Dynamic Ventilation Control System

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Contents

1 Introduction

1.1 Objective

Controlling heating and cooling in a home or apartment typically relies on a HVAC system with only a single thermostat. The temperature sensor on this thermostat determines the necessary temperature changes for the rest of the rooms. With this single thermostat configuration, there is a chance that several rooms are not meeting temperature expectations for a variety of reasons (more exposure to sunlight, poor insulation, etc) [1]. These straggling rooms consequently determine the overall user comfort level based on how frequently the rooms are occupied. Similarly, two individuals may prefer warmer or cooler temperatures for their associated rooms. A single temperature setting will not be convenient in this case either. Our product aims to solve these problems by dynamically controlling airflow of the building. Airflow is manipulated by remotely opening and closing the damper boxes of registers. This provides users with comfort and convenience within their occupying areas.

1.2 Background

There are several airflow controlling vents already on the market, such as Keen Home and Ecovent [2, 3]. Both products utilize a mobile application that allows a user to create zones in the house and set temperature preferences. However, both of these products require professional installation and/or high upfront cost [4]. In addition, Keen Home has received mixed customer reviews [5], meaning either the implementation or the physical configuration is flawed.

Intelligent thermostats are another element to the design that make an impact on overall energy savings. Nest and ecobee [6, 7] are examples of Wifi-enabled thermostats that can be scheduled remotely to adjust temperature based on time of day, weather conditions, user presence in home, and several other factors. In our proposed design, we can potentially interface with these intelligent thermostats by forwarding data collected by our temperature sensors, and the end result could create a better day-to-day heating/cooling system adjustment.

1.3 High Level Requirements

- The vent unit (described in detail in section 2) must have an energy-efficient design. During periods of inactivity, when the microcontroller is in the sleep state, other components in the vent unit must also power down. These components must remain off until the microcontroller wakes up.
- The interfacing between the user should be possible through physical buttons and an on-screen display. In addition, for a more advanced interface, the user should also be able to use a smartphone application to remotely adjust the temperature preferences. In this case, any modification should also be updated on the on-screen display.
- Damper adjustment should correspond to the user's desired room temperature to the nearest +/-0.5° C.

2 Design

This design consists of two primary units: a vent unit and a hub unit. The vent unit is powered by regular batteries through a voltage regulator to ensure continuous supply of required voltage. The hub unit is powered by any common power outlet through an AC-DC converter and voltage regulator circuit. The vent unit and the hub unit communicate with each other through Bluetooth Low Energy (BLE) communication between the two BLE transceivers. Bluetooth Smart Technology has the capability of 100 m distance range of communication that covers the entire floor [8]. In this design, however, we assume the distance between the vent unit and hub unit is no greater than 10 m. The two BLE transceivers both communicate with their associated microcontrol units (MCUs) through the universal asynchronous receiver/transmitter (UART) interface [9]. Additional sensors monitor the air pressure and temperature.

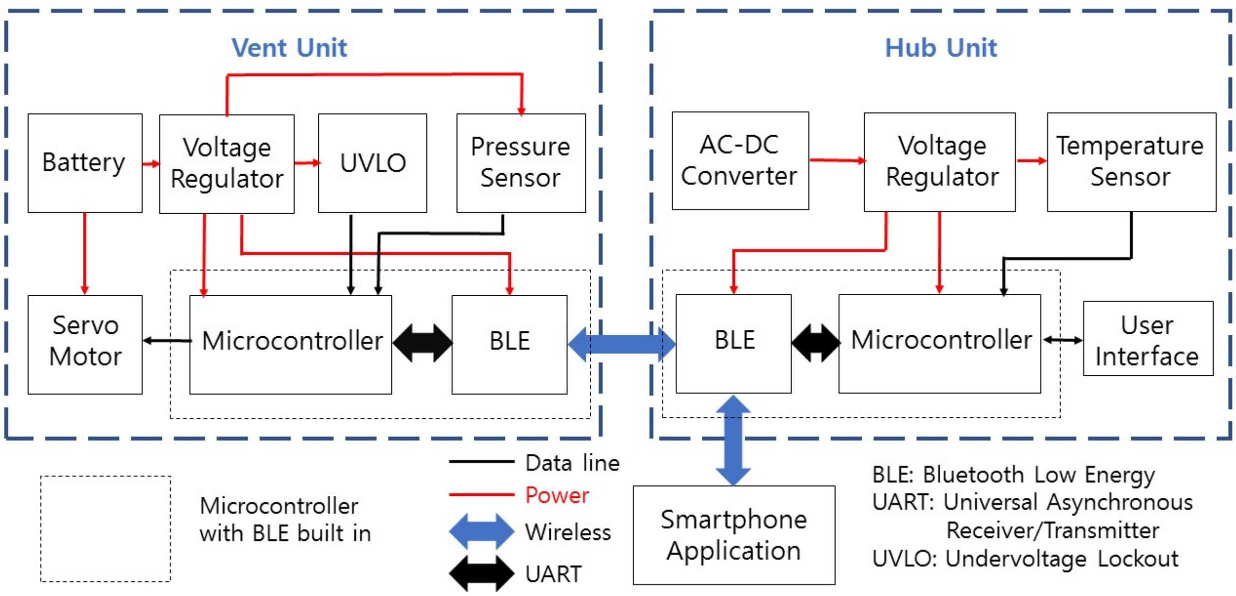
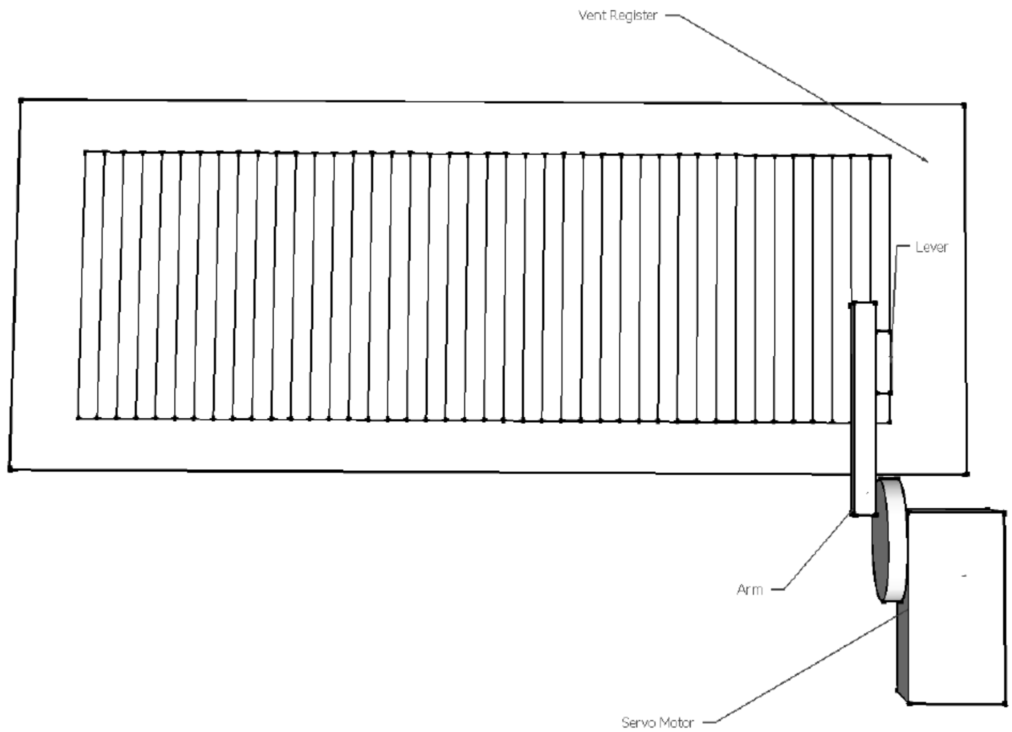


Figure 1: A high level block diagram of the proposed diagram.

2.1 Physical Design Sketches



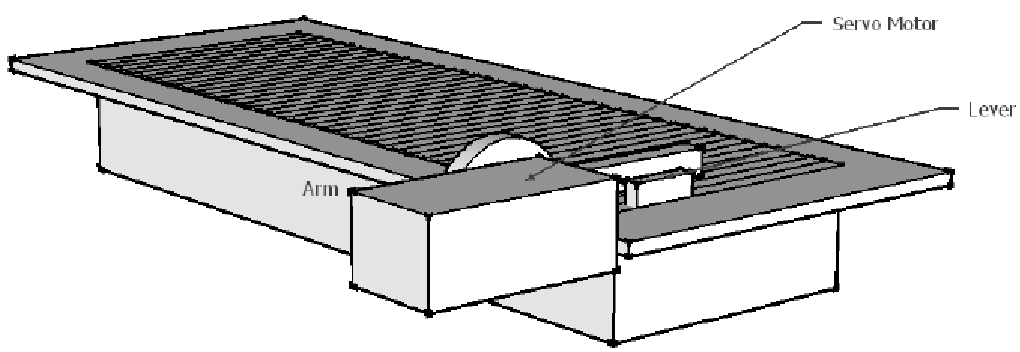


Figure 2: Initial designs of vent unit combined with register.

2.2 Vent Unit

The vent unit is responsible for controlling the state of the dampers. A microcontroller decides the state based on commands received from the hub unit and the data received from the pressure sensor.

2.2.1 Battery - Voltage Regulator

The vent unit is powered by 4 AA lithium batteries, and the voltage regulator (CC2640R2FRGZT) would ensure continuous supply of voltage. AA batteries will provide 6 V. The microcontroller is not able to work in a voltage of that order so it is be necessary to build a regulator. The specific reason we chose lithium batteries is discussed in-depth in section 2.7.

Requirement	Verification
1. The Voltage Regulator must ensure all components are provided with 3.3V (+/- 15%). 2. The Voltage Regulator must draw no more than 1 A (+/- 20%).	1. (a) Provide a constant voltage load (5V) as an input to the regulator. (b) Measure the voltage across output and compare to specified target threshold. 2. (a) Provide a constant voltage (5V) load as an input to the regulator. (b) Measure current draw across input/output terminals of regulator using multimeter over a period of 60 seconds. (c) Analyze peak current in time window and compare to specified upper limit.

2.2.2 Undervoltage Lockout

The Undervoltage Lockout module checks the output voltage level from the voltage regulator. It notifies the microcontroller when the voltage level drops below 3V (+/- 5%) by sending a signal.

Requirement	Verification
1. The current draw of this module must be minimum 0A and maximum 20mA.	1. (a) Sweep a load voltage from 2.5V to 3.3V in 0.1V increments. (b) Use a multimeter to measure the terminals and ensure the current draw is within the specified limit.

2.2.3 Pressure Sensor

The pressure sensor (LPS22HBTR) detects the level of air pressure of the heating or cooling air that comes from the main HVAC ventilation system of the house. The level of air pressure is used to decide the state of the vent to avoid damaging the HVAC by closing all of the vents while the air comes out of the HVAC system. This sensor is polled such that whenever the microcontroller is in the "active" state, it will first check the pressure reading before making decisions. If the pressure reading is too high initially, there will be a timer of 1 hour in which the sensor is read again. This is to avoid fluctuations that may cause erratic behavior. After 1 hour, if the reading is still too high, the microcontroller will open up the damper in small increments every 30 minutes. When pressure levels fall below 0.75" WC (or 0.187 kPA)[10] for two consecutive readings, the dampers will adjust back to their ordinary schedule. The overall vent unit algorithm is discussed in Section 2.10.2.

Requirement	Verification
1. The pressure sensor must be accurate to +/- 0.01 kPa.	1. (a) In a closed room, measure the air pressure with a pressure meter for 60 seconds. (b) Record the readings from the vent unit's pressure sensor for the same duration. (c) Compare the differences and identify worst-case error. This error cannot exceed the specified error tolerance.

2.2.4 Servo Motor

The servo motor (SM-34303R) operates based on commands from the microprocessor. The state of the vent is set by using the servo motor in combination with a lever arm. The servo motor cannot be a particularly loud component. Otherwise the sound of damper adjustment will be bothersome. Typical ambient sound in a room is about 40 dB [11]. To control the servo motor, the microcontroller sends an analog PWM signal, and depending on the pulse width, the servo motor spins clockwise (1.5ms width or greater) or counterclockwise. To stop rotation, a signal with identical pulse width is required.

Requirement	Verification
1. The servo motor must have quiet operation under 40 dB (up to 15% accuracy). 2. The servo motor must output an adequate 1 lb/in (+/- 10% error margin) of torque to properly adjust damper switch.	1. (a) Use a decibel meter to record the sound level of the servo motor. (b) Sweep speeds of servo motor from minimum to maximum RPM and ensure sound level is met. 2. (a) Probe servo motor using a torque meter and sweep speeds of servo motor. (b) Identify speed at which torque falls within error margin.

2.2.5 Microcontroller (MCU)

The MCU (CC2640R2FRGZT) controls the state of the vent based on commands from the hub unit and the pressure data from the pressure sensor. It communicates with the BLE transceiver via UART. What differentiates this MCU from the hub unit is that sleep power consumption must be kept to a minimum. Since the circuit operates on batteries, it must be as energy-efficient as possible. A main source of power savings is this sleep state. In addition, the largest packet size according to the BLE specification is 20 bytes. Therefore, the MCU must be able to handle and process enough of these packets within short time period to ensure stability and responsiveness.

Requirement	Verification
1. The MCU must be able to handle at least 60 20-byte packets per minute with a maximum of 5% bit error rate. 2. the MCU must not consume more than $5\mu A$ in the sleep state.	1. (a) Design a program on the hub unit that sends a packet every second. The packet data will be known beforehand, so comparison between the received packet and the sent packet can be made. (b) The number of errors over 60 seconds are counted. (c) Received data can be checked through USB debugging development boards. 2. (a) Transition the MCU to the sleep state by setting the correct signals. (b) Using a multimeter, probe the current of the MCU terminals and identify peak current draw over 60 seconds.

2.2.6 BLE

The BLE transceiver (CC2640R2FRGZT) connects the vent unit and the hub unit through BLE (Bluetooth 4.2) interface. It communicates with the microcontroller via UART for remote control of the ventilation register. BLE has a master-slave configuration. This means that one master can communicate to multiple slaves, but slaves cannot communicate with each other. The vent unit's BLE role is always a slave because it only communicates with the hub. Consequently, the vent and the hub pair with each other during initial calibration so that whenever the MCU goes in and out of sleep mode, it does not have to repeat the pairing process. See Section 2.10.2 for more details. Although the range according to the specification supports up to 100 meters [8], there may be potentially many walls and other sources of interference within the house. For this reason, we conservatively aim for 10 meters, which should be suitable for most room sizes.

Requirement	Verification
1. The BLE transceiver must have a range of at least 10m.	1. (a) Connect two BLE transceivers within 0m distance in between. Then start transmitting/receiving data packets. (b) Periodically move a BLE transceiver away from the other one. (c) Check the BLE connection every 1m. Ensure that the connection remains within 10m distance.

2.3 Hub Unit

The hub unit is the control center of this product. Based on the temperature sensors data, it decides which command to send to the vent unit to control the rooms temperature. It is powered by a voltage regulator connected to a power outlet.

2.3.1 Power Supply

The power supply ensures sufficient energy is being provided to the microprocessor, temperature sensor, and the BLE module. The source of power in this scenario comes from a conventional 120V wall outlet. This unit consists of the AC-DC Converter and Voltage Regulator.

2.3.2 AC-DC Converter

A commercial AC-DC converter (DPS-12FP A) is used to convert 120V AC to 12V DC. For safety considerations, we do not design this unit ourselves.

2.3.3 Voltage Regulator

Well use a switching voltage regulator (DC-DC converter). It will be installed in order to eliminate noise created by the AC-DC converter and to nullify any ripple created by the AC-DC converter, in order to obtain a truly constant DC constant voltage. A DC-DC converter will be used because of its good efficiency and regulation.

Requirement	Verification
1. The Voltage Regulator must ensure all components are provided with 3.3V (+/- 15%). 2. The Voltage Regulator must draw no more than 3 A (+/- 20%).	1. (a) Provide a constant voltage load (5V) as an input to the regulator. (b) Measure the voltage across output and compare to specified target threshold. 2. (a) Provide a constant voltage (5V) load as an input to the regulator. (b) Measure current draw across input/output terminals of regulator using multimeter over a period of 60 seconds. (c) Analyze peak current in time window and compare to specified upper limit.

2.3.4 Temperature Sensor

The temperature sensor (MAX31820MCR+) detects the rooms temperature where this product is installed and sends the data to the MCU. Most thermostats operate with 0.5° C granularity, and this product has to have the same granularity with thermostats. This sensor will be polled such that whenever the MCU arrives at the temperature checking phase, the sensor reading is taken. A low-pass filter is applied so that noise does not cause unnecessary modifications to dampers.

Requirement	Verification
1. The temperature sensor must be accurate by +/- 0.5° C.	1. (a) Heat water up to exactly 20° C. Connect a temperature sensor to a terminal, and seal the sensor and the terminal with moisture sealing electrical tape. (b) Detect the water's temperature with the sealed sensor. (c) Periodically increase the water's temperature by 0.5° C until it reaches 25° C, and measure it with the sealed sensor at every increment. (d) Ensure that the sensor's value is accurate to 0.5° C.

2.3.5 Microcontroller (MCU)

The MCU (CC2640R2FRGZT) of the hub unit communicates with the BLE module via UART. It reads data from the vent unit and the temperature sensor, then it decides a command to send to the vent unit for controlling the state of the vent. It also processes user requests sent via the BLE module. This MCU's requirements are different from the vent unit's MCU since the latter is operating on battery power. Therefore, active and standby modes suffice. The packet transmission size is also 20-bytes, similar to the vent unit.

Requirement	Verification
1. The MCU must be able to handle at least 60 20-byte packets per minute with a maximum of 5% bit error rate.	1. (a) Design a program on the hub unit that sends a packet every second. The packet data will be known beforehand, so comparison between the received packet and the sent packet can be made. (b) The number of errors over 60 seconds are counted. (c) Received data can be checked through USB debugging development boards.

2.3.6 BLE

The BLE transceiver (CC2640R2FRGZT) connects the vent unit and the hub unit through BLE (Bluetooth 4.2) interface. It communicates with the microcontroller via UART for remote control of the ventilation register. Unlike the transceiver in the vent unit, the role will change from master to slave depending on whether the smartphone application is active. If the user is using the smartphone application, then the transceiver must be a slave. When the user is done with changing the temperatures, the transceiver quickly transitions to a master in order to communicate with the vent unit in the room. This rapid change of roles is possible as of BLE 4.1 [8].

Requirement	Verification
1. The BLE transceiver must have a range of at least 10m.	1. (a) Connect two BLE transceivers within 0m distance in between. Then start transmitting/receiving data packets. (b) Periodically move a BLE transceiver away from the other one. (c) Check the BLE connection every 1m. Ensure that the connection remains within 10m distance.

2.3.7 User Interface

A physical user interface is needed when users are unable to use the smartphone application to control the vent unit. The user interface consists of a four digits seven segment led display (TDCG1060M) and two pushbutton switches (KS-01Q-01). The first two digits of the display show the room's current temperature in Fahrenheit, and the other two digits of the display show the desired temperature set by the user. The two buttons (up/down) are used to control the desired temperature.

2.4 Smartphone Application

To provide user input, we create a standard application for a mobile operating system such as Android or iOS. The interface is simplistic, and sliders allow adjustment of the temperature within a given room. Any potential hazards created by closing too many vents (explained in detail in section 5) are mitigated by providing error messages to the user that settings for the zone cannot be applied.

2.5 Risk Analysis

The power electronics of the voltage regulator of the vent unit is the most significant risk in our design. It must be ensured that they are able to provide enough power and current to fit the servo motor and microprocessor needs. If the system stops working or malfunctions, the microprocessor will not burn or explode, but it may exceed operating temperatures and get damaged [12]. If the servo motor stops receiving input current it will stop after some time, but if it gets higher current than its requirements, it will overheat and shorten the lifespan of the servo motor [13]. The system of the hub unit should be able to convert 120V AC to 12V used in the hub MCU. It should feature a AC-DC converter and a voltage regulator in order to eliminate the ripple obtained in the AC-DC converter.

Safety for the DC-DC converter of the vent unit can be ensured in many ways. Some of them include fuses or using a circuit that in case of the switch breaking, opens the path to the load [14], or using Mosfet transistors instead of diodes, which helps a lot with energy saving [15]. More complex (and more expensive) solutions would be integrated converters with PWM modulation systems. However, if designed correctly, DC-DC converters chance of failure under normal conditions are slim to none [16].

Another concern is the case of the batteries running out of power. In that case, there is a voltage drop due to the degradation of the battery. To cover that case, we implement a voltage lockout system that will indicate the MCU when the batteries start running low. A red LED will indicate to the user that the batteries are dying, and the micro controller will open the vent. That will make the system safe, not allowing the pressure to build up in the vent.

2.6 Calculations

In this section, we calculate the values of the components of the Buck Converter in the Hub unit. For the vent unit, most of the calculations are the same, and some others just follow the same logic with different values. We use a frequency of $200kHz$ in the PWM chip.

We begin by calculating the value of the inductance. Inductance current ripple is dangerous, so we want to minimize that effect. We compute a value that will make our system have a 10% ripple. Then, we compute a slightly larger inductance to ensure our components' safety.

$$\triangle I_L = 20.1 I_{out} \tag{1}$$

The I_{out} in our design will have values smaller than 3A, so that is the I_{out} we use for calculations.

$$\triangle I_L = 600mA \tag{2}$$

With that calculated number, we can obtain the value of L.

$$L = (V_{IN} - V_{OUT})Dt/ \triangle I_L \tag{3}$$

$$L = 14.5\mu H \tag{4}$$

We use an inductor of $100\mu H$ in order to obtain maximum protection for the circuits. For the capacitors, a stable DC voltage is essential. Microcontrollers need a voltage with no ripple in order to work properly. The equation used to calculate the capacitance is as follows:

$$Cout = \triangle I_L/(8fs \triangle V_{OUT}) \tag{5}$$

If we want a ripple of less than $50mV$ then:

$$C_{out} = 7.5\mu F \tag{6}$$

Again, we use a slightly larger value to obtain a constant no-ripple voltage.

The resistor used in the RT pin of the TL5001 (R_1) is $43k\Omega$ in order to have a $200kHz$ switching frequency. The Dead Time Control (DTC) resistor is chosen to limit the duty ratio. The data sheet proposes this equation in order to calculate R2:

$$R_2 = (R_1 + 1.25)[D(V_{OUT(100\%)} - V_{OUT(0\%)}) + V_{OUT(0\%)}] \tag{7}$$

We use a value of $D = 0.55$, which is much higher than the expected 0.275. $V_{OUT(100\%)}$ and $V_{OUT(0\%)}$ are values given in the datasheet.

$$R_2 = 47k\Omega \tag{8}$$

C_5 is set in order to obtain a Soft-Start timing of 5ms:

$$C_5 = t/R_2 = 0.1\mu F \tag{9}$$

In normal operation, SCP (ShortCut Protection) and the timing capacitor, C_4, are clamped to $185mV$. With a shortcut, C_4 is allowed to charge. If the voltage across C_4 reaches $1V$, then the converter will shut down. The protection enable period should be longer than the start timing. Otherwise, the system will never turn on. A time of $75ms$ should be sufficient.

$$C_4 = 12.46t = 1\mu F \tag{10}$$

Next, we have to create an output sense network. We must have a value of $1V$ (TL5001 reference voltage) when we have the desired output. We set the divider to have $0.5mA$. The voltage on R_6 is $1V$ and on R_5 is $2.3V$. Then, we get $R_5 = 7.5k\Omega$ and $R_6 = 3.24k\Omega$.

The feedback loop shapes the error-amplifier frequency response in order to stabilize the DC feedback without destroying the ability to respond to transients. The output filter creates some zero and complex poles, so we must be able to compensate them. The poles are located at $20.7kHz$ and $2.06kHz$ respectively. The compensation network has two zeros at $2kHz$ to compensate the poles of the system. Those two zeros provide a gain of $40dB$ at $20kHz$. The output filter gain at $20kHz$ is $-12dB$, so the gain provided by the compensation network integrator should be $-28dB$. This is done in order to obtain a grand total of 0 after the $40dB$ of the zeros. Because generally $C_2 >> C_1$, we obtain $C_2 = 0.027\mu F$. R_4 is chosen to create a zero at $2kHz$. $R_4 = 3k\Omega$. R_7 and C_3 are chosen to create a zero at $2kHz$ and a pole at $20kHz$. $R_7 = 820\Omega$ and $C_3 = 0.01\mu F$. C_1 is chosen to provide the pole at $100kHz$, and assuming $C_3 >> C_1$, we get $C_1 = 470\mu F$

[17] [18]

Most of the values are exactly the same for the vent PWM chip. The values that may change are due to the different output and input voltage and current. However, they can be re-calculated following the same methodology.

2.7 Tolerance

Our system is quite robust and is not significantly affected by different voltage drops in components. Some components like diodes and transistors may have a different voltage drop than the theoretical one, but a small difference of 0.1V compared to the 3.3V we have in the system is not relevant enough to be a concern. In our requirements, we propose a range of +-15% for the voltage across the circuits. That is a 0.5V margin, a big enough value to not be in danger because of resistor and components tolerance. Another aspect to consider is that batteries degrade over time. Consequently, batteries rated at 1.5V may drop to 1.3V-1.2V over the course of their lifespan [19].

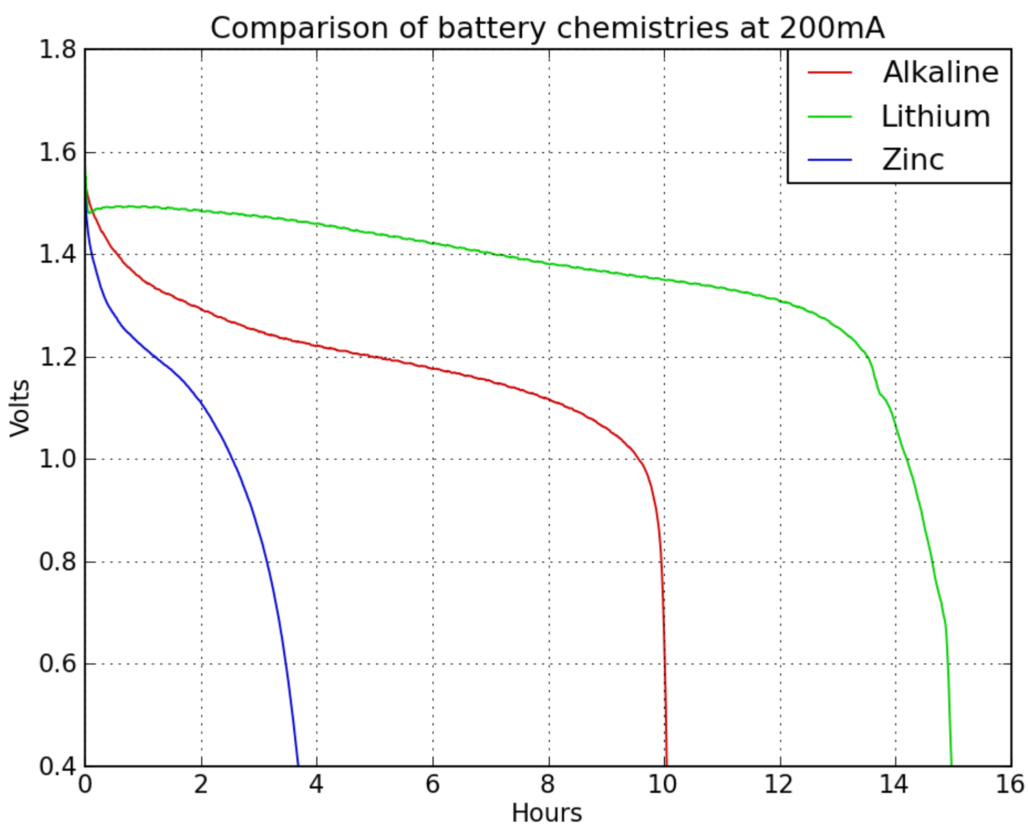


Figure 3: Batteries voltage behavior over time.

Our buck converter design takes into account this fact and is designed to convert voltages from 6V to 3.3V. Over time, if the batteries' voltage level drops below 2.1V, the undervoltage lockout circuit will detect and notify the MCU which will then notify the hub unit. At this stage, the damper will be fully opened and will not be adjustable until the batteries are replaced.

2.8 Schematics

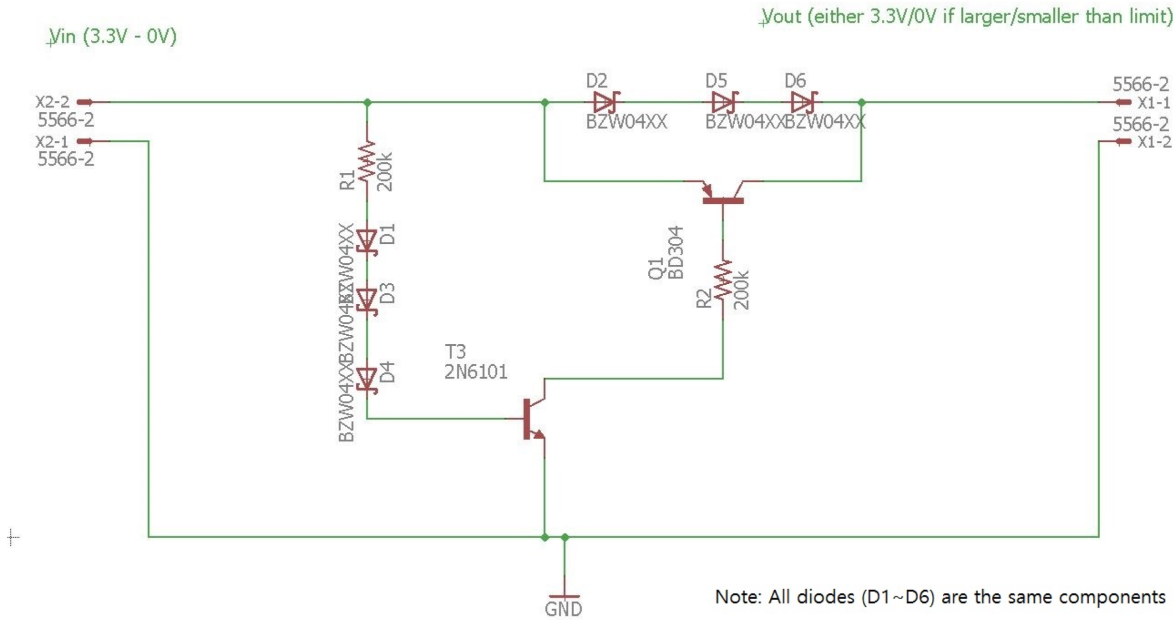


Figure 4: Voltage lockout schematic.

Table 1: Voltage lockout circuit component List.

Name	Component #	Description	Value
R1		Resistor	100 Ohm
R2		Resistor	1kOhm
D1		Series of Diodes	Lower_Limit (2.1V In simulation)
D2		Series of Diodes	Lower_Limit (2.1V In simulation)
T1		Transistor, NPN	
T2		Transistor, PNP	

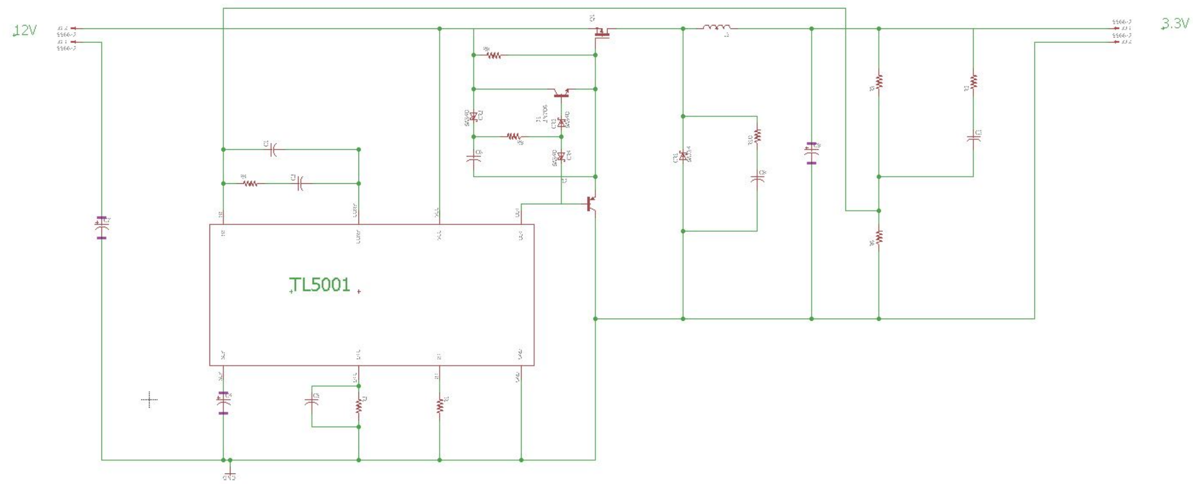


Figure 5: Hub unit DC-DC converter schematic.

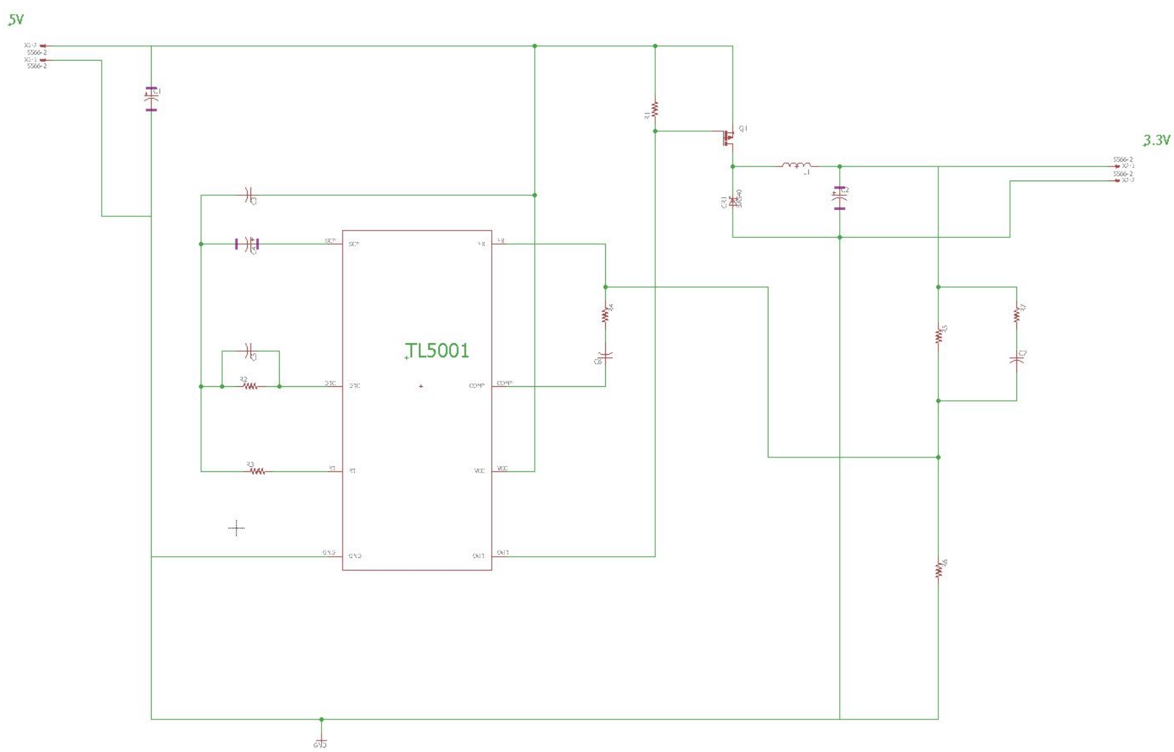


Figure 6: Vent unit DC-DC converter schematic.

Table 2: Hub unit DC-DC converter component list.

Name	Component #	Description	Value
U1	TI5001	Pwm Controller	
C1		Capacitor, Ceramic	470pF
C2		Capacitor, Ceramic	0.027uF
C3		Capacitor, Ceramic	0.01uF
C4		Capacitor, Tantalum	1.0uF
C5		Capacitor, Ceramic	0.1uF
C6		Capacitor, Ceramic	220pF
C7		Capacitor, Aluminum	100uF
C8		Capacitor, Ceramic	0.0012uF
C9		Capacitor, Aluminum	220uF
CR1		Diode, Schottky	30V, 5.5A
CR2-CR4		Diode, Switching	100V,200mA
L1		Core, Inductor	100uH
Q1	IRF9Z34S	Transistor, MOSFET	60V 18A 0.14Ohm
Q2	PMBT2222APH	Transistor, NPN	30V 150mA
Q3	PMBT2907APH	Transistor, PNP	40V 150mA
R1		Resistor	43kOhm
R2		Resistor	51kOhm
R4		Resistor	3kOhm
R5		Resistor	7.5kOhm
R6		Resistor	1.87kOhm
R7		Resistor	820 Ohm
R8		Resistor	10kOhm
R9		Resistor	2.2kOhm
R10		Resistor	43 Ohm

Table 3: Vent unit DC-DC converter component list.

Name	Component #	Description	Value
U1	TI5001	Pwm Controller	
C1		Capacitor, Aluminium	100uF
C2		Capacitor, Aluminium	100uF
C3		Capacitor, Ceramic	0.1uF
C4		Capacitor, Tantalum	1.0uF
C5		Capacitor, Ceramic	0.1uF
C6		Capacitor, Ceramic	0.012uF
C7		Capacitor, Aluminum	0.0047uF
CR1	MBRS140T3	Diode, Schottky	30V, 5.5A
L1		Core, Inductor	20uH
Q1	TPS1101	Transistor, P MOSFET	15V 10A
R1		Resistor	470 Ohm
R2		Resistor	56kOhm
R3		Resistor	43kOhm
R4		Resistor	5.1kOhm
R5		Resistor	7.5kOhm
R6		Resistor	3.24kOhm
R7		Resistor	2.0kOhm

2.9 Simulations

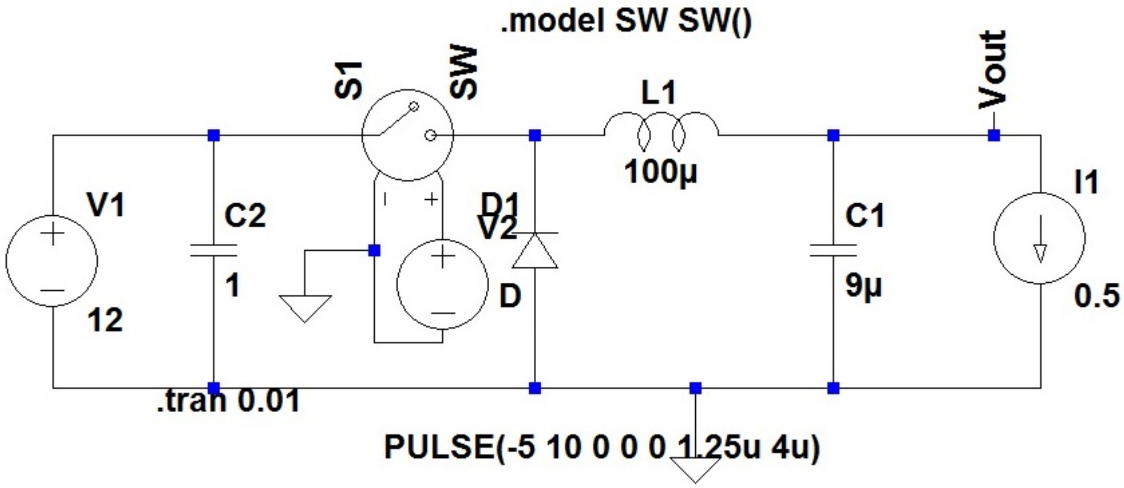


Figure 7: A simple buck converter schematic used for simulation.

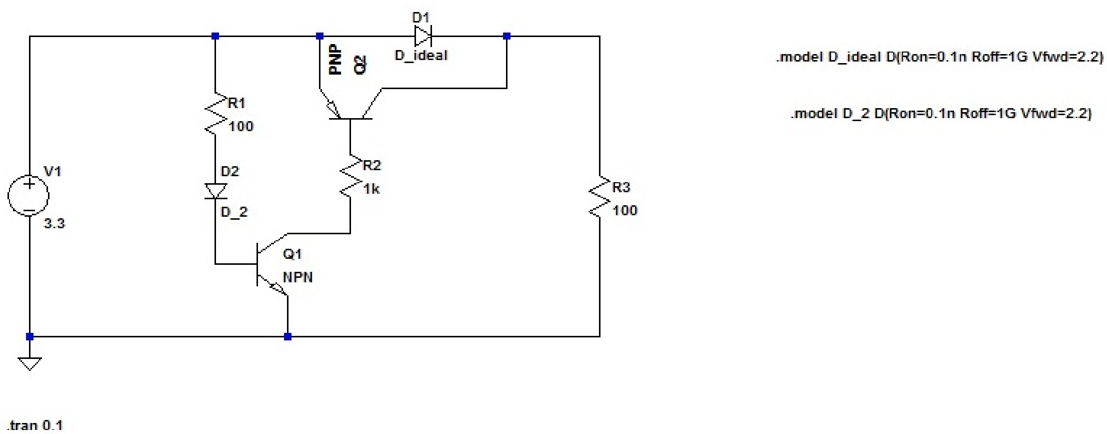


Figure 8: Voltage lockout circuit simulation

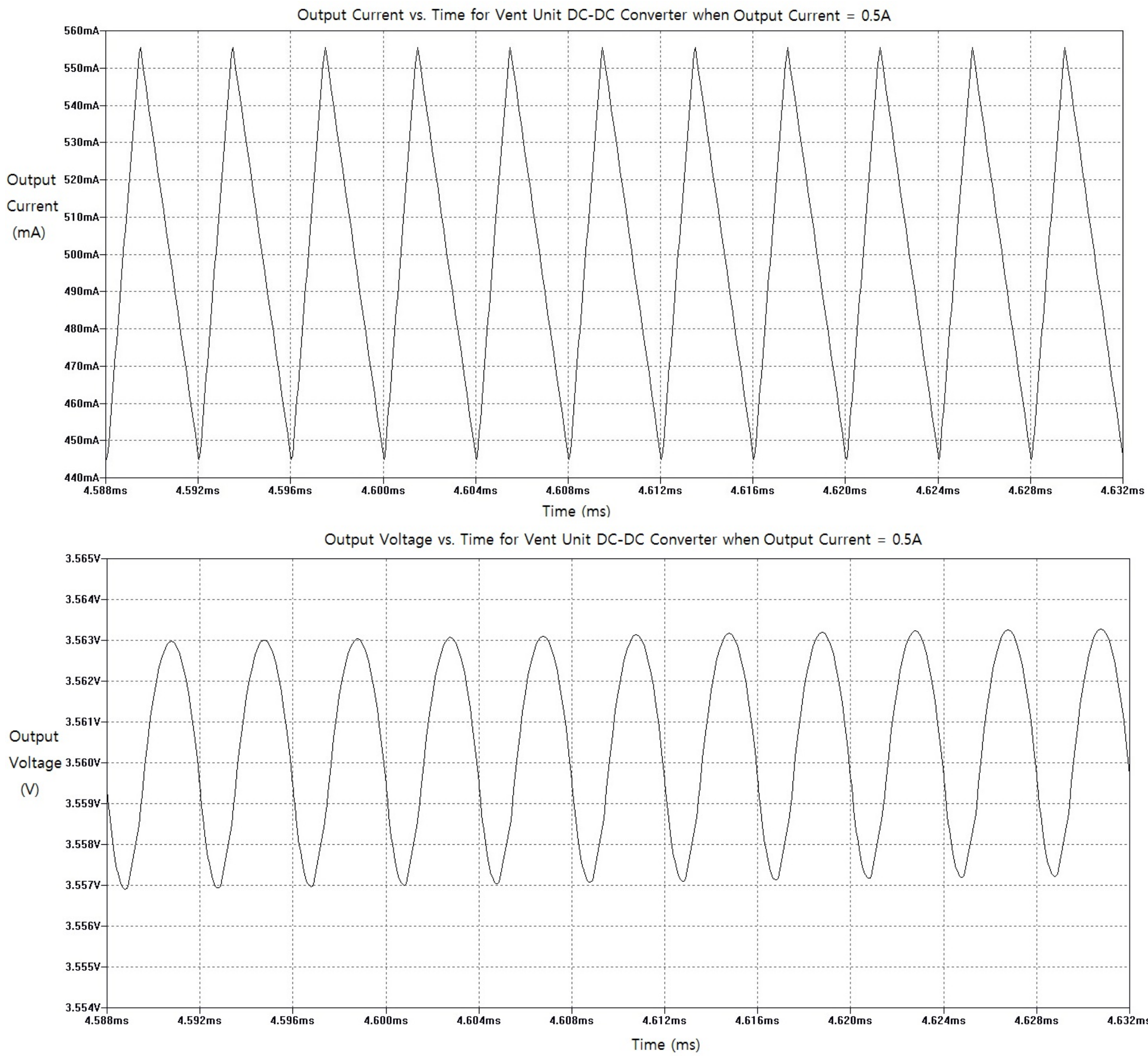


Figure 9: I_L and V_{out} for I_{out} at 0.5 A.

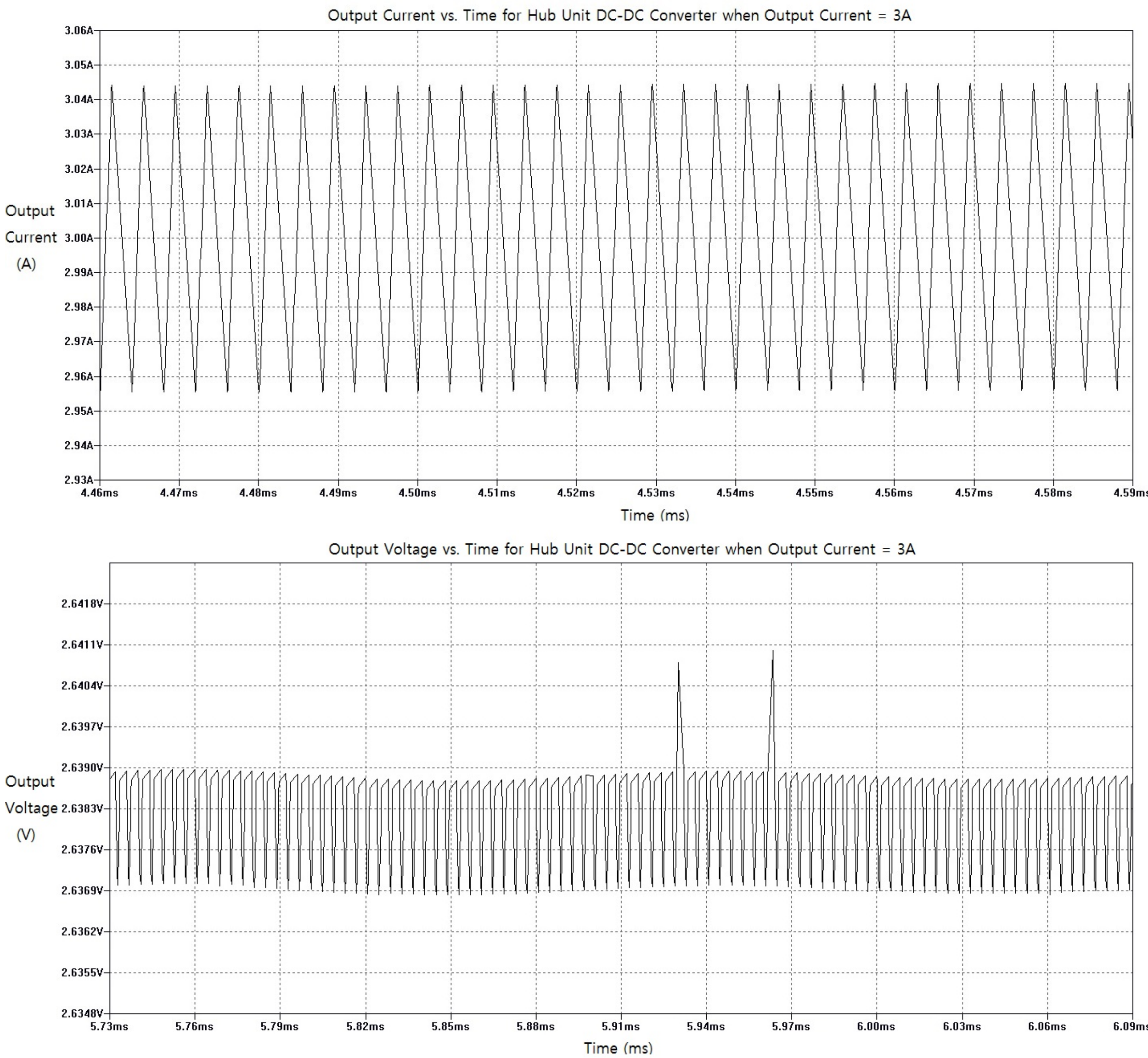


Figure 10: I_L and V_{out} for I_{out} at 3 A.

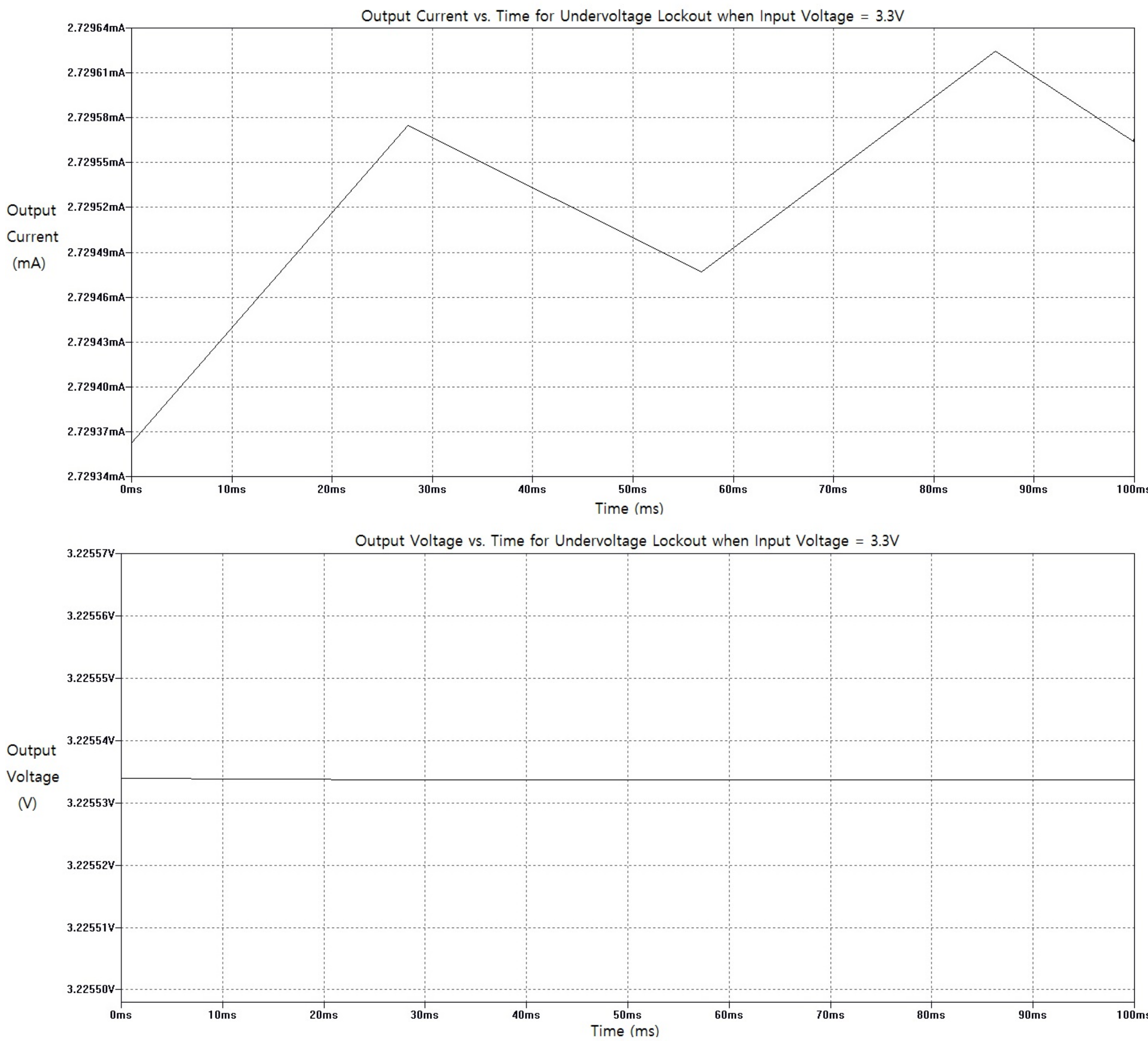


Figure 11: I_R and V_{out} for V_{IN} at 3.3 V.

2.10 Software Algorithms

2.10.1 Hub Unit

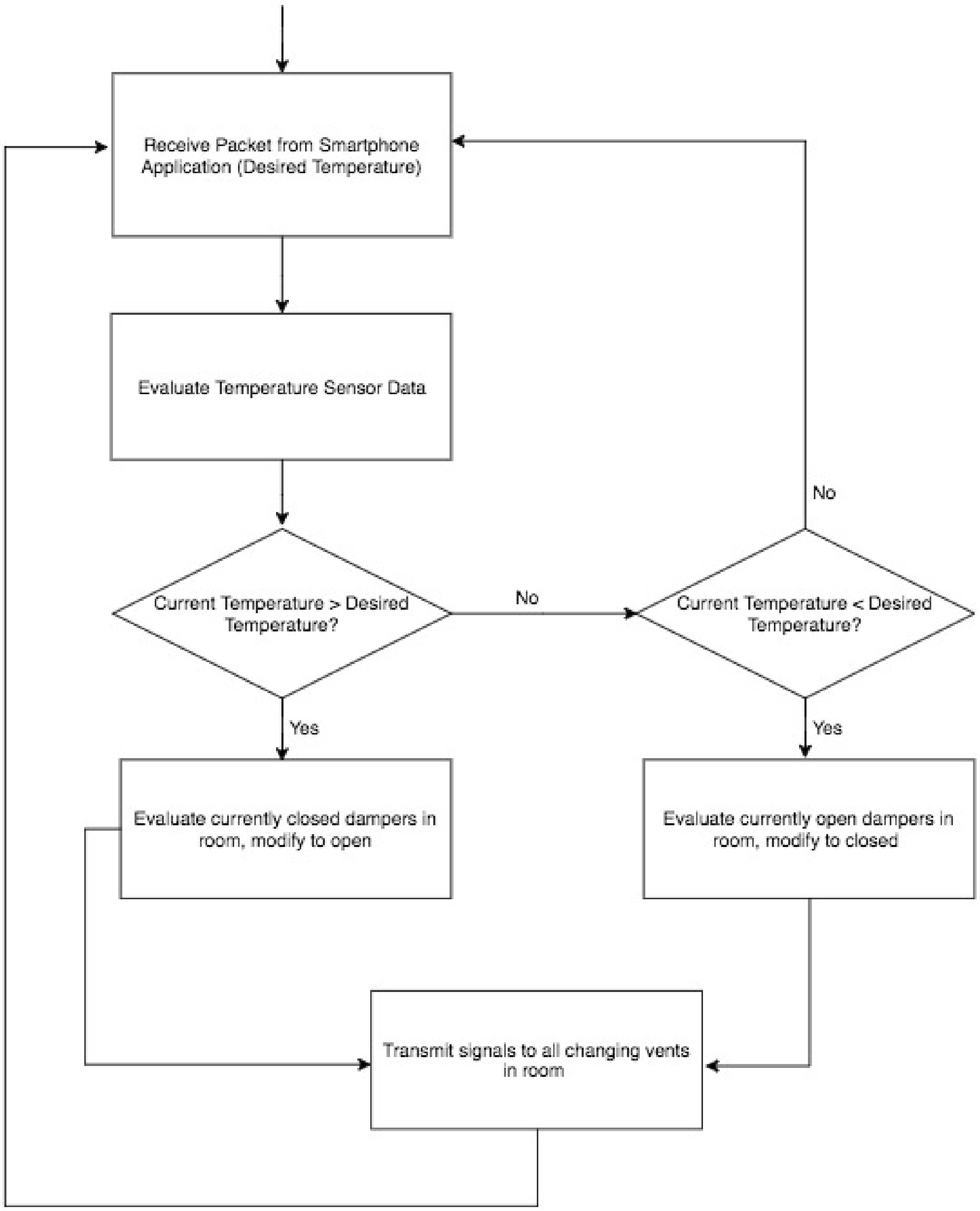


Figure 12: High-level flow chart for Hub Unit

This algorithm is assigned to the hub unit and composes the majority of the damper decision making in our design. The first stage in figure 12 receives user input. Then, in later stages, the decision to open and close dampers depends on the difference between the user's desired temperature and the current room temperature. A directory of all vent units and their current status (open/closed) is stored within onboard MCU flash memory. Note that the damper state is not a binary open and closed because vents can be partially opened and partially closed. However, to simplify the control flow, the main idea is to adjust the vents based on whether the room is too hot or too cold. As mentioned in Section 2.3.4, a low-pass filter is also used so that temperatures do not fluctuate too rapidly, causing unnecessary damper adjustments.

2.10.2 Vent Unit

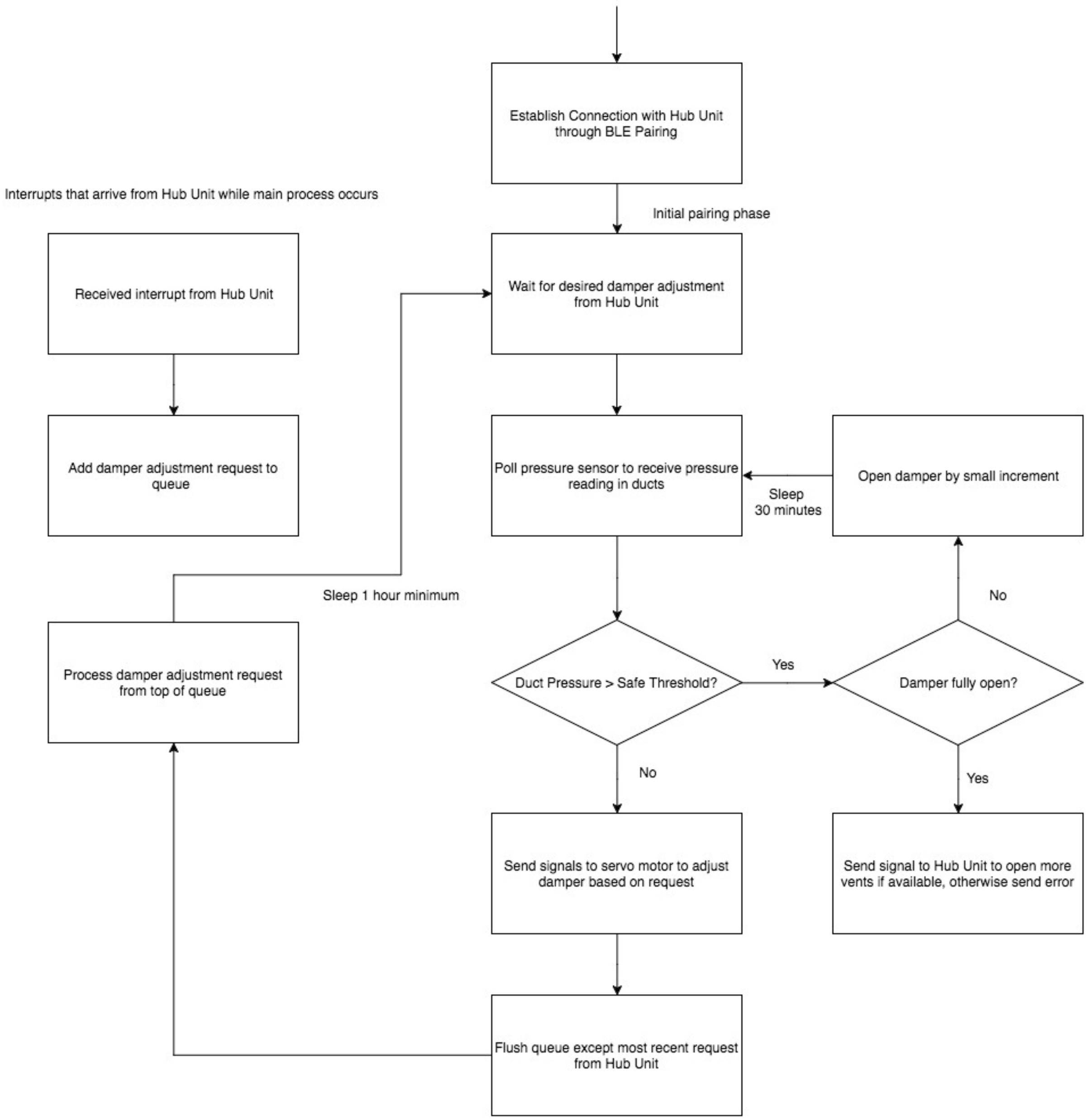


Figure 13: High-level flow chart for Vent Unit

The simplified algorithm is shown in Figure 13. Initially, the vent unit needs to be paired with the hub unit, so this process will only occur once. After this, the vent unit must correctly adjust the dampers based on both the requested settings and the pressure sensor readings. A small queue (two entries) is used in case the hub unit requests new changes during the adjustment phase. Once dampers are adjusted the first time, we only care about servicing the most recent hub unit request. If the queue is full, the last entry is replaced with the new request. The process of checking the vent for high pressures was described in Section 2.2.3.

3 Cost

3.1 Parts

Table 4: Parts Costs

Part	**Manufacturer**	**Retail Cost ($)**	**Bulk Purchase Cost ($)**
AC-DC Converter (DPS-12FP A)	Delta Electronics	8.78	7.03
Temperature Sensor (MAX31820MCR+)	Maxim Integrated	1.30	1.18
Microcontroller (CC2640R2FRGZT)	Texas Instruments	11.44	8.38
PWM (TL5001AQDRQ1)	Texas Instruments	2.09	1.02
Pressure Sensor (LPS22HBTR)	STMicroelectronics	3.65	2.69
Servo Motor (SM-34303R)	Spring Model Electronics	13.95	12.56
Misc RLC and Diodes		~3.00	~3.00
Misc Physical Components		~6.00	~6.00
4 AA Lithium Batteries	Energizer	7.78	5.94
Seven segment display (TDCG1060M)	Vishay Semiconductor	2.91	1.03
2 Pushbutton switches (KS-01Q-01)	E-Switch	1.06	0.62
Total		61.96	49.45

3.2 Labor

- $40/hr per person (3 total)
- 10 hrs/wk
- 16 weeks total
- Total Labor Cost = $19,200

3.3 Grand Total

Grand Total = Total Part Cost + Total Labor Cost = $19,261.96

4 Schedule

Week	Khalique	Alonso	Yunseong
2/6/17	Write design document	Write design document	Write design document
2/13/17	Write design document	Write design document	Write design document
2/20/17	Finish design document Begin microcontroller programming	Finish design document Design and simulate circuit schematic	Finish design document Begin researching BLE communication
2/27/17	Continue microcontroller programming	Begin first PCB design Revise circuit design for power efficiency	Begin programming BLE communication
3/6/17	Continue microcontroller programming Begin smartphone application design	Design and order first PCB Verify sensor requirements	Continue programming BLE communication Consult smartphone application design
3/13/17	Continue microcontroller programming Begin smartphone application programming	Verify servo motor requirements Assemble first prototype	Continue programming BLE communication Assemble first prototype
3/20/17	Continue smartphone application programming Debug microcontroller	Collect detailed power efficiency data	Continue programming BLE communication Consult smartphone application programming
3/27/17	Continue smartphone application programming Debug microcontroller	Modify circuit design to increase power efficiency	Debug BLE communication Consult smartphone application programming
4/3/17	Debug microcontroller Continue programming smartphone application	Finish and order second PCB	Debug BLE communication Consult smartphone application
4/10/17	Debug microcontroller Debug smartphone application	Assemble second prototype	Debug BLE communication Assemble second prototype
4/17/17	Debug any problems in microcontroller and smartphone application	Prepare presentation	Debug BLE communication
4/24/17	Prepare presentation	Prepare presentation	Prepare presentation
5/1/17	Write final paper	Write final paper	Write final paper

5 Safety and Ethical Considerations

5.1 Safety

Since this product operates on electricity, there is always a chance for fires. There is a serious risk of injury or death if the user misuses the electrical components, especially ones directly connected to the power source [20]. This product must remain dry in order to avoid any chance of malfunction caused by a short circuit.

One of the largest concerns by closing drafters within a HVAC system is the increased pressure within the ducts, causing potential breakdown if the pressure exceeds 0.75" WC, or 0.187 kPA [21, 10]. It is critical to relay to the consumer that dampers should not be shut off manually, for the pressure sensor within the vent unit will be able to automatically detect the static pressure and prevent the aforementioned hazard by opening the dampers accordingly. In the case that the batteries are low, the damper state could potentially be closed. As mentioned in section 2.5, special circuitry is designed to handle this hazard.

5.2 Ethical Considerations

All members of our team must comply to the latest iteration of the IEEE Code of Ethics [22]. One of the important points on this list for our design is #3, that is to be honest and realistic in stating claims or estimates based on available data. When we identify the power consumption of our circuit, we cannot create any false statistics that suggest an unusually long battery life if that is not truly the case. Another emphasis is placed on #7, which is to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others. As members of the University of Illinois, we must adhere to all class policies regarding plagiarism and we should strictly cite any external resources.

Points #8, #9, and #10 are related to group interactions, and since this project is worked on as a group, it is important to remind ourselves that we must create an atmosphere where we respect one another. As painfully simple as it may seem, conflicts do arise, and it is best to resolve any such issues in a professional manner. Examples of potential conflicts include irregular distribution of work and disagreement on implementation decisions. Engagement of the course staff will be required if more serious issues arise.

The rest of the points in the Code of Ethics should be adhered to, however, either we do not need to put much emphasis on them or their importance is already covered in this proposal (#1). General training (#6) is covered through lab safety seminars online. We do not see any potential conflicts of interests (#2), nor do we expect any form of bribery to occur (#4). As students, it is assumed that #5, which is to improve the understanding of technology, its appropriate application, and potential consequences, is constantly being adhered to.

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