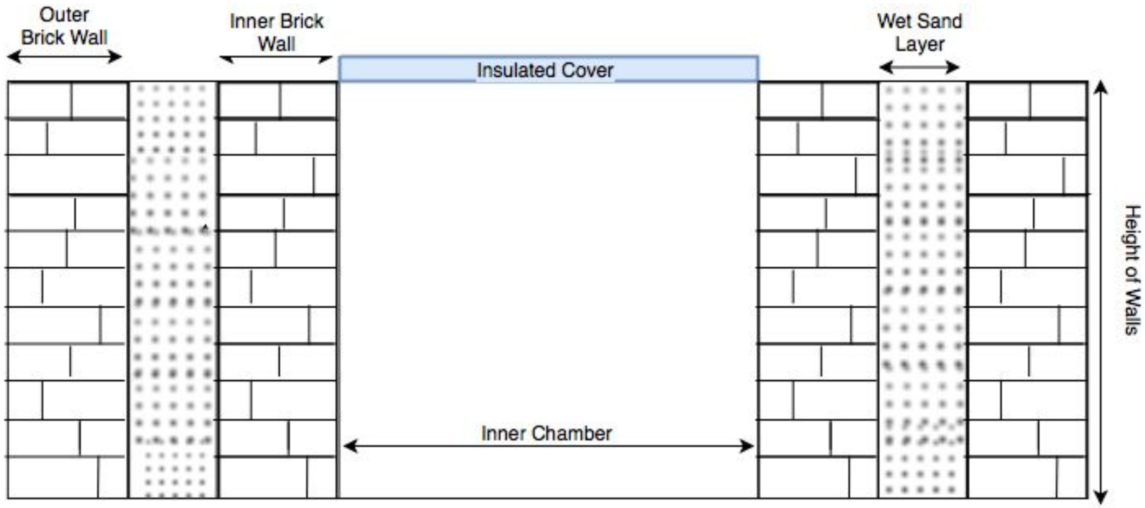
Zero Energy Cooling Chamber

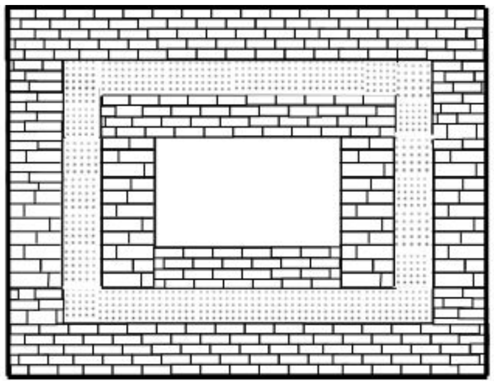
A sustainable solution to storing excess produce

What is a ZECC?

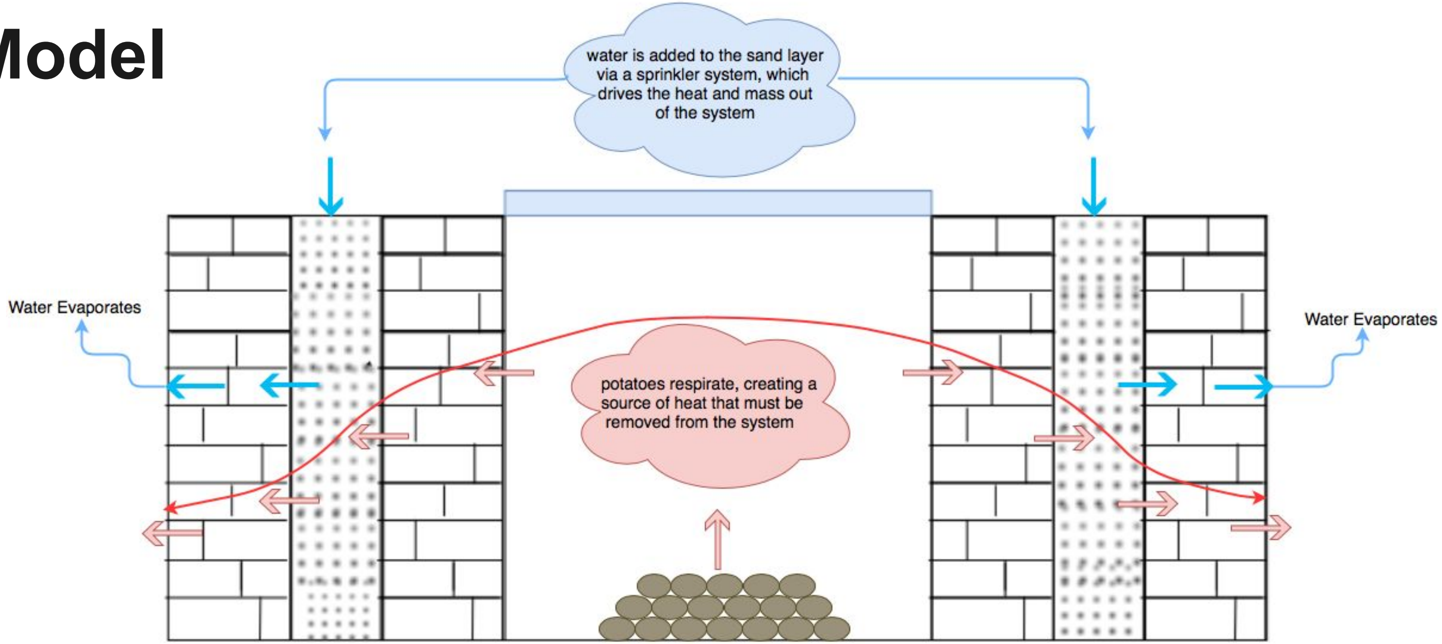
Side View



Top View



Model

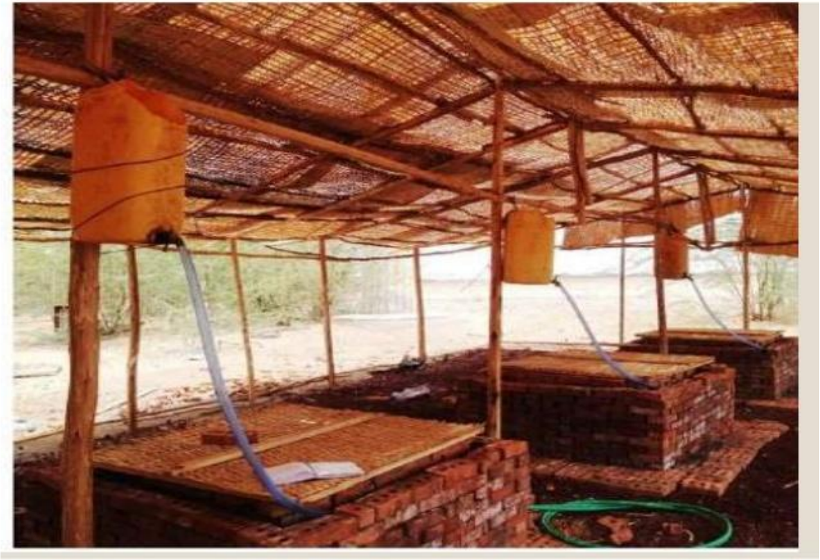


The long red arrow models the change of temperature throughout the layers. The thick red arrows indicate heat transfer and the thick blue elements indicate mass transfer occurring.

Usage

- Most commonly found in hot, arid climates where access to electricity is sparse
- Often used by small scale farmers to reduce postharvest loss in developing countries

Zero Energy Cooling Chambers (ZECC)



Mission

- Successfully model the mass and heat transfer through system via python code
- Create a GUI (Graphical User Interface) for ease of understanding
- Introduce simple concepts for first year students
- Compare model to real world examples ie. cooling towers, cooling the body via evaporation of sweat

PROBLEM: Find the optimal ZECC design by varying temperatures, relative humidity, and size.

Assumptions

- One metric ton of potatoes is being stored in the center of the inner chamber
- Sand remains saturated throughout the process
- Potatoes respirate, giving off a source of heat that drives the heat and mass transfer out of the system
- Water travels from the wet sand out through the brick, evaporating off of the surface of the outer brick wall, creating a cooling effect at each layer of the chamber (similar to sweat evaporating off skin to cool you down)

Independent Variables

- Inner Chamber Temperature
- Outer Air Temperature
- Outer Air Relative Humidity
- Size of Inner Chamber (length and width varied, fixed height)
- Size of Wet Sand Layer (thickness)

Dependent Variables Calculated by the Model

- Temperatures at each medium interface (HT)
- Dew Point Temperature at outer brick wall (HT)
- Diffusion of Water through the layers to the outer brick wall (MT)
- Evaporation of Water at outer brick surface (MT)
- Liters of Water needed to be added daily to replace lost water via MT
- Annual cost of design (both fixed and variable expenses)

General Balance

- IN + GENERATION = OUT
- IN = water is added into the system to force heat transfer outward
- GENERATION = heat is generated by the potatoes in the center of the storage container
- OUT = heat conducted out, water evaporated out at brick surface

Essential Equations- Heat Transfer

- Composite wall heat balance to find temperatures at each interface

$$q = \frac{(T_c - T_4)}{\frac{1}{h_c \cdot A_c}} = \frac{(T_4 - T_3)}{\frac{L_{inner\ brick}}{k_{brick} \cdot A_{inner\ brick}}} = \frac{(T_3 - T_2)}{\frac{L_{wet\ sand}}{k_{wet\ sand} \cdot A_{wet\ sand}}} = \frac{(T_2 - T_1)}{\frac{L_{outer\ brick}}{k_{brick} \cdot A_{outer\ brick}}} = \frac{(T_1 - T_{bulk})}{\frac{1}{h_{bulk} \cdot A_{bulk}}}$$

q = Heat produced by potato respiration

h_c = Heat transfer coefficient inside the chamber

A_c = Area of inner chamber

$L_{inner\ brick}$ = Length of the inner brick layer

k_{brick} = Thermal conductivity of brick

A_{bulk} = Area ouside of chamber

h_{bulk} = Heat transfer coefficient of outdoor air

$A_{inner\ brick}$ = Area of inner brick layer

$L_{wet\ sand}$ = Length of wet sand layer

$k_{wet\ sand}$ = Thermal conductivity of wet sand

$A_{wet\ sand}$ = Area of wet sand layer

$L_{outer\ brick}$ = Length of outer brick layer

$A_{outer\ brick}$ = Area of outer brick layer

T_c = Inner Chamber Temperature

T_4 = Inner Chamber / Inner Brick Interface Temperature

T_3 = Inner Brick / Wet Sand Interface Temperature

T_2 = Wet Sand / Outer Brick Interface Temperature

T_1 = Outer Brick / Bulk Air Interface Temperature

T_{bulk} = Temperature of outdoor air

Essential Equations- Heat Transfer

- Magnus Formula to find dew point temperature based on input value of bulk air temperature and relative humidity.

$$T_{dew\ point} = \frac{b\left(\frac{a \cdot T_{bulk}}{b + T_{bulk}} + \ln(RH)\right)}{a - \left(\frac{a \cdot T_{bulk}}{b + T_{bulk}} + \ln(RH)\right)} \quad where\ a = 17.27,\ b = 237.7,\ RH = 0 \rightarrow 1$$

- Dew Point temperature is critically dependent on both the design of the chamber and inputted values. If the outer brick wall temperature becomes too low, water will begin to condense on the surface of the brick, and no evaporation will occur, halting the cooling of the inner chamber.

Essential Equations- Mass Transfer

- Antoine equation to calculate pressure at a certain temperature

$$\ln\left(P^*\right) = A - \frac{B}{C + T} \; where \; A = 18.3036, \; B = 3816.44, \; C = -46.13$$

- Mass balance to calculate the outer mass transfer coefficient k_{bulk}

$$q + h_{bulk} \cdot A_{outer\ brick} \cdot \left(T_{bulk} - T_1\right) = \lambda \cdot k_{bulk} \cdot A_{bulk}\left(P^*\left(T_1\right) - P_{bulk}\right)$$

$$where \; \lambda = latent\ heat\ of\ evaporation, \; q = heat\ of\ respiration$$

- Finding the concentration of water moving from the sand through the outer brick

$$\frac{\varepsilon_{brick} \cdot D_{wb} \cdot A_{outer\ brick}\left(C_{sand} - C_{outer\ brick}\right)}{L_{outer\ brick}} = k_{bulk} \cdot A_{bulk}\left(P^*\left(T_1\right) - P_{bulk}\right)$$

Food for Thought

- Consider the region and time of year this would be implemented. How does that change the outer air temperature and relative humidity values you will be inputting?
- What is a normal refrigerator temperature? Do potatoes need to be stored at this temperature?
- How much is one metric ton of potatoes in kg? What kind of space might that many potatoes occupy? Will this affect your initial guesses?
- How will changing each variable affect your overall design? Which is the most costly to manipulate and why?
- Is this design useful? Does it make sense to build a ZECC here at Lehigh, or would it be better suited elsewhere? Can this be used year-round?