Project Deliverable J : Final Design Report

Engineering Design

GNG1103B

Construction of a Net-Zero Home

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Abstract

This project required us to design a Net-Zero shed for housing the Algonquins of Barriere Lake living on the Rapid Lake Reserve. This means that it was necessary that the shed had access to basic utilities such as water, heat and electricity, all powered by solar panels. We divided ourselves into four groups a construction group, a solar group, a water group, and an automation group. This report will explain in great detail the design process of the automation group. This report will look closely at the client meeting, and establish a list of needs and a problem statement, design criteria, conceptual design, and a series of prototypes. Additionally, this report will discuss the lessons learned as individuals and as a group, and what we would do differently in future work.

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1. Introduction

The Algonquins of Barriere Lake who have lived on the Rapid Lake Reserve since it was established in 1961, have faced many issues throughout the past two generations. In 2006, because of inhumane living conditions, INAC and Health Canada put into place an action plan to improve the health and safety of the houses on the Rapid Lake Reserve. However, as of today, the Algonquins of Barriere Lake still live in poor housing conditions, like so many other Native-American communities living on canadian reserves. Due to the limited budget of the Federal Government, the Algonquins of Barriere Lake live in Third World conditions. The lack of clean water, adequate living spaces, health care and employment has lead to a higher suicide rate within these communities, as well as a higher risk of contracting fatal illnesses. Thus, Net-Zero sheds, with access to all basic utilities such as clean water, electricity and heat, are essential in the process of rebuilding and improving life on the Rapid Lake Reserve.

In January of 2018, section B of the Engineering Design Course, taught by Dr. Muslim Majeed, was approached by our client and asked to build a Net-Zero shed for the Algonquins of Barriere Lake. The purpose of the shed was to offer an eco-friendly solution to the poor housing conditions on the Rapid Lake Reserve, to improve the lives of the people living in this community, through shelter, clean water, heating, electricity and to improve the surrounding environment on the Rapid Lake Reserve through a reduced use of fossil fuel. Our class was divided into three sheds, Shed 1, Shed 2, and Shed 3, and then divided into 4 groups, constructions, solar, water and automation. Our team of seven people took the responsibility of being the automation group for Shed 3. Our project was to create two motion sensor, one that would work with the lights in the shed, and another that would work with the water in the shed. We had a final budget of 100$, and had to create a sensor for the lights, and a sensor for the water, as well as a bypass for each system. Our systems had to be of low maintenance, and could not exceed the power usage created by the solar panels. In addition, our systems had to be eco-friendly, so as not to create a carbon footprint.

Our team started off by listing the clients needs and wants, prioritizing them from highest priority to lowest priority. Using this list, we were able to identify which clients needs and wants were plausible and relevant, and we created our problem statement. This problem statement was the base of our project. Using the clients needs, we made a list of design criteria and target specifications, and also did some benchmarking to compare other similar products to ours, in order to try and create the cheapest yet most efficient product on the market. Afterwards, each team member created three conceptual designs, and using all twenty-one of these designs, we created three solutions and a final global concept. Finally, we started creating a series of focused and comprehensive prototypes, until we had a final prototype that we could insert in the finished shed.

There are three main reasons our project is unique and better than similar projects. The first being that we barely used any of our budget, as all the components used (arduino, motion sensor, wires, lightbulb, ect…) were provided to us in our lab. Therefore, we were able to create an efficient motion sensor that works with the lights and water, at a very low budget. The second being that our motion sensors and all components are very low maintenance, and have a simple design that, if a problem does occur, can easily be fixed by an everyday person. The last being that we used the same code and wiring for both our motion sensors, the motion sensor for the light and the motion sensor for the water, which simplified the design and creation process, since we could treat both projects as one.

After 3 months of consistent work, outside and during lab sessions, the shed including all automation components was completed on March 29th, 2018 for the uOttawa Design Day competition where our components were presented in front of a group of judges.

2. Design Process

2.1. The Client/Users

During our client meeting, which took place during one of our usual engineering design classes, we were able to meet with the client who provided us with a list of all of their wants and needs regarding the creation of the shed. They clearly emphasized their main goal, which was to create a Net-Zero Home. From this meeting, our team was able to list the four main needs established by our client, that regard all 4 shed teams. To create a shed at the lowest cost possible, that is self-sufficient and portable, eco-friendly and that is livable (comes with all main utilities including water, heat and electricity). Since we are the automation team, we did not have to concern ourselves with the majority of the needs listed by the client, and we established a shorter list of needs relating solely to automation.

The client meeting was the beginning of the empathize step of the design process. We were empathizing with the client, and afterwards our team did research on the client and the user in order to gain as much information and perspective as possible.

2.2. The Problem Statement

After our client meeting, our team eagerly started on the define step of the design process. Using the list of clients needs gathered during the client meeting, and the information gathered on the client and user on our own time, we prepared the following problem statement:

"The process of designing and building the sensors should not go over the budget of 100$. The sensors should work for the lights and for the water, and there should be a bypass installed so that the lights and the water work without the sensors. The sensors should be low maintenance. All components of the sensors will be as cheap as possible, so as not to go over budget but the design will be fairly simple so as to keep the sensors low maintenance. The sensors for the lights and the water will be placed strategically in order to catch the movement of any individual trying to access the lights or water perfectly, and a manual bypass will be installed incase the sensors fail."

This problem statement was the basis of our entire project, and remained important throughout each step of the design process. It gave us our basic problem, that we could look back on periodically as we continued to progress through our project to ensure that we did not stray from our core goal.

2.3. Benchmarking

Once we had completed our problem statement, we moved to the ideate step of the design process. Since we finally had a clear goal in mind, we decided we needed to do research on pre-existing projects that were similar to ours. This would give us a different perspective on our project as a whole, as well as help us create the best product possible, at the lowest cost possible.

However, due to the nature of our project, we were not able to do the same type of benchmarking as other teams. There were no products similar enough to our product on the market as of yet. Thus, we thought it more appropriate to compare the closest pre-existing products on the market to date through a list of pros and cons.

Table [1] - Motion Light Sensor - Pros and Cons

Motion Light Sensor	First Alert Motion Sensing Light Socket	Sunforce LED Solar Motion Light	MAXSA Innovations Motion-Activated Duel Head LED Security Spotlight
Pros	-360 degrees -Simple installation -Affordable -Portable -Eco-friendly(compatible with fluorescent and incandescent lights)	-Eco-friendly(Sola r-powered) -Simple installation	-Almost 360 degrees -Eco-friendly (solar powered) -Simple installation
Cons	-No bypass	-High maintenance(Short battery life)	-High price

For our light motion sensor, we compared three pre-existing light motion sensors currently on the market. Each shared features that aligned with our goals, while also sharing features that did not align with our goal. Using the information gathered through this benchmarking, we were able to conceptualize an idea of our light motion sensor.

Table [2] - Motion Water Sensor - Pros and Cons

Motion Water Sensor	Moen Arbor Motionsense	Delta Faucet 9159T-AR-DST Trinsic	KOHLER K-7218-VS Sensate
Pros	-Multiple Sensors -Affordable	-Low maintenance	-Low maintenance -No batteries required
Cons	-Low GPM	-Not affordable	-Not affordable

For the water motion sensor, we compared three pre-existing water motion sensors currently on the market. Each shared features that aligned with our goals, like the light motion sensor, yet also shared features that did not align with our goals. Using the information gathered through this benchmarking, we were able to narrow down a water motion sensor that we were going to buy and implement into our shed. It wasn't until later on in the design process that we realized that this was not feasible financially and we decided to create our own water motion sensor using material supplied to us.

2.4. Design Criteria

2.4.1. Design Criteria

After benchmarking, our team proceeded to the design criteria stage of the ideate step, where we translated our customer needs into design criteria, shown in the table below.

Table [3] - Translating needs into Design Criteria:

Number	Need	Design Criteria
1	Budget	Cost ($)
2	Sensor for light	Sensor range (ft^3) Sensor activation Sensor sensitivity Sensor location Power source
3	Sensor for water	Sensor range (ft^3) Sensor activation Sensor sensitivity Sensor location Power source
4	Bypass for sensor for light	Bypass system Bypass location
5	Bypass for sensor for water	Bypass system Bypass location
6	Low maintenance	Material Size (ft^3)

7	Eco-friendly	Material Power source
8	Access to professionals on site	Cost ($) Available professionals on site

Using our list of design criteria, we were able to split them into Functional Requirements, Non-Functional Requirements, and Constraints. This is shown in the table below.

Table [4] - Functional Requirements, Non-Functional Requirements and Constraints:

	Design Specifications	**Relation**	**Value**	**Units**	**Verification Method**
	Functional Requirements				
1	Sensor Range	>	8x4xheight	ft3	Test
2	Sensor Activation	=	yes	N/A	Test
3	Sensor Sensitivity	=	yes	N/A	Test
4	Bypass system	=	yes	N/A	Test
5	Material	=	yes	N/A	Analysis
	Constraints				
1	Cost ($)	<=	100	$	Estimate
2	Size (ft3)	<	8x4xheight	ft3	Analysis
3	Power source	=	yes	N/A	Analysis
4	Available professionals on site	=	yes	N/A	Analysis
	Non-functional requirements				
1	Aesthetic	=	yes	N/A	Test

2	Product life	>	5	years	Test
3	Sensor location	=	yes	N/A	Analysis
4	Bypass location	=	yes	N/A	Analysis
5	Low maintenance	=	yes	N/A	Test

Our team was able to use the customer needs translated into design criteria later on in the design process, since it gave us a more precise description of what our automation components need to be. It also gave us a base to look back on during the testing process, as we specified whether or not we would analyse or test different design criteria at that stage.

2.4.2. Target Range and Design Specifications

Using our list of design criteria, we were able to create our target range and design specifications. We split them into to categories, ideal values and acceptable values.

For our ideal values, we noted that the production cost of the entire system would be 100$. The light sensor would work with an 8ft by 4ft by the height of the shed range, and it will turn off after 5 minutes of inactivity (This was later changed to 2 minutes of inactivity). The faucet sensor, on the other hand, would turn off after 3 seconds of inactivity. Both sensors would have a bypass system, and be of compact size and made of cheap, durable material. In addition, the product life of our systems would be of 5 years.

For our acceptable values, we noted that the product must be as low maintenance as possible, and be simple enough that minor problems can be fixed by the residents of the shed. In addition, the sensors would use as little power as possible.

2.5. Conceptual Design

After translating our clients needs in design criteria and target range and design specifications, each of our team members came up with three conceptual designs, and we condensed these conceptual designs into three general solutions.

2.5.1. Solutions

Our first solution was to use an arduino board to control the system, relying on arduino compatible motion sensors to control both the lights and the water. The board would have outputs connected to 2 separate relays, one for each system. The first relay would be connected to a manual switch, then to the lights. The other relay would be connected to an electrically operated valve feeding water to the faucet. With the faucet left open, it will act as a motion sensor. Should the system fail, the valve can be manually opened and the faucet used normally. The switch for the lights acts as both a backup and a kill switch for when the user wishes to keep the lights off (when sleeping, ect…)

Our second solution was to use a prebuilt motion sensing light source and faucet. These systems would wired into the main battery to provide power. This setup is rather simplistic but can be costly as the prebuilt systems will cost more than base components. A system like this would require less wiring and ultimately have a cleaner look and will likely be more user friendly. In addition to the cost, a major downside is that since the system would be mostly made of pre built systems, it will be harder to diagnose and solve issues as well as perform maintenance. Since the majority of the system would be purchased rather than built, it would be hard to confirm the quality o the final product or add desired features.

Our third solution was to use a prebuilt system for the lights and a custom system for the water. Prebuilt motion sensing faucets are rather expensive so using an electrically actuated valve would greatly reduce the cost and allow the addition of new features, such as a bypass system to turn off motion sensing (a reason one might want this is to fill a large container/pot/bucket). With a hybrid of pre build and custom it would allow lower costs while still getting a cleaner setup, wiring wise, than a fully custom system. In addition to the previously stated benefits, this system is easier to install and setup due to fewer wires and components.

Our final solution was to use a prebuilt motion sensing faucet and a custom system for the lighting. A prebuilt faucet will result in a cleaner looking and smoother functioning system for water usage. A major benefit is that the motion sensor would be properly placed and have it's sensitivity adjusted to function accurately. The simplicity of the lighting system means that wiring it will not be a huge problem and should result in a clean appearance and a good functionality with a reduced cost.

2.6. Project Schedule and Cost

Before starting the prototyping process, our team created a project schedule, shown in the table and figure below.

Tasks:

Table [5] - Prototype I:

Task	Estimated Duration	Responsibility
Draw a proof of concept for motion sensor	March 4th	Devin McInnis

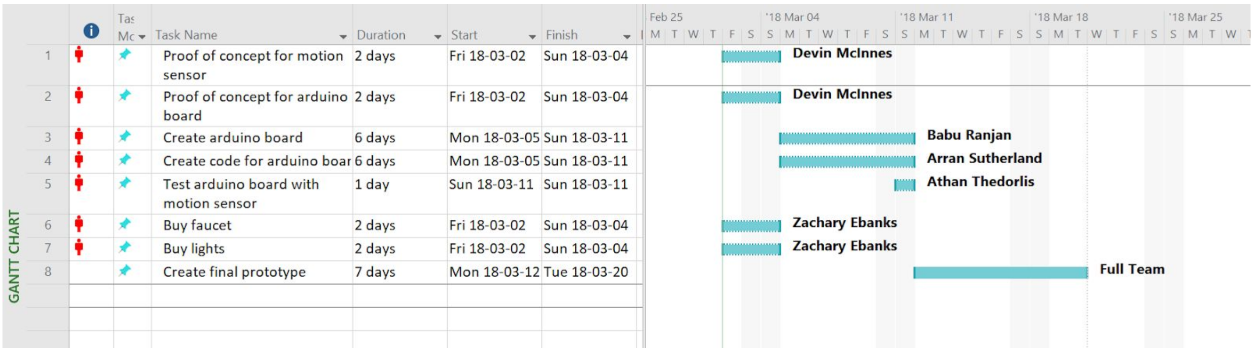
Table [6] - Prototype II:

Task	Estimated Duration	Responsibility
Draw a proof of concept for the arduino board	March 4th	Devin McInnis
Create arduino board	March 11th	Babu Ranjan
Create code for arduino board	March 11th	Arran Sutherland
Test arduino board with motion sensor	March 11th	Athan Theodorlis

Table [7] - Prototype III:

Task	Estimated Duration	Responsibility
Buy the faucet	March 4th	Zachary Ebanks
Buy light for motion sensor	March 4th	Zachary Ebanks
Create final prototype	March 18th	Automation Team B

Figure [1] - Gantt Chart



	Task Name	Duration	Start	Finish
1	Proof of concept for motion sensor	2 days	Fri 18-03-02	Sun 18-03-04
2	Proof of concept for arduino board	2 days	Fri 18-03-02	Sun 18-03-04
3	Create arduino board	6 days	Mon 18-03-05	Sun 18-03-11
4	Create code for arduino boar	6 days	Mon 18-03-05	Sun 18-03-11
5	Test arduino board with motion sensor	1 day	Sun 18-03-11	Sun 18-03-11
6	Buy faucet	2 days	Fri 18-03-02	Sun 18-03-04
7	Buy lights	2 days	Fri 18-03-02	Sun 18-03-04
8	Create final prototype	7 days	Mon 18-03-12	Tue 18-03-20

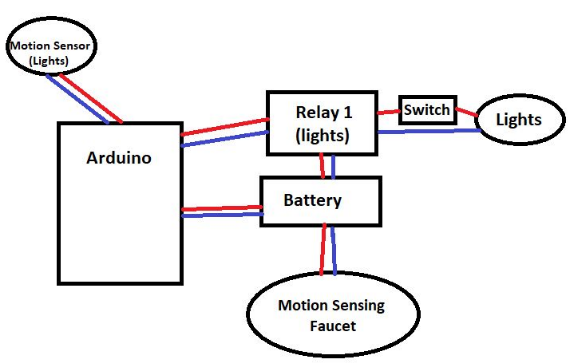
2.7. Prototyping

After our solutions and the global concept were made, the prototyping stage of the project had begun and we started working on our first of three prototypes. The prototypes were based off of the global concept and with each new iteration, we got closer and closer to the final product.

2.7.1. Prototype I

The first prototype had to be made of cheap materials and was required to be a general version of our global concept. The goal of this prototype was to ensure that the client understood what our team was planning to do and to get any feedback that would allow us to improve our project. Due to the nature of our project, the first prototype was a circuit diagram of how the system would look and how each component would be connect.

Figure [2] - Basic Proof:



In Figure [1], the battery is in the center of the circuit as it provides power for the entire automation system. The motion sensing faucet is directly connected to the battery as it does not need any additional control from the arduino. Additionally, directly off the battery is the arduino board. This provides power to the board which can then distribute it to other components. Both the motion sensor and relay are connected to the board as an input and output for the light circuit. The relay is connected to the battery as a power source (used to power the lights connected to it) and to the lights which it controls. In between the lights and the relay is a kill switch which can be used to keep the lights off when the motion sensing features are not wanted (when someone is sleeping, ect...).

The client understood what the diagram was trying to show and she said that the system should be simpler and have an easy installation, as well as have a manual bypass for the lights and water in case the sensors fail.

2.7.2. Prototype II

The second prototype was a simplified version of our system, which demonstrated how our final system would work. In order to do this, we built a small circuit consisting of an arduino board, momentary button, and an LED. We also made a proof of concept of the shed's layout showing where each of our components would be placed.

Figure [3] - Shed Proof of Concept:

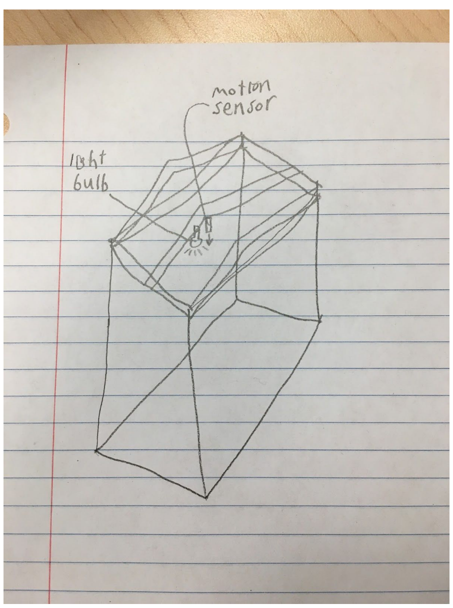


Figure [2] shows how the socket will be mounted in the middle of the ceiling in order to allow the light bulb to illuminate the room as evenly as possible. In addition, the motion sensor will be placed beside it to give it a full radius of detection.

Figure [4] - Arduino Circuit

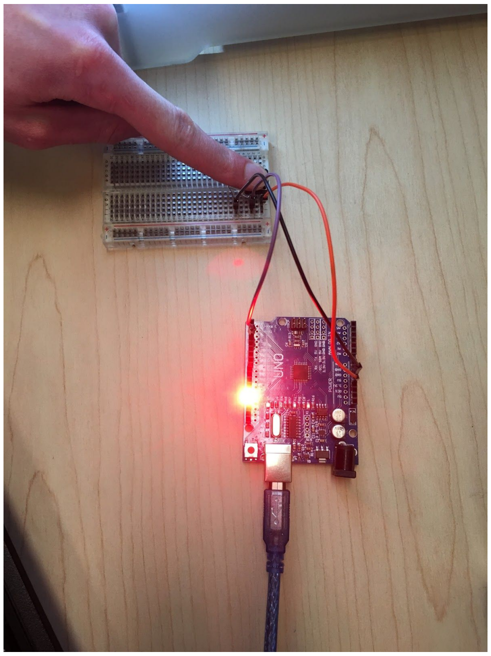


Figure [3] shows that the arduino was wired to the motion sensor (in this case, we used a momentary switch in place of the sensor due to lack of availability) as was planned in the circuit diagram. The 5V power on the arduino is connected via a breadboard to one leg of the switch and the other leg is connected to a wire going to an input pin on the arduino and a resistor. The resistor is connected by a wire to the ground on the board. Finally, the LED is connected with one leg on an output pin and the other on a ground. The code that was created verifies the state of the signal coming from the switch. If the switch was turned on, the arduino output gave power to the LED, turning it on, otherwise no power was allocated and the LED stayed off. The button being pressed represents the signal from the motion sensor since the motion sensor itself was not provided in the lab.

2.7.3. Prototype III and Final Product

The third and final prototype consisted of fully installing all our components into the shed. The goal of this prototype was to have the lightbulb turn on automatically when the motion sensor detected any motion, and for the light bulb to turn off when the motion sensor did not detect any motion for two straight minutes. Also, to have the pump turn on when the motion sensor detected motion in front of the sink, and for the pump to turn off immediately if the motion sensor detected no motion in front of the sink.

Figure [5] - Motion Sensor for Light

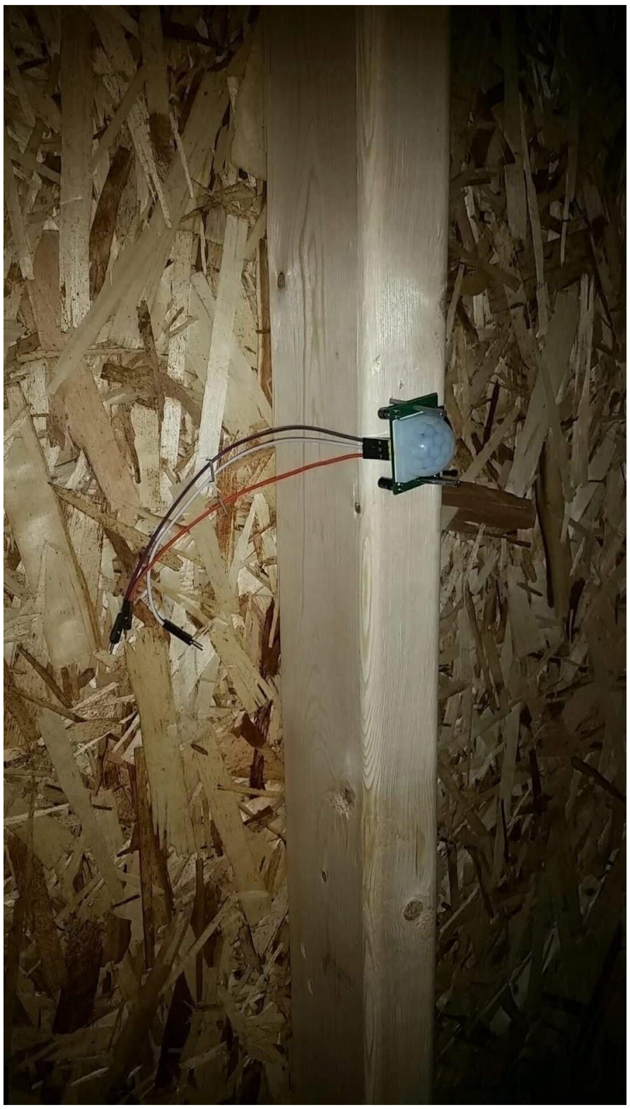


Figure [6] - Light Socket

Figure [7] - Sink with Motion Sensor

We used our initial global concept and our proof of concept of the shed from prototype II as a basis when connecting all our components into the shed. A tupperware container was mounted on one of the walls and contained the arduino board and relay, with wires running in and out of holes that were drilled into it.

To test the light system, we had people walk into the shed to see if the lights would turn on, and have them exist the shed for more than 2 minutes to see if the lights would turn off, which worked so we concluded that the system was working a intened. The water system, on the other hand, could not be tested with the pump because the water tank had no water in it, meaning no water would be able to flow through the faucet. However, it was made with the same principles as the lighting system, so we concluded that it was highly probably that it would work as intended as well.

3. Conclusion

In conclusion, our goal was to develop, design and implement an automatic system to control the lighting and the water flow in a Net-Zero Home. The automatic system, which served as an effective method to reduce energy and water consumption, was designed to be simple yet robust thus minimizing the risk of failure. In addition, the simplicity of the system ensured that in the event of a system malfunction an individual with limited technical ability would be able to apply the required adjustments. By communicating with the client and understanding the Net-Zero Home's requirements our team was able to layout a set of key criteria which were used to guide the design of the final product. From the key criteria multiple conceptual designs were developed, evaluated and modified resulting in the finalization of a global concept which would be used in the ultimate design. From the global concept, prototypes were created to allow for a visual representation of the final design. Additionally, the prototypes were used as platforms for testing various aspects of the final design leading to modifications and improvements to the completed product. The final design was then implemented into the Net-Zero Home and final tests were performed on the components which could be tested.

However, over the course of the project our team faced multiple challenges which provided significant opportunities to learn valuable lessons which would improve the overall quality of future work. One major lesson learned throughout the process of designing the system was the necessity of proper communication among all teams involved in the project. At certain moments during the installation process it became clear that a lack on communication was preventing work on the project resulting in delays to the project. If proper communication among teams had been achieved it is likely that significant delays and last-minute work would have been avoided. Additionally, the fact that last-minute work had to be done on the implementation of the system into the Net-Zero Home presents another problem which should be avoided during any future work. By delaying the installation the amount of tests which could have been performed on the system were significantly limited resulting in certain components such as the motion sensor for the water pump going untested. Moving forward it is crucial that all components are installed well ahead of the deadline to guarantee that adequate testing on all aspects of the final design can be carried out properly and effectively.

Finally, working on the project has allowed our team to gather valuable insights in regards to how this specific project as well as other projects can be improved in the future. First and foremost, it is essential that a strict schedule is followed and that delays are avoided. Creating a deadline for the completion of the project, which precedes the final due date by a significant amount of time, is crucial because it allows for the proper testing and required modifications to take place. In effect, more testing allows for a final product of higher quality.

Furthermore, it is clear that when working among a group of teams, clear channels of communication between all teams should be organized in order to ensure no conflicts arise. Finally, it is essential that all parties involved in the process have a clear understanding of what their roles are and when their duties must be accomplished to guarantee the final product is created and designed to the best of the team's ability. Overall, our team was proud of the work accomplished on the Net-Zero Home. Although there were time-constraints associated with the development of the project our team was able to complete our tasks admirably. Further work on the Net-Zero Home should focus on completing the water system and its automatic aspect. Additionally, a focus on improvements to the interior should be pursued by ensuring wiring is less exposed and improving the general safety of the Net-Zero Home.

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