Heating and cooling loads:

This part verifies the effectiveness of wall insulation by calculating the heat being transferred in some extreme temperature conditions. The whole calculation process is documented because it was later used for developing a HVAC design software to simplify the computation process.

Assumptions:

- Desired room temperature: 2 - 4 ^{o}C, here use 3 ^{o}C or 37.5^{o}F
- Relative humidity: 90% - 98%
- Outside temperature: -36 ^{o}C ~ 36 ^{o}C
- Elevation 236ft (average elevation in Ottawa), ignore air correction factor because it is nearly 1
- Heat from lighting is ignored because it is rarely turned on
- Heat from people is ignored because the client only visits the chamber for short period of time
- Fenestration is none because the structure is well insulated from inside
- 500 lbs of potatoes are brought in
- 10000 lbs of potatoes are already stored in the chamber

Heat gains to be calculated:

1. field heat from food (food just brought in) qc1
2. heat of respiration from food (already stored food) qc2
3. heat through walls qc3

4. heat through the floor qc4

- Field heat qc1

The first source of heat is the warm produce brought into the cooling facility. The heat energy it contains is called field heat. Assume food is brought into the root cellar at an average temperature of 20 ^{o}C or 68 ^{o}F, and it takes 24 hours to cool it down. The formula is:

$$qc1 = SH\ (Btu/lb/F) \times DT\ (F) \times W\ (lb)\ /\ H,$$

where SH is the specific heat of the food (numbers can be found in Appendix A), DT is the temperature difference, W is weight of the food, H is hours to cool down the food.

$$qc1 = 0.84 * (68 - 37.5) * 500 / 24 = 533.75\ Btu/h = 156.42W$$

- Heat respiration qc2

The second source of heat is the respiration of the crop itself. Horticultural crops are alive and give off heat as they respire. Note that this value is different for warm and cold crops, and less refrigeration is required to remove the heat of respiration when produce is cool than when it is warm. Here the stored potatoes are already at 3 ^{o}C, so cold heat respiration value is used.

$$qc2 = HR(Btu/h/lb) * W(lb),$$

where HR is heat respiration of a food, and W is the weight.

$$qc2 = 0.028 * 10000 = 280\ Btu/h = 82W$$

- Heat through wall qc3

Here only the temperature in the produce chamber is considered, so the antechamber is seen as a multi-layered wall with an air gap in the following calculation. Note that R value unit is ft2·°F·h/BTU for commercial insulation materials in North America, divide it by 5.678 to get SI unit m2·K/W. The specification of each insulation materials has already been given in the prototype section. Heat load from wall:

$$q = U(Btu/h/(ft^2*F)) * A(ft^2) * T(°F),$$

U is materials' u factor, it is an inverse of thermal resistance. A is the wall surface area, T is temperature difference.

To find the total qc3, three sections are considered, they are front wall to dividing wall, produce chamber side wall, and produce chamber rear wall. And the first one is comprised of the front wall, the whole antechamber, and the dividing wall.

- Front wall + antechamber + dividing wall

$$Ufw = 1/(Rsi + R1 + R2 + R3 + R4 + R5+ Rso)$$

Rsi is inside surface thermal resistance 0.12 m^2·K/W = 0.68136 ft^2·°F·h/BTU

Rso is outside wall surface thermal resistance 0.06 m^2·K/W = 0.34068 ft^2·°F·h/BTU

R1 is the thermal resistance of 1/8'' galvanized steel wall = length/thermal conductivity = 0.00318m / 52 (W/m*k) = 0.0000612 m^2·K/W = 0.000347 ft^2·°F·h/BTU

R2 is the R20 batt insulation = 20 ft^2·°F·h/BTU

R3 is the thermal resistance of the usable area of the antechamber (air) = 3.6576m / 0.024(W/m*k) = 152.4 m^2·K/W = 865.3272 ft^2·°F·h/BTU

R4 is another galvanized steel wall used for the dividing wall = 0.000347 ft2·°F·h/BTU

R5 is the R40 batt insulation on the second wall = 40 ft^2·°F·h/BTU

Ufw = 0.0011 Btu/h/(ft^2*F)

- Produce chamber side wall

Usw = 1 / (Rsi + R1 + R2 + Rso)

Rsi is 0.68136 ft^2·°F·h/BTU

Rso is 0.34068 ft^2·°F·h/BTU

R1 is the thermal resistance of 1/8’’ galvanized steel wall = 0.000347 ft^2·°F·h/BTU

R2 is the R48 closed spray foam insulation = 48 ft^2·°F·h/BTU

Usw = 0.0204 Btu/h/(ft^2*F)

- Produce chamber rear wall

Urw = 1 / (Rsi + R1 + R2 + Rso)

Rsi is 0.68136 ft2·°F·h/BTU

Rso is 0.34068 ft2·°F·h/BTU

R1 is galvanized steel = 0.000347 ft^2·°F·h/BTU

R2 is R40 batted insulation = 40 ft^2·°F·h/BTU

Urw = 0.0244 Btu/h/(ft^2*F)

For wall areas, assume the cross section of the chamber is an ellipse, use the usable area dimensions for calculation (ellipse's perimeter is estimated by using Ramanujan's formula):

Afw = pi*21*10/2 = 329.87 ft2

Asw = 100.47/2*24 = 1205.62 ft2

Arw = pi*21*10/2 = 329.87 ft2

qc3 = (Ufw * Afw + Usw * Asw + Urw * Arw) * TD

Winter: qc3 = 2320.35 Btu/h = 680W (from inside to outside)

Summer: qc3 = 1957.49 Btu/h = 575W (from outside to inside)

- Heat from floor:

The reported under floor temperature is constantly at around 3 ^{o}C, which means that the heat transfer between floor and chamber is 0 if the chamber is maintained at 3^{o}C, but the actual under floor temperature during different seasons still needs more investigation. Therefore, the calculation steps are included here for future testing use.

$$Uf = 1 / (Rsi + R1 + R2 + Rso)$$

Rsi and Rso are the same as previous part.

R1 is the thermal resistance of ¾'' plywood floor, the thermal conductivity is 0.1154 (W/m*k), so the R1 is = 0.01905/0.1154 = 0.165 $m^2 \cdot K/W$ = 0.937 $ft^2 \cdot °F \cdot h/BTU$

R2 is the thermal resistance of styrofoam which is 12 $ft^2 \cdot °F \cdot h/BTU$

Uf = 0.072 Btu/h/(ft^2*F)

Qc4 = Uf * Af * TD = 0

- Total heat transfer:

$$Q\ winter = -(qc1 + qc2) + qc3 + qc4 = 442W$$

$$Q\ summer = qc1 + qc2 + qc3 + qc4 = 813W$$