3 Toed Box Tortoise Habitat

Individual Analytical Analysis

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1. Introduction

Ponderosa High School's Greenhouse is the home to native fish, the largest bunny in Flagstaff, and a 3 toed box tortoise. A tortoise temperature must be kept around 75-85 degrees Fahrenheit with warmer zones for basking and a water zone for cooling. As the temperature drops in the winter months, the tortoise struggles to sustain homeostasis. This means the tortoise must live in a sanctuary down in Phoenix until Flagstaff heats up again. The faculty and students want to turn a recycled fiberglass tub into an enclosed tortoise habitat and ensure there is enough energy to keep their tortoise warm. With the help of the Ponderosa High School students, a wooden enclosure will be built with a plexiglass door. To ensure the habitat will have enough energy to keep the lamps running at night, the following analysis has been produced.

2. Analysis

2.1 Assumptions

For the analysis of the tortoise habitat, it is assumed that radiation is negligible and the enclosure operates in steady state. The back and bottom of the tank are insulated by dirt and drywall and the top is open, but encapsulated by a heat source. For the calculations, the inside temperature of the enclosure is an estimate 80 degrees Fahrenheit and the outside temperature is gathered from five years of Flagstaff weather data. The approximate calculated area of the enclosure is 2.169673 m^2 with a volume of .9187 m^3. There is convection on either side of the material with a convection coefficient of 5 W/m^2*K [1] and conduction through the material. For wood the conduction coefficient is .13 W/m*K [2] and for plexiglass it is .19 W/m*K [3]. The temperatures used for high, average, and low for every season is listed below. The area of each individual unique panel is also listed below with wood 1 being the front rectangular panels and wood 2 being the trapezoidal panels.

Table 1
Outside Temperature

Temperature			
K	High	Avg	Low
Winter	292.04	273.17	252.59
Spring/Fall	299.63	281.4	264.076
Summer	307.409	292.19	272.22

Table II
Area of Panels

Area (m^2)	
Wood 1	0.241935
Wood 2	0.479999
Plexi Glass	0.725805

2.2 Variable Table

Symbol	Description	Units
$\dot{Q}_{net}$	Net heat transfer	W
$\dot{W}_{net}$	Net Work	W
$\frac{dE_{cv}}{dt}$	Rate of energy in a control volume with respect to time	W/s
$\dot{Q}_{loss}$	Heat transfer loss	W
$\dot{Q}_{heater}$	Heat transfer from a heat source	W
$\dot{Q}_{evap}$	Heat transfer from water evaporation	W
$\dot{m}_{evap}$	Mass evaporation	kg/day
h_{fg}	Latent heat of evaporation	J/kg
t	time	hrs
E_{bask}	Energy of a heat lamp	kWh
T_{∞}	Surrounding temperature	K
T_i	Inside temperature	K
R_{tot}	Total resistance	K/W
ΔT	Inside minus outside temperature	K
A	Surface area	m^2
L	thickness	m
k	Conduction coefficient	W/m*K
h	Convection coefficient	W/m^2*K
q	Power	W
E	Energy	kWH

2.3 Structure

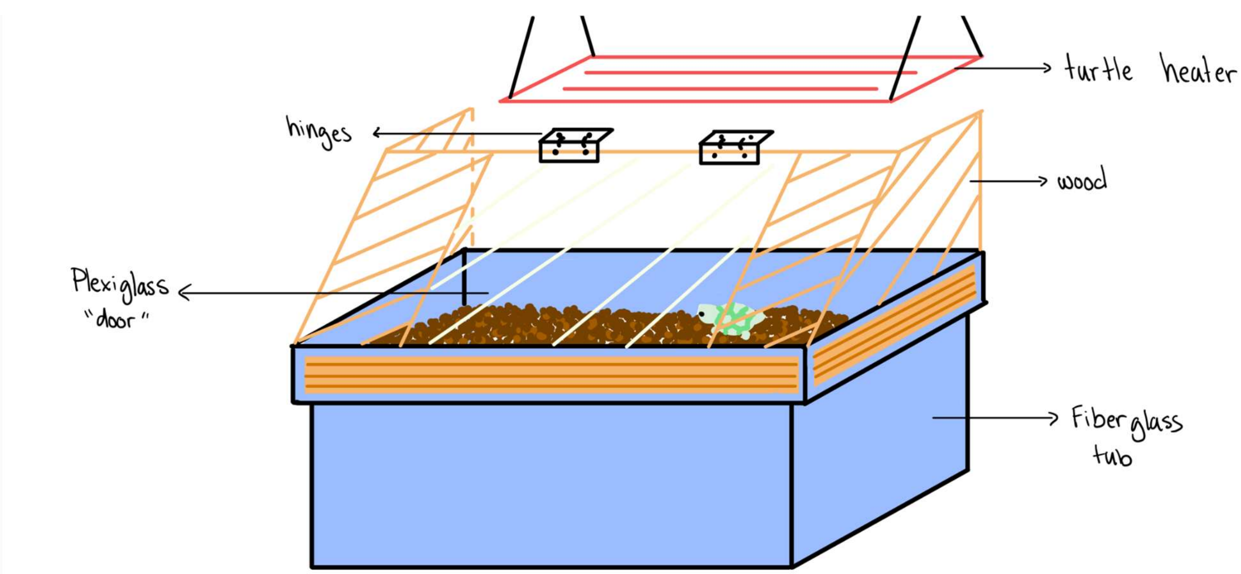

Fig 1. Tortoise Enclosure Sketch

The clients have a fiberglass tub and a frame with plexiglass that will act as the door for the tank. They also have a heater that consumes about 22 W of power. To enclose the space, slabs of wood will be purchased. The length and width of the structure are 76.5 by 34.5 inches with a hypotenuse of 29.5 inches and thickness of 1 inch for wood. The plexiglass has a length of 45 inches, height of 25 inches and a thickness of .25 inches.

2.4 Heat Transfer

To analyze the system, the equation below evaluates the first law of thermodynamics

$$\dot{Q}_{net} - \dot{W}_{net} = \frac{dE_{cv}}{dt} \tag{1}$$

Since the system is assumed to be steady state and there is no mechanical work the equation becomes

$$\dot{Q}_{loss} = \dot{Q}_{heater} = q + \dot{Q}_{evap} + E_{bask} \tag{2}$$

To evaluate q, the resistance through the material need to be evaluated. Since q remains the same through the material, the panels have convection on either side and conduction through the material, the total resistance formula is below.

$$R_{tot} = \frac{2}{hA} + \frac{L}{k} \tag{3}$$

The wood and plexiglass were evaluated separately. Wood 1 represents the wood on the front panel with the plexiglass, wood 2 represents the trapezoidal wood panels on the side of the box. The total resistance is accounted for one panel.

Table III
Total resistance

Total Resistance	
Rwood,1	2.460928
Rwood,2	1.240387
Rglass	0.594621

2.5 Power Consumption

Now that the resistance through the material is calculated, the power is equated below. Since the equation refers to one panel, the power consumed was multiplied by two to account for the second panel.

$$q = \frac{\Delta T}{R_{tot}} \tag{4}$$

Using the equation, the power for high, low, and average temperatures per season was calculated.

Table IV
Power Consumption of Wood

Power (Wood Total)			
W	High	Avg	Low
Winter	18.86001	64.62167	114.5303

Spring/Fall	0.453494	44.66309	86.67555
Summer	-18.4114	18.49625	66.92552

Table V
Power Consumption of Plexiglass

Power (Plexiglass)			
W	High	Avg	Low
Winter	13.07892	44.81341	79.42369
Spring/Fall	0.314486	30.97267	60.10719
Summer	-12.7678	12.82666	46.41107

Table VI
Total Power Consumption

Power Total			
W	High	Avg	Low
Winter	31.93893	109.4351	193.9539
Spring/Fall	0.76798	75.63576	146.7827
Summer	-31.1792	31.3229	113.3366

2.6 Yearly Energy Consumption

To convert the power into energy, the power is multiplied by the hours in a month and then divided by 1000 to get kilowatt hours. There is an average of 30.44 days/month and 730.5 hr/month. Assuming winter and summer is 3 months each and spring/fall is the remaining 6 months, the 3 month terms are 2191.5 hours and 6 months is 4383 hours. To covert to energy, the equation below is used.

$$E = \frac{q(W) \cdot t(hr)}{1000} \tag{5}$$

Assuming no heat lamp or pond has been added to the enclosure, the energy consumption would equate to the table below.

Table VIII
Energy Consumption, No Lamp or Pond

Energy (kWh) No Lamp or Evaporation			
W	High	Avg	Low
Winter	41.33172	141.6184	250.9931
Spring/Fall	1.987664	195.7583	379.8989
Summer	-40.3485	40.53453	146.6673
Total	2.970867	377.9113	777.5593

If a lamp was added, it draws 22 W from the batteries. For this calculation, the summer months are warmer than the temperature needed for the tortoise. For this reason, the lamp will not be used in the summer months and the lamp will be used a total of 275 days.

$$E_{bask} = lamp(kW) \cdot time(^{hr}/_{day}) \times 275 \,^{day}/_{year} \tag{6}$$

If the lamp is used 10 hours a day at 22 W, then the Energy from the lamp is 60.5 kWh.
Since the tortoise has yet to arrive back in the greenhouse, the evaporation must be estimated. Assuming a temperature of 80 degrees Fahrenheit, a relative humidity of 15% [4], an air speed on .1 m/s, and a surface area of water of 2 ft^2, the mass evaporation is roughly 2.154 kg/day [5]. The latent heat of evaporation is about 2.4 * 10^6 J/kg [6]. To calculate for the heat loss in watts, the equation below is used.

$$\dot{Q}_{evap} = \dot{m}_{evap} \cdot h_{fg} \tag{7}$$

The $\dot{Q}_{evap}$ is 60.87 watts. Since an average relative humidity was used, the evaporation loss will be assumed to be the same for all seasons. To convert to energy, the evaporation loss is multiplied by 2750 hours for the spring/fall/winter months and the divided by 1000 to convert into kilowatts. The energy required is equal to 167.4 kWh.

Using equation 2, the table below is the calculation of the expected heat loss or energy required of the tortoise enclosure.

Table IX
Total Energy of the Tortoise Enclosure

Energy (kWh) Lamp and Water			
W	High	Avg	Low
Winter	269.2242	369.5109	478.8856
Spring/Fall	229.8802	423.6508	607.7914
Summer	187.544	268.427	374.5598
Total	686.6484	1061.589	1461.237

The average energy consumption per year is 1061.589 kWh. For an enclosure 2.27 times smaller, the average energy consumption is 475.59 kWh/yr [7]. With a tank of that reference, the expected energy consumption would be 1078 kWh/year. The calculations in this analysis are close to the expected calculation of energy loss.

3. Cost Review

Table X
Bill of Materials

Bill of Materials		
Material	Cost	Source
Wood	55.92	Home Depot
Plexiglass	0	PHS
Hinges	0	PHS
Screws	2.66	Home Depot
Wood Glue	7.96	Home Depot
Paint	46.4	Home Depot

Total	112.94	

The total expected price for this project is $112.94. The material is pine wood which the students will paint with exterior paint. For creativity and design there will be four 8-oz containers of black, red, blue, and yellow paint. There will be a quart of white paint for priming and mixing. The screws will be used to drill the boards into the tub and the wood glue will be used to secure the pieces of wood together.

4. Results

The results of this analysis will help Ponderosa High School manage their energy usage for the greenhouse and have a structure to house their tortoise for the colder temperatures. The tortoise enclosure is expected to consume an average of 1061.589 kWh per year. This estimation came from calculating the evaporation heat loss, the heat loss from the lamp, and the heat loss through the material. The costs of building the enclosure is an estimated $112.94. These supplies are donated or pre installed from Ponderosa High School or bought from Home Depot. This project is planned to include the students and encourage more art in the school.

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[4] US, “Time Series Viewer,” *Weather.gov*, 2025. https://www.weather.gov/wrh/timeseries?site=QFLA3

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