ECE 445: Senior Design Spring 2017
Design Review

Wi-Fi Enabled Motorized Windows for Automatic Climate Control

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1. Introduction

1.1 Background

Climate change is one of the most important issues plaguing society today. Therefore, it is necessary to find new solutions to reduce the pollution caused by energy consumption. One such area that has not been significantly addressed is energy efficient climate control in buildings. According to the International Energy Agency, worldwide energy consumption in buildings accounts for about 40% of the world's total end use of energy, so the potential for savings in energy efficiency could contribute immensely to a global decrease in energy consumption [1]. Specifically, in developed countries HVAC (heating, ventilation, and air conditioning) systems account for almost 50% of energy consumption in buildings and around 10-20% of total energy consumption [2].

Opening windows with weather dependent timing is an easy solution to allow natural ventilation to heat or cool a building. Opening windows reduces the total energy usage of a building by reducing the use of HVAC systems. Therefore, natural ventilation is of the utmost importance specifically in hot summers and the more moderate seasons [3]. In addition, many people would prefer to use natural climate control rather than air conditioning and heating as it is more environmentally friendly and allows fresh air to flow throughout the building.

However, there are several potential issues and inconveniences in opening and closing windows for temperature control in a building. First, it is cumbersome to continuously open and close windows throughout the day to maintain a comfortable temperature inside buildings. Many individuals are not home during the day to tend to the windows and most are sleeping throughout the night. Second, if a window is accidentally left open during inclement weather, a home could experience water damage near the windows. It is unrealistic to expect an individual to manually monitor the weather and open and close the windows accordingly which is why there is a critical need for an automatic system.

There are no commercially available products in the market that perform automatic climate control. There have been a few attempts at various pieces of the puzzle, but our system seeks to be a complete solution to automatic climate control. Shein, Tan, and Lim investigated a home temperature control system and proved that it could achieve a favorable cost efficiency compared to that of a traditional HVAC system [4]. Moreover, previous Senior Design students Cao, Nie, and Wan demonstrated a window that could automatically close in response to rain, decreased air quality, or an abrupt change in temperature [5]. Our system will be the first to utilize Wi-Fi communications with the capability of controlling multiple windows for synchronized automatic climate control.

1.2 Solution

Our solution is an automatic climate control system that consists of a motorized window that automatically opens and closes to efficiently regulate the indoor temperature. Each window will have three sensors: moisture, temperature, and IR (for motion detection to prevent closing on objects). In addition, each window will have a microcontroller that processes the sensor data and a Wi-Fi module to send data to a hub. The hub is the central processing unit. It contains a temperature sensor to measure the indoor temperature, a microcontroller, and Wi-Fi module. A mobile phone application will be used to enable the automatic climate control, set the desired temperature range, and manually open and close each window. Each window will receive 120V 60Hz AC power from the grid. A power management system will provide the necessary DC voltages for the microcontrollers, sensors, and motor.

1.3 Objectives

- Each window will open or close in 30 seconds or less according to a local control system based on local sensors (close if raining, remain open if path is obstructed).
- The central hub unit can communicate data to and from the window unit over a Wi-Fi connection within 5 seconds.
- Each window will open and close according to the central hub control system based on a local window temperature sensor and an indoor temperature sensor

2. Design

2.1 Block Diagram

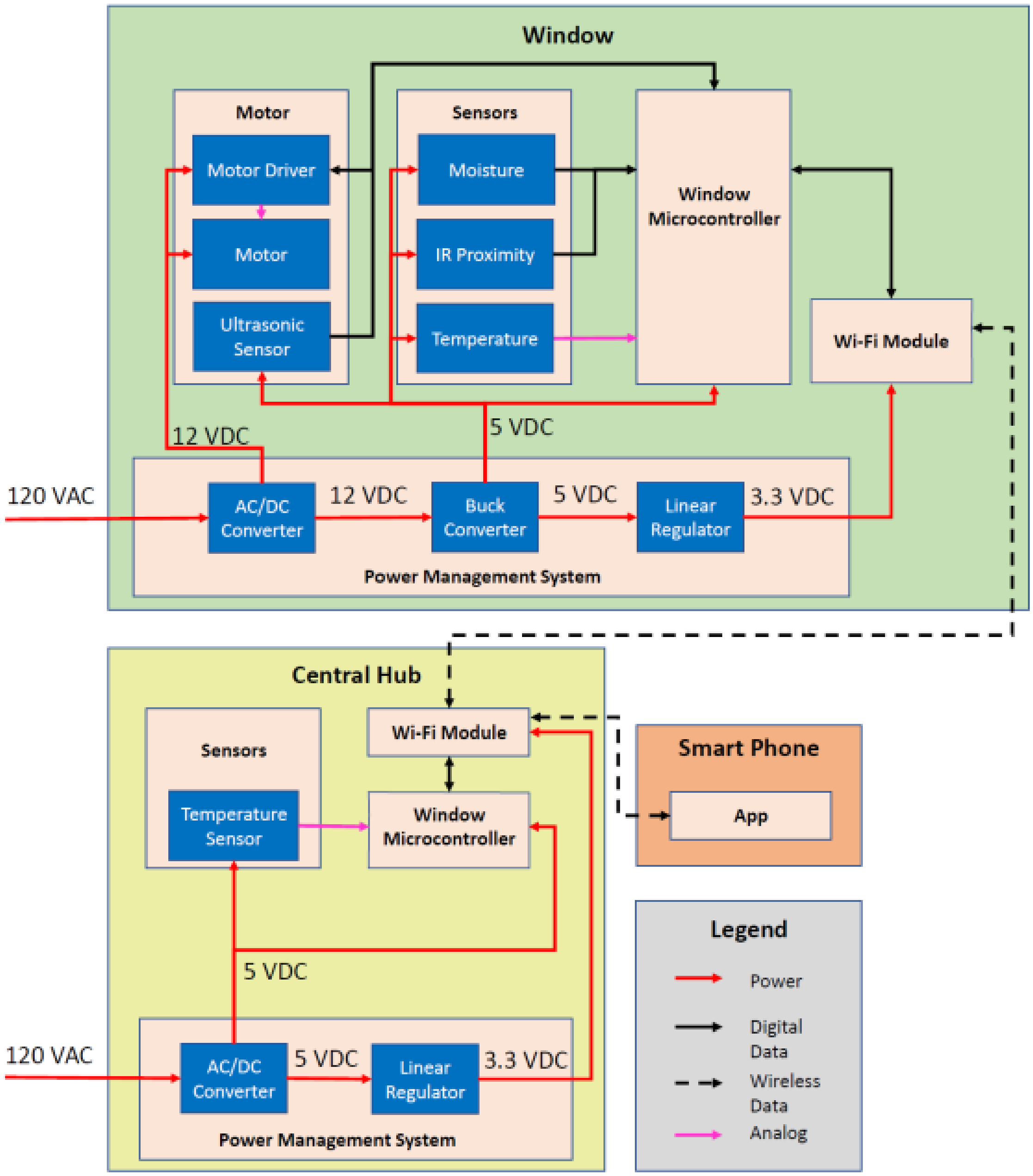

Figure 1: Block Diagram

2.2 Physical Design

The window will be a single hung window. The stepper motor will attach to the end of the threaded rod mechanism. There will be a mounted sensor array on the exterior frame of the window that contains the moisture sensor and temperature sensor. These will connect to a window control module that is mounted on the inner frame of the window. The two modules are on the same side of the frame so that their interconnecting wires can be routed through a drilled hole in the frame. The window control module contains the microcontroller, Wi-Fi module, and power management system. The motor and motor driver will be attached to the bottom of the threaded rod mechanism, and the IR sensor will be mounted next to the window control unit facing towards the window. The ultrasonic sensor is position at the top of the window facing down so that it is pointed at the top of the moveable part of the window. The central hub will contain a microcontroller, Wi-Fi module, power management system, and temperature sensor in an enclosure that is 4 inches by 4 inches by 2 inches.

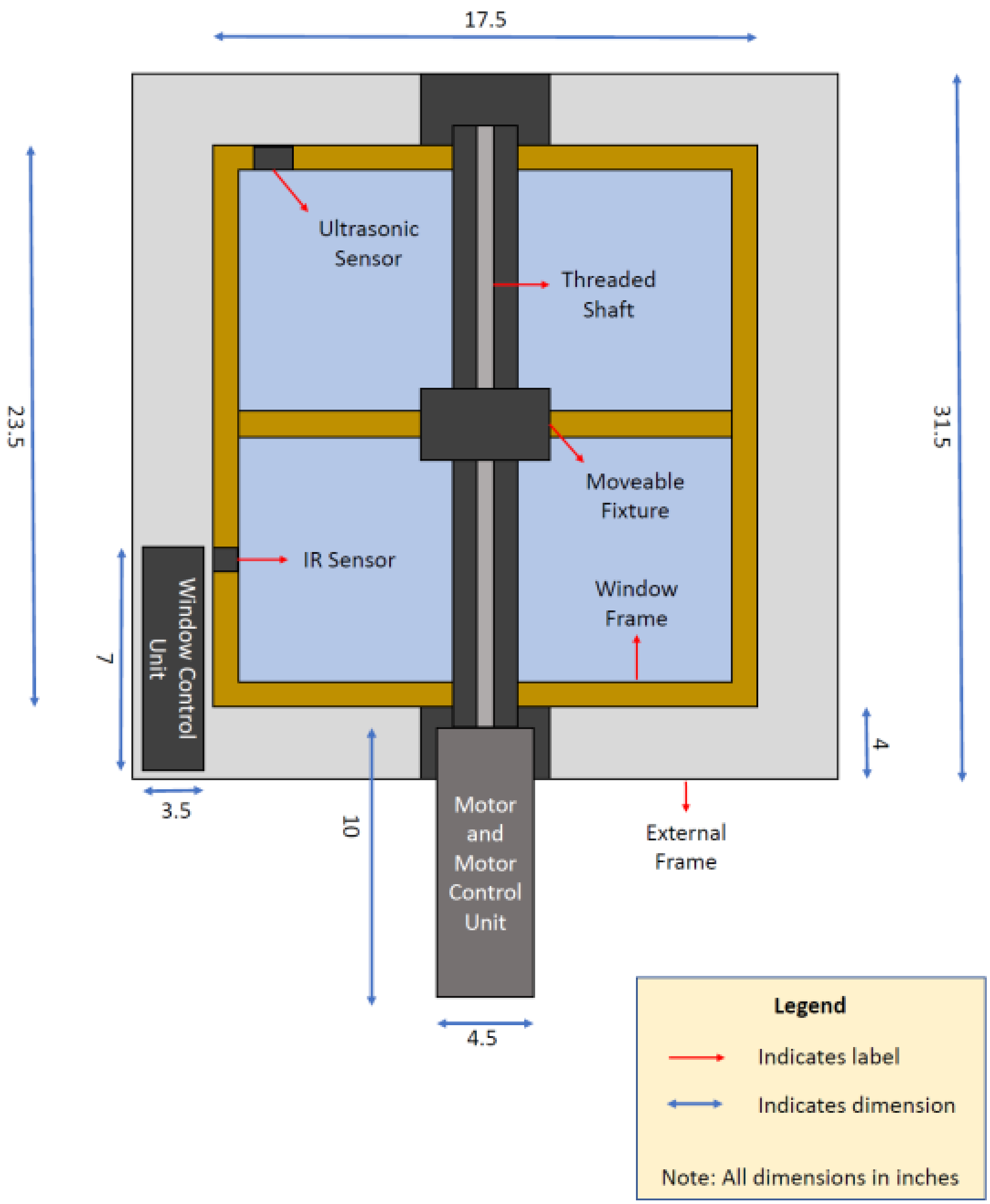

Figure 2: Window (Inside View)

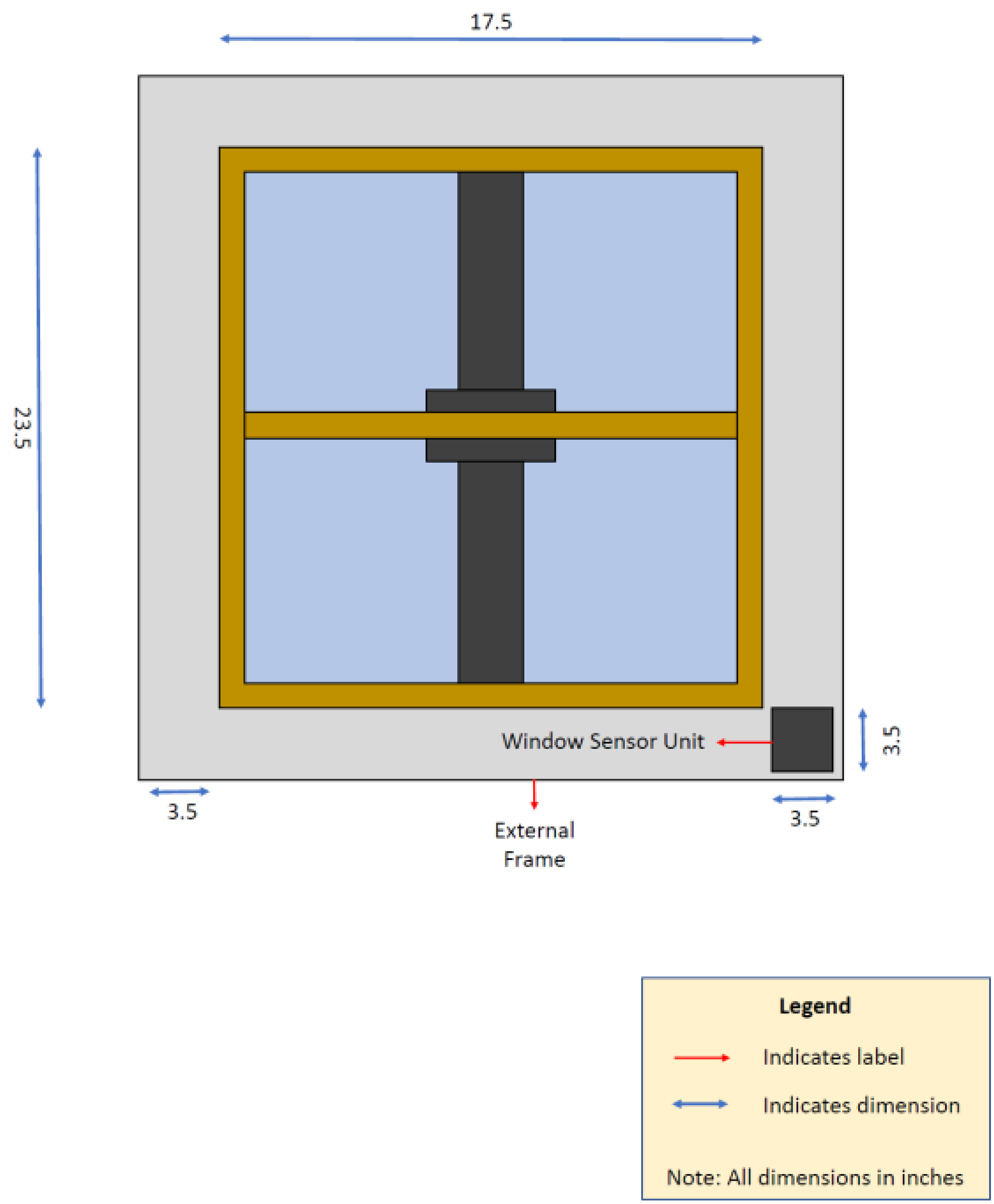

Figure 3: Window (Outside View)

2.3 Block Descriptions

2.3.1 Sensing Module

The sensing module is responsible for receiving all external inputs to the system. By using a combination of sensors, information on the environment can be known and used to help the controller make decisions. Temperature, moisture, and movement data are collected and sent as signals to be the microcontroller to be processed.

2.3.1.1 Temperature Sensor

One temperature sensor will be located on the outside of the window and will monitor the temperature of the immediate environment. The other will be placed indoors near the hub to indicate home temperature. We will use the TI LM35 which provides an analog output signal that is linearly correlated to the measured temperature. This analog output signal will be routed from each temperature sensor to either the hub or a window unit. Besides the analog output signal, the sensor will take 5V and GND inputs. This sensor was chosen due to its price, its ability to deal with extreme temperatures (rated for -50°C to 150°C), and because it's accuracy (0.5° Celsius) near room temperature met our requirement.

Pins	Connection
1	VOUT – Contains temperature information
4	GND
8	5V
2,3,5,6,7	N.C.

Table 1: Temperature Sensor Pin Connections

2.3.1.2 Rain Sensor

The rain sensor will be located on the outside of the window. This sensor will detect the presence of raindrops and send a signal to the window microcontroller accordingly. It is composed of a rain board and a control board. The control board receives an analog voltage from the rain board. It then takes this and determines whether there was any rain or not. It passes this via a digital output where a high signal indicates no rain and a low signal indicates rain. It also passes the analog signal to the output for more precise monitoring of the amount of water on the board. The board requires 5V and GND inputs. Additionally, a potentiometer on the control board allows for adjustment of the rain detection sensitivity.

Pins	Connection
1	5V
2	GND
3	Digital Output
4	Analog Output

Table 2: Rain Sensor Pin Connections

2.3.1.3 IR Sensor

A PIR sensor will be used to detect if anything is in the way of the window closing such as a hand or tail. This sensor will be mounted on the side of the window frame so that any object that moves under the moving window will be detected. After initially calibrating the IR levels the sensor will send a digital high signal to the microcontroller is a sudden change in IR patterns is detected. This will signal the controller to stop closing the window if something is in the way.

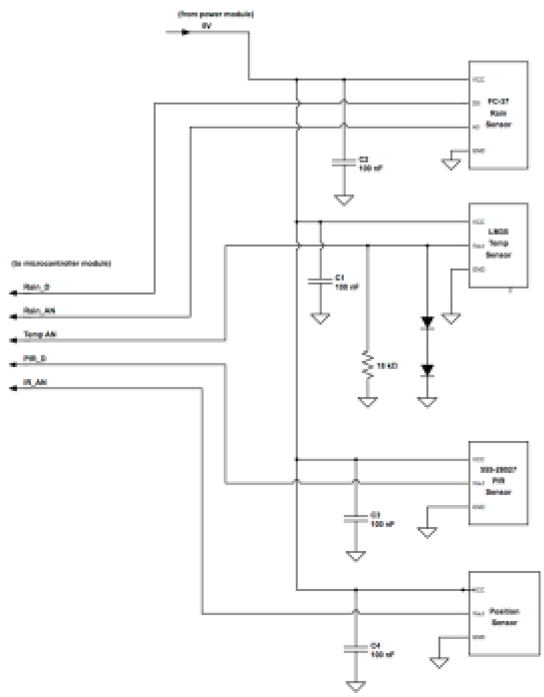

Figure 4: Sensor Module Schematic

2.3.2 Power Supply

This module provides power to each area of the system. The window module and Hub modules each have separate power systems due to different specifications. The power source for the controller will be from the power grid of the home. Since the different modules of the system require a variety of DC voltages, an AC-DC Converter and multiple DC-DC converters will be used to supply each module with the necessary voltage.

2.3.2.1 AC-DC Converter

We will use two AC-DC converters in our design. A Triad Magnetics ALS75-12 will supply the window unit with 12VDC via a 6 foot power cable from an outlet. The power demand on the first converter is the greatest since it must drive the motor module, microprocessor, Wi-Fi module, and sensors so it has a maximum current output of 6.2A. We will use a 6.3A fuse (0679L type) at the input to the converter to prevent exceeding this current limit. The other AC-DC converter is a CUI Inc. SWI10-N and will be used to supply 5VDC from a regular 120VAC outlet for the central hub.

2.3.2.2 DC-DC Converter

The window unit will require 12V, 5V and 3.3V DC supplies for the motor, microcontroller and sensors, and Wi-Fi modules respectively. The TS30013 buck converter steps down the voltage from 12 to 5 volts. The inductor assists in the transfer of stored energy between 12 and 5 volts. The bootstrap capacitor allows the high-side FET gate driver to function properly. The PG pin outputs low when the voltage into the feedback pin is below the desired output. A pull-up resistor brings the voltage high when the output is at a satisfactory level and this will be monitored by the microcontroller. The 5-volt output powers the microcontroller, rain sensor and temperature sensor in the window unit and powers the microcontroller and temperature sensor in the hub unit.

2.3.2.3 Linear Regulator

The Wi-Fi module requires 3.3 volts, so we will use an LM2937ET linear regulator to power the Wi-Fi module in the window and hub units. It is a very simple three pin device. It has an input pin which is driven by the 5V rail, a ground pin which is connected to the system ground, and an output pin which is the 3.3 rail that drives the Wi-Fi module.

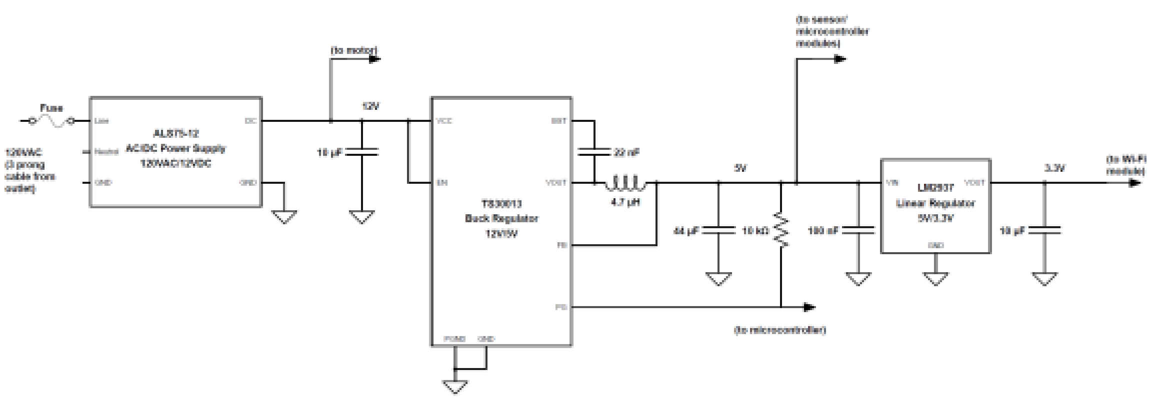

Figure 5: Window Unit Power Schematic

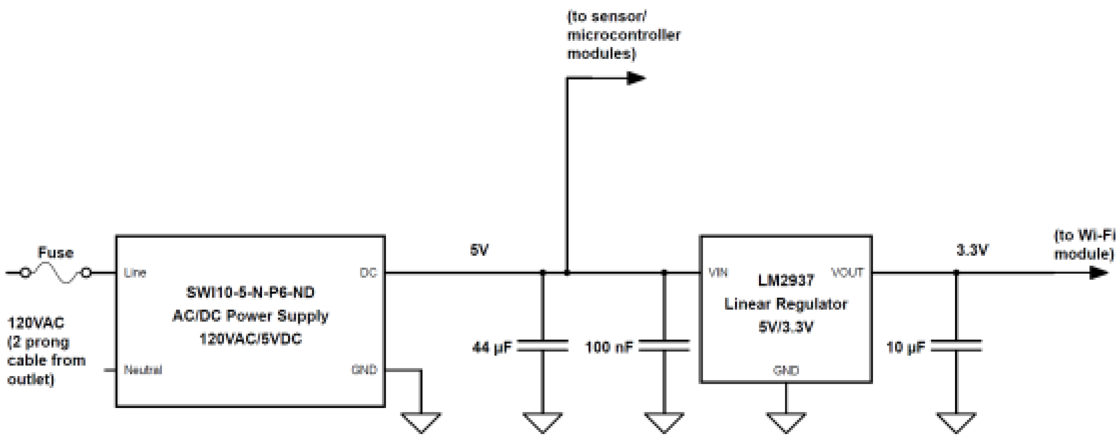

Figure 6: Hub Unit Power Schematic

2.3.3 Controller Unit

2.3.3.1 Microcontroller on the Window

Our controller, run by the atmega328, is responsible for reading all inputs, deciding the appropriate action, and then outputting signals to dictate those actions. An analog temperature sensor and various digital signals from the sensor module are sent to the microcontroller along with digital signals from the Wi-Fi module. The controller will then, accordingly, send a control signal to the motor module to command the window to open or close and regularly send window position data to the Wi-Fi module.

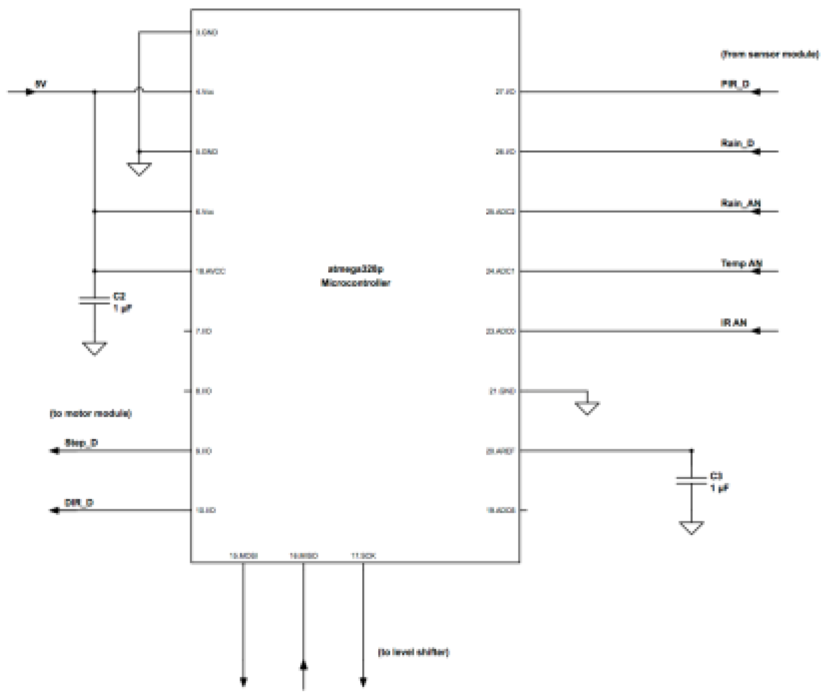

Figure 7: Microcontroller Connections

2.3.3.2 Microcontroller on the Hub

The hub microcontroller is the central processing unit. It provides a link between a phone and window, as well as tracking indoor temperature. Signals from the interior sensor module are sent to the microcontroller along with digital signals from the Wi-Fi module.

2.3.4 Wi-Fi Module

There will be two Wi-Fi modules in out design: one at the window and one near the central hub. The Wi-Fi module at the window will provide one half of the communication between the window unit and the central hub. The Wi-Fi module at the hub will provide the other half of the communication between the window unit and the central hub, but additionally will provide the communication with the smartphone app.

The communication protocol that the Wi-Fi modules accept is 802.11 b/g/n. The specific module that we are using is the ESP-1 module for the ESP8266 chip. We will control these modules from the microcontrollers using UART.

Pin	Connection	Function
2 - TX	Level Converter Input	Transmit to microcontroller
7 - RX	Level Converter Output	Receive from microcontroller
4 - CHPD	3.3V	Chip enable – high for normal use
6 - RST	Level Converter Input	Reset signal received from microcontroller
3 – GPIO2	3.3V through resistor	Can be used for flash updates, but we don't need this functionality
5 – GPIO0	3.3V through resistor	Unused, set high according to [6]
8 – 3.3 V	3.3V	Power
8 - GND	GND	Ground

Table 3: Wi-Fi Module Pin Connections

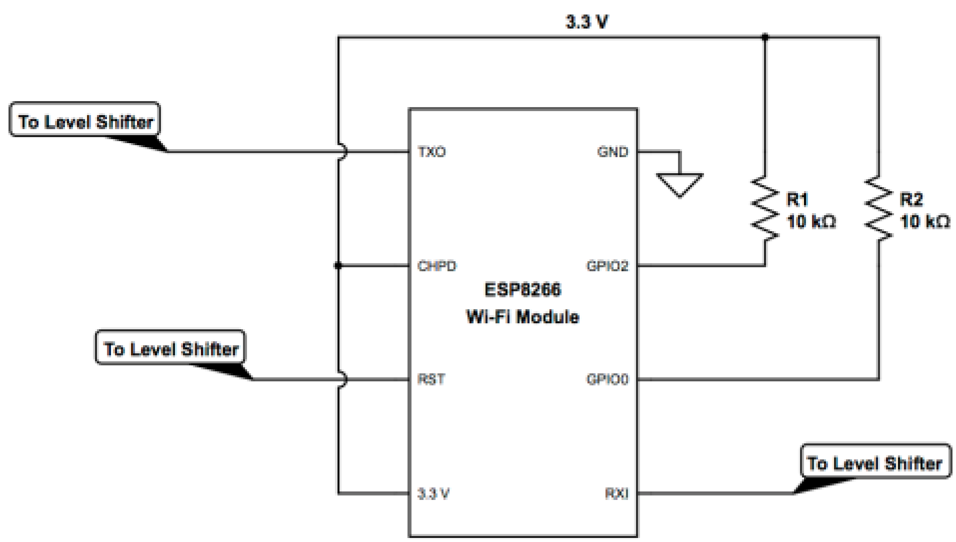

Figure 8: Wi-Fi Module Circuit Schematic

2.3.5 Motor

The motor module contains a stepper motor, gearbox, threaded rod, motor driver, and position sensor. The stepper motor and gearbox are combined and drive a threaded rod. The motor driver is on a PCB mounted with the stepper motor. The position sensor will be located on the underside of the top of the window, so that it can detect the position of the moveable portion of the window.

2.3.5.1 Stepper Motor

We will be using a Nema 17 stepper motor with a planetary gearbox. We chose to use a stepper motor because they can be moved in exact increments (.067° for the Nema 17) which will allow us to open and close the window with precision. A gearbox allows us to increase the torque at the expense of speed. A planetary gearbox in particular is designed for high torque, low speed applications such as opening a window. The gearbox has a gear ratio of 27:1 which allows a holding torque of 3 Nm and a moment permissible torque of 5 Nm. The frame is 4.2cm x 4.2cm, the height of the motor is 4.8 cm, and the height of the bearbox is 3.5 cm. The maximum axial load is 50N and the maximum radial load is 100N. Since the entire window, itself, weighs less than 45 N, we are well within the specifications of this particular motor. The biggest tradeoff is the speed. Due to the gear ratio of 27:1, the maximum speed is decreased by this ratio as well, so that the maximum speed is 7.2 rpm. This means that it might take a few minutes for the window to close, but it was a necessary tradeoff to obtain greater torque and a smaller motor/gearbox.

2.3.5.2 Motor Driver

There are several ways to drive a stepper motor. The most common are the parallel and step/direction methods. The parallel method typically uses two single phase drivers to drive each phase of the stepper motor. The microcontroller must have a DAC that can provide precise analog voltages in order to control the current through the phases. This method involves a more advanced microcontroller and overall, a more advanced control system. Therefore, we chose to use a DRV8886 that utilizes the step/direction method. This method typically uses one driver with two integrated H-bridges and an indexer. The indexer takes two inputs, step and direction, and converts these inputs into the same precise voltage output as that of the parallel method. The direction input is a one bit signal that controls which direction the motor turns. The motor turns one step each time the step pin is brought to logic high. The motor driver has three inputs and five outputs. The three inputs are step, direction, and nSleep. Four outputs go to the two phases of the stepper motor, and one output goes to the microcontroller for fault detection.

2.3.5.3 Position Sensor

It is possible to use a stepper motor with open loop control. However, it is much more reliable to use a stepper motor in a closed loop system in case the stepper misses a step or the power goes out. There were several ideas of how to accomplish position control: limit switch, potentiometer, rotary encoder, IR sensor, or an ultrasonic sensor. A limit switch can only provide position sensing at the edges of motion. Potentiometers and rotary encoders are expensive, so we ruled out these solutions. IR sensors have a large field of view, whereas ultrasonic sensors have a small field of view. Therefore, we chose to use an ultrasonic sensor because the sensor only needs to detect the position of the window. Specifically, we will use the PING Ultrasonic Distance Sensor (#28015). This component can provide precise distance measurements from 2 cm to 3 meters. It contains a transmitter and receiver on the same PCB. It operates by emitting a chirp and recording the time between the chirp and the sound reflections. It has three pins: 5V, GND, and SIG. SIG is an I/O pin that will interface with the microcontroller. SIG is asserted high to emit a chirp. Then, the microcontroller times how long the SIG pin stays high after the echo returns. The distance can then be computed based on two simple formulas.

$$v = 331.5 + (.6T)$$

$$d = \frac{vt}{2}$$

Where v = speed of sound (m/s), T = temperature (°C), d = distance (m), t = round trip time (s)

2.3.6 Smartphone Application

The smartphone app will serve as the interface between our system and a user. It will allow the user to set many parameters regarding the system and provide manual control of the motorized windows. First, and most importantly will be the ability to turn on and off the system of automatic climate control. Additionally, the app will allow the user to input a comfortable range of indoor temperatures (e.g. set the system to keep the indoor temperature between 65 and 75 degrees). Lastly, the user will be able to manually open and close windows for situations where they may wish to override the system temporarily, or only for particular windows. A situation where this may be desired is if a user is playing loud music and need the windows in that room to be closed so as to not disturb their neighbors.

In order for our product to be secure, whenever the user opens the app for the first time and attempts to change a setting, they will be required to enter a password. This password will allow them to change settings and the password will also be sent to the microcontroller to let it know that an authorized user is making changes to the settings.

The interface of the app will be kept simple. When the system is in automatic climate control mode, the manual control of individual windows will be turned off and thus grayed out as shown in Figure 9. Since our product is for being design in America, we will use Fahrenheit on the app for setting a comfortable range and convert to Celsius in the microcontroller programming. A more detailed description of the control logic that determines when and how the user can interact with the system can be found in section 2.4.

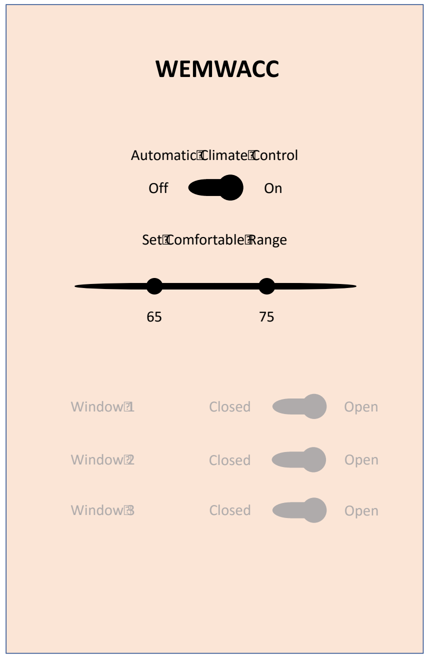

Figure 9: Smartphone Application User Interface

2.4 Control Description and Flowcharts

When the window controller turns on the system begins initialization. This includes an exchange between the window and hub systems and a 40 second delay for the PIR sensor to calibrate itself. Once the PIR sensor is calibrated and a wireless connection has been established between the separate units the window module checks for a command to switch to User Override. In the User Override state the temperature and rain sensors are not used to make decisions and only the user can control the window based on communication through their phone.

Continuing into automatic mode the controller begins rain detection as shown in Figure 10. After determining there is no rain the controller again checks for user override before going into the standard climate control procedure. Displayed in Figure 12 this procedure entails measuring the outdoor temperature and comparing this temperature against the indoor and desired temperatures to decide on the optimal window position. After a decision has been made and executed the controller repeats the previous procedures starting with rain detection.

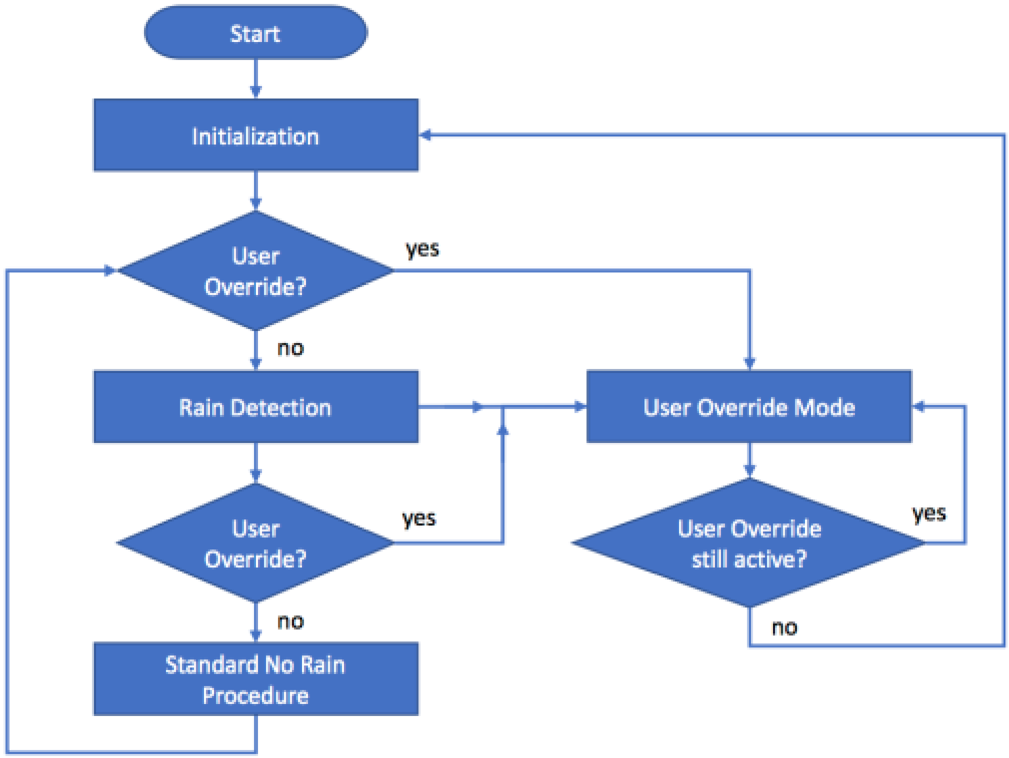

Figure control 10: Top-Level Procedure

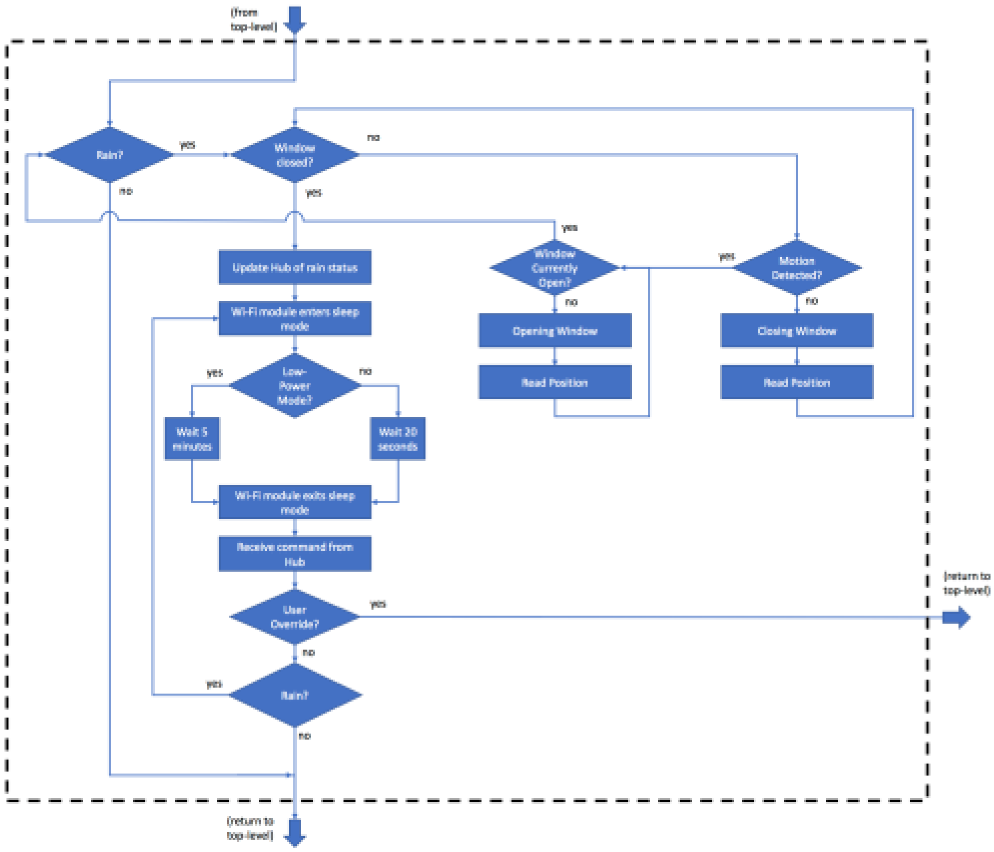

Figure control 11: Rain Detection Procedure

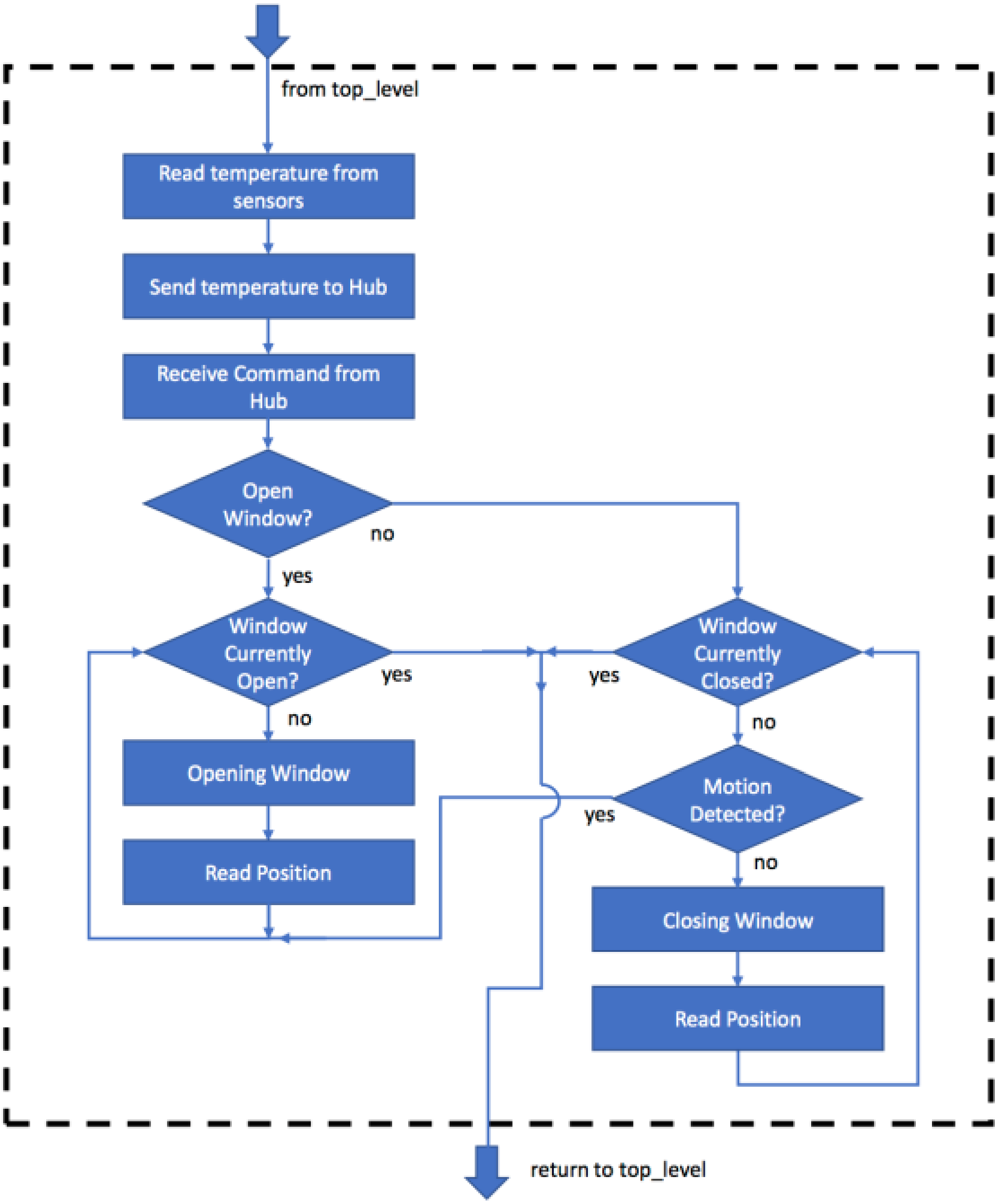

Figure control 12: Standard No Rain Procedure

2.5 Tolerance Analysis

All of the power for our window module is regulated by the 120-12V AC/DC converter. This component must function in order for any components of the system to work so it is paramount that the current rating of 6 amps is not exceeded. Our accepted tolerance is for the maximum current to never be above 5.9 amps. A high estimation of the current consumption of the converter load has been calculated to ensure that it is well below the 6 amp limit of the converter.

Module	Current Consumption (A)
Wi-Fi	0.215
Sensor	0.083
Microcontroller	0.0018
Motor	3.72

Based on the maximum current consumption for each module the total current draw is:

$$3.72 + 0.083 + 0.0018 + 0.215 = 4.02\ A$$

Most of this current is from the motor, while the other 300 mA of current must also go through the buck converter. The buck converter steps down the voltage from 12 volts to 5 volts and the current drawn by this converter is given by:

$$Iin = Iout\frac{12}{5} = \ 0.72\ A$$

This can be verified by simulating the buck converter for this load as shown in Figure 13. The simulated input current is shown to reach up to 0.6 A in Figure 14.

The efficiency of the buck converter for the calculated output current is given to be around 83%. For this efficiency, the necessary input current is found from:

$$Iin_{real} = \frac{0.72}{0.83} = \ 0.87\ A$$

$$Max\ current\ load = I_{motor} + I_{buck} = \ 3.72 + 0.87 = 4.59\ A$$

This current is the highest our system can draw from the AC-DC converter and is still well below the components current rating and our tolerance level.

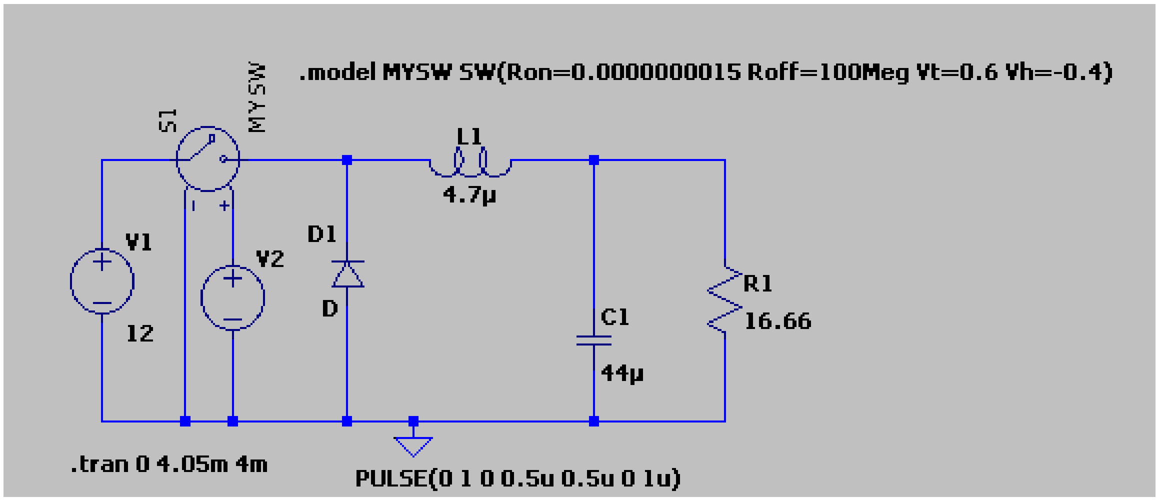

Figure 13: Simulated Buck Circuit

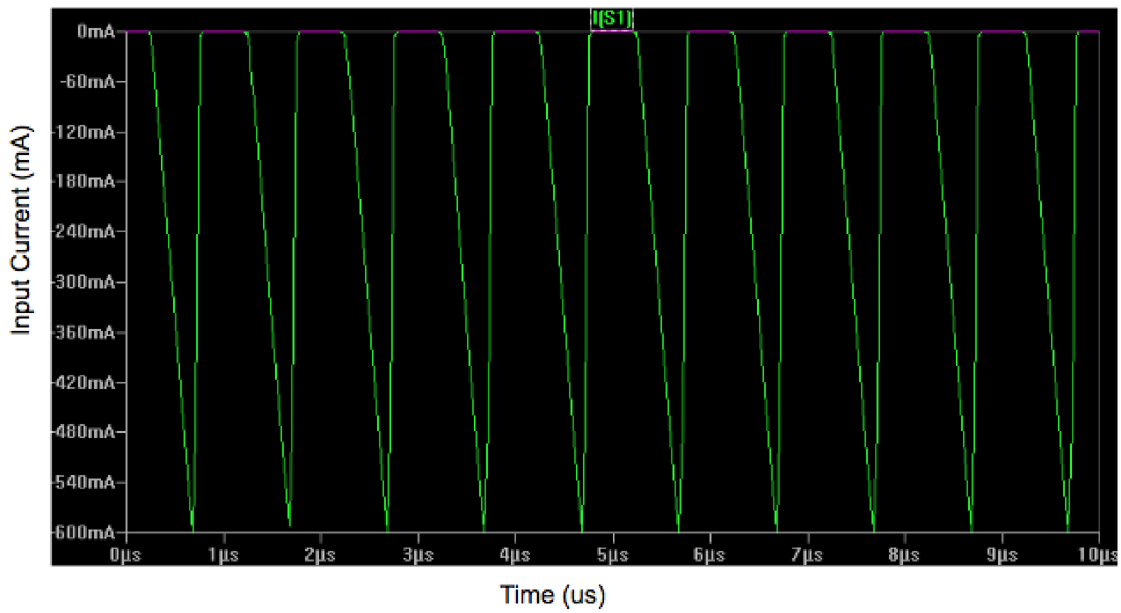

Figure 14: Simulation Plot of Input Current

3. Requirements and Verification

Module	Requirements	Verification	Points
Temperature Sensor	1. Accurately read temperatures within 1°C while temperature within range of 15°C to 25°C (59°F to 77°F or comfortable indoor temperature range).	1. a) Set apartment thermostat so that a thermometer reads 15°C, 17°C, 18°C, 20°C, 22°C, 24°C, and 25°C. 1. b) Compare thermometer readout at each temperature to temperature sensor readout. Ensure temperature readout from the sensor is within 1°C of the	3

		thermometer reading. Note. Read temperature sensor output voltage using multimeter, then manually calculated temperature from this voltage.	
Rain Sensor	1. Correct output 90% of the time when no water is present on the sensor pad. 2. Correct output 75% of the time in very light rain. 3. Correct output 90% of the time in heavy rain.	1. Read output when sensor pad is dry and ensure correct output. Both initially, and as verifications 2 and 3 are carried out. Record functionality during tests and determine accuracy. 2. a) Add two drops of water to pad using an eye dropper. 2. b) Read output voltage using a multimeter. 2. c) Wipe pad clear of water until output indicates no water. 2. d) Repeat 16 times to determine accuracy. 3. a) Add water so that sensor pad is more than 35% covered. 3. b) Read output voltage using a multimeter. 3. c) Wipe pad clear of water until output indicates no water. 3. d) Repeat 20 times to determine accuracy.	4
IR Sensor	1. Proper object detection when an object isn't in the way. Accuracy within one foot. 2. Proper object detection when an object is in the way or the window closing. Accurate 95% of the time and not dependent on distance of object to IR sensor. 3. The IR sensor gives its output quick enough.	1. a) Read output voltage of IR sensor using a multimeter with IR sensor attached to window and no objects within one foot of the window. Verify correct output. 2. a) Place hand 4 inches from the IR sensor, directly under where the window would be closed. Verify correct output voltage. 2. b) Place hand 10 inches from the IR sensor, directly under where the window would be closed. Verify correct output voltage. 2. c) Place hand 16 inches from the IR sensor, directly under where the window would be closed. Verify correct output voltage. 2. d) Repeat each test 10 times and determine accuracy. 3. Measure rise time of IR sensor voltage on oscilloscope.	4
AC-DC Converter (12V)	1. Output voltage is 12V +- 2% 2. Maintain output voltage of 12V +- 2% for 2 amp load.	1. Verify voltage at output pin is in allowed range with Mulitmeter. 2. a) Apply 6 ohm resistive load for 120V AC input.	3

		2. b) Verify voltage at output pin is in allowed range with Multimeter.	
AC-DC Converter (5V)	1. Output voltage is 5V +- 2%	1. Verify voltage at output pin is in allowed range with Mulitmeter.	3
DC-DC Converter (12-5V Buck)	1. Output voltage is 5V +- 2%	1. Verify voltage at output pin is in allowed range with Mulitmeter.	2
DC-DC Converter (5-3.3V Linear Regulator	1. Output voltage is 3.3V +- 2%	1. Verify voltage at output pin is in allowed range with Mulitmeter.	2
Window Microcontroller	1. Read correct value from rain sensor. 2. Read correct value from temperature sensor to within 5mV. 3. Reliably communicate with Wi-Fi Module (both receiving and transmitting). 4. Compute desired actions based on input signals. 5. Send appropriate control signal to motor.	1. a) Print value read from rain sensor pin for both wet and dry case. 1. b) Measure voltage at rain sensor pin with Multimeter. 1. c) Verify that microcontroller and Multimeter readings match. 2. a) Print value read from temperature sensor pin. 2. b) Measure voltage at temperature sensor pin with Multimeter. 2. c) Verify that microcontroller and Multimeter readings match. 3. a) Send 100 packets to Wi-Fi module. 3. b) Read back and verify 99 packets were received correctly. 4. Print computed values for temperature, position, obstruction and rain and compare to printed values read from sensor. 5. a) Set signal HIGH and verify pin voltage with a Multimeter. 5. b) Set signal LOW and verify pin voltage with a Multimeter.	5
Hub Microcontroller	1. Accurately read in signals from temperature sensor. 2. Reliably communicate with Wi-Fi Module (both receiving and transmitting). 3. Compute desired actions based on input signals.	1. Print value read by Microcontroller and compare to voltage measured at input pin. 2. Send and receive 100 packets and ensure 99 were transmit correctly each way. 3. Print computed values for temperature, position, obstruction and rain and compare to printed values read from sensor.	5

Wi-Fi Module	1. Proper level shifters operation changing 5V to 3-3.3V and 3V to 4-5V. 2. Microcontroller can communicate with the Wi-Fi module. 3. Wi-Fi module can connect to home's Wi-Fi. 4. Wi-Fi module can send and receive data with 99% accuracy.	1. a) Use a function generator to generate inputs to pins on level shifters. 1. b) Measure output voltages with multimeter. 2. a) Use UART communication protocol and AT commands to verify connection. Use ATMEGA328 Microcontroller to program. 2. b) 'AT' command should return 'OK'. 3. a) Use UART communication protocol and AT commands to connect to home network. Use ATMEGA328 Microcontroller to program. 3. b) 'AT+CIFSR' command should return correct IP address. 4. a) Send dummy packets from one Wi-Fi to the other, verify that received messages match sent messages. 4. b) Determine correct number of packets received by recording all packets and comparing to what was sent. 4. c) Switch which module is sending and which is receiving. 4. d) Determine accuracy of each module.	5
Smartphone Application	1. Smartphone application has functioning buttons and sliders. 2. User input into the app is successfully obtained.	1. a) Button for controlling if system is on can slide to left and right, 'On' and 'Off' become bold as they are selected. 1. b) Comfortable range sliders allows user to set lower and upper bounds on their preferred temperature range. 1. c) When system is on, window control is grayed out. When it is off, window control is not grayed out. 1. d) User can change switches on windows from 'Closed' to 'Open' and proper bolding of window status is done. 1. e) Password pop-up opens when user attempts to change a setting, and closes when password is entered. 2. In app building software, return values of the various settings to the command line to verify that they match.	5

	3. Data obtained from app is successfully sent to microcontroller.	3. a) Set comfortable range on app and turn automatic climate control. 3. b) Read out the received comfortable range and system status from the microcontroller. 3. c) Turn off automatic control. 3. d) Change position of window and verify that window changes position properly.	
Motor	1. Motor moves one step when given a step input 2. Motor can move in both directions 3. Motor can move fixture up to a height of at least 10 inches	1. a) Pulse step pin with 5373 steps (.067° per step) 1. b) Ensure that motor has turned 360°±2° 2. a) Apply logic high to direction input. 2. b) Pulse step pin with a 1kHz PWM signal. The motor should move one direction (up/down). 2. c) Apply logic low to direction input. 2. d) Pulse step pin with PWM signal. The motor should move the opposition direction(down/up) 3. a) Connect stepper motor to threaded shaft with fixture. Do not attach fixture to window. 3. b) Use microcontroller, motor driver, and stepper motor to move fixture at least 10 inches by applying step and direction inputs.	5
Ultrasonic Sensor (Motor Position Sensor)	1. Sensor must provide distance measurements with less than 12% error (worst case spec) between 2 inches and 24 inches 2. Sensor must be able to make 20 measurements per second at maximum distance of 24 inches.	1. a) Place sensor face up on table in room at room temperature (68-72°F). 1. b) Place 2ft x .5ft piece of cardboard (to replicate window pane) centered directly over sensor. 1. c) Send chirp and measure distance at 2 inch increments in 2in-24in range. 1. d) Ensure less than 12% average error. 2. a). Place sensor face up on table in room at room temperature (68-72°F). 2. b) Place a 2ft x 2ft piece of cardboard (or larger), directly centered, 24 inches above the sensor. 2. c) Send pulses every 50ms to SIG pin and measure echo time on SIG pin. 2. d) Sensor must measure distance to within 12% error on at least 18/20 pulses.	4

Table 4: Requirements and Verifications

4. Cost and Schedule

4.1 Cost Analysis

4.1.1 Labor

Name	Hourly Rate	Total Hours	Total Cost
Trevor Bush	$30	200	$15,000
Alex Casino	$30	200	$15,000
Ryan Stark	$30	200	$15,000
Total		600	$45,000

Table 5: Labor Cost

4.1.2 Parts

Part	Part Number	Vendor	Unit Cost	Quantity	Total Cost
Temperature Sensor	LM35DMX/NOPB	Digi-Key	$1.97	2	$3.94
Rain Sensor	a13090400ux0745	Amazon	$6.57	1	$6.57
IR Sensor	555-28027-ND	Digi-Key	$12.99	1	$12.99
Wi-Fi Module	WRL-13678	Sparkfun	$6.95	2	$13.90
Microcontroller	ATMEGA328-PU	Microchip Direct	$1.90	2	$3.80
Buck Converter	TS30013-M050QFNR	Digi-Key	$1.21	1	$1.21
Linear Regulator	LM2937ET-3.3/NOPB	Digi-Key	$1.53	2	$3.06
120VAC-12VDC Converter	ALS75-12	Digi-Key	$24.28	1	$24.28
Power Cord to Cable	Q941-ND	Digi-Key	$4.44	1	$4.44
Fuse	507-1995-1-ND	Digi-Key	$0.35	2	$0.70
120VAC-5VDC Converter	SWI10-5-N-P6-ND	Digi-Key	$6.38	1	$6.38
Power Jack	EJ508A-ND	Digi-Key	$0.83	1	$0.83
Stepper Motor Driver	DRV8886	TI	$5.03	1	$5.03
Stepper Motor	17HS19-1684S-PG27	Stepper Online	$29.65	1	$29.65
Ultrasonic Sensor	28015-ND	Digi-Key	$29.99	1	$29.99
Window	VSH1824	Menards	$39.99	1	$39.99
Total					$186.76

Table 6: Parts Cost

4.1.3 Total Cost

Labor	$45,000
Parts	$186.76
Grand Total	$45,186.76

Table 7: Total Cost

4.2 Schedule

Week	Task	Responsibility
2/13	Research power components	Alex
	Research sensors	Trevor
	Research Wi-Fi modules	Ryan
2/20 (Mock Design)	Research physical design and motors	Alex
	Finalize initial components	Trevor
	Prepare mock design review document	Ryan
2/27 (Design Review)	Begin initial testing of components that have arrived	Alex
	Order any remaining components	Trevor
	Begin PCB design	Ryan
3/6	Continue testing components	Alex
	Begin initial app development and control system implementation	Trevor
	Finalize PCB Designs	Ryan
3/13	Finalize testing of individual components and begin setting up motor system	Alex
	Continue app and control system development	Trevor
	Order PCBs and begin Wi-Fi programming	Ryan
3/20 (Spring Break)	Spring Break	Alex
		Trevor
		Ryan
3/27	Get motor system working (able to open and close the window)	Alex
	Finalize app and control system functionality	Trevor
	Solder parts and assemble sensor system for hub and window unit	Ryan
4/3	Begin mounting different components to the window	Alex
	Begin initial system testing and documentation	Trevor
	Finalize Wi-Fi system	Ryan
4/10	Finalize system mounting	Alex
	Complete system testing and mock demo preparation	Trevor
	Begin final report, presentation, and supplementary documentation	Ryan
4/17 (Mock Demo)	Troubleshoot any problems relating to power and motors	Alex
	Troubleshoot any problems relating to smartphone application and the control system	Trevor
	Troubleshoot any problems relating to the Wi-Fi system and sensors	Ryan
4/24 (Final Demo)	Final Demo Preparation	Alex
	Final Demo Preparation	Trevor
	Final Demo Preparation	Ryan
5/1 (Final	Finish final paper	Alex
	Finish final paper	Trevor

Papers)	Finish final paper	Ryan

Table 8: Schedule

5. Discussion of Ethics and Safety

5.1 Ethics

Throughout our project, we plan to follow the IEEE code of ethics as closely as possible. This involves the acceptance of criticism, acknowledgment and correction of errors, fair treatment of everyone, and to hold each other accountable, as well as to give proper credit to the contributions of others [7]. Specifically, of relevance to our project, we will ensure that we make “decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment” [7]. Additionally, we will need “to be honest and realistic” when we discuss the potential of scaling our project to larger homes and different window types as our design is a proof of concept rather than a market ready product [7].

5.2 Safety

In terms of safety, there are a couple of primary concerns. First, the system could accidentally close on someone or something that it is not supposed to. Second, because the system is designed to be integrated into a window and wall and uses power from the grid, there are standard electrical risks such as shock and fire. There were an estimated 52,500 electrical fires in 2006 in US homes alone, and we want to make sure none of these are because of our product [8]. These risks are largely preventable with correct installation of our product, and therefore we will recommend that the system be installed by a professional electrician. Lastly, someone could take advantage of the system to gain access to the house.

5.2.1 Physical Safety

Since the windows will have the capability of closing automatically, there is the potential that they will attempt to close while a hand, the tail of a pet, or some other object is in the way of the window closing. To avoid this, we will use an IR sensor to detect the presence of such an object and immediately stop the movement of the window.

5.2.2 Burglary

There are two main ways someone could break into a home because of our system. First, the system could automatically open the windows when the user isn’t home in order to regulate the temperature, which could allow an intruder to enter. Second, someone could hack into the central hub and open a window to gain access to the home.

5.2.2.1 Opening the window automatically when nobody is home

This problem can be solved by allowing the user to turn off automatic climate control, preventing the windows from opening until the user enters their password on the app and changes the settings again.

5.2.2.2 Allowing someone to hack in and open the window

This problem will be solved by using password protection to ensure only the owner can open the window. The password will prevent anybody who gains access to the user's phone from using it to break into their house, as well as prevents someone to use their own phone to open the windows.

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