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Project Title: **T21HEAT OTMO Heat Recovery**

Design Description: Pump driven heat transfer from industrial baking oven to On the Move Organic's office space.

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1 Need / Challenge

On the Move Organics needs a way to capture wasted heat energy from their bakery oven because they want to achieve monetary benefits by reducing their heating bill, environmental benefits by reducing energy consumption, and have the office space of 136 cubic meters (4800 cubic feet) heated to an optimal temperature range of 20 °C to 25 °C using a maximum energy output of 11,000 J/s.

Supporting insight and sources:

The aforementioned need statement was developed with the support of our studio instructor and client insights. Our studio instructor directed us to establish boundaries within which our design solution must remain; he recommended we find the maximum energy output of the client's oven to ensure our solutions remains within that threshold. Additionally, following our second client meeting, we were able to develop an understanding of the volume of the room that must be heated which allowed us to approach this issue from a more quantitative and technical perspective. Upon calculating the volume of the office space, our team began working on the calculations necessary to determine the energy output needed to increase the temperature of the room by one °C. Upon arriving at this value, we will have the necessary data to decide on a suitable heat transfer method.

2 Final Design Documentation

Sustainability is our project's main goal; we must develop a solution that does not significantly hinder the oven's operational capacity while ensuring economic and environmental viability. We decided that to minimize oven overworking, we will run our design once the oven is off.

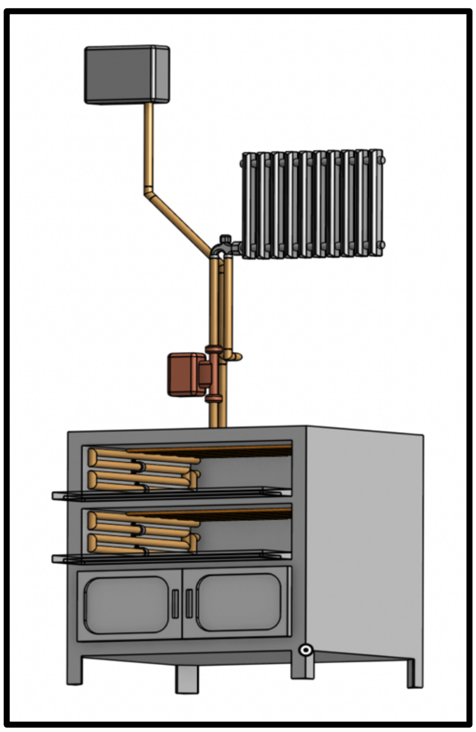

Figure 2.1 CAD Model

We plan to construct a system that will utilize an integrated coil system to extract waste heat from the oven (Exhibit 2.1). This system (Exhibit 2.2) will consist of ethylene glycol-filled copper coiling (Exhibit 2.3) located on the interior side of the industrial oven. The decision to use ethylene glycol was primarily due to the liquid's high boiling point (197°C) and minimal thermal expansion. This subsystem will extend out of a hole drilled in the oven and connect to insulated polyethylene piping. A pump (Exhibit 2.4) will run the liquid through this piping system to a plumbed single panel radiator will be located on the second floor (Exhibit 2.5).

Additionally, to mitigate any risks related to fluid expansion and leakage, an expansion tank will be plumbed into the system. After passing through the radiators, the ethylene glycol will be re-circulated through the oven repetitively.

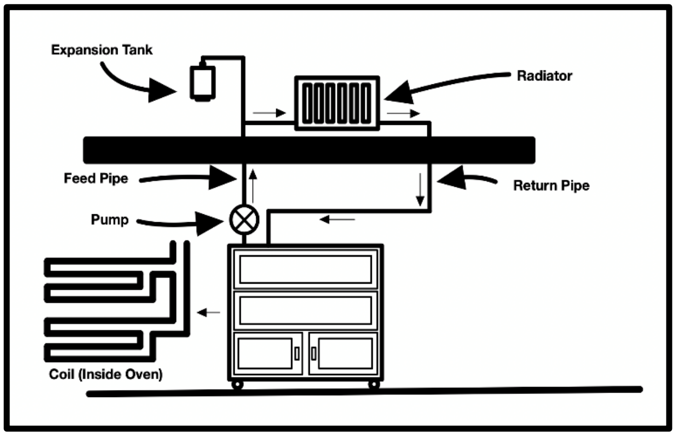

Figure 2.2 Design Sketch

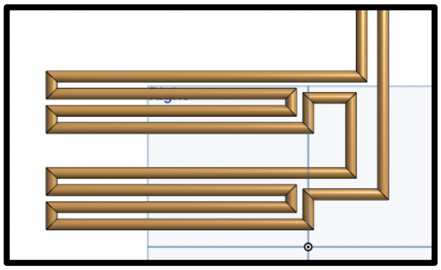

Exhibit 2.3

Exhibit 2.4

Exhibit 2.5

For the purchasing of all the sub-systems (including coil piping, single panel radiator, circulating pump, pipe insulating, heat resistance putty, polyethylene piping, and thermal expansion tank), the cost is around 900 dollars (Exhibit 2.5), which is 600 dollars lower than the budget of 1500 dollars. Thus, there is room left for installation costs. After the construction is completed, there would be an estimated saving per day of $1.56 (see Appendix 7.5 for calculations), which translates to $1220 over five years (assuming the system runs three days per week).

Item	Cost
Coil Piping	$ 70.00
Single Panel Radiator	$ 230.00
Circulating Pump	$ 275.00
Pipe Insulation	$ 50.00
Heat Resistant Putty	$ 25.00
Polyethelyne Piping	$ 200.00
Thermal Expansion Tank	$ 50.00
Total	$ 900.00

Figure 2.6 Project Costs

2.1 Instructions for Implementation

1. Create four holes using a hole saw drill bit rated for stainless steel in the back of the oven (as pictured). Each with diameter of 12.7 mm (½ inch) to accommodate the coils in each bank of the oven.

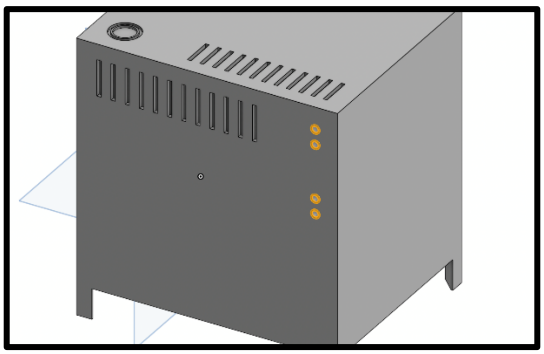

Figure 2.7 Holes in Rear of Oven

2. Bend approximately 4.5 m (15 ft) of 12.7 mm (½ inch) copper tubing into a coil as pictured. A pipe bending tool will need to be utilized. Repeat twice for each oven bank.

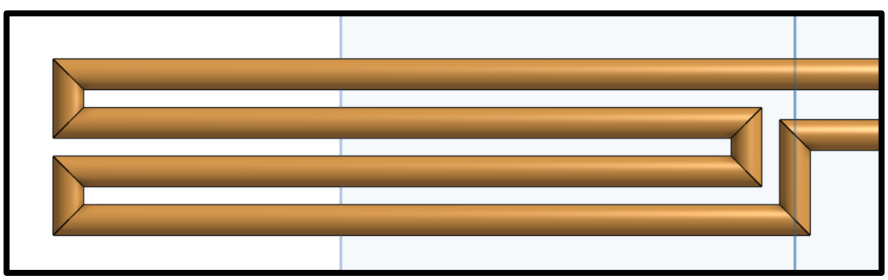

Figure 2.8 Copper Coil Layout

3. Install the copper coils to the interior of the oven and fix in place with 12.7 mm pipe brackets using self-tapping sheet metal screws.

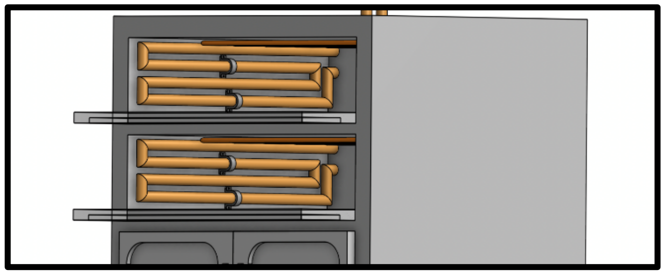

Figure 2.9 Installation of Copper Coils

4. Attach the two coils together at the back of the oven by using copper fittings and solder. Extend the copper tubing upwards until the height of the oven is reached.

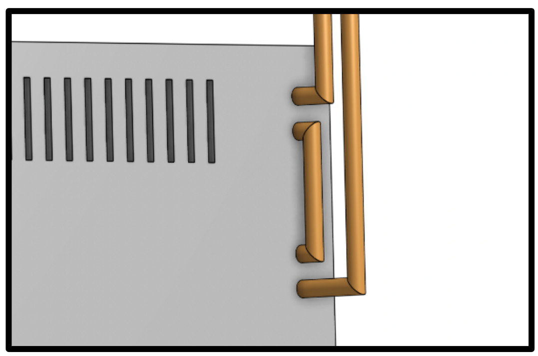

Figure 2.10 Connection of Copper Coils

5. Install the variable speed circulating pump directly to the copper tubing.

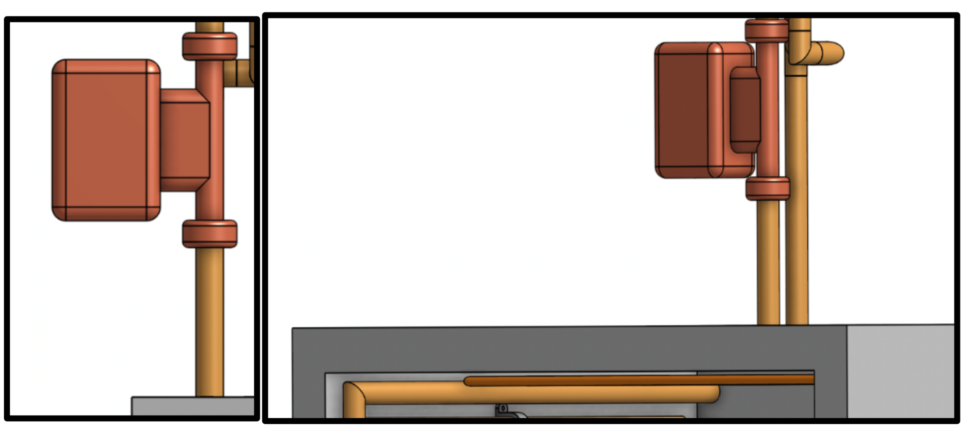

Figure 2.11 Circulating Pump Installation

6. Run two sets of polyethylene (PEX) piping (feed pipe and return pipe) from the oven to the desired location of the radiator in the office (near stairwell).

Figure 2.12 Plumbing

7. Hang the radiator on the wall, off the floor, as to not create any tripping hazards.

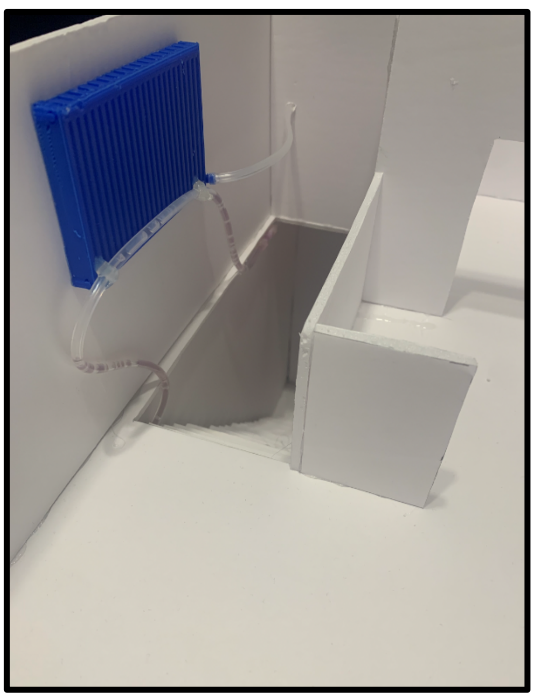

Figure 2.13 Radiator Positioning

8. Plumb the radiator using the PEX, according to manufacture directions.

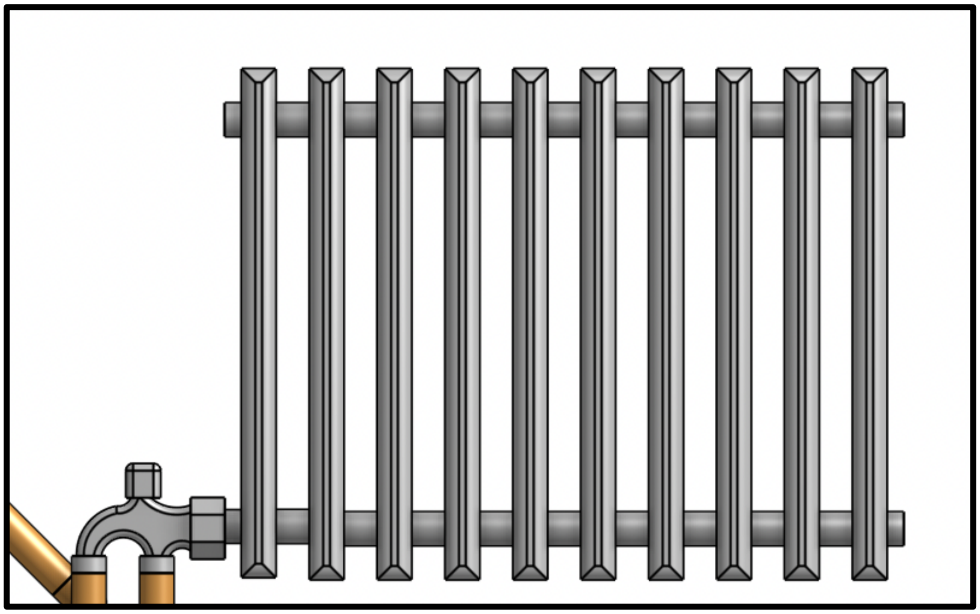

Figure 2.14 Plumbed Radiator

9. Hang the thermal expansion tank on the wall, in a desired location (must be hung above radiator to function).

10. Plumb thermal expansion tank using additional PEX.

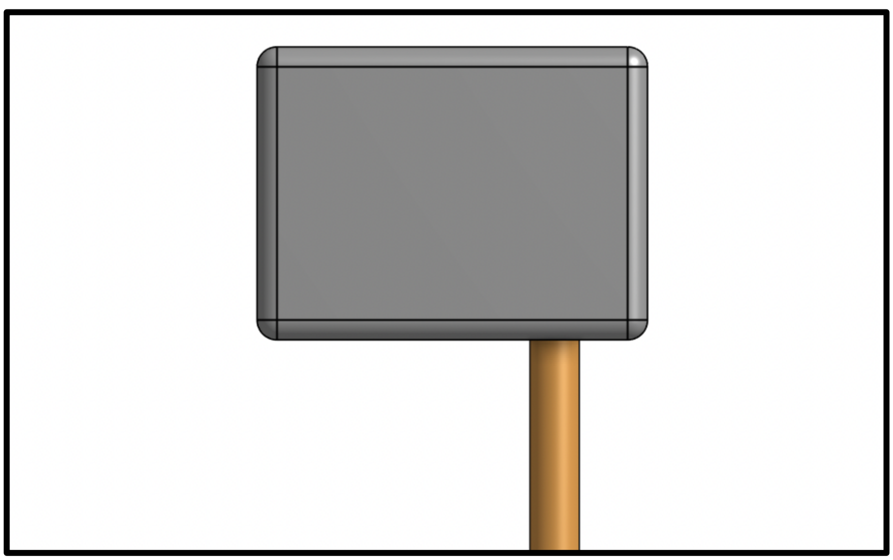

Figure 2.15 Thermal Expansion Tank

11. Make sure to connect the copper piping exiting the oven to the PEX properly and perform through leak testing.

12. Seal the newly formed holes in the oven with thermal putty to insulate the oven when baking. This will prevent cold spots.

Figure 2.16 Thermal Putty

13. Insulate all the piping on the exterior of the oven to minimize heat loss.

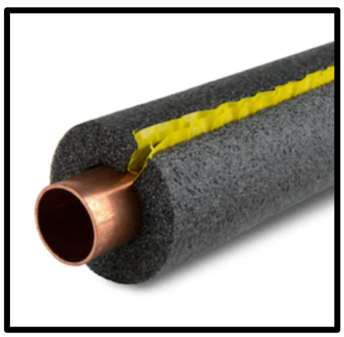

Figure 2.17 Foam Pipe Insulation

14. Install a switch to control the electrical outlet and plug in the circulating pump; set to a low speed. The Arduino will be used in tandem with the switch and pump to run the pump for the desired length of time (3 hours as seen in the code in Appendix 7.2). This diagram shows the circuit used in our prototype demonstration.

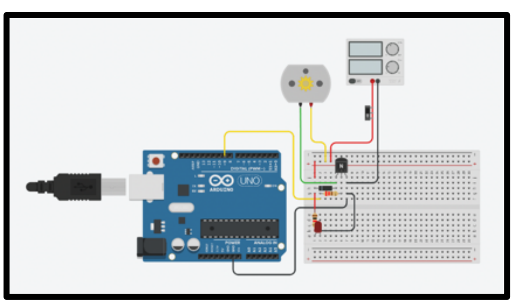

Figure 2.18 Circuit Diagram

15. Ensure that the pump turns on and off with the switch and perform necessary testing.

3 Testing and Validation

3.1 Objectives (and Functional Capabilities)

#	Objective	Assessment	Evidence
1	We need to have minimal heat loss through piping/duct work.	Met	After considering heat loss in the transfer process, research into standard ventilation systems showed that using an insulative coating will prevent heat loss from the pipes. We decided to move forward with foam as it delivered an excellent outcome for the costs associated. Additionally, most of our piping is polyethylene, which is a very poor conductor of heat (Manufacturing, 2022).
2	Flexibility for minor shift and movements.	Met	Due to the flexibility of our polyethylene piping, the system can manage small shifts without breakage (Manufacturing, 2022).
3	System needs to be portable and practical due to limited space in the building	Not-Met	The project requires large construction as the entire system is designed to be sustainable and efficient. Meanwhile, considering potential danger it could causes, the system is partly fixed in the wall.
4	The pipes/ducting used in the design must be durable	Met	The polyethylene material gives the piping stability and allows for flexibility. The possible problem with this material is the deteriorating overtime (Manufacturing, 2022).
5	The material used to capture heat energy needs to be highly conductive of heat.	Met	Taking current vetted systems as a model along with research, decided that polyethylene was a material perfect for the job because of its conductivity and low pricing.
6	Maximize efficiency of heat absorption and heat transfer	Met	Using research in heat transfer and using existing systems as references, we found that a coil system will provide an efficient method of absorbing heat. This is because the liquid during its flow will remain within the oven for a lengthy period before it travels up the pipe, so it has enough time to absorb heat.
7	Minimize the risk of system crash (pipe bursting)	Met	The installation of expansion tank provides a buffer for the flow of pipe system, meanwhile, extreme situations (maximum temperature system/oven could reach) are considered when choosing the material for building sub-systems.

3.2 Testing and Validation: Constraints

#	Constraint	Assessment	Evidence
1	Ensure that all materials used in the design solution will remain functional under exposure to high temperatures.	Met	Using research from articles online to confirm the boiling point of the materials to ensure no melting during operation. Further research also led us to replacing the liquid from water to Ethelene glycol an industrial liquid with a high boiling point *(*Encyclopedia Britannica, 2022*).*
2	The solution must introduce energy bill savings compared to current energy expenses	Met	Using the heat from the oven as an auxiliary to the current heating system provided with the company will reduce the amount of power that the heating system will need to use, with our calculations, that will result in savings of about $1.25 a day from saved power (see appendix 7.5).
3	Any modifications made to the oven must not interfere with the regular operation of the oven.	Met	The research on the industrial liquid and implementation of the insulating valves ensured us that with no flow within our system, it will isolate the heat to remain in the oven, not draw too much heat from the oven during its operational times and thus not overtax the oven
4	The material used for the system must be heat resistant up to 260 °C.	Met	Use of copper which is known to be highly conductive and has a high boiling point so there is no danger of melting inside the oven *(Metal Supermarkets, 2022).*
5	Product needs to be above the ground to not limit office ground space and create possible tripping or fire hazards	Met	The system will be implemented into the oven and linked to a radiator intended to be mounted on a wall which ensures that we do not take up extra office space or create any safety hazards

4 Comparison

4.1 Design Comparison

Name / Description / Link (as applies):

Practicality Comparison	On the Move Organics' current operation in the bakery has adverse effects on their energy utilities bill. They use an industrial bakery oven that needs a lot of energy to operate on a day-to-day basis. The oven is currently only used 2-3 days per week which equates to 3-4 hours per day. However, the OTMO wants to reduce their energy utilities bill and reuse the waste heat from the oven. With a budget of $1500, we implemented a solution that would not only fit within the budget but also be a more practical approach. The total cost for the materials will approximately be $900, leaving room for maintenance and/or unexpected costs. The office space will be heated when the oven is not operational to minimize overtaxing. With the implementation of this design, the estimated savings is roughly $1.56 per day and $1220 over 5 years.
Comparison of Strengths	As the bakery is relatively small, housing only 1-2 people, their current approach is sustainable. The oven is electric meaning there is minimal heat loss to begin with. Furthermore, the HVAC system they use efficiently circulates heat throughout the building. Thus, there is very little automation and only a small carbon footprint. In contrast, our final design is more cost effective and budget friendly. The system is also designed to work in conjunction with the current HVAC system to minimize waste energy. Our system also uses a thermal expansion tank which helps reduce the risk of pipe bursting.
Comparison of Weaknesses	The current system OTMO has in place does not allow for sustainable heat transfer to the second-floor office space. In addition, the bakery is producing waste heat from the oven which can be costly for the company. In contrast, our design may have the oven work harder than it should. The installations of coils in the interior walls of the oven may be tricky and have the oven use up more energy than it was designed to. There are various risks associated with our system, namely the pipes bursting/leaking, radiator failure and sealant failure.
Other Comparisons	One important aspect of the bakery is that it is relatively small, housing only 1-2 people. Thus, the implemented design must be within the constraints of the dimensions. OTMO clearly stated that space is an issue. With the current system, the oven is operational, and heat is transferred throughout the facility. In contrast, with our final design, we implemented interior coils and insulated pipes so space would not be an issue.

4.2 Current HVAC System VS. Coil System

Practicality Comparison	The current HVAC system uses ventilating ducts that run down through the roof dropping down to the ceiling. It provides sustainable heating, air conditioning and ventilation throughout the facility. However, the office space needs to be heated to an optimal temperature. In contrast, the coil system allows for heat to be transferred to the office space. Furthermore, with the coil system, OTMO will save money on the electrical and energy bills when the oven is running.
Comparison of Strengths	The HVAC system provides heating, air conditioning and ventilation for the building. Thus, the air quality is reasonable. In contrast, the coil system is completely inside the interior panel of the oven, so no modifications will be made to the exterior. The coil system will also help generate monetary saving and will produce a return of investment in 5 years.

Comparison of Weaknesses	The current HVAC system does not provide sustainable heating for the office space upstairs. It also generates costly expenses (electrical and energy usage) for the company. The implemented coil system may cause the oven to overwork and there are also risks such as radiator failure or coil leakage.
Other Comparisons	The more standard approach in the industry is the HVAC system. This system is known for its reliability and efficiency. The coil system on the other hand is a less common approach to heat transfer. This may make the coil system the less favourable option. With the status quo, they are avoiding the risks of potential error with modifications done to the oven and failure within the subsystems of the coil system. However, with the coil system, they could reuse waste heat energy and transfer it to the office space while saving money.

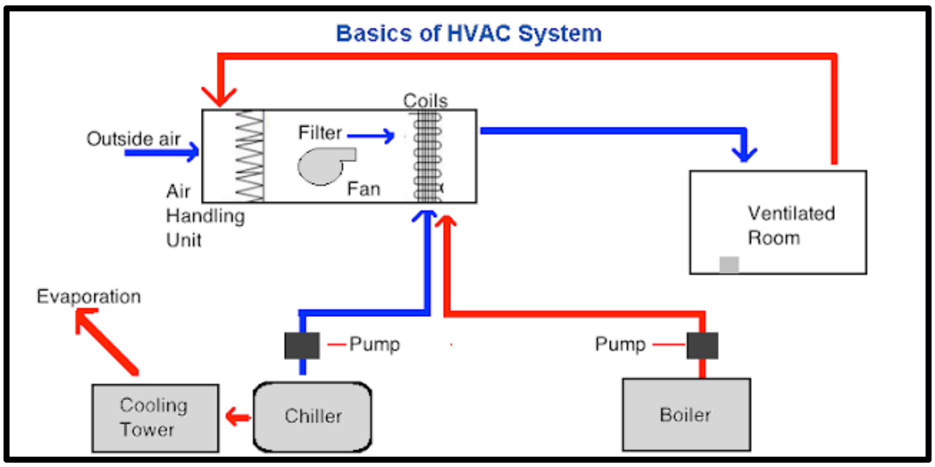

Figure 4.1: HVAC System Diagram

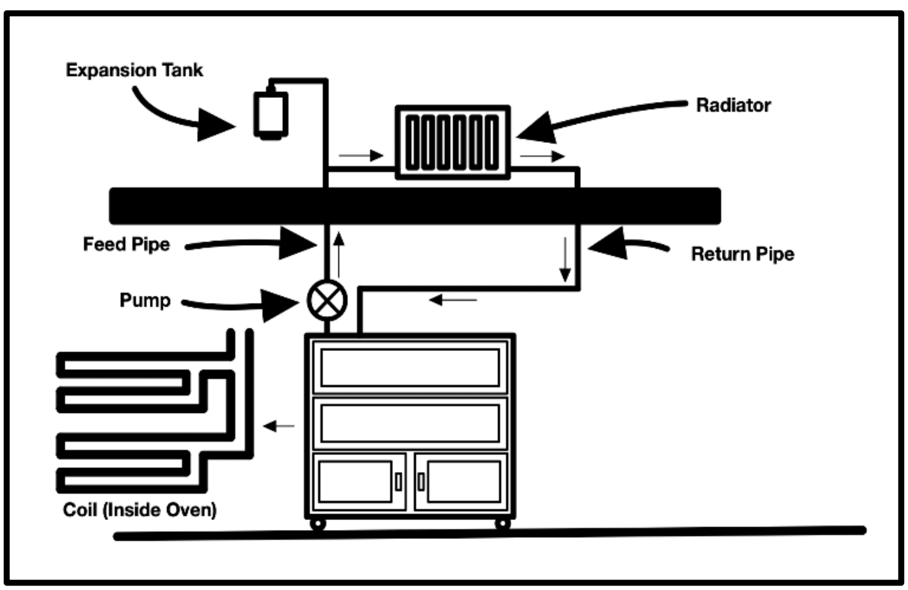

Figure 4.2: Coil System Diagram

5 Potential Improvements

Although our design solution for On the Move Organics is both feasible and realistic, there are improvements that can be made to further enhance the convenience and environmental perks for our client. Our clients, being a very environmentally conscious company will appreciate additional measures that will reduce their overall carbon footprint and save money in the long run.

Probably most importantly, we would want to find a solution to expel the wasted heat in the summer months as our solution focuses on heating the office space during the colder months of the year. By using a coil system, it would be simple to route additional plumbing to the brewery kettles to preheat them when the office space does not require heating. Currently, the kettles are preheated using a boiler system, which runs off gas, to create a steam jacket which in turn warms the kettles. By utilizing the coil system to preheat the kettles, On the Move Organics will be saving on a percentage of the energy costs associated with the boiler. Not only would it create a monetary benefit, but also reduce their gas consumption. For these reasons, this addition would create the greatest benefit to OTMO.

Secondly, in the case that we had more time to perfect our solution, the implementation of a temperature control system would have been another consideration. Currently the temperature of our system can be controlled by varying the speed of the circulating pump, however this can be difficult to change. Adding a temperature sensor to the Arduino to shut down the system when an inputted temperature is reached, would simply increase the usability and convenience of our system. It would also allow for more accurate temperature control within the office space itself.

Finally, if we were to do this project over again, it may be beneficial to find a system that can run when the oven is in operation and baking. The issue with our specific system is that it is not in operation when our client is baking which is when the most amount of heat is produced. Creating a system that can function when the baking is occurring would allow for the highest degree of heat transfer. The issue we faced, however, is the reality that the oven is electric making other, more conventional heat, capturing techniques such as a heat recovery ventilator (HRV) difficult to implement.

Figure 5.1 Brewery Kettles

6 References

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7 Appendix A – Examples of Design Documentation

7.1 CAD Models or Drawings

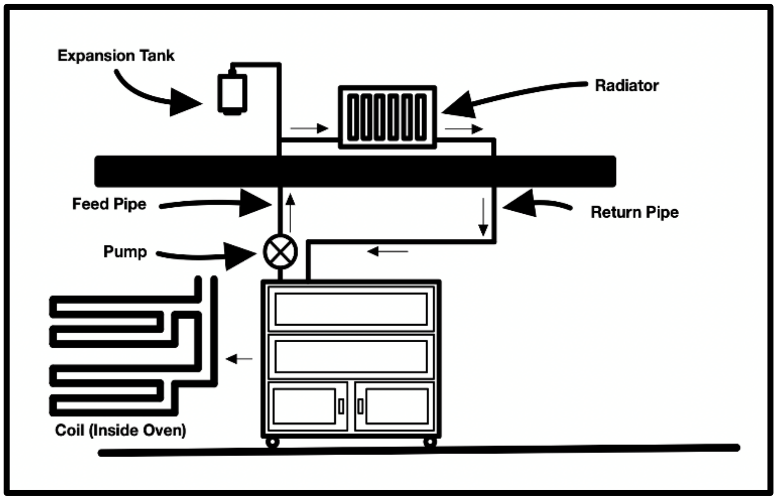

Figure 7.1 Preliminary Sketch

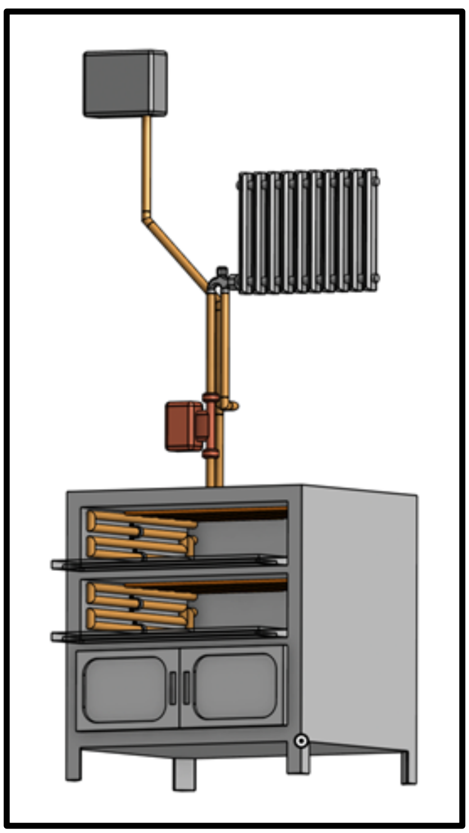

Figure 7.2 Front Facing View of Oven

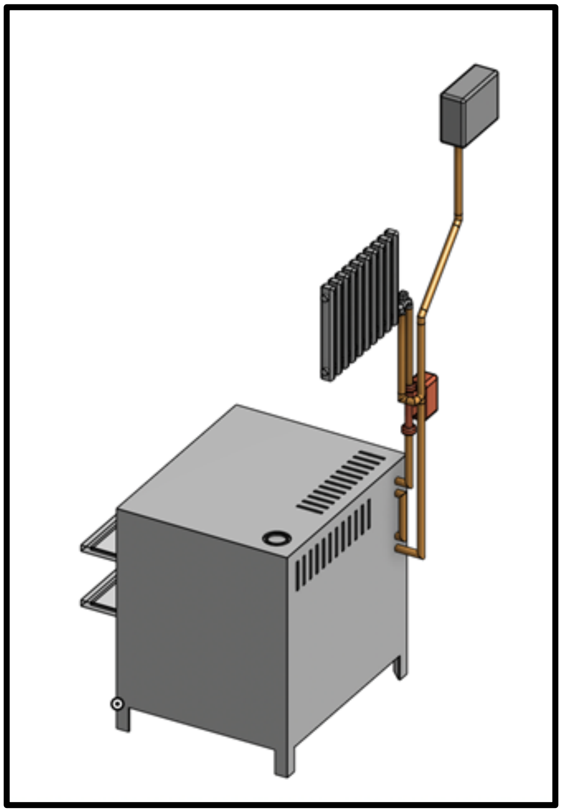

Figure 7.3 Rear Facing View of Oven

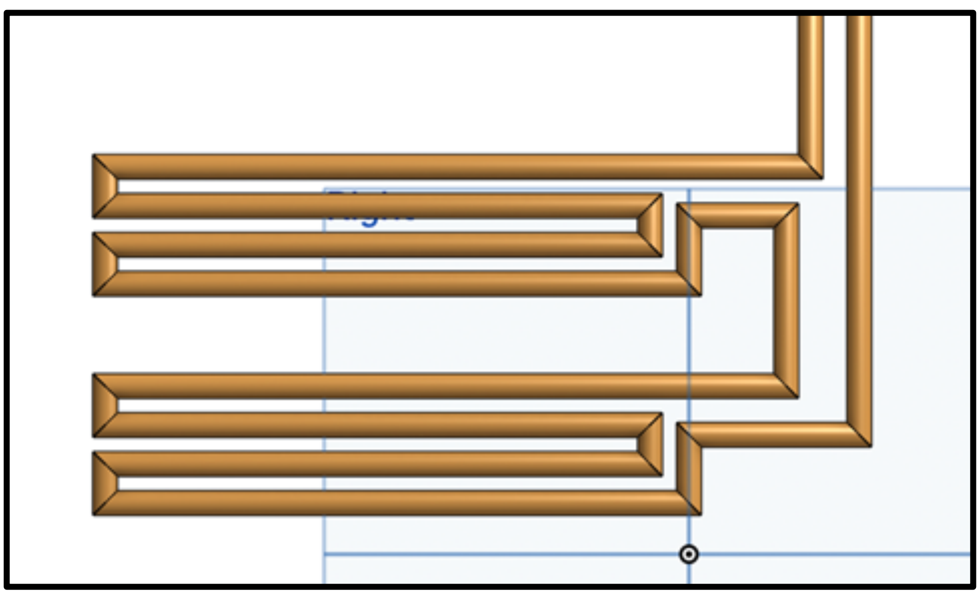

Figure 7.4 Coil System

7.2 Arduino Code

OTMO_Oven

```
int DC = 9;

void setup() {
  Serial.begin (9600);
  pinMode (DC, OUTPUT);

  // speed up
  for (int x = 0; x <= 255; x+=5) {
    Serial.print (String (x) + ", ");
    analogWrite (DC, x);
    delay (50);
  }

  delay (10800000);

  //slow down
  for (int x = 255; x >= 0; x-=5) {
    Serial.print (String (x) + ", ");
    analogWrite (DC, x);
    delay (50);
  }

  Serial.println("");
}

void loop() {
  // put your main code here, to run repeatedly:

}
```

Figure 7.5: Arduino Code

7.3 Subsystems

Figure 7.6: Radiator

Figure 7.7: Pump

Figure 7.8: Thermal Expansion Tank

7.4 Prototype Documentation

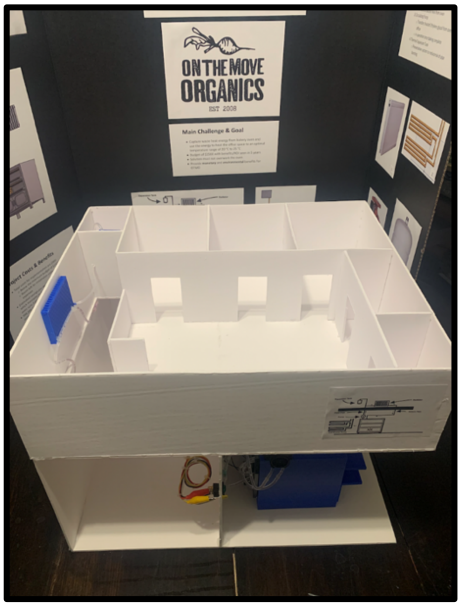

Figure 7.9

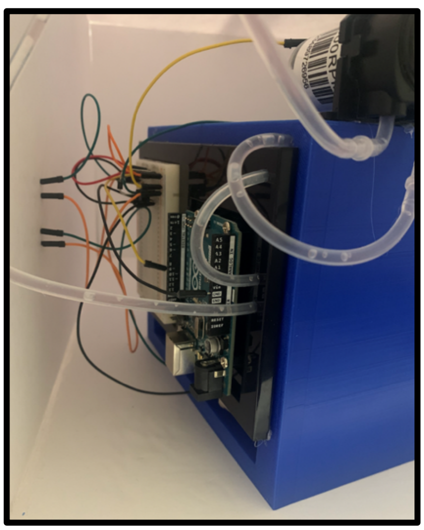

Figure 7.10

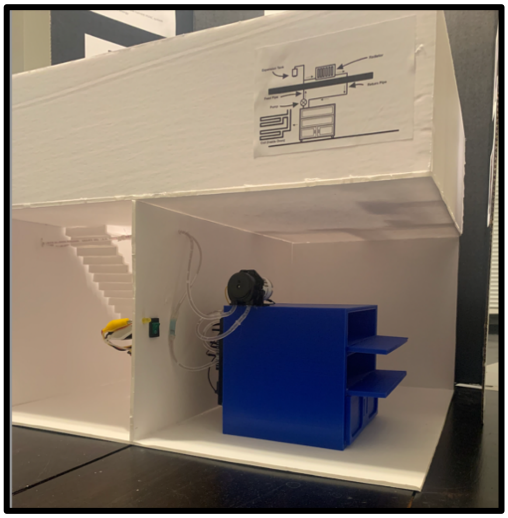

Figure 7.11

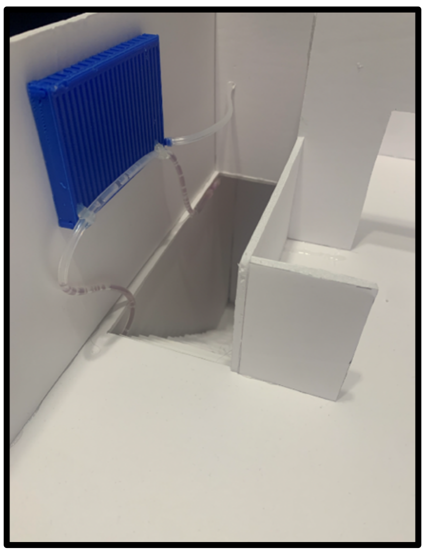

Figure 7.12

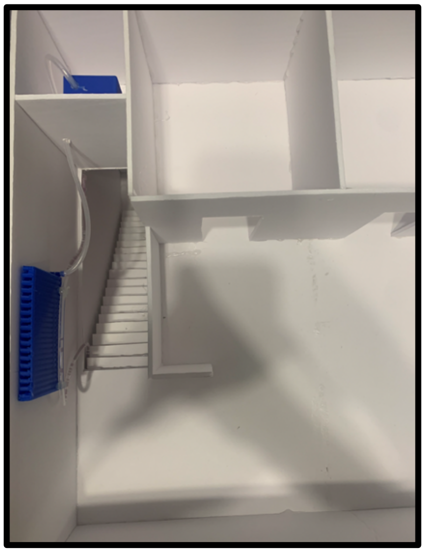

Figure 7.13

Figure 7.14

7.5 Calculations

Oven Side Dimension	0.313	meters	
Oven Base Dimension	1.34	meters	
Number of Levels	2	number	
Oven Width	1.4	meters	
Volume of Air in Oven	1.17	cubic meters	Oven Side*Oven Base*Number of Levels*Width
Thickness of Oven Material	0.001	meters	
Side SA	*4.2*	square meters	
Face SA	3.752	square meters	
Total interior Material	0.007952	cubic meter	Side SA*Face SA* Thickness of Oven
Stainless Steal Heat Capacity (mateiral of interior)	420	j/kg*K	
Air Heat Capacity	1006	j/kg*K	
Air Density	1.225	kilogram/cubic meter	
Mass of Interior Walls	61.2304	kilogram	Total interior Material*Steel Density
Mass of Air in Oven	1.44	kilogram/cubic meter	Volume of Air in Oven*Air Density
Temprature of the Oven	176.7	celcius	
Steel Density	7700	kilogram/cubic meter	
Amount of enegry in the air inside the oven	**226,782.86**	joules	Mass of Air *Change in Temprature*Heat Capacity of Air
Amount of energy absorbed by the metal lining the interiror	**771,503.04**	joules	Mass of Steel *Change in Temprature* Heat Capaicty of Steel
Total Joules Absorbed by Coil	49,914.30	joules	Total Joules in Oven* 5% (we assuemd only 5% of all heat will be transferred to the coil)
Power	192.88	watts	Total Joules Absorbed/Number of Hours the System Runs (3 hours is assumed)
Daily Savings	1.56	dollars	
Total Savings Over 5 years at 2% MARR	1,220.14	dollars	Excel NPV Function was Used

Figure 7.15