# Down to Earth (DTE):
# The Electric Food Composter

## Senior Design 2021/2022

Team LANCE

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DR1.2

11/23/21

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## EXECUTIVE SUMMARY

In terms of our project, we are building our own electric composter. However, you may wonder why we need to pay for a gadget to do something that Mother Nature does for free. Although you could resort to composting, urbanization is increasing by the minute and billions of people live in apartment complexes, condominiums, or suburban areas without much yard space in which traditional composting could become a nightmare. To compete with companies making electric composters, we plan on being able to break small bones and shells in our composter as most electric composters for home appliances are unable to do so. By applying this feature, we are catering to both industrial use as well as home appliances. Our heating chamber is also bigger than many composters, which will allow a substantial amount of food waste to be inputted. Furthermore, we plan to make this as energy and cost efficient as possible as we want to cater towards 3rd world countries as well.

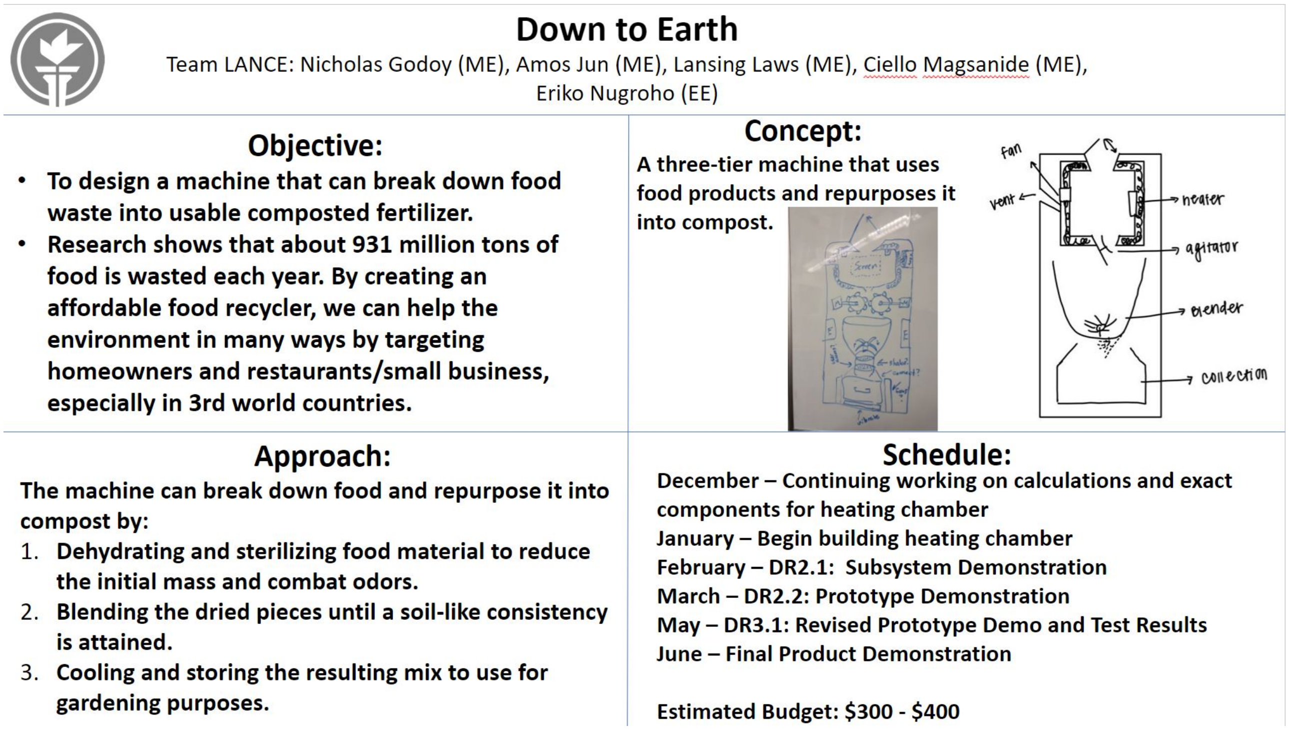
Although we were planning to have a grinder in our system, we decided to take out this component as this was the biggest concern as well as the most expensive. Therefore, our RRP consists of a sample heating chamber, which is simply a Styrofoam box lined with aluminum foil, a blow dryer, sensor, and flexible duct to recycle the air from the blow dryer. Furthermore, we have a trap door with part of the official housing of our heating chamber to demonstrate how our food will travel from the heating chamber into our blender. With this we demonstrate that we can achieve our desired temperature specs as well as how our food will travel from the heating to blending chamber.

Although we have reduced one of our biggest risks, we still have some remaining concerns. This includes the overall weight and dimensions of our system, whether our components in our heating chamber can withstand up to 10 hours of heating, methane production, how our food will travel from the blender to our collection chamber, material for the outer layer of the heating chamber as well as our overall housing, and energy efficiency. Due to our remaining risks, we are not completely confident in how well our final design will be considering our expectations and desired specifications for our project. However, we do think that this project is possible as we think we will be able to complete the heating chamber, the trap doors to allow food to travel, and our blender.

Therefore, key items we need to address during the first week of winter quarter is the best possible components to use, more analysis on how our food will travel, analyses on our blender housing as well as how the food will travel from the blender to the collection chamber, and test runs for our heating chamber to figure out heat transfer and energy consumption as well as other risks that could affect our design. Furthermore, we plan to do extensive research and building of our actual heating chamber during winter break for us to have a better idea going forward.

## UPDATED QUAD CHART

### Quad Chart



**Down to Earth**

Team LANCE: Nicholas Godoy (ME), Amos Jun (ME), Lansing Laws (ME), Ciello Magsanide (ME),
Eriko Nugroho (EE)

**Objective:**

- **To design a machine that can break down food waste into usable composted fertilizer.**
- **Research shows that about 931 million tons of food is wasted each year. By creating an affordable food recycler, we can help the environment in many ways by targeting homeowners and restaurants/small business, especially in 3rd world countries.**

**Concept:**

**A three-tier machine that uses food products and repurposes it into compost.**

**Approach:**

**The machine can break down food and repurpose it into compost by:**

1. **Dehydrating and sterilizing food material to reduce the initial mass and combat odors.**
2. **Blending the dried pieces until a soil-like consistency is attained.**
3. **Cooling and storing the resulting mix to use for gardening purposes.**

**Schedule:**

**December – Continuing working on calculations and exact components for heating chamber**
**January – Begin building heating chamber**
**February – DR2.1: Subsystem Demonstration**
**March – DR2.2: Prototype Demonstration**
**May – DR3.1: Revised Prototype Demo and Test Results**
**June – Final Product Demonstration**

**Estimated Budget: $300 - $400**

## Budget

Below is a detailed excel sheet of the purchases we made over autumn quarter for our risk reduction prototypes. Our purchases come from Amazon, Home Depot, and Lowes. So far, we have spent $272.58, however, most of the items we purchased will be returned during winter break. Creating our RRP's we found that we no longer need certain items based on testing and more research. This will allow us to make more purchases of items we need for the coming quarters.

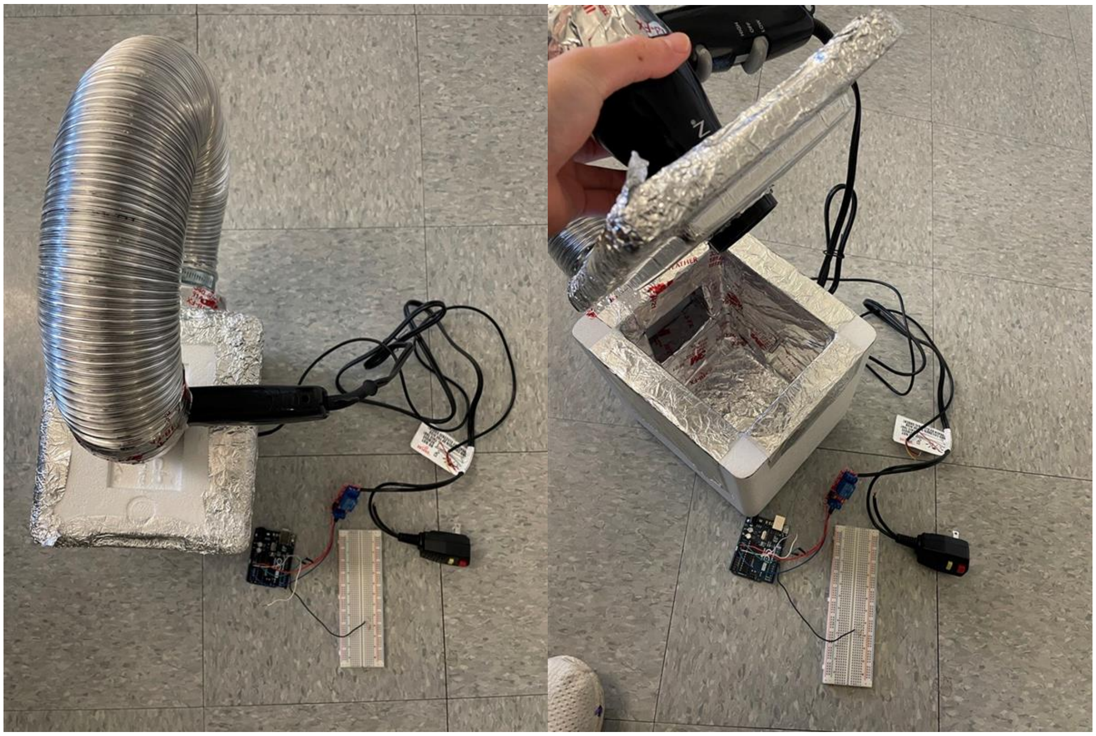
| Budget | $750 | | Without tax | | Potential Arrival Dates if ordered today (AMAZON) | Received (Y/N) | Date? |
|---|---|---|---|---|---|---|---|
| | Autumn Quarter | | | | | | |
| | Amazon Purchases (Ciello Bought) | Ventilation Fan | 17.99 | | 11/9/2021 | Y | 11/8/21 |
| | | AC DC Power Supply | 10.99 | | 11/9/2021 | Y | 11/8/21 |
| | | Cooling Fans | 14.99 | | 11/9/2021 | Y | 11/8/21 |
| | | Ceramic Fiber Insulation | 19.5 | | 11/9/2021 | Y | 11/8/21 |
| | | Lock | 18.88 | | 11/11/2021 | Y | 11/11/21 |
| | | TAX | 8.45 | | | | |
| | | Total | 90.8 | | | | |
| | Sent to Robin | | | | | | |
| | amazon | Ceramic Heater | 34.39 | | Nov 22-Dec 9 | | |
| | amazon | 6in Cooling Fan | 26.68 | | Nov 12- Nov 15 | | |
| | | TAX | 5.83 | | | | |
| | | Total | 66.9 | | | | |
| | Home Depot Purchases | Hinge, SPR ADJ 3.5" | 18.35 | | | | |
| | | Hinge, UTL Norem NRRW 2.5" | 3.47 | | | | |
| | | Sheet Metal Zinc x2 | 51.16 | | | | |
| | | TAX | 7.48 | | | | |
| | | Total | 80.46 | | | | |
| | Lowes | 4 in Sofit Exhaust Louver | 11.68 | | | | |
| | | Foil tape | 5.98 | | | | |
| | | 3in duct | 11.28 | | | | |
| | | 8x5/8 screws | 2.28 | | | | |
| | | TAX | 3.2 | | | | |
| | | Total | 34.42 | | | | |
| | | Total | 272.58 | | | | |

For the upcoming quarters, we believe that our budget for the winter quarter will be around $300 to $400. This amount will ensure that we will be able to complete our next subsystems we will be focusing on, which will be finishing our heating chamber and beginning our blender chamber.

# RISK REDUCTION PROTOTYPE

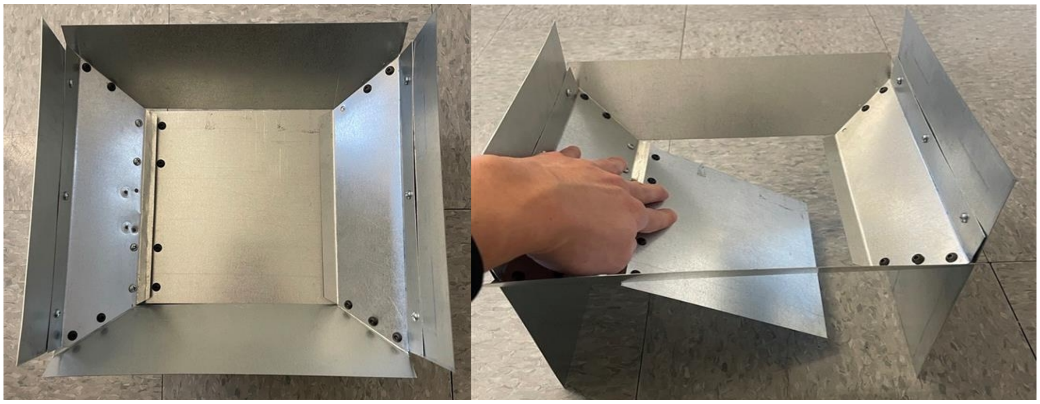
## Heating Chamber

One of the RRP's that we built was a Styrofoam heating chamber. This heating chamber is a 6" length by 5" width by 6-½" depth Styrofoam box lined with aluminum foil on the inside. A hair dryer inserted on top of the box acts as our heater and fan. A 3in duct is attached to the side of the Styrofoam box and connected to the top of the hair dryer. Creating this RRP helped us demonstrate the ability to generate the heat we want for our heating chamber. According to the test we conducted, this heating chamber can reach our desired temperature range. It reached a value of 185 degrees Fahrenheit and the max value we wanted for our heating chamber is 150 degrees Fahrenheit. Therefore, our RRP 001 has been met. Furthermore, this test shows that through testing and careful building of our real heating chamber, we can be energy efficient as we will be able to lessen the frequency of activating components such as our heater and fan in our chamber.



**Trap Door**

Our second RRP is the inner metal compartment of our heating chamber, that will be placed within the insulated enclosure. This is meant to hold the food during initial heating and equipped with a spring-loaded hinge that is designed to drop the food inside, once an electric lock disengages. The spring-loaded hinge is designed to freely open when a load is placed on it, and close unassisted once the load falls off the trap door mechanism. This was not in our original RRP specified in DR 1.1, but some expectations of this door are that it is calibrated, such that with any load applied, the door will be able to open on its own. Also, it must be able to close unassisted. During our tests we wanted to find the minimum weight required to open the door unassisted, to be able to justify a minimum suggested load the user would want to put in the chamber. To test this, we placed a specified weight at the center of the trap door to observe if it would open by itself. We found that the minimum weight required to open the door is 150g. Ideally, we would like to make this number as small as possible, while still having the door being able to close unassisted.



**Old Specifications:**

| Spec ID | Requirement | Threshold (Shall) | Objective (Should) | Validation Method | Why this threshold value | Relates to critical feature(s) |
|---|---|---|---|---|---|---|
| RRP 001 | Heating Process | 14 hours or less | 10-12 hours | Timer | Demonstrates how long it will take to fully dehydrate and sterilize the food waste | 1 |
| RRP 002 | Heating Temperature | 130°F-139°F | 140°F-150°F | Temperature Sensor | Demonstrates ability to generate heat and keep the temperature of the heating chamber | 1 |
| RRP 003 | RPM of the grinder | 10-15 RPM | 20-25 RPM | RPM measured or given by manufacturer | Demonstrates ability to grind down food into smaller pieces, as well as pulling the food into the teeth | 2 |
| RRP 004 | RPM for blender blade | 20,000 RPM | 30,000 RPM | RPM measured or given by manufacturer | Demonstrates how quickly we can get the blades rotating and if they can break down the food enough to reach the desired size of fertilizer | 2 |
| RRP 005 | Size of processed food waste | 7 mm - 8mm | 4 mm | Observation will fit through a filter or strainer | Demonstrates ability to process material into soil-like consistency. | 2 |

**New Specifications:**

| Spec ID | Requirement | Threshold (Shall) | Objective (Should) | Validation Method | Why this threshold value | Relates to critical feature(s) |
|---|---|---|---|---|---|---|
| RRP 001 | Heating Temperature | 120°F-160°F | 120°F-170°F | Temperature Sensor | Demonstrates ability to generate heat and keep the temperature of the heating chamber | 1 |
| RRP 002 | Minimum weight needed to open door unassisted | 1.5 lbs. | 0.5 lbs. | Testing varying weights/ distances and observing | Demonstrates ability to drop dehydrated food waste into blender chamber | 1 |

## ENGINEERING ANALYSES

### Mechanical Analyses

#### Size:

For calculating the appropriate size, we decided to make 3D models of our inside heating chamber to see potential options. For the heating chamber we decided to go with a 9x9x9 in. cube and inserted on the inside of the heating chamber located towards the bottom, is a 9x7x2 in. trapezoidal prism that will help the food waste slide through the trap door easier. We decided to go with these dimensions because with further research on hotel plans, although there was not a fan that resembles a 9x9x9 cube, a 6x7x6 in. hotel pan can hold 2.7 quarts of food. This is approximately 10 cups, thus with our dimensions we will be able to hold more than enough food waste.

Also, including 3D models of the heater and duct work helped us find that our outside heating chamber will be bigger than we anticipated. With the dimensions of the ductwork and the heater, they add extra inches to the outside of the inside heating chamber. With this finding, we decided that our outside heating chamber will be about 15x15x15 in. cube. This dimension will eventually change in the future because of the other components that will be included such as insulation and wiring. However, creating a 3D model helped us determine an approximate overall size of the entire system.

### Materials:

For the material of our heating chamber, we are using 26-gauge galvanized sheet metal. Doing research, we found the galvanized sheet metal is dangerous to weld, so we will instead rivet the sheet metal together. Galvanized sheet metal can get up to 392 degrees Fahrenheit. Galvanized steel is regular steel sheets that have been coated in zinc to make them corrosion resistant. In the long term, using this material, our heating chamber will not be able to rust easily. For our heater, we are using a ceramic heater which can get to our desired specification of 120-160 degrees Fahrenheit. This is within our threshold of our RRP; thus, our heating chamber will be able to reach the temperature we want it to reach. This heater is also strong and gets to the temperature we want quicker. This will help us reduce our power consumption as we will not need to leave the heater on as often. For our exhaust fan and duct work, they are made from metal. This will help withstand the heat within the heating chamber and recycle the air. We will also be using a spilt duct system which has a pathway to help us ventilate the air and release excess moisture out of the heating chamber. This will be done on a timely basis in which a door-like system will open for the air to be released out of the pathway.

### Heat Production:

In terms of the heat production for our heating chamber, we developed some theoretical calculations involving heat transfer. As our heating chamber functions like an oven, we have formulas that give heat energy from radiation, conduction, and convection. Furthermore, there are some other functions shown here such as heat transfer through the plate, heat flux, internal heat generation, R-value for insulation, as well as the thermal resistance network for our layers of walls for our heating chamber.

$radiation: Q = \sigma A F(T_1^4 - T_2^4)$

$Conduction: Q = -kA\left(\frac{\Delta T}{\Delta x}\right)$

$Convection: Q = hA(T_{fluid} - T)$

Heat transfer through a plate (Fourier's law): $q = \left(\frac{k}{s}\right)Adt = UAdt$

Heat transferred expressed as a function of heat exchange (Heat flux): $\emptyset = \frac{Q}{A} = U\Delta T = \frac{1}{\frac{e}{\lambda}} = \frac{(T_{skin1} - T_{skin2})}{\frac{e}{\lambda}}$

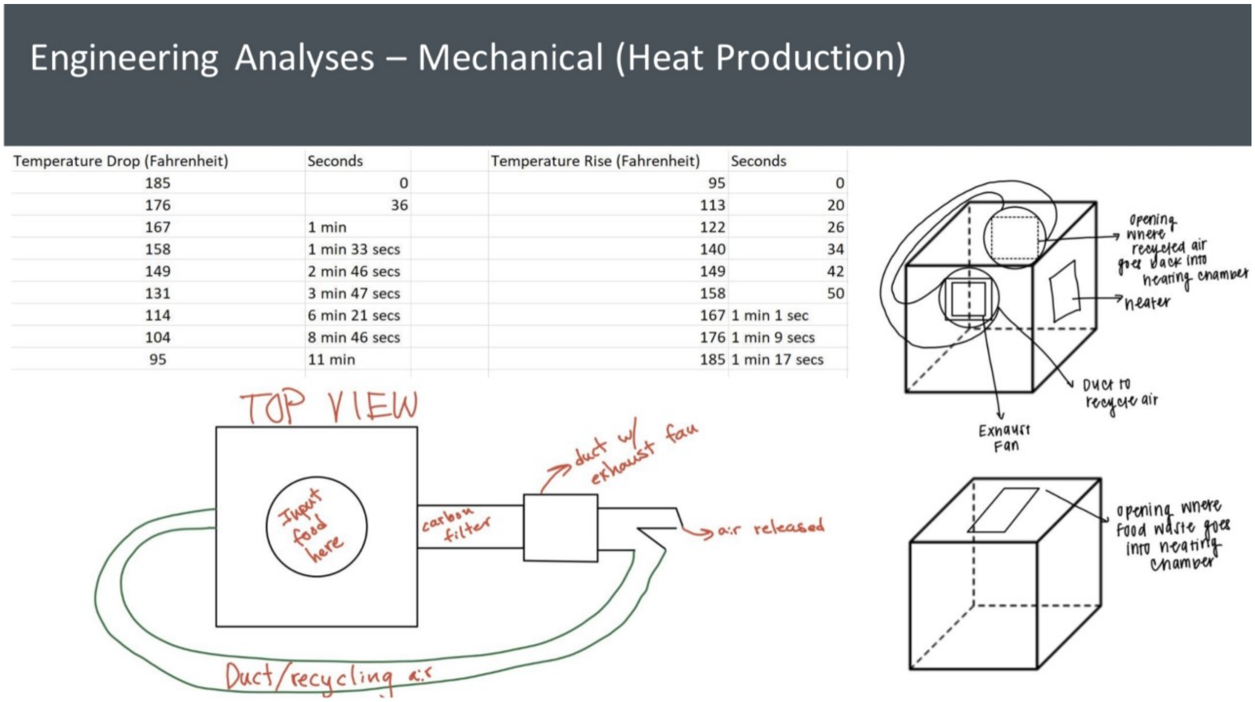
internal heat generation: $\dot{q}_1 V = (V\rho C_p + (\overset{\cdot}{\frac{A}{R_t}}))(T_f - T_a)$

R-value for insulation: $R = \frac{s}{k}$

Thermal resistance network through our inner layer of metal, insulation, and outer material:

$$R_{total} = \frac{1}{h_o} + \frac{L_p}{k_p} + \frac{L_i}{k_f} + \frac{L_p}{k_p} + \frac{1}{h_i}$$

Although we have some equations listed, this is simply a gathering of some of the formulas we will need to analyze and demonstrate what is happening in our heating chamber. We do not have the necessary values for the equations due to a couple of reasons. First, we have not finalized all the parts we need for our heating chamber. This is because we have found better materials to use than the ones we currently have bought. For example, we have found insulation with better R-values in which corresponds to how well our heating chamber retains its heat as well as the rate that the temperature will drop from our upper threshold range to our lower threshold range when our fan and heater are turned off. Furthermore, we have not yet decided on the best material for the outer layer of our heating chamber. This is because we realized that our dimensions for the outer layer are bigger than we expected, using our galvanized sheet metal would result in the heating chamber being heavier than we would like it to be. If our heating chamber is too heavy, there could be structural failure in our overall housing of our systems as this chamber is physically located at the top of our overall housing. Therefore, we are researching alternatives to our galvanized sheet metal which has thermal resistant properties, low cost, and light weight. Also, through talking with our professors, we realized that it would not be as effective or useful to do these calculations without some test runs of our actual heating chamber. This consists of data such as how fast our real heating chamber gets to our desired upper threshold range for temperature as well as the rate the temperature drops from its upper to lower threshold when our heater and fan are turned off. Finally, another reason we have been so delayed in our building time is due to changing the design of our heater one too many times. Although we are trying to find the best possible design and configuration of our heating chamber, this has been hindering our process of being able to build our systems.



## Engineering Analyses – Mechanical (Heat Production)

| Temperature Drop (Fahrenheit) | Seconds | Temperature Rise (Fahrenheit) | Seconds |
|---|---|---|---|
| 185 | 0 | 95 | 0 |
| 176 | 36 | 113 | 20 |
| 167 | 1 min | 122 | 26 |
| 158 | 1 min 33 secs | 140 | 34 |
| 149 | 2 min 46 secs | 149 | 42 |
| 131 | 3 min 47 secs | 158 | 50 |
| 114 | 6 min 21 secs | 167 | 1 min 1 sec |
| 104 | 8 min 46 secs | 176 | 1 min 9 secs |
| 95 | 11 min | 185 | 1 min 17 secs |

From this image, we demonstrate our final design of our heating chamber through drawings. From the drawings, we see that the food waste input would be located at the top, the carbon filter attached to the right of the heating chamber, a fan located inside of a duct connected to the carbon filter, and this being attached to the split air ducts. The split air duct has one pathway to recycle the air back into the heating chamber and the other pathway leads the air out into the atmosphere. We decided to recycle the air as this would be more effective in quickly heating our food waste. However, as we do not want excess moisture and the possibility of methane production or smell, we decided we needed a pathway to direct the air out of the system for the system to have some form of ventilation. Furthermore, this pathway will have a door-like function to open the pathway on a timely basis. Lastly, we show our data of the performance of our heating chamber prototype which demonstrates that we will be able to meet our temperature specifications. From our prototype, we were able to get up to 185 degrees Fahrenheit in less than two minutes and the temperature dropped from 185 degrees Fahrenheit to 149 degrees Fahrenheit in little under three minutes. This is what we are looking for as we want to be energy efficient, in which we want the components, like the heater, to be running as little as possible. Although our prototype consisted of slightly smaller dimensions than our actual heating chamber, this test was able to give us a particularly promising idea of how our actual heating chamber will perform. Furthermore, we predict that through better insulation and more thickness of insulation, we will see similar or even better results compared to our prototype. Therefore, from this heating chamber prototype, we realize that it is feasible to complete the heating chamber with the characteristics and function we would like it to have.

## Electrical Analyses

### Microcontroller Requirements:

For the RRP, we need to be able to choose a microcontroller that can perform the required tasks for the project. Hence, Arduino Uno was chosen to be the suitable microcontroller to do this task. It has 14 I/O pins that we can use, low power consumption and the electrical components required for the project are compatible with this board.

Since the composting process is 10 hours, we need to make sure that we can monitor the temperature of the heating chamber every second while controlling its temperature at the same time. Arduino Uno has 16MHz clock speed which is enough to do the required task.

Arduino Uno itself uses 0.6 W (50mA) to operate with an input voltage of 12 V DC, for this RRP, 3 pins are used which draws 20 mA per pins, resulting in the power consumption to be 1.32 W. As we need the heat sensor and the microcontroller to be active for the whole composting process, only the Arduino and the temperature sensor will be on, which requires 0.84 W to operate.

### Electrical Components:

The temperature required for the composting process is from 130° F - 150°F. So, we need to find a temperature sensor that can withstand hot temperature and is water resistant. Thus, DS18B20's chosen to be the suitable temperature sensor because of its wide range of temperatures (-67°F – 257°F) while having an accuracy of ±32.9°F (0.5°C) between 50°F – 185°F (-10°C - 85°C).

The relays used in the circuit are rated for 5V DC With maximum load of 25 V/10A AC or 30V/10A DC which is what we need because the blow dryer uses power from the wall which is around 110V AC. We used the NO and COM pins of this relay and connected it to the blow dryer cables that we split. The idea is to simulate an open circuit when the relay is off and a closed circuit when the relay is on. This way, we can control the blow dryer to activate and deactivate based on the temperature inside the chamber.

We are also using a power adapter to convert the wall power into a 12V/5A DC so we can power up the Arduino from the wall. Later, the cable of the power adapter, located before the adapter/converter, will be split so we can connect the cable of the heater to it so we can use only one plug that goes to the wall because for this RRP, we are using two wall plugs to power our heating chamber subsystem.

### Power Consumption:

$$System\ Power(W) = \sum V_{Component} * I_{Component}$$

One of our objectives for the project is to keep power consumption to a minimum. That is why it is important for us to choose a component that does not draw too much power. Unlike what the datasheet says, we did a calculation that is based on our design, here we are using 120°F as our lower temperature threshold and 170°F as our upper temperature threshold. The idea is that we want to know the actual power consumption of the heater and Arduino board since the heater will not be fully active during the composting process (it will be on and off according to the temperature inside). Based on our design for this RRP, the blow dryer consumes 243.75 W/hr. and the Arduino uses 1.8 W/he when all 5 pins are used. Based on this calculation, we can conclude that our design for the RRP is power efficient.

## RISKS REDUCED OR REMAINING

### Reduced Risks

Creating the Styrofoam heating chamber validates that our heating chamber is feasible to execute. Although we were unsure of how our project would turn out, we now have a much better understanding of what we need to do for our heating chamber as our RRP shows that even with a blow dryer, an insulated enclosure was able to exceed our expectations regarding the temperature we were able to achieve in a short amount of time. We may still run into some problems while building our real heating chamber, but through considerable planning and blueprints of our design, we are confident that we will be able to make a heating chamber.

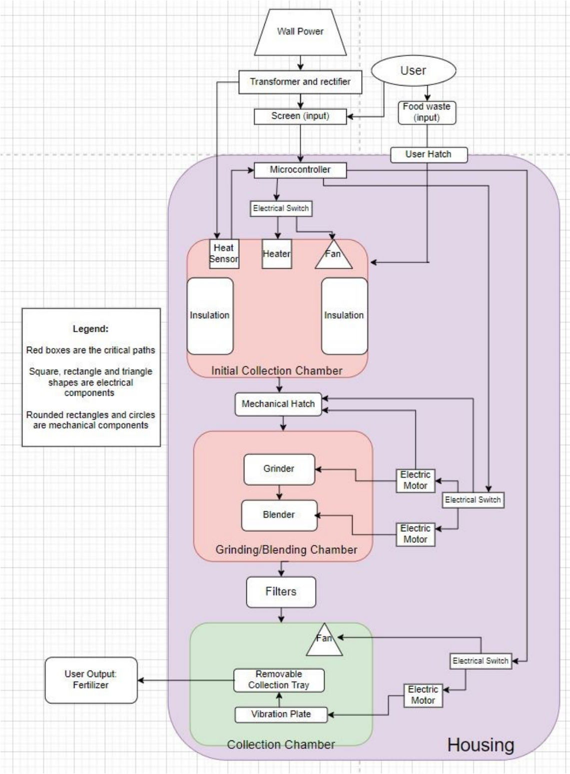
Creating and testing the trap door mechanism validates our concept of how we can transport food from the heating chamber, and our calculations are able to justify a suggested minimum weight to load the heating chamber with.

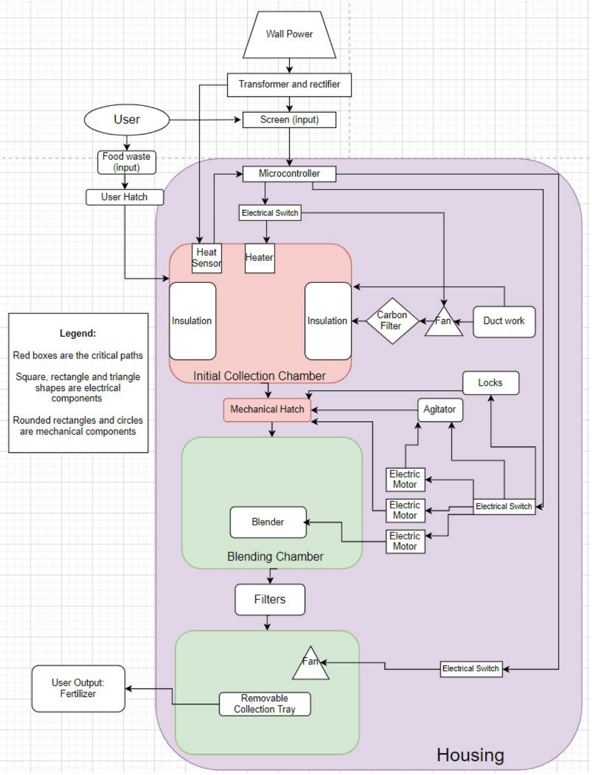
### Risks that Remain

We have yet to obtain our designated heating element, so we are unable to physically see its efficiency in heating the chamber. We are still unsure of the material we want to use for the outer layer of the heating chamber as we need to find something that is thermal resistant, light weight, and low cost. We do not want the heating chamber to be too heavy as this could lead to structural failure in our overall housing of all our components. In terms of the blender, we do not have a clear idea of how to let the food travel from the blender to the collection chamber. Furthermore, we are brainstorming but still unsure of the material to use for the overall housing as we are aiming to have our electric composter be as light as possible.

## UPDATED PROJECT

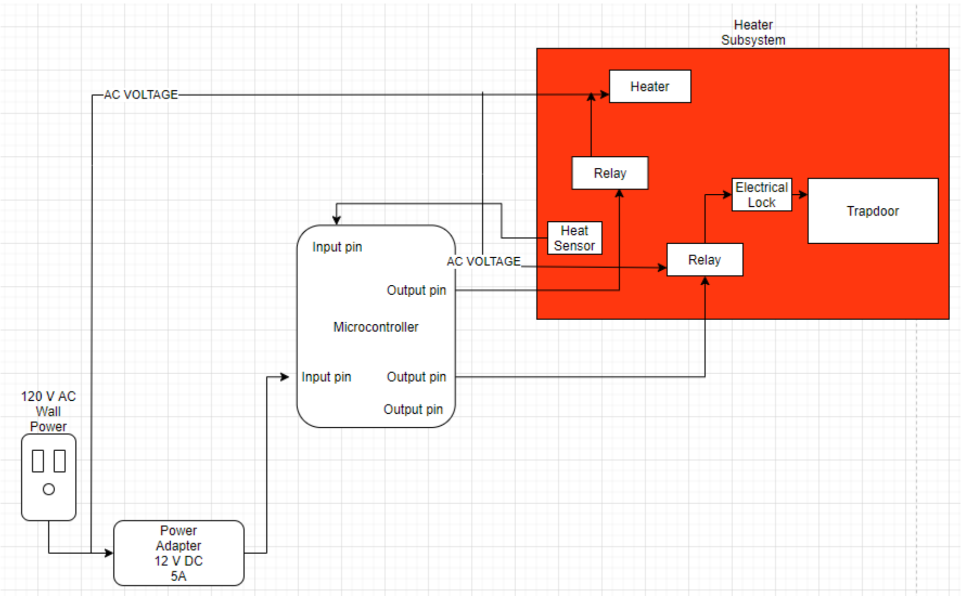
### Updated Block Diagram





The picture on the left side above, is our block diagram from DR1.1. The picture on the right is our updated block diagram. As the quarter went on, the design of our project has changed a lot since we created our first design. For the updated block diagram, we decided to omit the grinder in our grinding/ blending chamber, which is now called the blending chamber, due to cost and time constraints. We also updated our design of the heating chamber as there will only be one fan, which is the exhaust fan, a carbon filter, and ductwork. Due to our RRP, we have a better idea of how our food will travel in which we integrate locks into our mechanical hatch. Furthermore, we removed the vibration plate as it seemed like an unnecessary attachment to our system.

## Heating Subsystem for RRP



## RIGOROUS WINTER BREAK AND FIRST WEEK SCHEDULE

### Winter Break

During winter break, the main tasks that we want to focus on will be to start planning and gathering all the materials we need to finish our heating chamber and creating our winter and spring schedule in Microsoft Project. These are most important because by the first couple of weeks into winter quarter, we want to be done with our heating chamber to move on to the blending chamber. We also want our schedule to be complete, so we can stay on task with our assignments and progress on our overall project as much as possible.

Other things we can also start and think about are designing our website, brainstorming our blending chamber, researching materials for the overall housing of our project, and comparing individual schedules of the team early so we will be able to meet in person more rather than just on teams.

### Immediate Tasks (First Week)

For immediate tasks, as we begin the first week of winter quarter, we want to take inventory of parts that will be delivered during winter break and begin building and testing these products for the heating chamber. Also, we will be updating the professors on our progress and talking to them about our ideas for the blending chamber because safety is the biggest concern for our project.

## APPENDIX

### Power Consumption Calculation

**P=V*I**

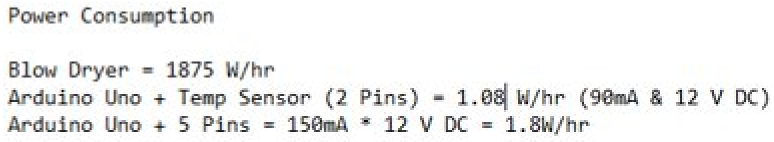
**P= Power (W)**

**V= Voltage (V)**

**I=Current (A)**

**Each Arduino pins = 20 mA**

**Arduino Uno = 12 V * 50ma = 0.6 W**



```
Power Consumption

Blow Dryer = 1875 W/hr
Arduino Uno + Temp Sensor (2 Pins) = 1.08 W/hr (90mA & 12 V DC)
Arduino Uno + 5 Pins = 150mA * 12 V DC = 1.8W/hr
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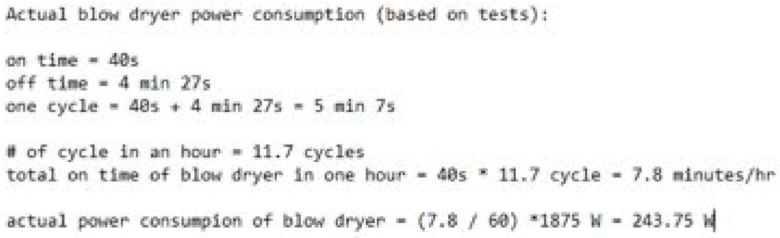


```
Actual blow dryer power consumption (based on tests):

on time = 40s
off time = 4 min 27s
one cycle = 40s + 4 min 27s = 5 min 7s

# of cycle in an hour = 11.7 cycles
total on time of blow dryer in one hour = 40s * 11.7 cycle = 7.8 minutes/hr

actual power consumpion of blow dryer = (7.8 / 60) *1875 W = 243.75 W
```

**Heat Production Calculations:**

How to calculate heater wattage:

Need to know desired temp, size & weight of material, how fast we need to get desired temp.

kW requirement $= (W_t \times C_p \times \Delta T) \div 3412 \times h$

$W_t$ = weight of material
$C_p$ = specific heat of material
$\Delta T$ = change in temp
$h$ = amount of hours to get to desired temp

Heat Transfer in an oven:

A = area of food exposed

Radiation: $\dot{Q}_{1\to 2} = \sigma A F_{1-2}(T_1^4 - T_2^4)$
Conduction: $\dot{Q} = -kA\left(\frac{\Delta T}{\Delta x}\right)$
Convection: $\dot{Q} = hA(T_{fluid} - T)$

$\dot{Q}$ means heat energy per min (for example)

Insulation required:

Using 30 gauge galvanized steel sheet metal has $1/80$ thickness in inches
specific heat: 0.47 $J/g \cdot °C$
thermal conductivity 52.0 $W/m \cdot K$

Heat transfer through a plate: fouriers law

$$q = \left(\frac{k}{s}\right) A\,dt = UA\,dt$$

$U = \frac{k}{s}$ = coefficient of heat transfer
$k$ = thermal conductivity ($W/m \cdot K$ or $W/m \cdot °C$, $Btu/(hr\,°F\,ft^2/ft)$)
$s$ = material thickness (m, ft)
$dT = t_1 - t_2$
$q$ = heat transfer ($W$, $J/s$, $Btu/hr$)

OR

$$Q = k_x A_x (T_1 - T_2)/x$$

Heat flux: heat transferred expressed as a function of heat exchange area

$$\phi = \frac{Q}{A} = U\Delta T$$

$\phi$ = heat flux ($W/m^2$)
$Q$ = heat transferred in W
$U$ = overall heat transfer coefficient ($W/m^2 \cdot °C$)
$A$ = heat transfer area

$$U = \frac{1}{R} = 1/(e/\lambda)$$

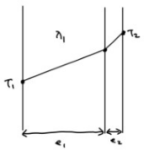
$R$ = heat transfer resistance in $m^2\,°C/W$
$e$ = wall thickness (m)
$\lambda$ = material thermal conductivity ($W/m\,°C$)

$$\phi = \frac{Q}{A} = (T_{skin_1} - T_{skin_2}) = (T_{skin_1} - T_{skin_2})/(e/\lambda)$$

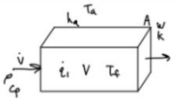
$T_{skin_1}$ = temperature on surface wall 1 (°C)
$T_{skin_2}$ = temperature on surface wall 2 (°C)

Calculating R-Value:

$$R = \frac{\Delta T \times Area \times time}{Heat\ loss}$$



$$\dot{q}_1 V = \left(\dot{V} \rho C_p + (A/R_t)\right)(T_f - T_a)$$



$\dot{V}$ = air flow ($m^3/s$)

$\rho$ = air density ($kg/m^3$)

$C_p$ = air specific heat ($J/kg \cdot °C$)

$h_a$ = air convection coefficient ($W/m^2 \cdot °C$)

$T_a$ = air temp (K)

$A$ = area ($m^2$)

$w$ = wall thickness (m)

$k$ = wall thermal conductivity ($W/m \cdot K$)

$\dot{q}_1$ = internal heat generation ($W/m^3$)

$V$ = volume of container

$T_f$ = final temp

$R_t = \left(\frac{w}{k} + \frac{1}{h_a}\right)$

$\dot{V} = 100$ cfm $= 0.047194745 \frac{m^3}{s}$

$\rho$ (at room temp) $\approx 1.225\ kg/m^3$

$C_p = 0.47\ J/kg \cdot °C$

$h_a = 10 \frac{W}{m^2 \cdot K}$

$T_a \approx 288\ K = 14.85°C$

$A = (0.254 m)^2 = 0.064516\ m^2$

$k = 52\ W/m \cdot K$

$w = \frac{1}{80}$ in $= 0.0003175 m$

$V = (0.254)^3 = 0.01639\ m^3$

$T_f = 150°F = 338.706\ K = 65.556°C$

$R_t$ (down below) $= 0.64 \frac{m^2 \cdot K}{W}$

$$\left(\frac{T_f}{T_a} - 1\right) = (\alpha \dot{q}_1)\left[1 + \alpha\left(\frac{A}{V}\right)\left(\frac{1}{R_t}\right)\right]^{-1}$$

$\alpha = \tau / \rho C_p T_a$

$\tau = \frac{V}{\dot{V}}$ => turnover time (how often does one entire volume of air in the container get exchanged)

$\tau \to 0$ => good ventilation

for small $\alpha$: $\left(\frac{T_f}{T_a} - 1\right) \approx (\tau)\left[\rho C_p T_a\right]^{-1}(\dot{q}_1)$

$$\left(\frac{65.556°C}{14.85°C} - 1\right) = \left(\frac{0.01639\ m^3}{0.047194745 \frac{m^3}{s}}\right)\left(1.225 \frac{kg}{m^3}\left(0.47\ J/kg \cdot °C\right)(14.85°C)\right)^{-1}(\dot{q}_1)$$

$\dot{q}_1 = 84.064\ W/m$

Heat transfer through a plate: fouriers law

$q = \left(\frac{k}{s}\right) A\, dt = U A\, dt$

$U = \frac{k}{s}$ = coefficient of heat transfer

$k$ = thermal conductivity ($W/m \cdot K$ or $W/m \cdot °C$, $Btu/(hr\,°F\,ft^2/ft)$)

$s$ = material thickness (m, ft)

$dT = t_1 - t_2$

$q$ = heat transfer (W, J/s, Btu/hr)

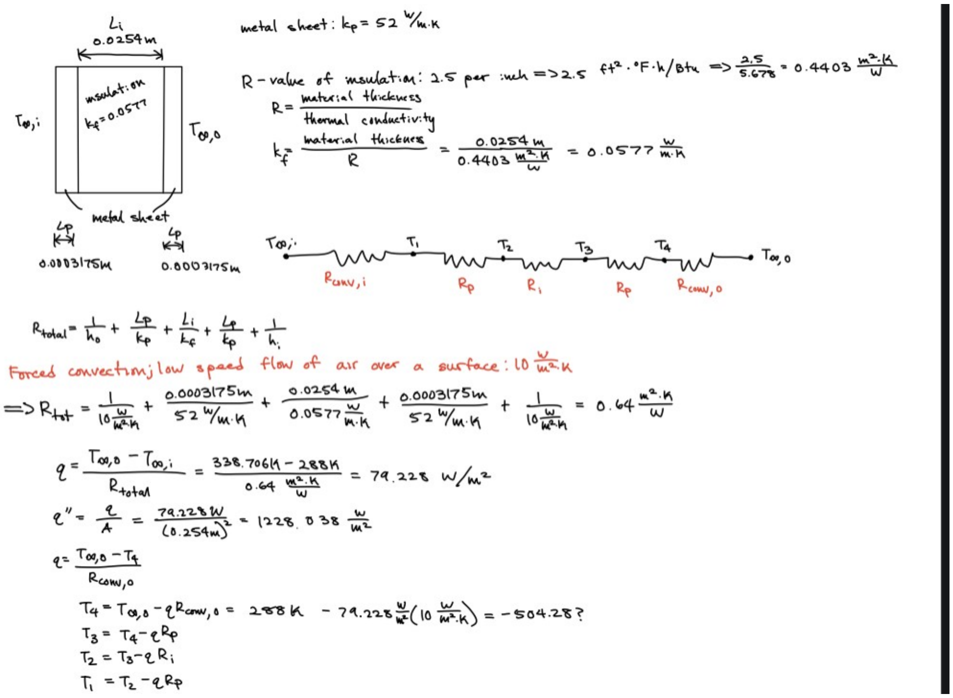
OR

$Q = k_x A_x (T_1 - T_2)/x$

$$q = \left(\frac{52\ W/m\,K}{\underset{\frac{1}{80}\text{ in}}{0.0003175\ m}}\right)\left(\overset{10\text{ in}}{0.254 m \cdot 0.254 m}\right)\left(\overset{150°F}{338.706 K} - 288\ K\right) = 535779.9\ W$$

Since we know cfm: 100 cfm from fan above heater

sensible heat loss from infiltration: $Q = \underset{\text{volumetric air flow rate (cfm)}}{V} \times \underset{\text{density of air}}{\rho_{air}} \times C_p \times (T_i - T_o) \times 60$



metal sheet: $k_p = 52\ W/m\cdot K$

R-value of insulation: 2.5 per inch $\Rightarrow 2.5\ ft^2\cdot{}^\circ F\cdot h/Btu \Rightarrow \frac{2.5}{5.678} = 0.4403\ \frac{m^2\cdot K}{W}$

$$R = \frac{\text{material thickness}}{\text{thermal conductivity}}$$

$$k_f = \frac{\text{material thickness}}{R} = \frac{0.0254\ m}{0.4403\ \frac{m^2\cdot K}{W}} = 0.0577\ \frac{W}{m\cdot K}$$

$$R_{total} = \frac{1}{h_o} + \frac{L_p}{k_p} + \frac{L_i}{k_f} + \frac{L_p}{k_p} + \frac{1}{h_i}$$

Forced convection; low speed flow of air over a surface: $10\ \frac{W}{m^2\cdot K}$

$$\Rightarrow R_{tot} = \frac{1}{10\frac{W}{m^2\cdot K}} + \frac{0.0003175m}{52\ W/m\cdot K} + \frac{0.0254\ m}{0.0577\frac{W}{m\cdot K}} + \frac{0.0003175m}{52\ W/m\cdot K} + \frac{1}{10\frac{W}{m^2\cdot K}} = 0.64\ \frac{m^2\cdot K}{W}$$

$$q = \frac{T_{\infty,o} - T_{\infty,i}}{R_{total}} = \frac{338.706K - 288K}{0.64\ \frac{m^2\cdot K}{W}} = 79.228\ W/m^2$$

$$q'' = \frac{q}{A} = \frac{79.228W}{(0.254m)^2} = 1228.038\ \frac{W}{m^2}$$

$$q = \frac{T_{\infty,o} - T_4}{R_{conv,o}}$$

$$T_4 = T_{\infty,o} - qR_{conv,o} = 288K - 79.228\frac{W}{m^2}\left(10\ \frac{W}{m^2\cdot K}\right) = -504.28?$$

$$T_3 = T_4 - qR_p$$

$$T_2 = T_3 - qR_i$$

$$T_1 = T_2 - qR_p$$

In terms of the heat production inside our heating chamber, we developed some theoretical calculations involving heat transfer. As our heating chamber functions like an oven, we have formulas that give heat energy from radiation, conduction, and convection. Furthermore, there are some other functions shown here such as heat transfer through the plate, heat flux, internal heat generation, R-value for insulation, as well as the thermal resistance network for our layers of walls for our heating chamber.