FAST TOWEL DISINFECTING CABINET

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Abstract

This paper includes the design and verification processes of a fast towel disinfecting cabinet (FTDC). The FTDC uses UVC LEDs to disinfect bacteria on the towel, and two 100W heating elements to dry the towel in 4 hours. Each operation consists of a disinfecting cycle and a drying cycle. For the disinfecting cycle, the cabinet will shine UVC light on the towel surface for two minutes with 100% light intensity. Once the disinfecting cycle is done, the FTDC will turn on the heating elements and initiate a 4-hours drying cycle. During the drying cycle, the heating elements would continue producing heat until the bottom sensor reads 75℃. In the meantime, the bottom fan would push the heat upward to speed up the evaporation of water on the towel, and the top fan would pull any excess water vapor out through the vents on top.

Contents

1 Introduction

1.1 Objective

With society progressing rapidly, people have higher standards of living. The well-being of the population is imperative for any country. This awakening of rising concerns over personal health has led to a huge increase in the global personal hygiene market [1]. However, bath towels are often overlooked by people for how dirty they are. Sadly, more often than not, people wash their towels about two or three times a month, leaving their damp, warm towels to dry in dark, poorly ventilated bathrooms between uses. This creates a perfect environment for bacteria to thrive into a decent-sized colony on the towels. Although many of the bacteria are harmless, there is still a small portion that makes people sick. A study conducted by Charle Gerba, a microbiologist at the University of Arizona, suggests that nearly 90% of bathroom towels were contaminated with coliform bacteria and about 14% carried E.coli [2].

We would like to solve this problem by building a wall-mounted towel disinfecting and drying cabinet that uses UVC light to kill all the bacteria and dry it faster than air drying to prevent any bacteria to thrive on the towel.

1.2 Background

The recommended uses between cleaning of a bath towel is every two to three days [3], but from speaking with our friends and acquaintances we have determined that the average person only cleans their towel once every 10-15 days. We would like to increase the personal health of people, by disinfecting one of the least likely places people expect to contain disease-causing bacteria.

Currently, no products exist in the market to solve this problem. There are heated towel racks available that can dry your towel faster than air drying, but that does not prevent bacteria to grow on the towel. There are hot towel sterilization cabinets that use ozone or UV-C light intended to be used in salons and spas to keep cleaned face or hand towels damp, warm and bacteria-free [4]. Our product should be a sleek, disinfecting, and drying wall-mounted cabinet to keep bath towels clean and dry between uses. This cabinet should neutralize a substantial portion of the E. coli determined to be present on the towel.

1.3 Functionality

Our goal was to build a cabinet that would allow the user to hang the towel in after having a bath so that the towel can be disinfected and dried to prevent bacteria to grow on it. To achieve this goal we identified three key high-level functionalities the cabinet should have:

- The cabinet shall be designed such that the UVC light, in a worst-case scenario, covers 85% or more of the towel so as to kill most of the bacteria residing on the towel.
- The humidity in the cabinet shall be no more than 50% upon completion, less than 7 hours. This was required to be able to quantify whether the towel is dried or not and to ensure that it dries within a reasonable amount of time, at least faster than air drying (8 hours [5]).
- The cabinet shall not open while the UVC lights are on because exposure to UVC light is harmful to humans. UVC light is also known to cause skin cancer and possibly eye irritation when prolonged exposure is experienced.

1.4 Subsystem Overview

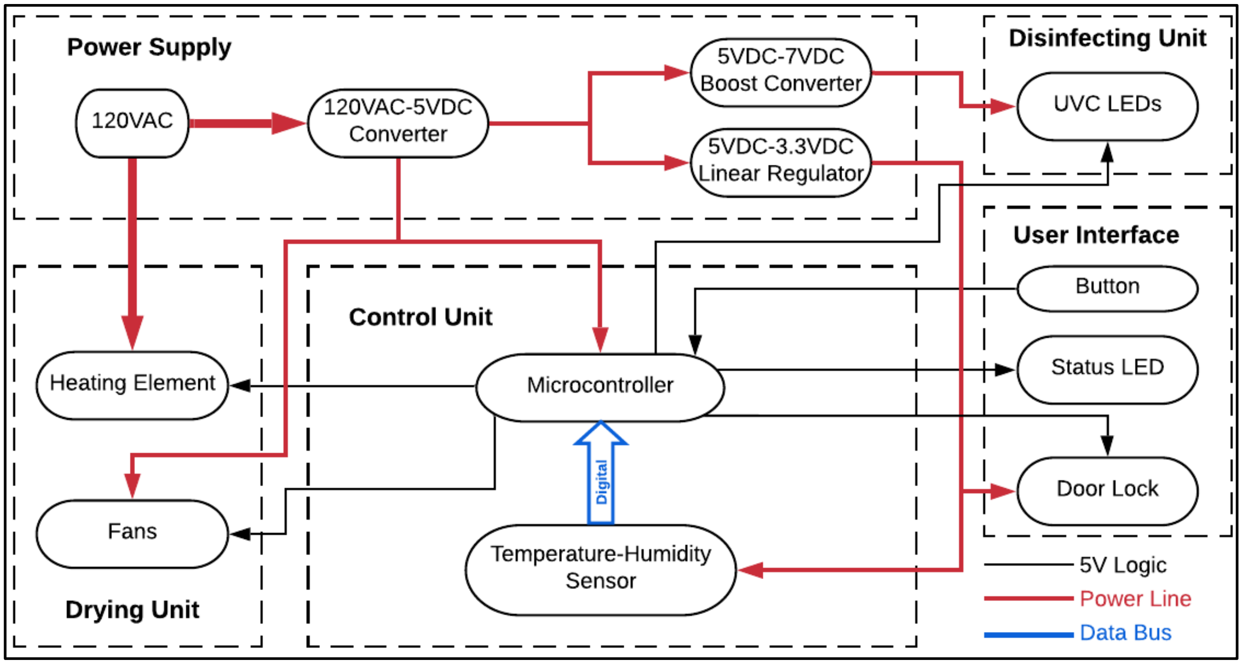


Figure 1: Block Diagram

The electrical aspect of the cabinet can be broken down into five key modules - Power Supply, Control Unit, Drying Unit, Disinfecting Unit and User Interface. The Power Supply module provides power to all the devices in our cabinet by converting 120VAC from the wall outlet to the DC voltage required for each device. The control unit consists of the MCU and two temperature-humidity sensors. The MCU controls all the other devices in the cabinet, it is like the brain of the cabinet that tells each device when to turn on/off based on input from the user and the temperature-humidity sensors. The disinfecting unit consists of the UVC LEDs to be able to kill the bacteria on the towel, thereby covering the first high-level requirement. The drying unit consists of the heating element and fans to be able to dry the towel and reduce the humidity in the cabinet, thus covering the second high-level requirement. The User Interface module consists of the button for the user to be able to trigger a cycle, the status LED to show the cycle status and the door lock to keep the door locked during a cycle. The MCU commands the solenoid door lock to remain in the active/locked position during a cycle, thus covering high-level requirement 3.

2 Design

2.1 Physical Design

We will be using twelve UVC LEDs in our cabinet. To achieve full coverage under average conditions, we will put six lights in the door of the cabinet and six against the back wall. The front and back UVC lights will each be 3” away from the towel, plus or minus the thickness of the towel and mount thickness for the lights. The UVC light needs to come in contact with the surface that it is killing bacteria on. This makes it extremely important for the towel to be covered as much as possible by the light in order to kill the majority of bacteria residing on the towel. There will be a rod at the top with moveable clips to hang towel of any size that does not exceed the dimensions of inside the cabinet. We will implement a heating element and fan into the bottom of our cabinet to successfully convection dry our towel and decrease humidity. There will be vents at the top of the cabinet for the fresh air to flow in and moist air to flow out. There will be a door lock to keep the door closed. The door lock is a necessity to keep the user from shining the harmful UVC light on them accidentally or on purpose.

2.2 Power Supply

Since the cabinet will be powered by mains electricity an AC-DC converter will be used to convert 120VAC from the wall outlet and regulate it to 5VDC for the microcontroller(MCU) and fans. The temperature-humidity sensor initially chosen (HDC2010) works in the range 1.6-3.6V. The solenoid door lock works in the range 2.5-5VDC but it draws more current at higher voltages and simply dissipates the extra power drawn as heat. So, we decided to run the solenoid and the temperature-humidity sensor at 3.3VDC. Figure 2 shows the schematic using the LM1117-3.3 linear voltage regulator to convert 5VDC to 3.3VDC. While testing the UVC LEDs, we found out that they emit maximum intensity at 6.5-8VDC, so we used an off-the-shelf boost converter to convert 5VDC to 7VDC.

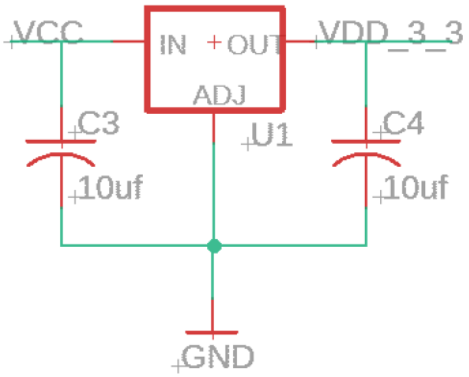


Figure 2: Linear Regulator Schematic

2.3 Control Unit

2.3.1 Microcontroller (MCU)

The control unit consists of the ATMega328PU MCU that controls every operation of the cabinet, specifically: accepting user input from the button, locking the door, controlling the UVC LEDs and drying unit, maintaining the desired temperature based on readings from the sensors, displaying status on the status LED. The ATMega328PU GPIO pins can handle a maximum of 20mA of current which is quite less compared to the current drawn by some of our devices. So, we will be using MOSFETs to control the fans, the UVC LEDs, and the solenoid. Since the heating element is powered directly by 120VAC we will be using a relay to control it. Figure 3 shows the MCU schematic. Figures 4,5 show how the disinfecting and drying units connect to the MCU.

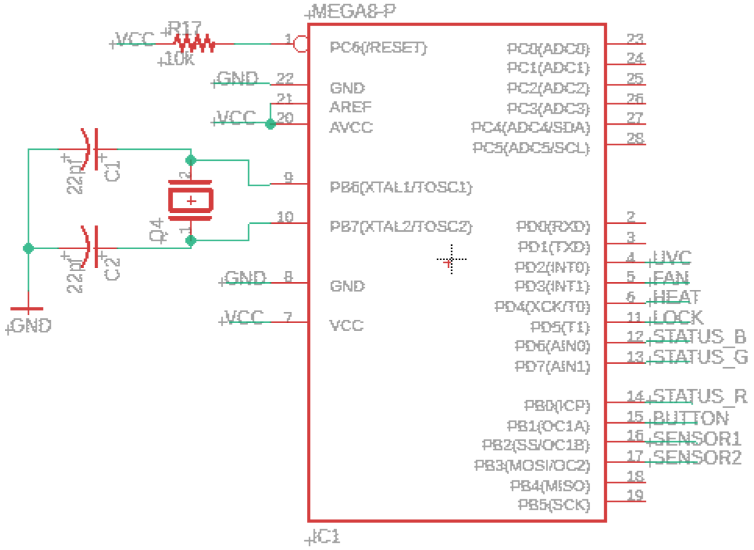


Figure 3: MCU Schematic

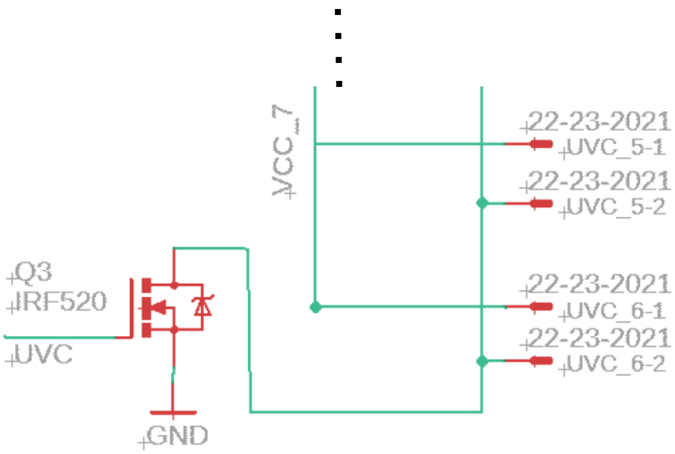


Figure 4: Disinfecting Unit Schematic

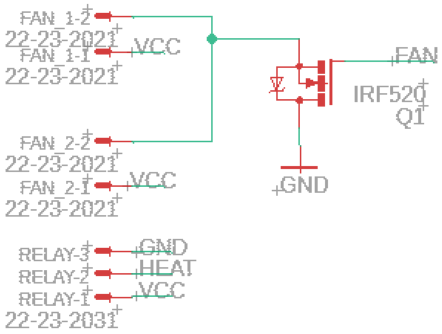


Figure 5: Drying Unit Schematic

Figure 6 shows the software flowchart. A cycle can be triggered by pressing the button. A cycle consists of three modes - disinfecting mode which lasts for two minutes, drying mode which is active till humidity is more than 15% or time for this mode is less than 8 hours, and finally the done mode in which the user can take out the towel. In addition to this control flow, the user can also stop a cycle by pressing and holding the button for 5 seconds. We implemented this functionality for the user to be able to get the towel out earlier if needed or to able to stop the cycle if the user suspects that the cabinet has malfunctioned.

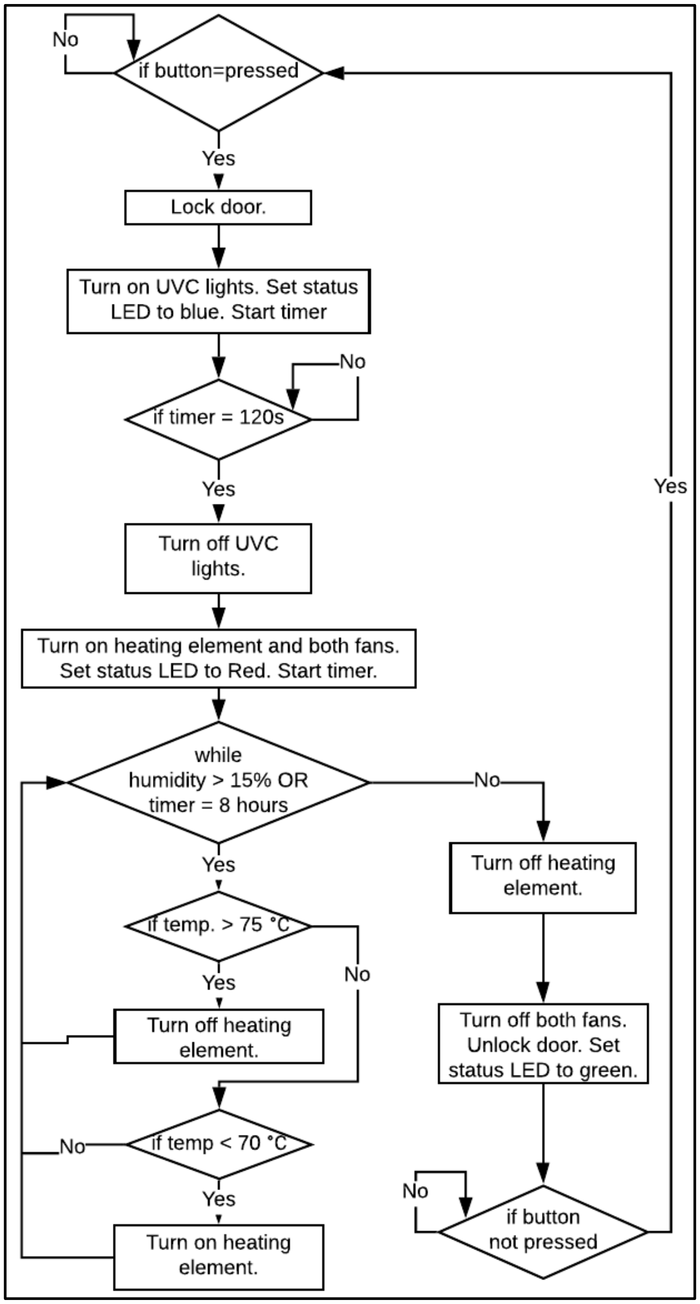


Figure 6: Controls Flowchart

2.3.2 Temperature-Humidity Sensor

There are two temperature-humidity sensors in the cabinet - one at the bottom to measure the temperature to prevent the fan from melting and one in the middle of the cabinet to measure the humidity to indicate when to stop the cycle. We also used the sensor in the middle for collecting the temperature, humidity data inside the cabinet for an entire cycle. We had initially planned to use the HDC2010 sensor which is a BGA surface mount device. It fit our requirements really well, communicated via I2C and was really cheap. We designed the PCB for it and soldered it on but couldn't get it to work. We used the Wire library for the Arduino to check if it could at least see the sensor but the Arduino wasn't able to detect it. We thought that we might have soldered on the sensor in the incorrect orientation so we even tried the opposite combination of pins but it still did not work. Due to the limited amount of time we had remaining, instead of debugging this sensor, we decided to use another sensor, the DHT22, which was slightly more expensive but much easier to use. The DHT22 sensor communicates via a single digital pin. The default state of the pin is high. When the MCU wants to get a reading it sets the pin to low for 1ms, pulls it back to high and waits for the sensor to respond. The sensor responds by pulling the pin to low for 80µs and pulls it back to high to indicate it is ready to start sending the data. It sends 40 bits of data - 16 for temperature, 16 for humidity and 8 for checksum. It sends 0 and 1 by varying the time the pin stays high - if it wants to send a 0 it pulls the pin to low and back to high for 28µs and if it wants to send a 1 it pulls it to high for 70µs. Refer to Figure 7 for clarity.

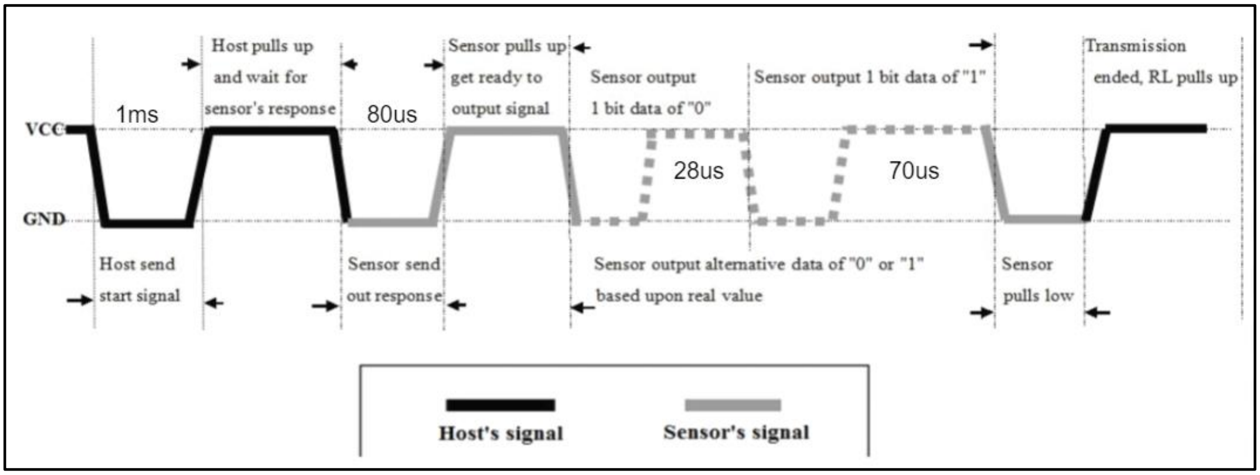


Figure 7 : DHT22 Temperature-Humidity Sensor Communication Protocol

2.4 User Interface

The user interface consists of three elements: a button for the user to trigger a disinfecting-drying cycle, a status LED to show progress, and a door lock to prevent shining UVC light on the user. Figure 8 shows the schematic for the user interface module.

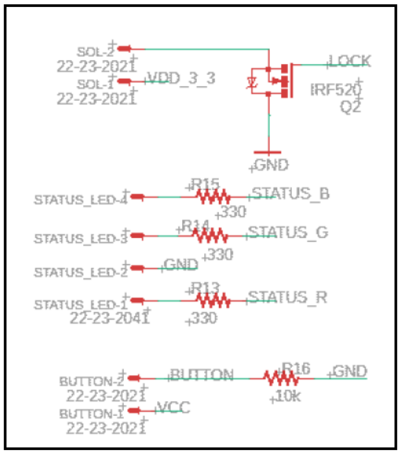


Figure 8: User Interface Schematic

2.5 Disinfecting Unit

We mounted six UVC LEDs on either side of the towel, so as to disinfect it from bacteria. The lights are arranged in an array such that we will achieve the best possible coverage of a standard sized hand towel for the number of lights used. We chose to use UVC over other alternative methods for disinfection our towel for a few reasons. The leading reason for choosing UVC over ozone, for example, is that UVC neutralizes the bacteria much quicker than ozone. The implementation of UVC is much simpler and safer to operate than again comparing to ozone. When our UVC cycle is complete, it is completely safe to open the cabinet immediately. Whereas for ozone, the air must be filtered carefully before one could open the cabinet as the air inside the cabinet would be harmful to breathe. Another aspect to add to this is the fact that our cabinet would have needed to be airtight for us to safely operate the ozone system. Our cabinet had many cracks and crevices, primarily where the door meets the chassis, that would allow the harmful air to escape from our project. Needless to say, we felt much more comfortable working with UVC than an ozone-based solution.

The UVC LED based solution has a set of drawbacks to it as well though. The largest issue is that UVC light must come into direct contact with the surface that it is trying to disinfect, but ozone based solutions can actually penetrate into the material and disinfect bacteria trapped in the towel itself. The UVC light can cause ulcers to form on the skin when exposed to UVC light for prolonged periods. UVC light is also known to cause skin cancer and possibly eye irritation when prolonged exposure is experienced. We took special precaution to take these factors into account while designing the chassis of our project and demonstrating the project to those interested.

2.6 Drying Unit

The drying unit is composed of two fans and two heating elements. The fans are rated for approximately 80℃ and are controlled by MCU using an NMOS. The MCU pulls the gate signal to the NMOS to either high or low depending on which mode of operation we want to operate under at that moment. The fans run continuously once a cycle has begun. The heating elements are each 100W elements that pull directly from the incoming 120VAC source supplied to our project. As with the fans, the heating elements are controlled by the MCU, but we chose to use a higher power rated relay to do the switching for the heating elements instead of a MOSFET.

The cabinet is designed such that one fan can be placed on the top plate and one can be placed on the bottom plate. We considered two alternative air flows using the fans as shown below. In the first alternative, as shown in Figure 9, the top fan brings in cool air from the outside through the vents and blows it down onto the towel. The bottom fan continues to pull this air downward and blows it onto the heating element. This causes the air to increase in temperature and naturally rise, thereby creating a convection current in the cabinet. This method is primarily to ensure that the bottom fan does not melt since it blows cooler air onto the heating element instead of pulling hot air up. In the second alternative, which we choose as the final design, we flipped the bottom fan such that it blows hot air up. We were able to flip the fan to pull hot air up and still prevent it from melting by capping the temperature at the bottom at 75℃. If the temperature at the bottom reaches 75℃ the heating elements will be turned off until it cools down to 70℃ (refer to figure 6). We closed all but two vents at the top to aid in preventing the heat from leaking through the top of the cabinet. Two vents were left open to allow the humid air to escape and fresh air to come in. This choice was made to increase the internal temperature of the cabinet, as we thought that too much of our heated air might be escaping. Upon testing both methods, we found out that using the second method allowed the cabinet to reach greater temperatures and dry the towel in merely four hours.

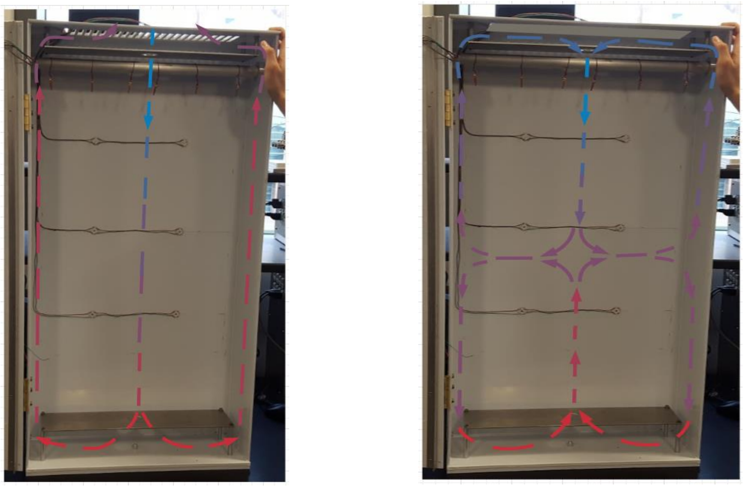


Figure 9: Heat Flow

3. Design Verification

After all the design processes are done, we need to verify all the functionalities of the project. Namely, the cabinet can disinfect a towel, dry a wet towel, and safely lock itself during operation.

3.1 Disinfection

One of the main functionalities we want to achieve with our cabinet is to disinfect a standard-size hand towel, using UVC light. Due to unavailability of a petri-dish sampler, our verification on disinfection relies heavily upon the datasheet of the UVC LED.

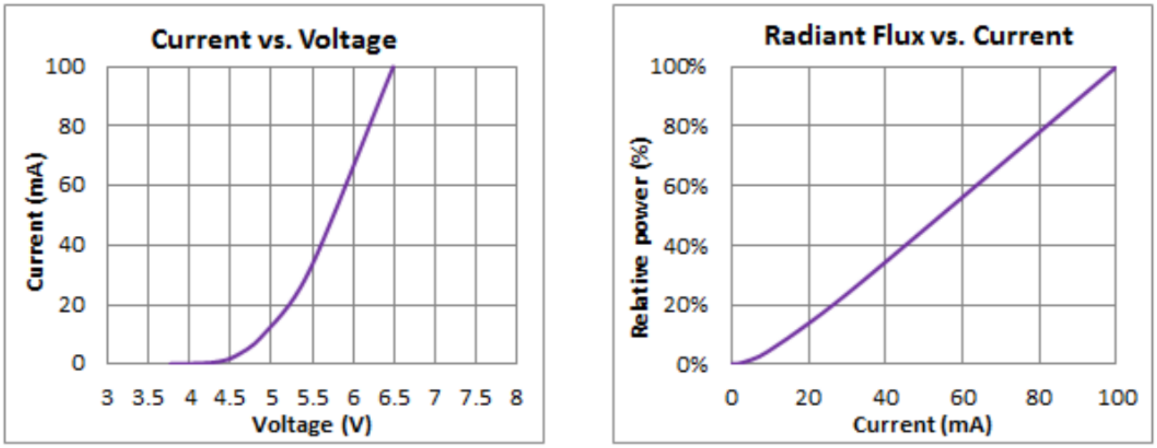


Figure 10: UVC LED Light Intensity vs Input Voltage [6]

In Figure 10, it shows that UVC LEDs output with 100% power intensity when the input voltage reaches over 6.5VDC. So to maximize the effect of disinfection, we power the UVC LEDs with 7VDC to guarantee the full power intensity during operation. The actual test results agree with the datasheet statistics. When the input voltage exceeds 6.5VDC, the light intensity stops increasing but the current still goes up with the same rate. For 7VDC, the current is about 160mA across each LED.

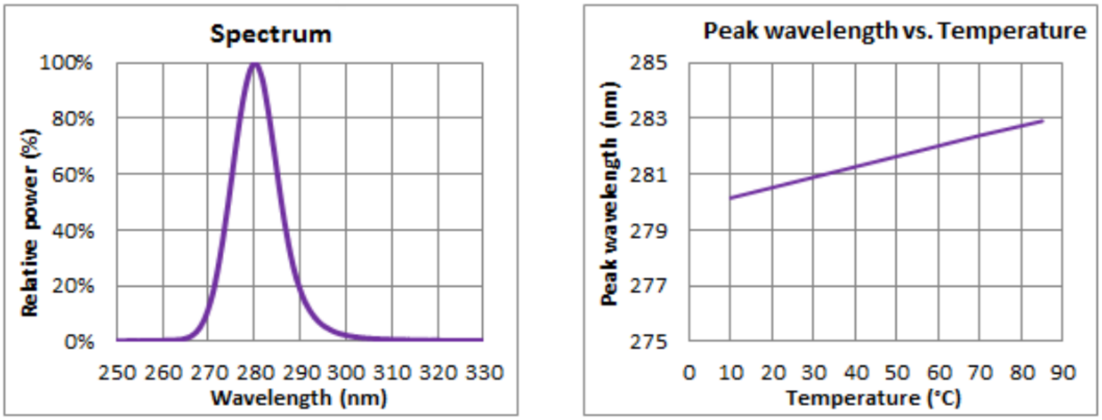


Figure 11: UVC wavelength vs relative power (temperature) [6]

Because the ambient temperature in the cabinet is between 24°C and 43°C during an operation, the datasheet suggests the wavelength of the UVC light is always around 280 nm. One of the performance features of these UVC LEDs is the proven effectiveness for disinfection at 280 nm. Although we cannot get a quantifiable result for disinfection, we believe with only 3 inches away from the towel surface and 100% light intensity, these UVC LEDs can neutralize enough bacteria to disinfect a towel.

3.2 Drying

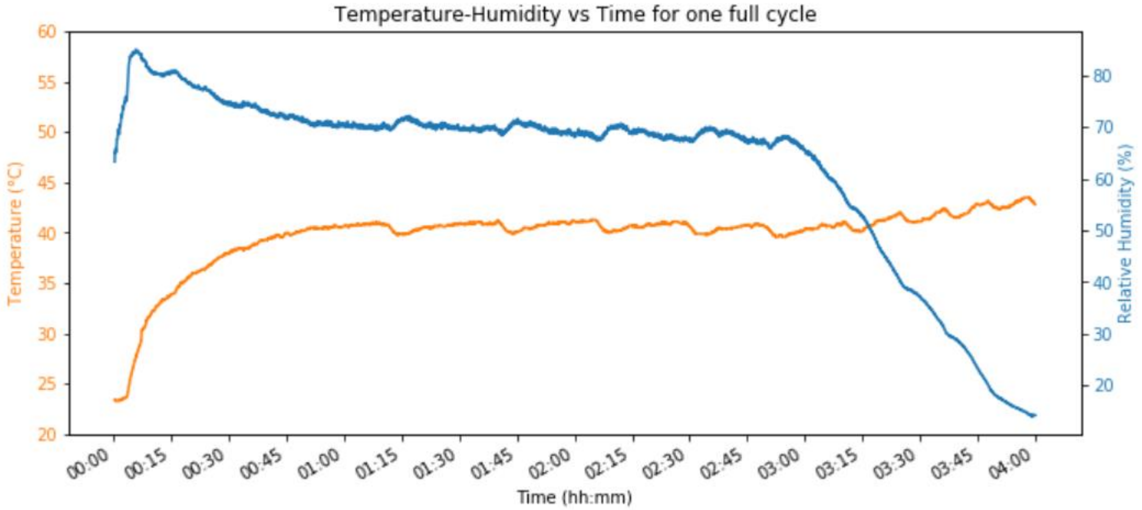


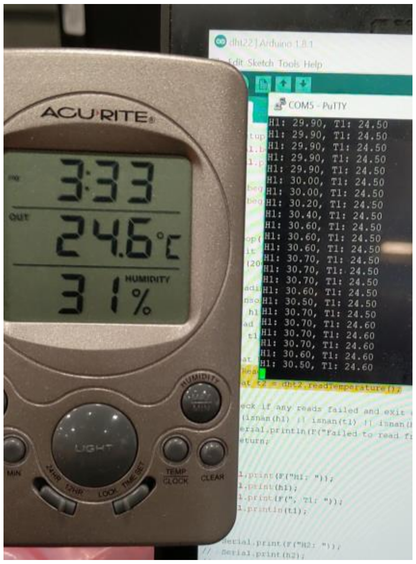
Figure 12: Temperature-humidity vs time

To verify the drying functionality, we designed a test that lets us compare the air-dry towel, reference towel (dry towel), and our testing towel after one operation. For the testing towel, we evenly distributed 10 ounces of water onto the towel. Then we put the towel into our cabinet and started the operation. Figure 13 and 14 show the test set-up and how we compare the result with a reference towel. Figure 12 shows the humidity-temperature data of one 4-hour test. The relative humidity at first peaks at 84% after most water in the towel becomes water vapor and leaves the towel. At the 4 hours mark when we terminate the cycle, the relative humidity is about 14.2%. The big change in relative humidity verifies the success of drying functionality of the cabinet.

To test the accuracy of our temperature/humidity sensors, we borrowed a reliable third-party sensor from our TA. In Figure 15, it shows the instantaneous test results comparison between our sensors and the reference sensor. The difference between the two sensors is very small and constant; the instantaneous temperature readings match and the humidity readings only differ by ±0.5%.

Figure 13: Before operation

Figure 14: After operation



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H1: 29.90, T1: 24.50
H1: 29.90, T1: 24.50
H1: 29.90, T1: 24.50
H1: 29.90, T1: 24.50
H1: 29.90, T1: 24.50
H1: 30.00, T1: 24.50
H1: 30.00, T1: 24.50
H1: 30.20, T1: 24.50
H1: 30.40, T1: 24.50
H1: 30.60, T1: 24.50
H1: 30.60, T1: 24.50
H1: 30.60, T1: 24.50
H1: 30.70, T1: 24.50
H1: 30.70, T1: 24.50
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H1: 30.60, T1: 24.50
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H1: 30.70, T1: 24.60
H1: 30.70, T1: 24.60
H1: 30.60, T1: 24.60
H1: 30.50, T1: 24.60
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Figure 15: Verification of our sensors

Figure 13 and 14 show the test set-up and how we compare the result with a reference towel.

4. Costs

4.1 Parts

Below we have tabulated the information for each of our part and the overall price within Table 1**.** We can see that the cost of materials and UVC LEDs made up over two-thirds of the overall cost of our project without taking into account the labor. These are two regions in which we can greatly improve on to increase the overall affordability of our project. The material we used was very expensive because as a prototype, we wanted to be prepared for the very worst conditions imaginable. Now that we have tested and simulated our cabinet, we know that the temperature rating for the material we used can be much lower. This will open up a wider range of more affordable materials to make our cabinet out of. The UVC LEDs were the single most expensive component overall. The bulk price of the same UVC LEDs is $7.50, which would save us a little over $4 per LED. With more time and research into UVC LEDs, we could probably even find a more cost-effective one than the one we used though, which would only further improve the overall affordability of our product.

Table 1: Parts

Description	**Manufacturer**	**Part Number/Link**	**Quantity**	**Price per unit**	**Total Price**
Status LED	Digikey	1568-1215-ND	1	$1.05	$1.05
Button	Supplied by us	Sparkfun	1	$0.50	$0.50
Humidity/Temperature Sensor	Amazon	B073F472JL	2	$6.45	$12.90
Fan	Mouser	670-OD402005HB	2	$9.97	$19.94
Fan Guard	Mouser	562-08149	2	$0.41	$0.82
Heating Element	Bloomfield	8572-18	2	$6.89	$13.78
Relay	Supplied by us	N/A	1	$0.50	$0.50
Solenoid	Digikey	1568-1592-ND	1	$4.95	$4.95
AC/DC	Mouser	709-EPS25-5	1	$12.89	$12.89
5V to 7V	Banggood	1100757	1	$1.88	$1.88
5V to 3.3V	Mouser	LM1117IMPX33NOPB	1	$1.10	$1.10
MCU	Digikey	ATMEGA328-PU-ND	1	$1.96	$1.96
Crystal Oscillator	Digikey	300-6034-ND	1	$0.59	$0.59
UVC LED	Digikey	1807-1022-ND	12	$11.75	$141
Chassis	Machine Shop	N/A	1	Free	N/A
Chassis Material (Polypropylene)	Machine Shop	N/A	$.03/sq. in.	$73.92	$73.92
Rated Cable	Menards	N/A	1 (10 ft)	$5	$5
Water Repellent	NANOPROTECH	857111005055	1	$25.73	$25.73
Clips to Hold Towel	Digikey	CTM-30C-ND	4	$0.32	$1.28
PCB orders	PCBWay	N/A	1	$15	$15
Total					$334.79

4.2 Labor

From the statistics on the ECE official website, the average starting salary for students graduating with a bachelor's degree in electrical engineering is \$71,166 (2016-2017) [7]. That gives us a \$35.58 hourly rate for our work, assuming salary is based on 50 weeks of working 40 hours per week. We estimate that we will work 9 hrs/week on average each.

$$\$35.58\text{/hour} * 9 \text{ hrs/week} * 10 \text{ weeks} * 3 \text{ workers} = \$9606.60 \tag{1}$$

$$\text{Per person: } \$3202.20 \tag{2}$$

The schedule that we used to successfully complete our project on time can be found in Table 2. We had to slightly accelerate our efforts from what we predicted in order to complete our project in time to gather results on our system while operating successfully.

Table 2: Weekly Schedule

Week	Harsh	Chris	Jacky
2/18/19	Work on design doc: R&V, PCB Layout, Controls flowchart	Finish the CAD model for the chassis and communicate with the machine shop	Finalize the selection of parts and place the order on the website
2/25/19	Acquire datasheets of all parts that were ordered and start designing the circuit.	Send in the build order to the machine shop, and help designing the schematics	Start designing the circuit schematics for each module
3/4/19	Begin circuit and PCB design on Eagle.	Revise schematics for necessary changes	Contact biology/chemistry department for petri-dish testing
3/11/19	Finalize the PCB design and send in the first order.	Start receiving parts from manufacturers, and start testing requirements for each part	Follow up with the progress with the machine shop, and biology/chemistry department.
3/18/19	Individual Progress Report	Individual Progress Report	Individual Progress Report
3/25/19	Begin version 1 protocol design and programming.	RSO Competition	Help out with putting parts together with the chassis. Once finish putting things in place, spray the water repellent over circuits.
4/1/19	Integrating the control unit with the rest of the units.	Integrating heating element and ventilation with rest of	Integrating UVC and solenoid door lock with the rest of the

		the design	design
4/8/19	Modularly testing each of the systems.	Modularly testing each of the systems.	Modularly testing each of the systems.
4/15/19	Debugging and gathering results/data.	Debugging and gathering results/data.	Debugging and gathering results/data.
4/22/19	Presentation : Controls, temp./hum. communication	Presentation: Chassis, Power module, drying unit	Presentation (UVC module, sample results)
4/29/19	Final Paper	Final Paper	Final Paper

4.3 Overall Development

We see that the cost of raw materials plays a significant role in the overall cost of the project. The time contributions we made for labor were relatively minimum when taking into account that we had to design, test, and construct our product from scratch. The overall cost for creating the first model of our project is nearly \$10,000, but most of this cost is the money we would have paid ourselves for developing the product.

$$\$9606.60 + \$326.97 = \mathbf{\$9933.57} \tag{3}$$

4.4 Recurring Operating

Table 3: Power consumed during one cycle

Device	Quantity	Voltage (V)	Current (A)	Time (hrs)	Power Consumption (Wh)
UVC LEDs	12	7	0.1	0.0833	0.7
Solenoid	1	3.3	0.733	~4	9.7
Heating Element	2	120	0.833	~4	800
Fan	2	5	0.3	~4	1.2
Others	~	5	Negligible	~4	Negligible
			Total power consumption		**811.6**

In Table 3 we find the total power consumption that our project uses to complete a full cycle. We find the power consumption by implementing Equation 4, where P is power, V is voltage, I is current, and n is the number of elements. The standard for measuring consumption is to multiply the power consumption by the time in which that power is being drawn, as is seen in the last column of Table 3.

$$P = IVn \tag{4}$$

We can take this knowledge and figure out that it cost us 9.74 cents to operate our product assuming average electricity rates in Illinois. To put this cost more into perspective it is helpful to look at a broader timeline of a month. The monthly cost of operating our product is $2.92. We are proud to have achieved such affordable operating costs.

$$\text{Total cost assuming 12 cents per kWh [8]} = 12*0.8116 = \mathbf{9.74\ cents.} \tag{5}$$
$$\text{Total monthly cost} = 30*0.0974 = \mathbf{\$2.92.} \tag{6}$$

5. Conclusion

Overall, the project is very successful. We meet all our high-level requirements with a very reasonable budget. In the following sections, we will talk more about the final results of the project in greater details.

5.1 Accomplishments

In addition to satisfying all our high-level requirements, we actually exceeded some at the end. First, we managed to dry a damp towel right about 4 hours, saving nearly 50% of the time that we aim to reach. We did it by changing the directions of the airflow in the cabinet and closing some of the vents on the top of the cabinet. These two changes allow greater heat utilization and less heat leakage. Second, the final UVC coverage exceeded the 85% UVC coverage in the high-level requirements by 8%. In the worst-case scenario, the UVC can cover about 93% surface area of both the front and back of the towel. This allows potentially better disinfecting performance by UVC LEDs. We did it by mounting 6 UVC LEDs on both the front and back of the towel.

5.2 Uncertainty

Unable to find a professional to take petri-dish samples for our project, we have no way of quantifying how much bacteria is killed in one operation cycle. This remains as the biggest uncertainty of our project. If we are given more time to work on this project, we would try to contact professor Jiang and ask him to assist us with petri-dish samplings.

5.3 Ethical considerations

There will most definitely be some safety concerns that we need to account for with our project. One of the first that comes to mind is the potential harm that can come from UVC light exposure. To mitigate this concern and abide by the IEEE Code of Ethics, #1: “to hold paramount…” [9], the first step we will take is to implement a self-locking mechanism that will not allow users to open the door and expose themselves to UVC light when our cabinet during a towel cleaning cycle. The second step we will take is to inform the user of all potential hazards with using this product and explain how to avoid harming themselves complying with the IEEE Code of Ethics, #1: “to disclose promptly factors that might endanger the public” [9]. One way the user can be exposed to UVC light is if they intentionally leave the cabinet open and trigger a cycle. We haven’t incorporated a solution to this in our design but if we have extra time we might add a feature to only trigger a cycle if the door is closed.

We will need some sort of safe voltage regulation if we are to use the 120VAC from a wall plug. The hazards of using 120V in wet conditions are quite obvious when it comes to the potential of electrocution. We would need to safely step down the voltage to power the heating element, sensors, lights, and microcontroller.

The moisture that we expect to experience inside of our cabinet could be detrimental to any PCBs that we use. We currently plan on spraying the PCBs with a hydrophobic coat of sort to keep the water that accumulates on the surface from shorting any of our components. We would also like to incorporate some type of ventilation if we have spare time in an effort to keep moisture from accumulating on our components. Another way to combat this issue would be to keep the microcontroller in an enclosure inside the cabinet so that the moisture does not reach it.

Since our product is in the development phase and is more of a proof-of-concept design at this point, we conservatively claim that our project would kill most but not all bacteria. After formulating a method to test the effectiveness of our disinfection unit, we would report the achieved bacteria kill rate. This is the encouraged practice by the IEEE Code of Ethics, #3 “to be honest and realistic in stating claims...” [9].

We are incorporating a convection system, which means we will need a heater. The issue we expect the user could encounter with the heating system is potential fire hazards such as lighting up the towel on fire. We will design the system to maintain a safe temperature inside the cabinet to avoid the possibility of burning the towel. We would also purchase a fan with a guard to avoid any potential injury to the user if they intentionally put their hand in the fan.

We know that wires are not typically a safety concern, but due to the nature and size of our project, we will have wires spread all throughout our cabinet. We do not want the wires to be in the way of other components, so we plan on wrapping wires in a bunch against the wall.

5.4 Future work

If we are to take this project further and possibly turn it into a commercialized product, we need to improve on a number of aspects of the project.

First, the current cost of the cabinet is about 350 US dollars. This price is not very economically appealing, and probably very few people would purchase it. However, we can develop a production line that manufactures and assembles the cabinet much faster and cheaper. Moreover, the material, used to build the cabinet, is rated for 180 degrees Celsius. However, nowhere in the cabinet reaches over 70℃. So we can definitely save the cost by picking a cheaper material with a lower heating rating.

Second, we need to come up with a better mechanical design. The solenoid does successfully lock the door, but the length of pull on the solenoid is not much longer than a few millimeters. It is perceivable that the door could be forced open during use if someone intentionally tried to harm themselves.

Third, the cabinet is not assembled perfectly. The cabinet itself has a warped door that allows a lot of the heat to escape from the cabinet. This loss of heat will slow down the drying time for the towel as we cannot heat the cabinet up as high or as quickly to the max, or desired temperature inside the cabinet. We could look into materials that hold their shape better when trying to make improvements to our current model.

Aesthetic improvement can also be something we can work on to turn our project into a product. We can cover up all the wires and only have openings for all the UVC LEDs. Moreover, we can also enclose all the power supply components in a clean-looking box.

Last but not least, we can offer different sizes for the cabinet. For example, we can design a model that supports most bath towels, and a model that supports most hand towels, etc. So customers can choose the cabinet that suits their needs the best.

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Appendix A   Requirement and Verification Table

Note: All requirements were met.

Table 4: 120VAC - 5VDC Converter

Requirement	Verification
1. The converter should take the 120VAC and step it down into a range of 5DC ± 2% required by the components with a power rating of 25W.	From the datasheet, we know that the output voltage will be in a range of 5VDC ±2% [10].

Table 5: 5VDC - 7VDC Boost Converter

Requirement	Verification
1. The converter should take our 5VDC as input and output 7VDC with a tolerance of ±5%.	We can test this by simply applying 5VDC to the converter and measure the output voltage across a load. We will then compare the output with our design requirement.

Table 6: 5VDC - 3.3VDC Converter

Requirement	Verification
1. The converter should take our 5VDC as input and output 3.3V to our solenoid and sensors.	The linear regulator we have chosen will output 3.3VDC with a tolerance of ±1%, according to the datasheet [11].

Table 7: Microcontroller

Requirement	Verification
1. Both sensors require about 1.1 mA to take regular measurements.	● The datasheet specifies that the current is within the range of 1.2 mA to 1.46mA [12].
2. The microcontroller should output voltage within the range of 5V ±5%.	● We can verify the control pins by measuring it with a voltmeter.

3. The microcontroller should keep the door locked during a disinfection-drying cycle and pressing the button during the cycle has no effect.	● Trigger a cycle by pressing the button and make sure that the door does not open until the cycle is complete. Press the button a few times during the cycle to make sure it has no effect.

Table 8 : Temperature-Humidity Sensor

Requirements	Verification
1. The temperature-humidity sensor must work in 3.3VDC ± 5% with 2.5mA maximum current.	● Referencing the datasheet, we know that the sensor will accept a voltage in the range of 3VDC to 5.5VDC [13].
2. Should read temperature with a ±1℃ accuracy and humidity with a ±5% accuracy.	● We will take measurement from our sensors and compare the readings to those of an existing verified product, ensuring that they are within ±1℃ and 5% for humidity.

Table 9: UVC LEDs

Requirement	Verification
1. The LED should work at 7 ±1 V with 100mA nominal current.	● Provide a couple different voltages from 5V to 8V [14]. ● Check if the LEDs turns on.
2. The LEDs shall cover at least 85% of the towel.	● We calculate the area covered by one LED in the configuration we will be implementing. Apply trigonometry to the distance from the towel and viewing angle of the LED to find the radius of our circle. Graphical derivation can be found in Tolerance Analysis.

Table 10: Heating Element

Requirements	Verification
1. Each heating element should work at 120VAC drawing a maximum of 1A.	● Power the heating element with 120VAC. ● Use a multimeter to measure the current ensuring that it is no more than 1A.

Table 11: Fans

Requirements	Verification
1. Each fan should work at 5VDC drawing a maximum of 300mA.	● Power the fan with a 5V power supply and check if the fan turns on. ● The datasheet specifies that the current will be no more than 280mA [15].
2. The drying unit should reduce the humidity inside the cabinet to 50% within 7 hours.	● Hang a wet towel in the cabinet and start a cycle. Check the cabinet after 7 hours to make sure the cycle has ended. ● Use the temperature-humidity sensor to ensure humidity is ≤50%.

Table 12: Button

Requirements	Verification
1. Should be a robust easy-to-use push button.	● Press the button a couple of times to make sure it can be pressed easily. ● Press the button really hard to ensure it does not break and is still functional.

Table 13 : Status LED

Requirements	Verification
1. RGB Common Anode LED that works at 5V drawing a maximum of 100mA current.	● Connect common anode (CA) pin to 5V. ● Connect red pin to GND via a 330Ω resistor. Connect green and blue pins to GND via 330Ω resistors. Check if the LED lights up showing red color. ● Repeat the step above to ensure the LED

	can show green and blue colors also. ● Check that the current is no more than 100mA on each route (CA - red, CA - green, CA - blue) using a multimeter.

Table 14: Door Lock

Requirements	Verification
1. A solenoid lock that can be operated at 3.3VDC drawing a maximum of 1.2A current.	● The default position of the solenoid should be unlocked or inactive where it does not use any power. ● Apply 3.3VDC and check if the solenoid locks. ● The datasheet lists the resistance of the solenoid at 4.5 ohms. With 3.3V applied, the datasheet would suggest the current will be 0.733A [16].