1.3.2–P2 The thermostat shall be able to turn the air conditioning on and off
R1.3.3–P1 The thermostat shall have a LCD display to indicate the current temperature, statuses, and alarms
R1.3.4–P1 The thermostat shall have two physical buttons to manually change the temperature as a backup
R1.3.5–P1 The thermostat shall have a physical button to change the zone for individual zone temperature changes
R1.3.6–P1 The thermostat shall have an LED indicator for pairing with the router module and temperature sensors
R1.3.7–P1 The thermostat shall have a button for pairing with the router module and temperature sensors
R1.3.8–P3 The thermostat LCD shall display the status of the battery life
R1.3.9–P1 The thermostat shall have a physical button to turn on the LCD display
R1.3.10–P1 The thermostat shall have wireless capabilities
R.1.3.11–P1 The thermostat shall be able to control the ambient temperature in each zone
R1.3.12–P1 The thermostat shall be able to control the vents in each individual zone
R1.3.13–P2 The thermostat shall be able to control any number of available vents in any zone in unison
R1.3.14–P1 The thermostat shall provide sensor and furnace data to the Router Module
R1.3.15–P1 The thermostat shall receive temperature data from the temperature sensors
R1.3.16–P1 The thermostat shall receive commands from the Router Module and execute them
R1.3.17–P1 The thermostat shall be able to change the temperature settings stored on the temperature sensors
R1.3.18–P2 The thermostat shall be powered by battery
R1.3.19–P3 The thermostat shall be capable of recharging the battery by taking power from the 24VAC power line from the furnace
R1.3.20–P3 The thermostat shall be capable of recharging the battery by taking power from the 24VAC signal line from the furnace when the furnace is signalled to turn on heat
R1.3.21–P4 The thermostat shall last a minimum of 1.5 years on a fully charged battery

Router Module and Web Application

R1.4.1–P1 The module shall have a touch sensitive display for physical navigation
R1.4.2–P1 The module shall be powered using a 5V micro-USB adapter
R1.4.3–P1 The module shall be connected to the internet through a router via Ethernet
R1.4.4–P1 The module shall receive temperature data from the thermostat
R1.4.5–P1 The module shall host a server for users to access a web application for managing the system
R1.4.6–P1 The web app shall let users set schedules for when to turn vents on or off
R1.4.7–P1 The web app shall store logs of temperature readings
R1.4.8–P2 The web app shall estimate total amount of savings from using our system
R1.4.9–P4 The web app shall have large, easy-to-read icons
R1.4.10–P4 The web app shall have colour coded symbols to represent the opened or closed status of the vents

Wireless Protocol and Radio

R1.5.1–P1 The wireless protocol shall allow for multiple devices in the network
R1.5.2–P1 The wireless protocol shall transmit on the 915MHz amateur radio band
R1.5.3–P1 The wireless protocol shall be capable of resolving data collisions involving multiple transmitters
R1.5.4–P1 The wireless protocol shall be capable of transmitting temperature, vent state, vent command, and time data
R1.5.5–P1 The wireless protocol shall acknowledge (verify) all messages sent to avoid lost data
R1.5.6–P1 The wireless protocol shall allow for VentNet system modules to wirelessly pair with each other
R1.5.7–P3 The wireless protocol shall be capable of preserving data about paired modules for the host module in the event of loss of power
R1.5.8–P2 The radio module shall allow for a low-power sleep mode
R1.5.9–P1 The radio module shall interface with their attached module's processor via the SPI bus
R1.5.10–P2 The radio module shall be capable of transmitting a message through 3 vertical walls and 1 horizontal floor of a wood and drywall house with at least a 33% first send success rate

5.2 Physical Requirements

Vent Cover

R2.1.1–P2 The vents shall expose a button for pairing with a temperature sensor
R2.1.2–P4 The vents shall provide an enclosure that protects the microcontroller and battery component from heat damage
R2.1.3–P2 The vents shall be sized at common industry lengths [6]
R2.1.4–P1 The vents shall be able to withstand temperatures up to 60°C [7]
R2.1.5–P1 The vents shall operate properly within -10°C to 60°C
R2.1.6–P4 The vent's circuitry and microcontroller shall be enclosed and hidden from the user
R2.1.7–P1 The vent shall have a button to initiate pairing or unpairing
R2.1.8–P4 The vent shall have an LED to display information during pairing, unpairing, and low battery state

Temperature Sensor

R2.2.1–P2 The temperature sensor shall expose a button for pairing with a vent cover
R2.2.2–P1 The temperature sensor shall have a button to initiate pairing or unpairing
R2.2.3–P1 The temperature sensor shall have an LED to display information during pairing and unpairing
R2.2.4–P1 The temperature sensor shall be no larger than 10cm x 10cm x 10cm

Master Thermostat

R2.3.1–P1 The thermostat shall be able to withstand temperatures up to 60°C and operate properly
R2.3.2–P1 The thermostat shall provide an enclosure that protects the single board computer and battery component from high temperatures
R2.3.3–P1 The thermostat circuitry shall be enclosed and hidden from the user
R2.3.4–P1 The thermostat shall expose the physical buttons used to manually manipulate the temperature

R2.3.5–P2 The thermostat shall expose the physical button that controls the backlight of the LCD screen
R2.3.6–P2 The thermostat shall expose the physical button that controls the zone of the thermostat
R2.3.7–P4 The thermostat shall have physical indicators (labels) for all physical buttons
R2.3.8–P4 The thermostat shall not harm the user when the physical buttons are actuated
R2.3.9–P4 The thermostat shall not break when falling from 1.5 metres (5 feet)
R2.3.10–P2 The thermostat case shall be sized at common industry lengths to not be obtrusive

Router Module

R2.4.1 – P1 The router module shall be no larger than 95mm by 65mm by 30mm

Wireless Protocol and Radio

R2.5.1–P1 The radio module's main circuit board shall be no larger than 3cm by 3cm by 1cm
R2.5.2–P1 The radio module's antenna shall fit within the enclosure of the module it is attached to
R2.5.3–P1 The radio module shall be capable of operating when ambient temperature is between -10°C to 60°C

5.3 Mechanical Requirements

Vent Cover

R3.1.1–P4 The vent's microcontroller circuit board is designed internally at Aeolus Systems
R3.1.2–P4 The vent's opening mechanism shall be designed internally at Aeolus Systems
R3.1.3–P4 The vents shall be able close at 25%, 50% and 75% to partially restrict airflow

5.4 Standards Requirements

R4.6.1–P1 The creation of VentNet conforms to the CSA Electrical Standards [8]
R4.6.2–P1 The radio module shall comply with Canadian wireless standards RSS-Gen [9], RSS-102 [10], RSS-119 [11], and RSS-210 [12]
R4.6.3–P1 VentNet shall comply with UL standard, UL-873 (Standard for Temperature-Indicating and Regulating Equipment) [13]
R4.6.4–P1 VentNet shall comply with UL standard, UL-1642 (Standard for Lithium Batteries) for all modules that include a battery [14]
R4.6.5–P1 The VentNet Thermostat and WebApp shall comply with UL standard, UL-1998 (Standard for Software in Programmable Components) [15]
R4.6.6–P1 All VentNet modules utilizing a battery shall comply with UL standard, UL-2054 (Standard for Household and Commercial Batteries) [16]
R 4.6.7 – P1 The web application shall comply with the W3C standards for web development [17]

5.5 Documentation Requirements

R5.6.1–P4 The user manual shall specify the procedure to pair and unpair a vent with a temperature sensor
R5.6.2–P4 The user manual shall specify the procedure to change batteries

6 Safety

To us at Aeolus Systems, safety is a paramount concern and we want consumers to feel safe letting the VentNet system operate their home heating utilities. Designing for safety will be involved in every step of the development process until the proof of concept is complete but we've already considered some key safety concerns and proposed solutions:

- All modules in the VentNet system will strictly adhere to the CSA electrical standards regarding power supply, handling external power, and safe management of battery power.
- The wireless protocol will adhere to Canadian radio standards specifications to ensure that we are not interfering with bands used for other purposes (ie. Emergency and aviation frequencies). Attention will also be given to ensuring the transmission power does not exceed safe limits specified by Canadian radio standard RSS-102.
- Durable plastic enclosures will be designed for each component where circuit boards and other electrical components can be secured to the enclosure frame. This will also protect consumers from harming themselves via direct contact with the electrical components.
- Special logic in the firmware will check that at least one heating zone has vents open before turning on the blower fan lest air pressure from the fan build up in the ducts with nowhere to go.
- Implementation of a secure system with password protection for our web application, so homeowners can rest easy knowing that no one malicious will be able to tamper with their VentNet system.

7 Sustainability

We fully embrace the cradle-to-cradle design principle here at Aeolus Systems. While deciding what materials to use for the VentNet, we considered the impact the materials would have on the environment during its production, during its lifetime, and at the end of its life.

With any electronic devices, printed circuit boards are a necessary component but can be costly to the environment. Not only does manufacturing require very high temperatures and substantial resources, toxic fumes can be released endangering the health of factory workers. Additionally, if PCBs are not properly disposed, heavy metals like lead and nickel will end up in landfills. We will take care that the workers work in an environment with strong airflow for protection against fumes.

To address this, we have designed our system to work modularly. In the event of a component failure, users only need to replace the broken module and not the entire system. We will accept any VentNet system components that fail or break so that they do not end up in the landfill. We can repurpose the enclosures for new products by melting them down and ensure that our PCBs are recycled. We have access to electronics recycling depots locally at which we can safely dispose of our products at the end of the life cycle. There, metals can be salvaged from our PCBs and recycled instead of leaching chemicals in a landfill.

Our cases and enclosures will be 3D printed from Acrylonitrile Butadiene Styrene (ABS). ABS is a recyclable thermoplastic that is easy to melt and mold, while providing toughness and durability once cooled. One issue with 3D printing with ABS is the release of toxic fumes, which can be addressed by manufacturing in a well-ventilated facility. Using ABS for our enclosures allows us to potentially build them in-house, saving money from shipping them long distances and burning fuel.

8 Conclusion

This requirements specification document provides a high-level understanding about the intended capabilities and functional requirements of VentNet. The system, physical, mechanical, standards, and documentation requirements are detailed out with a concise numbering notation for defining its category and scheduling priority. For example, the main modules with requirements detailed out include the Vent Cover, Temperature Sensor, Master Thermostat, Router Module & Web Application, and the Wireless Protocol & Radio where each individual module's requirements are sorted into categories by requirement type and priority. Additionally, concerns about requirements justification, sustainability, and safety are acknowledged.

VentNet is currently in the early stages of development, where the focus is placed on research and experimentation of the individual modules. As development progresses, Aeolus Systems intends to follow through with all P1 and P2 requirements for the Proof-of-Concept stage and we hope to tackle any P3 stretch goals within this time period as well. Our objective is to address the heating inflexibility revolving around forced-air furnaces and provide an easy solution for homeowners that would promote a more comfortable home environment. We intend to deliver this proof-of-concept prototype by April 2017.

References

[1] "Serial Peripheral Interface (SPI) - learn.sparkfun.com", *Learn.sparkfun.com*, 2017. [Online]. Available: https://learn.sparkfun.com/tutorials/serial-peripheral-interface-spi. [Accessed: 18- Feb- 2017].

[2] Government of Canada, "Households and the environment: Energy use: Analysis," in *Statistics Canada*, 2015. [Online]. Available: http://www.statcan.gc.ca/pub/11-526-s/2013002/part-partie1-eng.htm. Accessed: Jan. 23, 2017.

[3] American Council for an Energy-Efficient Economy, "Types of heating systems," in *Smarter House*, 2015. [Online]. Available: http://smarterhouse.org/heating-systems/types-heating-systems. Accessed: Jan. 23, 2017.

[4] Ideal Services Heating & Cooling, "Potential issues with forced air heating," in *Ideal Services Heating & Cooling*, 2016. [Online]. Available: http://www.idealservicesonline.com/blog/potential-issues-with-forced-air-heating/. Accessed: Jan. 23, 2017.

[5] "Standard Register Sizes » All American Wood Register - Manufacturing & Supply", *Allamericanwood.com*, 2017. [Online]. Available: http://www.allamericanwood.com/registers/standard-register-sizes/. [Accessed: 11- Feb- 2017].

[6] "Vent Temperature as a Diagnostic", *York Central Tech Talk*, 2013. [Online]. Available: https://yorkcentraltechtalk.wordpress.com/2013/01/17/vent-temperature-as-a-diagnostic/. [Accessed: 16- Feb- 2017].

[7] Government of Canada, "CANSIM - 153-0060 - households and the environment survey, use of thermostats, Canada, provinces and census metropolitan areas (CMA)," in *Statistics Canada*, 2016. [Online]. Available: http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=1530060&p2=33. Accessed: Jan. 23, 2017.

[8] CSA Group, "Canadian electrical code," 2015. [Online]. Available: http://www.csagroup.org/services/codes-and-standards/installation-codes/canadian-electrical-code/. Accessed: Feb. 18, 2017.

[9] Industry Canada, "RSS-Gen — General Requirements for Compliance of Radio Apparatus", in *Innovation, Science and Economic Development Canada*, 2016. [Online]. Available: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08449.html. [Accessed: 10- Feb- 2017].

[10] Industry Canada, "RSS-102 — Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands)", in *Innovation, Science and Economic Development Canada*, 2016. [Online]. Available: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01904.html. [Accessed: 10- Feb- 2017].

[11] Industry Canada, "RSS-119 — Land Mobile and Fixed Equipment Operating in the Frequency Range 27.41-960 MHz", in *Innovation, Science and Economic Development Canada*, 2012. [Online]. Available: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01063.html. [Accessed: 10- Feb- 2017].

[12] Industry Canada, "RSS-210 — Licence-Exempt Radio Apparatus: Category I Equipment", in *Innovation, Science and Economic Development Canada*, 2016. [Online]. Available: http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01320.html. [Accessed: 10- Feb- 2017].

[13] UL Standards, "UL-873 — Standard for Temperature-Indicating and –Regulating Equipment", in UL *Standards*, 2007. [Online]. Available: https://standardscatalog.ul.com/standards/en/standard_873. [Accessed: 10- Feb- 2017].

[14] UL Standards, "UL-1642 — Standard for Lithium Batteries", in UL *Standards*, 2012. [Online]. Available: https://standardscatalog.ul.com/standards/en/standard_873. [Accessed: 10- Feb- 2017].

[15] UL Standards, "UL-1998 — Standard for Software in Programmable Components", in UL *Standards*, 2013. [Online]. Available: https://standardscatalog.ul.com/standards/en/standard_1998_3. [Accessed: 10- Feb- 2017].

[16] UL Standards, "UL-2054 — Standard for Household and Commercial Batteries", in UL *Standards*, 2004. [Online]. Available: https://standardscatalog.ul.com/standards/en/standard_2054_2. [Accessed: 10- Feb- 2017].

[17] W3C, “Standards”, 2017. [Online]. Available: https://www.w3.org/standards. Accessed: Feb. 10, 2017.