Final simulation model(s) & Report for Tiny House Project

Jose Espinosa, *Student, Mt. San Antonio College* and Bryan Nguyen, *Student, Mt. San Antonio College*

***Abstract*— In this report, we delve into a comprehensive comparative analysis of annual temperature heating cost for households in California, ranging from an Average California House to a Tiny House with Styrofoam insulation. Using temperature data collection techniques and Simulink models, we evaluated efficiency and cost of varying household setups. This report provides valuable insight into energy-efficient sustainable living practices within the state of California with its ranging diverse climate.**

***Index Terms*— Average California House, Tiny House, Temperature, Simulink.**

I. INTRODUCTION

IN this report, we delve into a comparative analysis within the drive towards sustainable living and innovative housing approaches within the state of California. We focus on the new innovative housing approach that is the development of Tiny Houses that can be either be built on a trailer or in the ground. The analysis is for the economic cost of energy consumption from traditional average sized California house vs. a Tiny House using cheap (Styrofoam) insulation, vs. Tiny House using standard insulation techniques.

II. METHODOLOGY AND PROCESSES

A. Average California House.

To model the Average House in California, we researched its specifications. According to the article “Household energy use in California*,”* the average area of household in California is 1,583 square feet. According to the specifications of the project the home must be a single-story square building, using the area from the article we calculated the dimensions of the house. Additionally, from the article “Cost of electricity in Los Angeles: How to save money with LADWP*”* we were able to determine the current cost of electricity in Los Angeles is $0.285 per kWh. These parameters were changed and incorporated into the model, as shown *Table 1.*

Set- Up Parameters	
House Area	1,583 sf.
House Length	12.12 m
House Width	12.12 m
House Height	4 m
Window Material	Glass
Window Quantity	6
Window Length	1 m
Window Width	1 m
Window Thickness	0.01 m
Window Thermal Conductivity	0.78 W/m. K
Insulation Material	Glass Wool
Insulation Thickness	0.2 m
Thermal Conductivity	0.038 W/m. K
Mdot	1800 kg/hour
Cost	$0.285 per 3.6 J

Table 1. Set-Up parameters for Average California House

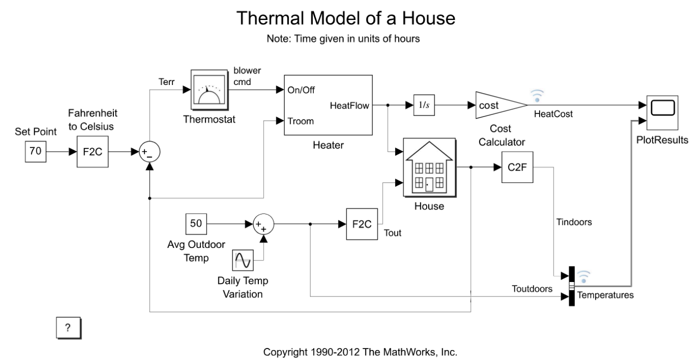

Figure # 1Average California House Simulink Model.

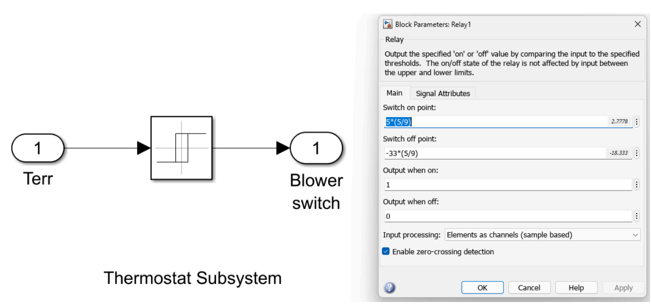

Figure # 2 Thermostat Subsystem – Switch off Point changed to
-1 Fahrenheit.

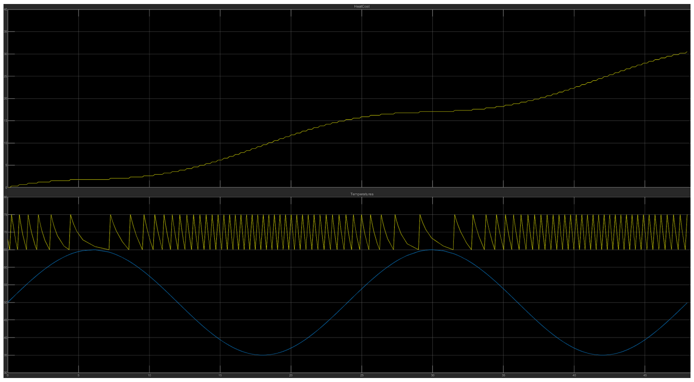

Figure # 3 Average California House Temperature and Cost graph, Time (X-axis) and Temperature (Y-axis). Bottom graph portrays inside temperature (Yellow) and Outside Temperature (Blue).

B. Tiny House using Standard Insulation Techniques

To model the Tiny House using standard insulation techniques, we researched its specifications, particularly focusing on one being built on a trailer due to the dimensional constraints due to the size of a trailer and law requirements. According to the article "Tiny House Dimensions: What Size Can a Tiny House Be Without Breaking the Law?" we were able to determine the maximum dimensions possible for Tiny house built on top of a trailer. In addition, the heater parameter Mdot had to be adjusted to 50% of its previous value to represent a smaller heating unit. These parameters were changed and incorporated into the model, as shown *Table 2.*

Set- Up Parameters	
House Area	254.99 sf.
House Length	9.1440 m
House Width	2.5908 m
House Height	4.1148 m
Window Material	Glass
Window Quantity	6
Window Length	1 m
Window Width	1 m
Window Thickness	0.01 m
Window Thermal Conductivity	0.78 W/m. K
Insulation Material	Glass Wool
Insulation Thickness	0.2 m
Insulation Thermal Conductivity	0.038 W/m. K
Mdot	900 kg/hour
Cost	$0.285 per 3.6 J

Table 2. Set-Up parameters for Tiny House using Standard Insulation Techniques

C. Tiny House using Styrofoam Insulation

To simulate the Tiny House using Styrofoam insulation, we built a model made out of a 1m*1m*1m wooden frame, with Styrofoam walls to function as insulation, and 1 wall using acrylic to represent a window. Inside the model we a placed a LabPro data tracker with 2 temperature probes, and a mason jar filled with water. 1 temperature probe was hanged inside the model and the other temperature probe placed on the outside, the LabPro data tracker was used to record the temperature data inside and outside the tiny house model over 48-hour period, and the mason jar filled with water was used a as a mass to trap heat. The built Tiny House model can be seen in *Figure # -#*. In addition, other parameters had to be adjusted to best represent our model such as the characteristics of Styrofoam insulation and acrylic windows. These parameters were changed and incorporated into the model, as shown *Table 3*.

Table 3. Set-Up parameters for Tiny House using Styrofoam Insulation.

Figure # 4 Internal Temperature probe and LabPro device inside Tiny House Model.

Figure # 5 Tiny House Model placed on Roof.

Figure # 6 Temperature probe hanged on box to record Outside Temperature

Figure # Tiny House Model Styrofoam Insulation.

III. DATA AND GRAPHS

A. *Weather Stations and Temperature Data*

From the spread sheet “NOAA”, we were given the data (station name, latitude, and longitude) of Los Angeles weather stations. Extracting and analyzing the data we chose the weather station that best fit visually based on terrain and proximity to Walnut, CA, as seen in *Figure #*.

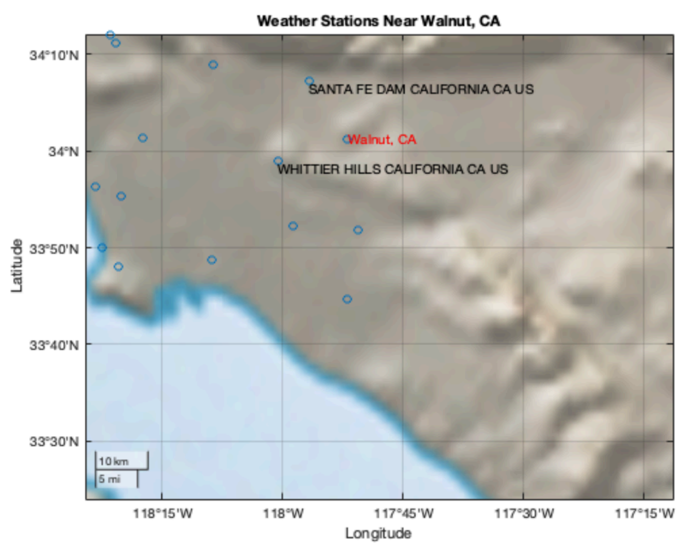

Figure # 7 Aerial Map of Los Angeles weather stations. Whitter hills and Santa Fe Dam are the closest weather stations to Walnut, CA.

The Santa Fe Dam weather station was chosen as it is the closest in proximity to Walnut. Weather data was extracted and sanitized, focusing on the weather’s station recorded maximum and minimum temperatures. An average of the maximum and minimum temperatures was computed to detect if there are any anomalies. The weather temperature data is illustrated in *Figure #.* The computed average was then utilized to fit sinusoids with frequencies 1,5,8 for a comparative analysis. This enabled us to determine which sinusoid frequency best aligned with the computed average and therefore select that sinusoid for our Simulink model, as illustrated in *Figure #*.

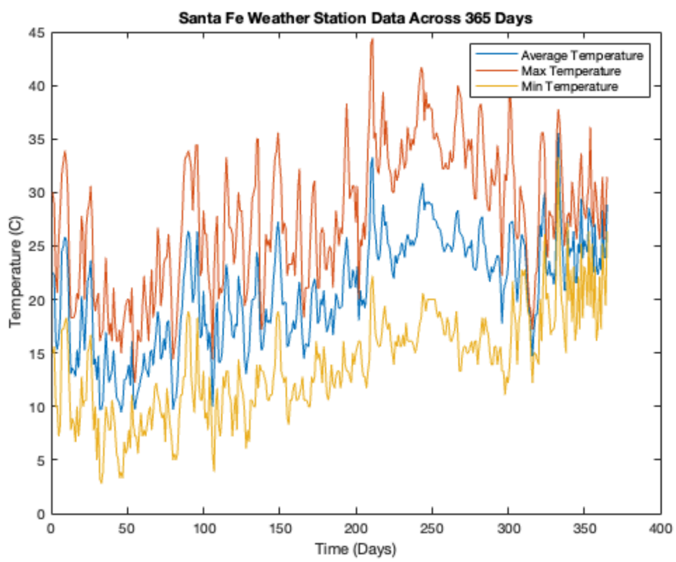

Figure # 8 Santa Fe Weather Station Temperature Data (Average, Max, and Min.)

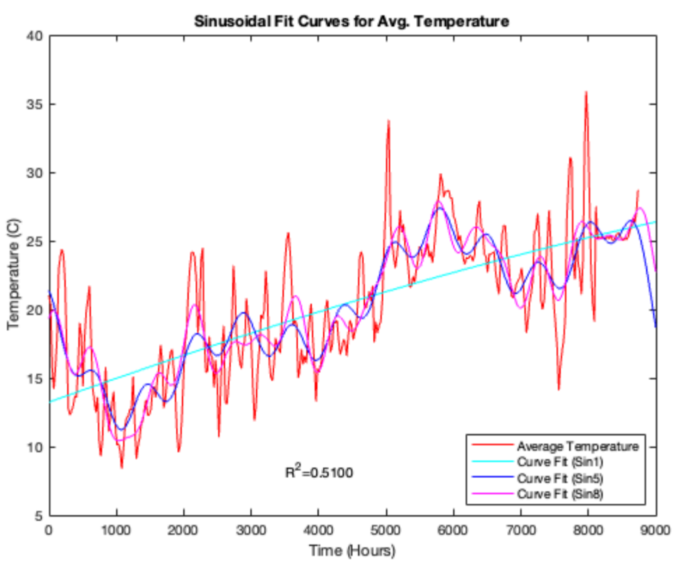

Figure # 9 Sinusoidal Curves for Average Data (fitted to 1,5,8 Sinusoids)

B. 48-hour Temperature Data collection

From our Tiny House Styrofoam model, we collected external and internal temperature data using the LabPro data tracker, as can be seen in *Table 4.* This data was eventually graphed to see the fluctuations in temperature and to enable a better comparison between internal and external temperature. The external temperature was then normalized to have a zero-average temperature over the 48 hours, as shown in *Figure #.*

Time (hrs)	Outside Temp (°C)	Inside Temperature (
0	24.1628	19.0714
0.5	27.8837	20.5814
1	29.6429	21.2857
1.5	32.2381	24.5581
2	33.7143	25.6818
2.5	34.5238	26.6977
3	36.5122	27.093
3.5	34.881	25.7045
4	36.2439	28
4.5	33.4286	26.2326
5	37	27.7907

Table 4. 48-Hour Temperature Data Sample

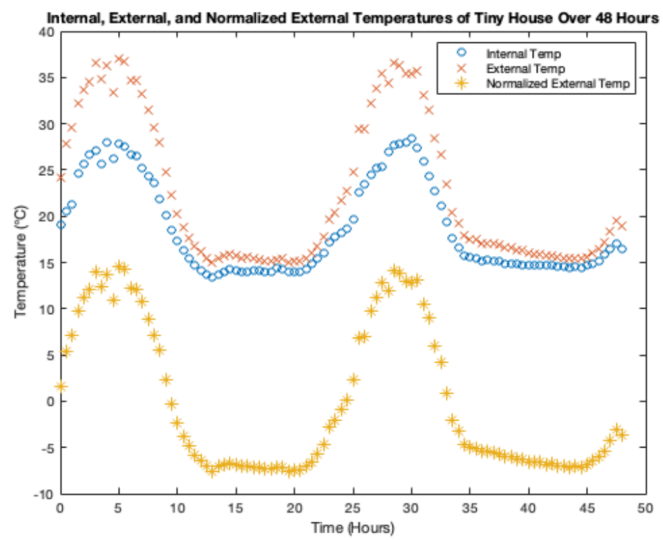

Figure # 10 Internal, External, Normalized 48 Hour Temperature Data.

IV. MATHEMATICAL MODELING AND ANALYSIS

A. Simulink Model

In order to model the Tiny House, we used the Thermal Model of a House created by MATLAB. Making specific adjustments are necessary for it to be applicable in the context of a tiny house. Specifically, we need to modify the dimensions, insulation coefficients, cost, outside average temperature, and daily temperature variation. We have already adjusted the dimensions, insulation coefficients, and cost. The next steps involve changing the outside average temperature and daily temperature variation.

1) Average Outside Temperature

For our average outside temperature, we cannot use the given constant in the Thermal Model of a House. Instead, we must use the data collected from the Santa Fe Weather Station. The weather station data has given us 365 days' worth of weather. With that data, we fitted 8 sinusoids in MATLAB using the fit function to get the most accurate fit of the weather station data. This can be seen in *Fig #* After obtaining the fit coefficients of each sinusoid, we created a Simulink model consisting of 8 sinusoids being added together.

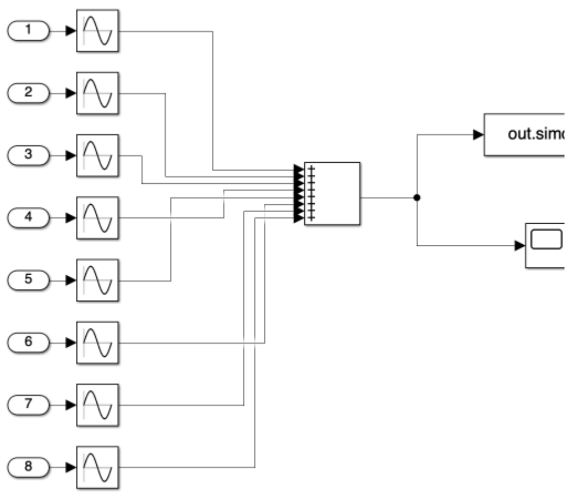

Figure # 11 SIMULINK Sinusoid Model consisting of 8 sinusoid waves.

2) *Daily Temperature Variation*

The daily temperature variation given in the provided model is a single sin wave. Instead, we are going to be using the 48-hour data collected from our tiny house on the roof. We condense it down from two data points an hour to one data point an hour, by taking the average of both for each hour. We then normalize the external temperature in MATLAB which can be seen in *Figure # 11* show casing the normalized external temperature. Next, we used a Repeating Stair Sequence in Simulink, inputting our normalized data as a vector.

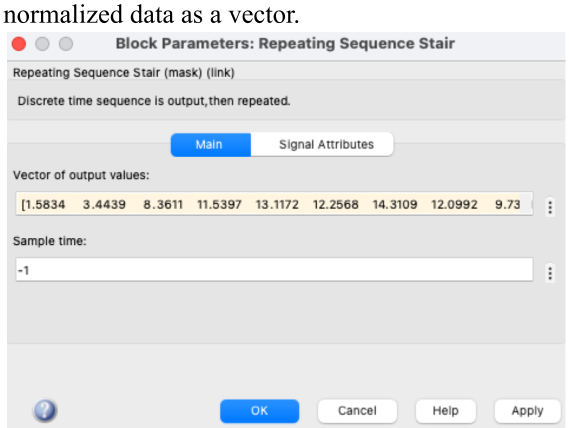

Figure # 12 Repeating Sequence Stair containing 48 hour normalized external temperature.

B. *Simulink Graphs with Various Insulation Types*

The model shown below [*Figure 13]* showcases the dataset of the average California sized house. Looking at the second plot, the inside temperature of the house [yellow line] does a good and consistent job at insulating the house from the outside temperature [blue line]. We can see that when the outside temperature increases the inside temperature of the house stays below the trend of the outside temperature. Then when the temperature drops towards the night, it holds a steady temperature range of 70-65F while the outside temperature is around 55 F. The average California sized home costs $28 to heat for 48 hours and for the first 24 hours it costs $15.

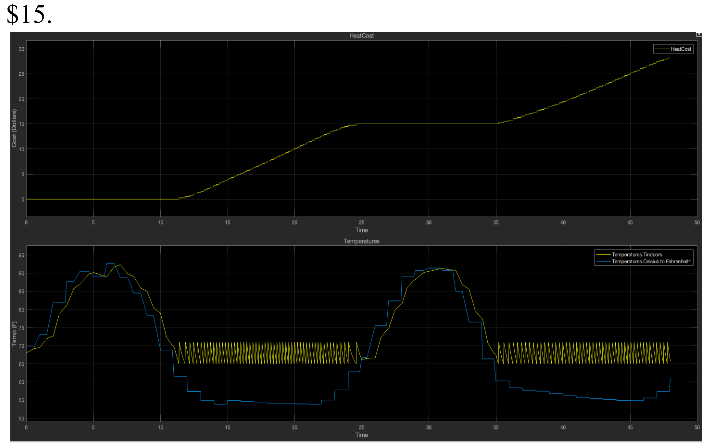

Figure 13 Simulation of an average California sized home with standard insulation.

The next model [*Figure 14*] contains the simulation data of the tiny house with standard insulation. We can see that the second plot looks nearly identical to the average California-sized house, as the inside temperature can withstand the outside temperature, staying below increasing external temperatures and above colder temperatures. This was very predictable and obvious since both houses share the same type of insulation. The tiny house with standard insulation has the same cost trend as the average California house, with steady increase during the night and no change during the day. The total cost to heat the tiny house is $24 for 48 hours and $13 for 24 hours.

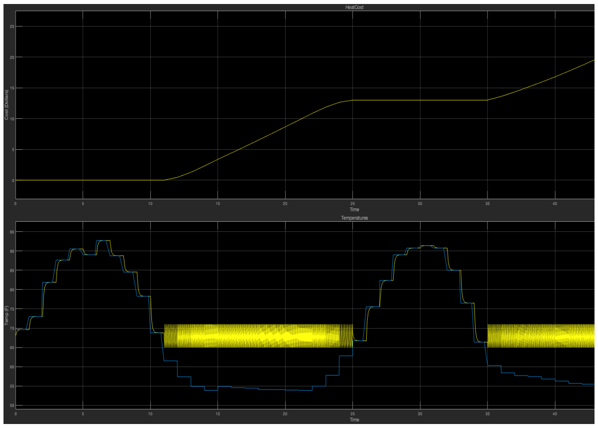

Figure 14 Simulation of the tiny house with standard insulation.

The last model shown [*Figure 15*] contains the simulation data of the tiny house with Styrofoam insulation. Looking at the temperature graph we can see that during the day, the inside of the tiny house does not stay below increasing outdoor temperatures. Rather it moves in sync with the increasing temperature. During the night, the inside temperature of the tiny house ranges briefly then dropping to the bottom. This means that the Styrofoam insulation preformed worse than that of the standard insulation. It did not protect the inside of the house from increasing temperatures and did a worse job of insulating colder temperatures during the night. Looking at the heat cost graph, it costs much more to heat the house over 48 hours than that of both the other homes combined. This is quite surprising but makes sense as during the night the temperature was nearly 10 degrees lower for each of the nights compared to the standard insulation homes. This is also because the tiny house was losing heat much more rapidly, which would lead to the graph not having the same range as the standard insulation homes, making the heating cost much higher.

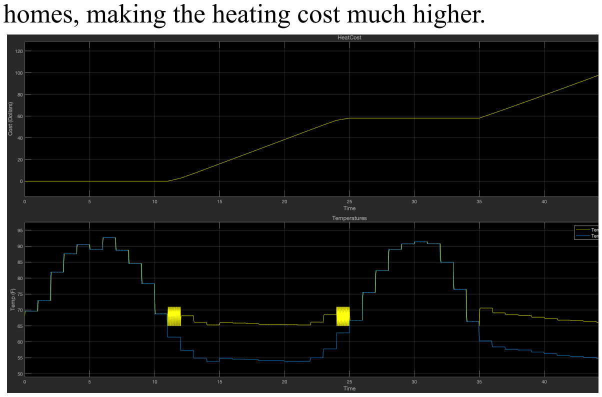

Figure 15 Simulation of the tiny house with Styrofoam insulation.

V. CONCLUSION

A. *Cost Comparisons*

Looking at the costs of heating up the average sized California house and the tiny houses, we can see a significant difference. The cost of the tiny home with standard insulation and the cost of the average California sized home was about 15%. Where for the 48 hours it costs the tiny house $24 to heat up while the latter to be $28. If we look at the Styrofoam insulation this is a significant difference as the cost to heat up the tiny house with Styrofoam insulation was $118. This is much higher than both other houses combined. The standard insulation proved to do a better job than the Styrofoam insulation.

B. *Sustainability*

The tiny house project is a rather sustainable project as most of the materials can be reused for future projects. The costs for materials to build the tiny houses with Styrofoam and tape are inexpensive. The analysis and functions through MATLAB and Simulink are very accessible and the project is not too difficult to replicate.

C. *Suggestions*

After completion of the tiny house project, a few suggestions came to mind to help improve this project for future students. Firstly, would to be possible to extend the time the tiny house is up on the roof for longer data collection. This would ensure more accurate data as you would have more points spread out over time. Instead of 48 hours, possibly a whole week would be sufficient. Another suggestion that would be very interesting would be to add a cooling element to the tiny homes. Not only to heat up the tiny houses and find the costs but finding the costs to cool them down. Next would be not putting them on the roof of the building or trying to cover the temperature probes as much as possible. As the roof shingles radiate heat, the data read much higher than it was. Lastly it would be interesting to see the tiny house project done in different seasons of the year. Especially during the winter months, seeing how much more it would cost to heat the house.

REFERENCES AND FOOTNOTES

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https://thetinylife.com/tiny-house-dimensions-what-size-can-a-tiny-house-be-without-breaking-the-law/

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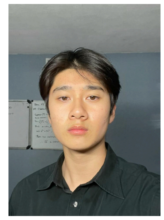
Jose Espinosa First Year student at Mt. Sac Antonio College, pursuing a Bachelor of Science in Civil Engineering General Sub option. Plans to transfer to a 4-year University, within the next 2 years.



Bryan Nguyen Second year student at Mt. San Antonio College, pursuing a Bachelor of Science in Mechanical Engineering.