

MAE 4344 Design Projects

Safety Shower Team Project Final Report

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1 Introduction

In the situation of a work site located away from civilization where workers could be exposed to hazardous chemicals, it would be ideal to have an emergency shower to give the workers the safety that they need. For this purpose, Emergency Site Protection LLC exists and has designed emergency shower trailers that are able to be placed out in remote locations and operate while meeting industry standards. The shower trailers operate and heat the water with solar panels and batteries that are attached to the trailer so that the water doesn't drop below a certain temperature. This is especially vital in locations that have colder temperatures where the water could freeze or even cause health problems to the user.

With recent events in the oil and gas industry, it has become of increasing interest to Emergency Site Protection LLC to optimize the design of their trailers and to reduce costs when assembling the trailers in the first place. In addition, they are in need of a system that keeps track of each of the trailers that they have in various locations across the United States. Our team's job is to address these problems and to develop a software as a solution to them.

1.1 Problem Statement

Our goal is to develop a trailer configuration and thermal design software for use on emergency shower trailers that use solar panels and batteries in order to keep the temperature of water at or above safety standards with the lowest energy cost possible. The program will be able to assign the appropriate amount of batteries and solar panels for a trailer in a specified location. The software needs to be able to interpret weather data of the trailer's specific location for the next seven days of use and retrieve normalized weather data for each meteorological season according to location. This will allow the program to predict when each trailer needs to be replaced or recharged. With this program, trailers will require significantly less attention in the field and can operate more efficiently than before, which will prove to be highly beneficial for the sponsors involved.

1.2 Background

1.2.1 Understanding Our Task

After being assigned our problem statement, we met with Dr. Delahoussaye and Dr. Fisher at the Oklahoma State University Mechanical and Aerospace Engineering office in order to completely understand what was expected of us when completing this project. As a result of the meeting we were able to construct a detailed list of deliverables that will be discussed in a later section along with a plan of attack to tackle this task. With their guidance, we chose to use VB.net as the platform for our software and EnergyPlus as the code base for the thermal and energy calculations. In addition, we were given access to a lab in Oklahoma State University's Advanced Technology Research Center where we had access to help from teaching assistants in both of these programs.

1.2.2 Codes and Standards

Codes and standards are very pertinent in Engineering. Several different codes and standards were reviewed for this project. One code used was the ASHRAE Standard 90 Building Efficiency Code. This code requires more accurate building designs with lower energy consumption. This code resulted in the creation of thermal simulation software like EnergyPlus. This code pertained to our project because we will be using EnergyPlus as the basis of our configuration software. A

very important standard pertaining to this project is the OSHA, ANSI/ISEA Z358.1-2009 Standard that states the use of tepid water in a safety shower trailer. Appendix B6 defines tepid water as 60°F for the lower limit and 100°F as the upper limit. This will be the limits set for the water heater in our EnergyPlus input file for our safety shower trailer.

1.2.3 Understanding Current Events

Current Events are very important in Engineering. Current events must always be researched so that you can have the correct scope for your project. Our project closely relates to the oil field, therefore research of current events in the oil field was very important. Recently, Crude oil prices have dropped almost 50% per barrel. Due to the drop in oil prices, businesses in the oil field are extremely sensitive to expenditures and efficiency of operations in order to decrease cost and increase profits. By developing out Safety Shower Configuration software, each safety shower trailer will have the optimum design of batteries and solar panels by largely decreasing or removing the need of external energy as well as minimizing future trailer cost including maintenance and upkeep.

2 Detailed List of Deliverables

Below is a full list of what is to be given as a final result of our work on this project.

- A piece of software written in VB.net that configures an emergency shower trailer for a known time
 - Configuration will display the minimum number of batteries and solar panels needed to keep the water between 60 and 100 degrees Fahrenheit for a user specified location and time.
- Software will include a weekly weather forecast
 - User can check the weekly weather to predict whether or not a trailer already in the field will need special attention in the case of extreme weather.
- Detailed software and user manual in video form
- Validations of software
- Documentation of decisions made

3 Final Design

Our final design is a piece of software that is controlled and run solely through a user interface constructed in VB.net. The user friendly software includes a configuration button where the user will input a trailer location, causing the software to then run the EnergyPlus calculations which will model the trailer in the specified location and complete the necessary calculations to display the minimum number of solar panels and batteries that should be placed on this trailer. The user will also be able to name the trailer and keep track of the location of each trailer currently out in the field. The user interface has a current list of trailers, where all configured trailers will be listed until removed by the user with the “Remove Selected” button.

The user interface will include a “Check Selected” button that will read a weather forecast from the internet for the next seven days and run the selected trailers in EnergyPlus with this forecast. This is done to check whether or not the trailers will have enough power for the week in the case of extreme weather. In the case of a trailer not having enough power, the trailer will be flagged and

sent to a separate box on the user interface for the user to identify and address according to the situation.

All trailers can be viewed from the main user interface and the user will have no direct interaction in running EnergyPlus unless they desire to edit the software. The figure below is a sneak peek at the overall software design. Each form has a specific purpose and the flow between each form is seamless. The main userform below displays all of the active and flagged trailers and is also the link between all of the other userforms.

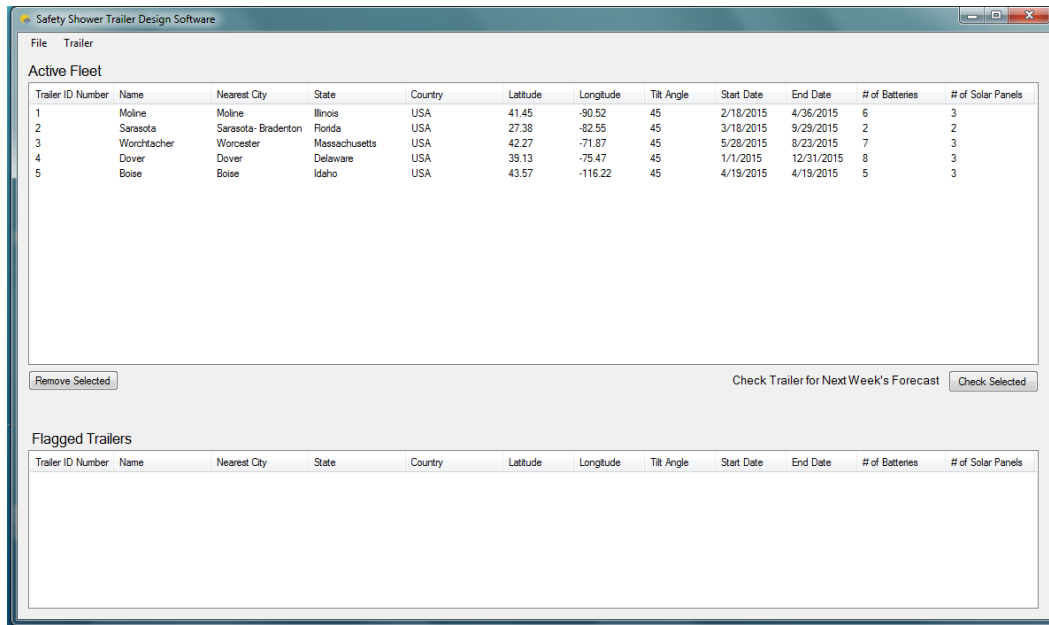


Figure 1: Main Userform

The new trailer configuration form enables the user to specify characteristics of a trailer and the program then optimizes the required number of solar panels and batteries for the given location. The archive of trailers form displays all of the trailers that have ever been issued through the software. The last form is the trailer details form which shows the individual details of a single trailer alongside a 3D model of the trailer. A further description and display of the program is seen in section 5.

4 Detailed Description of Work Done

4.1 Learning EnergyPlus

EnergyPlus is a building energy simulation program that models energy and water use in buildings and allows the team to model the trailer thermally, with the water heater and battery included. It is a software program that is completely new to this design team, and a sophisticated approach was needed to learn the facets of EnergyPlus required to complete this design project. The efficient use of EnergyPlus would reduce the amount of calculation-based code needed in the VB.NET framework. The design team was embedded into the BETSRG Simulation Laboratory in ATRC 303 so it could be in close communication with the graduate and PhD students there. Matt Mitchell, a PhD student under Dr. Fisher, proved to be a tremendous help in learning EnergyPlus. He started us out

on a very basic example on EnergyPlus and from there we gradually learned new objects to put into the input file. In other words, every time we added a new object to our thermal “environment” we ran EnergyPlus to make sure the thermal system accepted the object and reacted correctly. This input file is the “meat” of the thermal processing of our software. All the specifications of the trailer, including the weather, will be inputted into the EnergyPlus input file. A more detailed description of the input file is found later under section 4.3.

4.2 Learning VB.NET

Visual Basic .NET, or VB.NET, is an object oriented programming language developed by Microsoft. VB.NET is a merge between the programming language Visual Basic and the .NET framework which were both developed by Microsoft. Similarly to EnergyPlus, none of the team members had any experience with programming in the vb.NET language and had to learn the very basics first. The team researched various web tutorials starting from the very basics of vb.NET from downloading Microsoft Visual Studio to creating a new project file and adding code to create our program. The syntax of vb.NET is closely related to that of Visual Basic for Applications which our team learned in a course in the Mechanical and Aerospace curriculum. This helped accelerate the learning process of vb.NET. Additionally, Rachel Grundmann, a Masters student under Dr. Fisher, was very helpful in troubleshooting our code when our team was unsure of issues that we were trying to solve. This made the coding process more productive because our team was not slowed by every single issue that we came across. A more detailed description of what we did in vb.NET is found later in section 4.4.

4.3 Creating EnergyPlus Input File

EnergyPlus outputs thermal information according to the inputs entered into the EnergyPlus specific .idf file. The .idf file is able to be edited as a .txt file and this is primarily how we edited the inputs in EnergyPlus. From the basic example referenced in section 4.1, the team gradually added complexity to our thermal model. First we added the water heater, then added the PV solar array, then added the battery, and finally the fins and overhang that are over the actual emergency shower head. For each addition of an object, we ran tests on the outputs to make sure the outputted values were reasonable and that all behavior passed our engineering judgment. The Figure below shows an example section of the .idf file, specifically the water heater object EnergyPlus uses to calculate the thermal losses from the tank.

```

293
294 !- ===== ALL OBJECTS IN CLASS: WATERHEATER:MIXED =====
295
296 WaterHeater:Mixed,
297 Outdoor Electric Tank,           !- Name
298 0.151,                          !- Tank Volume {m3}
299 Water Heater Setpoint Schedule,  !- Setpoint Temperature Schedule Name
300 0,                               !- Deadband Temperature Difference {deltaC}
301 40,                              !- Maximum Temperature Limit {C}
302 CYCLE,                          !- Heater Control Type
303 38000,                          !- Heater Maximum Capacity {W}
304 ,                               !- Heater Minimum Capacity {W}
305 ,                               !- Heater Ignition Minimum Flow Rate {m3/s}
306 ,                               !- Heater Ignition Delay {s}
307 ELECTRICITY,                   !- Heater Fuel Type
308 1,                              !- Heater Thermal Efficiency
309 ,                               !- Part Load Factor Curve Name
310 0,                              !- Off Cycle Parasitic Fuel Consumption Rate {W}
311 ELECTRICITY,                   !- Off Cycle Parasitic Fuel Type
312 0,                              !- Off Cycle Parasitic Heat Fraction to Tank
313 0,                              !- On Cycle Parasitic Fuel Consumption Rate {W}
314 ELECTRICITY,                   !- On Cycle Parasitic Fuel Type
315 0,                              !- On Cycle Parasitic Heat Fraction to Tank
316 Zone,                          !- Ambient Temperature Indicator
317 ,                               !- Ambient Temperature Schedule Name
318 ZONE ONE,                      !- Ambient Temperature Zone Name
319 ,                               !- Ambient Temperature Outdoor Air Node Name
320 0.9,                           !- Off Cycle Loss Coefficient to Ambient Temperature {W/K}
321 ,                               !- Off Cycle Loss Fraction to Zone
322 0.9,                           !- On Cycle Loss Coefficient to Ambient Temperature {W/K}
323 ,                               !- On Cycle Loss Fraction to Zone
324 0,                              !- Peak Use Flow Rate {m3/s}
325 Hot Water Demand Schedule,      !- Use Flow Rate Fraction Schedule Name
326 Constant Mains Temp Schedule;   !- Cold Water Supply Temperature Schedule Name
327

```

Figure 2: Water Heater Object in EnergyPlus Input File.

From the figure, one can see the text in black. That text is what our team could change and what affects the output values of our model. For example, the green text saying “Off Cycle Loss Coefficient to Ambient Temperature (W/K)” highlights what the black text entered is for. This particular row is the UA value of the water heater where U is the heat loss coefficient and A is the surface area of the water tank.

When EnergyPlus outputs values from the inputted thermal system, it creates a .csv file that is able to be opened in excel. An example of this can be seen in the figure below.

	A	B	C	D	E	F	G	H
1	Date/Time	OUTDOOR	OUTDOOR	BATTERY:CH	BATTERY:CH	BATTERY:CH	Whole Bu	PV:ZONE S
2	01/01 01:	20.94734	0	8640000	0	0	0	0
3	01/01 02:	20.83351	0	8640000	0	0	0	0
4	01/01 03:	20.70588	0	8640000	0	0	0	0
5	01/01 04:	20.57163	0	8640000	0	0	0	0
6	01/01 05:	20.92056	87.56802	8324755	0	87.56802	0	0
7	01/01 06:	20.79417	0	8324755	0	0	0	0
8	01/01 07:	20.6549	0	8324755	0	0	0	0
9	01/01 08:	20.7063	87.56795	8300227	75.21127	51.04769	0	111.7315
10	01/01 09:	20.88138	0	8630771	63.40445	0	0	562.2192
11	01/01 10:	20.76447	0	8640000	0	0	0	948.1546
12	01/01 11:	20.67142	0	8640000	0	0	0	1177.925
13	01/01 12:	20.59982	0	8640000	0	0	0	1028.55
14	01/01 13:	20.54007	0	8640000	0	0	0	551.7975
15	01/01 14:	20.88754	87.53673	8640000	0	0	0	346.6435
16	01/01 15:	20.91321	0	8640000	0	0	0	259.8301
17	01/01 16:	20.84271	0	8640000	0	0	0	98.33113
18	01/01 17:	20.76477	0	8640000	0	0	0	7.583044
19	01/01 18:	20.67908	0	8640000	0	0	0	0
20	01/01 19:	20.58835	0	8640000	0	0	0	0
21	01/01 20:	20.77635	87.55122	8403612	0	87.55122	0	0

Figure 3: Output variables after EnergyPlus Simulation

Each column represents a different output value from the system.

- Column A: Date/Time
- Column B: Water Temperature [C]
- Column C: Water Heater Electric Power Requested [W]
- Column D: Electric Storage Charge State [J]
- Column E: Electric Storage Charge Power [W]
- Column F: Storage Discharge Power [W]
- Column G: Purchased Power [W]
- Column H: PV Produced DC Electric Power [W]

Column G is important to note as that is the “purchased” power of the system. It is **essential** to our project for this output to be 0 at all times. If it becomes nonzero, that results in a failure of our system since the chief requirement of our project is to have enough energy stored to cover the desired power from the water heater in order to keep the water at a safe temperature.

In the process of creating a usable EnergyPlus input file that represented the emergency shower trailer system well, the team ran into a few challenges.

- Creating a second surface in EnergyPlus that can be tilted specific to a user input to “fix” the PV solar array onto.

- Since the roof of the trailer is fixed, we could not name that as the surface for our PV solar array. We had to create a second surface that could be tilted according to a user input. This surface was placed above the trailer as to not conflict with any other solar calculations. The figure below shows the DXF file generated by EnergyPlus showing the trailer with fins and overhang as well as the PV solar array surface above it.

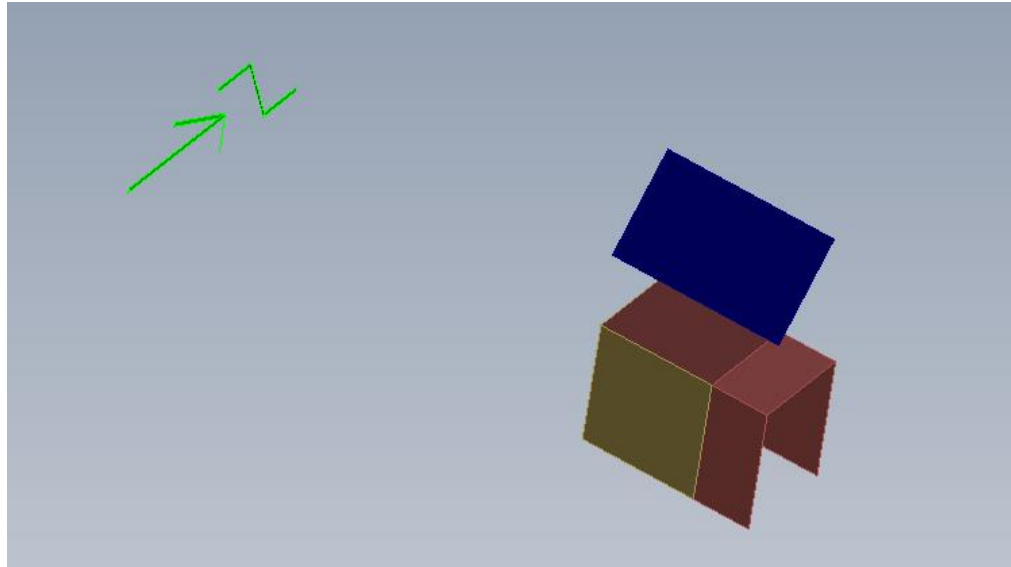


Figure 4: 3D model from EnergyPlus simulation

- Calculating the heat loss from the water heater to ambient air, the value $U \cdot A$.
 - The water heater object takes a figure to simulate the heat loss from the water heater to ambient air. This needed to be calculated by using what we know about the actual components inside the trailer and the following equations:
 - $U = 1 / R$
 - $R = d/k$ where d is insulation thickness and k is thermal conductivity
 - For fiberglass, $k = 0.048$ [W / m-K] and $d = 18$ [in] = 0.4572 [m] yields a value $R = 9.525$ [m²-K/W] which yields a value $U = 0.105$ [W/m²-K].
 - For $A = 8.59$ [m²] (from previous semester's work) $U \cdot A = 0.90$ [W/K]
- Refining the construction from the original basic example, "Example 1A", to the construction of the actual trailer (plywood and aluminum).
 - Since the actual trailer walls are much more thin than those of the walls in "Example 1A", they affected the sophisticated battery object (named "kibam") poorly and EnergyPlus would crash every run with the thin walls. To preserve accurate thermal modeling, we replaced the sophisticated battery with a simple battery that was essentially an energy bucket. It was able to retrieve energy and could output energy according to a user-inputted storage capacity and charge/discharge rates.
 - To find the storage capacity and discharge/charge rates of the simple battery, the team used the specifications from Trojan T6V-AGm 200Ah Deep Cycle Batteries as recommended from last semester's team

- In calculations, the team used the 20 hr rate for 100 Amps per 6V so not to go under 50% charge the amount of storage capacity is dependent on the number n of batteries in parallel in the trailer. This number is $n \cdot \text{Amps} \cdot \text{voltage} = n2400 \text{ [amp-h-V]} = n8.64 \times 10^6 \text{ [J]}$ of capacity.
 - The max discharge rate at 32 [F] was 1400 [A] which equated to 33600 [W]
 - PV solar array energy production was $n300 \text{ [W]}$ where n is between 1 and 4 panels connected in parallel. Based calculations off of Renogy's Poly-300 panels which measure 6.5' x 3.5'
- Analysis of behavior between the PV solar array and the simple battery
 - Upon analysis of outputs from trials ran using our fully refined EnergyPlus, the team noticed some problems that did not make sense. At times the simple battery was not outputting enough power to cover the requested power from the water heater, but it appeared that it had enough energy to discharge to the water heater. We brought this problem to Matt Mitchell and he explored the EnergyPlus code to see what was calling the system to purchase energy and not use energy from the simple battery. He could not find out why the system was behaving as such. We then decided to manipulate the raw output values for the batter, PV solar array, and requested power from the water in our VB.NET framework, rather than have EnergyPlus do those calculations. The figure below shows "trouble spots" where the purchased power is nonzero, but there appears to be enough energy stored in the battery to cover the requested amount from the water heater. The columns are the same format as mentioned above.

2091	03/29 02:	20.61949	0	8324875	0	0	0	0
2092	03/29 03:	20.56892	0	8324875	0	0	0	0
2093	03/29 04:	20.60805	87.53581	8257375	0	75	12.53581	0
2094	03/29 05:	20.55005	0	8054875	0	0	0	0
2095	03/29 06:	20.89478	0	8062720	8.716847	0	0	8.716847
2096	03/29 07:	20.82846	0	8256548	84.60492	0	0	84.60492
2097	03/29 08:	20.76462	0	8590055	69.21301	0	0	170.8109
2098	03/29 09:	20.71047	0	8640000	0	0	0	305.9241
2099	03/29 10:	20.67143	0	8640000	0	0	0	362.8094
2100	03/29 11:	20.64709	0	8640000	0	0	0	454.694
2101	03/29 12:	20.63614	0	8640000	0	0	0	492.8613
2102	03/29 13:	20.63653	0	8640000	0	0	0	497.036
2103	03/29 14:	20.64552	0	8640000	0	0	0	420.2407
2104	03/29 15:	20.65602	0	8640000	0	0	0	372.751
2105	03/29 16:	20.65877	0	8640000	0	0	0	196.9363
2106	03/29 17:	20.6432	0	8640000	0	0	0	141.9702
2107	03/29 18:	20.60985	0	8640000	0	0	0	48.10103
2108	03/29 19:	20.56103	0	8640000	0	0	0	0
2109	03/29 20:	20.73903	87.53938	8505000	0	75	12.53938	0
2110	03/29 21:	20.93103	0	8370000	0	0	0	0
2111	03/29 22:	20.85791	0	8370000	0	0	0	0

Figure 5: Error in output variables after EnergyPlus Simulation

4.4 Creating VB.NET Foundation

Began with the main userform that loads when the program is launched. This form is intended to display a running log of the active trailers and also be the link between all of the other options and features of the program. The first objective was to insert an object onto the form that could display all of the trailer information in a neat itemized list. A listview had all of the functionality that was needed. Another listview was added to house all of the flagged trailers as they appeared from the weekly weather simulation. Next, a top menu strip was added so that the end user could add a new trailer, view the full archive of trailers and exit the program. The figure below displays the initial and the final configuration of the main userform and it should be noted how the form has adapted and evolved to better suit all of the desired characteristics of the home page.

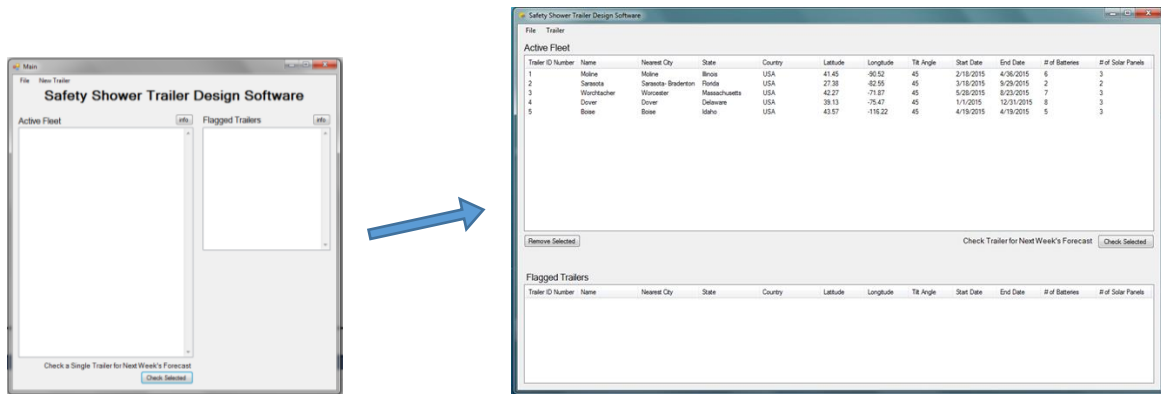


Figure 6: Evolution of main userform

From the main userform, all other forms could then be created to guide the user through all aspects of the program with user-friendly controls and features that anyone could use.

The next form that needed to be created was a way for the user to add a trailer and specify all of its location characteristics. The form flows into another form that is displayed while the number of panels and batteries is being optimized. Once the trailer has been optimized, a form shows its details and then returns to the main form. This is the main foundation for the entire program. It is intended to be an extremely user friendly interface with little to no background knowledge of thermal analysis software or programming.

4.5 Researching EnergyPlus Weather Files

Energy Plus uses a very specifically formatted weather file when running energy calculations. This format is required in order to run EnergyPlus successfully. Safety shower trailers can be placed anywhere in the country therefore we have to be able to have a weather file for both the yearly normalized forecast and the seven day hourly forecast. In order to know how to update these weather files based on the location we had to understand how the weather file was formatted. Shown below is a portion of an EnergyPlus Weather file or EPW. This file is very hard to understand when looking at it as a text file.

```

1 LOCATION:OKLAHOMA, CITY, OK, USA, TMY2-13967,723530,35.40,-97.60,-6.0,397.0
2 DESIGN CONDITIONS:1:Climate Design Data 2009 ASHRAE Handbook, Heating,1,-11.4,-0.1,-17.9,0.0,-9.3,-14.6,1.1,-6.3,14.1,5.8,12.7,5.3,6.1,0.0,Cooling,7,11.7,37.5,23.4,36.23,4.34,5.23,2.
3 TYPICAL/EXTREME PERIODS:6,Summer - Week Nearest Typical Temperature For Period,Extreme,8/12,8/18,Summer - Week Nearest Average Temperature For Period,Typical,7/29,8/ 4,Winter - Week Ne
4 GROUND TEMPERATURES:3.5,,,,,3.49,2.35,4.37,7.53,15.79,22.16,26.46,27.77,25.54,20.59,13.98,7.84,2,,,,,7.68,5.65,6.06,7.74,13.27,18.26,22.26,24.40,23.95,21.14,16.58,11.75,4,,,,,11.14,9
5 HOLIDAY/DAYLIGHT SAVINGS:86,0,0,0
6 COMMENTS:1,TMY2-13967 -- WMO#723530
7 COMMENTS:2, - Ground temps produced with a standard soil diffusivity of 2.32257406E-03 (m**2/day)
8 DATA PERIODS:1,1,Data,Bundary, 1/ 1,12/31
9 1962,1,1,1.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-2.2,-4.4,85.98400,0.0,237.0,0.0,0.0,0.0,0.0,0.0,4.1,0.0,24.1,7.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
10 1962,1,1,1.2.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-2.8,-4.8,88.98400,0.0,245.0,0.0,0.0,0.0,0.0,0.0,5.2,3.3,24.1,7.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
11 1962,1,1,1.3.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-3.3,-5.0,88.98400,0.0,240.0,0.0,0.0,0.0,0.0,0.0,3.6,2.19,3.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
12 1962,1,1,1.4.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-4.4,-6.1,88.98400,0.0,228.0,0.0,0.0,0.0,0.0,0.0,3.6,0.0,19.3,7.7777,0.99999999,7.0,0.0500,0.21,0.000,0.0,0.0
13 1962,1,1,1.5.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-4.4,-6.1,88.98400,0.0,228.0,0.0,0.0,0.0,0.0,0.0,4.1,0.0,19.3,7.7777,0.99999999,7.0,0.0500,0.21,0.000,0.0,0.0
14 1962,1,1,1.6.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-5.0,-6.7,88.98300,0.0,225.0,0.0,0.0,0.0,0.0,0.0,3.1,0.0,19.3,7.7777,0.99999999,7.0,0.0500,0.21,0.000,0.0,0.0
15 1962,1,1,1.7.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,-5.0,-6.7,88.98300,0.0,225.0,0.0,0.0,0.0,0.0,0.0,3.6,0.0,16.1,7.7777,0.99999999,7.0,0.0500,0.21,0.000,0.0,0.0
16 1962,1,1,1.8.60,A7A7A7A7*05504515141515A7A7A7A7A7E7F8A7E7,-5.0,-6.7,88.98400,44,377,225,16,80,6,0,0,0,0,0,2.6,1,0,11.3,7.7777,0.99999999,7.0,0.0500,0.21,0.000,0.0,0.0
17 1962,1,1,1.9.60,A7A7A7A7*05504515141515A7A7A7A7A7E7F8A7E7,-3.3,-5.0,88.98400,199,1415,237,94,472,27,9600,33400,4900,530,315,2.6,1,11.3,7.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
18 1962,1,1,1.10.60,A7A7A7A7*05504515141515A7A7A7A7A7E7F8A7E7,-1.1,-3.9,82.98400,420,1415,251,213,448,80,22800,38200,11500,1460,315,3.6,5,3.19,3.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
19 1962,1,1,1.11.60,A7A7A7A7*04440514141515A7A7A7A7A7E7F8A7E7,1.1,-3.3,73.98300,591,1415,249,420,895,46,44800,64500,8800,1180,283,2.6,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
20 1962,1,1,1.12.60,A7A7A7A7*04440514141515A7A7A7A7A7E7F8A7E7,3.3,-2.8,65.98200,701,1415,267,467,750,95,48800,73500,12400,1930,248,3.1,2,19.3,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
21 1962,1,1,1.13.60,A7A7A7A7*04440514141515A7A7A7A7A7E7F8A7E7,5.6,-2.8,55.98000,741,1415,267,545,929,58,58100,92100,9800,1480,248,5.7,1,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
22 1962,1,1,1.14.60,A7A7A7A7*04440514141515A7A7A7A7A7E7F8A7E7,7.2,-1.7,54.97800,708,1415,274,504,895,56,54000,83300,9600,1420,248,7.2,1,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
23 1962,1,1,1.15.60,A7A7A7A7*04440514141515A7A7A7A7A7E7F8A7E7,9.9,-1.7,48.97800,606,1415,281,431,896,47,46400,87100,8900,1220,240,5.7,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
24 1962,1,1,1.16.60,A7A7A7A7*04440514141515A7A7A7A7A7E7F8A7E7,10.6,-1.1,45.97700,445,1415,288,290,812,37,31500,74900,7900,960,225,5.2,0,0,24.1,7.7777,0.99999999,10.0,0.0500,0.21,0.000,0.0,0.0
25 1962,1,1,1.17.60,A7A7A7A7*05504515141515A7A7A7A7A7E7F8A7E7,10.0,-0.6,49.97700,225,1415,286,123,615,29,13400,49100,9600,800,248,7.2,0,0,24.1,7.7777,0.99999999,10.0,0.0500,0.21,0.000,0.0,0.0
26 1962,1,1,1.18.60,A7A7A7A7*05504515141515A7A7A7A7A7E7F8A7E7,7.8,-1.1,54.97700,599,542,277,22,124,9,0,0,0,0,248,6.2,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
27 1962,1,1,1.19.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,6.1,-1.7,58.97700,0.0,270.0,0.0,0.0,0.0,0.0,0.0,248,5.2,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
28 1962,1,1,1.20.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,6.1,-1.7,58.97700,0.0,270.0,0.0,0.0,0.0,0.0,0.0,338,4.6,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
29 1962,1,1,1.21.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,3.9,-2.2,65.97700,0.0,261.0,0.0,0.0,0.0,0.0,0.0,248,3.6,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
30 1962,1,1,1.22.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,3.9,-2.2,65.97700,0.0,261.0,0.0,0.0,0.0,0.0,0.0,293,4.1,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
31 1962,1,1,1.23.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,2.8,-2.8,67.97800,0.0,256.0,0.0,0.0,0.0,0.0,0.0,315,3.6,0,0,24.1,7.7777,0.99999999,9.0,0.0500,0.21,0.000,0.0,0.0
32 1962,1,1,1.24.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,2.2,-3.3,67.97700,0.0,253.0,0.0,0.0,0.0,0.0,0.0,315,3.6,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.21,0.000,0.0,0.0
33 1962,1,1,1.25.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,1.7,-3.3,70.97700,0.0,252.0,0.0,0.0,0.0,0.0,0.0,338,3.1,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.22,0.000,0.0,0.0
34 1962,1,1,2.2.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,1.1,-3.3,73.97600,0.0,249.0,0.0,0.0,0.0,0.0,0.0,315,4.1,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.22,0.000,0.0,0.0
35 1962,1,1,2.3.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,0.0,-3.9,75.97600,0.0,245.0,0.0,0.0,0.0,0.0,0.0,315,3.6,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.22,0.000,0.0,0.0
36 1962,1,1,2.4.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,0.0,-3.9,75.97600,0.0,245.0,0.0,0.0,0.0,0.0,0.0,315,2.6,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.22,0.000,0.0,0.0
37 1962,1,1,2.5.60,A7A7A7A7*0707070707070707A7A7A7A7A7E7F8A7E7,0.0,-3.9,75.97600,0.0,245.0,0.0,0.0,0.0,0.0,0.0,315,2.6,0,0,24.1,7.7777,0.99999999,8.0,0.0500,0.22,0.000,0.0,0.0

```

Figure 7: Complicated EnergyPlus weather file (illegible)

The next step was to find what all of these numbers and letters actually meant. We then used the EnergyPlus Weather Data Information Document to research what these values represented. The table shown below is a list of values included in the weather file. The values in this table that are included in Energy plus, are in the same order as they are in the EnergyPlus weather file. Although we now know the order with the list, the EPW is still very hard to follow and we do not know the units used.

Table 1. Comparison of E/E with ESP-r,DOE-2, and BLAST Weather Data Formats

Data Element	DOE-2	BLAST	ESP-r	E/E
Location (name, latitude, longitude, elevation, time zone)	X	X	X	X
Data source				X
Commentary			X	X
Design conditions				X
Typical/extreme periods				X
Data periods				X
Holiday/Daylight Savings		X		X
Solar Angles/Equation of Time Hours		X		
Degree Days		X		X
Year	X	X	X	X
Month	X	X	X	X
Day	X	X	X	X
Hour	X	X	X	X
Minute				X
Data source and uncertainty flags				X
Dry bulb temperature	X	X	X	X
Wet bulb temperature	X	X		X
Dew point temperature	X	X		X
Atmospheric station pressure	X	X		X
Humidity ratio	X	X		X
Relative humidity			X	X
Enthalpy	X			
Density	X			
Wind Speed	X	X	X	X
Wind Direction	X	X	X	X
Infrared Sky Temperature		X		X
Solar Radiation (global, normal, diffuse)	X	X	X	X
Illuminance (global, normal, diffuse)				X
Sky cover (cloud amount)	X			X
Opaque sky cover				X
Visibility				X
Ceiling height				X
Clearness (monthly)	X			
Ground temperatures (monthly)	X			X
Present weather observation and codes (rain, snow)		X		X
Precipitable water				X
Aerosol optical depth				X
Snow depth				X
Days since last snowfall				X

Figure 8: Reference guide for EnergyPlus weather file data

I then began researching weather file converters to see if we could convert the EPW to an easier to read format. Inside EnergyPlus there is a weather file converter. Below you can see a screenshot of the weather file converter.

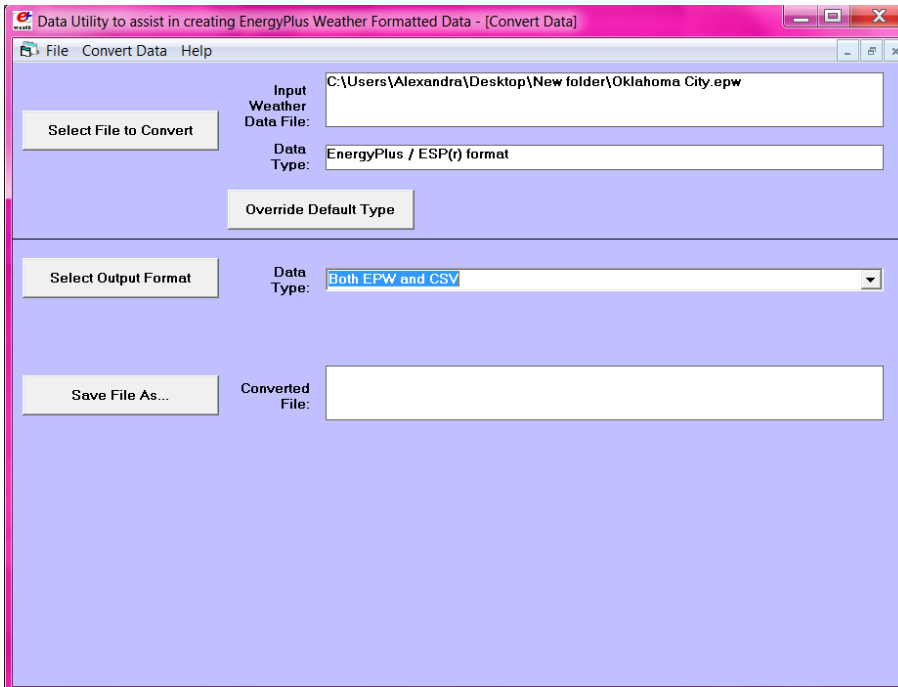


Figure 9: EnergyPlus weather file converter userform

This allows us to convert the EPW to multiple different formats, including a CSV. By converting to a CSV, we then got an excel file that have the weather file in an organized format with captions and units. An example of a CSV file can be seen below.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W					
1	Location	Latitude (°)	Longitude	TimeZone	Elevation (m)																						
2	LOCATION	35.4	-97.6	-6	397																						
3	Number of Title of Design Condit	Design Sta	ColdestMc	DB996	DB990	DP996	HR_DP996	DB_DP996	DP990	HR_DP990	DB_DP990	WS004c	DB_WS004	WS010c	DB_WS010	WS_DB999	WD_DB999	Design Sta	HottestMc	DBR	DB004	W					
4		Units	(°)	(°C)	(°C)	(°C)	(°)	(°C)	(°C)	(°)	(°C)	(m/s)	(°C)	(m/s)	(°C)	(m/s)	(deg)	Units	(°)	(°C)	(°C)	(°)					
5	1	Climate Design Data	Heating	1	-10	-7.3	-16.8	0.9	-7.8	-13.9	1.2	-4.7	14.2	6.9	12.7	6.7	5.6	0	Cooling	7	11.7	37.5					
6	Number of Period	Nar	Period Typ	Period Sta	Period End	<repeat to # periods>																					
7	6	Summer - Extreme	12-Aug	18-Aug	Summer - Typical	29-Jul	4-Aug	Winter - W.Extreme	8-Jan	14-Jan	Winter - W.Typical	1-Jan	7-Jan	Autumn - Typical	29-Oct	4-Nov	Spring - W.Typical										
8	Number of Ground Te	Soil Condu	Soil Densit	Soil Specif	Jan (C)	Feb (C)	Mar (C)	Apr (C)	May (C)	Jun (C)	Jul (C)	Aug (C)	Sep (C)	Oct (C)	Nov (C)	Dec (C)	<repeat to Number of temperature depths>										
9	3	0.5			3.49	2.35	4.37	7.53	15.79	22.16	26.46	27.77	25.54	20.59	13.98	7.84	2				7.68	5.65					
10	Leap Year	Daylight S	Daylight S	Number of Holiday	Nc	Holiday Dc	<repeat for # Holidays>																				
11	No	0	0	0																							
12	Comment Line #1																										
13	TMV2-13967	--	WMO#723530																								
14	Comment Line #2																										
15	--	Ground temps produced with a standard soil diffusivity of 2.3225760E-03 (m**2/day)																									
16	Number of DP Name/	DP Start D	DP Start D	DP End D	<repeat to # Data Periods>																						
17	1	1	Data	Sunday	1-Jan	31-Dec																					
18	Date	HH:MM	Datasourc	DryBulb (C)	DewPoint	RelHum (%)	Atmos Pre	ExtHorzRa	ExtDirRad	HorzIRSky	GloHorzRa	DirNormR	DirHorzRa	GloHorzLl	DirNormll	DirHorzLl	ZenLum	(C)	WindDir	(d)	WindSpd	(T)	TotSkycvr	OpaqSkyc	Visibility (k	Ceiling Hgt	P
19	Date	HH:MM	Datasourc	Dry Bulb T	Dew Point	Relative H	Atmospheric	Extraterre	Extraterre	Horizontal	Global	Hor Direct	Nor	Diffuse	Ho Global	Hor Direct	Nor	Diffuse	Ho Zenith	Lun	Wind Dire	Wind Spee	Total Sky	C Opaque	Sk Visibility (k	Ceiling Hgt	P
20	1/1/1962	1:00	A7A7A7A7	-2.2	-4.4	85	98400	0	0	237	0	0	0	0	0	0	0	0	0	0	4.1	0	0	0	24.1	77777	
21	1/1/1962	2:00	A7A7A7A7	-2.8	-4.4	88	98400	0	0	245	0	0	0	0	0	0	0	0	0	0	5.2	3	3	24.1	77777		
22	1/1/1962	3:00	A7A7A7A7	-3.3	-5	88	98400	0	0	240	0	0	0	0	0	0	0	0	0	0	3.6	2	2	19.3	77777		
23	1/1/1962	4:00	A7A7A7A7	-4.4	-6.1	88	98400	0	0	228	0	0	0	0	0	0	0	0	0	0	3.6	0	0	19.3	77777		
24	1/1/1962	5:00	A7A7A7A7	-4.4	-6.1	88	98400	0	0	228	0	0	0	0	0	0	0	0	0	0	4.1	0	0	19.3	77777		
25	1/1/1962	6:00	A7A7A7A7	-5	-6.7	88	98300	0	0	225	0	0	0	0	0	0	0	0	0	0	3.1	0	0	19.3	77777		
26	1/1/1962	7:00	A7A7A7A7	-5	-6.7	88	98300	0	0	225	0	0	0	0	0	0	0	0	0	0	3.6	0	0	16.1	77777		
27	1/1/1962	8:00	A7A7A7A7	-5	-6.7	88	98400	44	377	225	16	80	6	0	0	0	0	0	0	0	2.6	1	0	11.3	77777		
28	1/1/1962	9:00	A7A7A7A7	-3.3	-5	88	98400	199	1415	237	94	472	27	9600	33400	4900	530	315	2.6	1	1	11.3	77777				
29	1/1/1962	10:00	A7A7A7A7	-1.1	-3.9	82	98400	420	1415	251	213	448	80	22800	38200	11500	1460	315	3.6	5	3	19.3	77777				
30	1/1/1962	11:00	A7A7A7A7	1.1	-3.3	73	98300	591	1415	249	420	895	46	44900	86500	8800	1190	293	2.6	0	0	24.1	77777				
31	1/1/1962	12:00	A7A7A7A7	3.3	-2.8	65	98200	701	1415	267	467	750	95	48800	73500	12400	1930	248	3.1	2	2	19.3	77777				
32	1/1/1962	13:00	A7A7A7A7	5.6	-2.8	55	98000	741	1415	267	545	929	58	58100	92100	9800	1480	248	5.7	1	0	24.1	77777				
33	1/1/1962	14:00	A7A7A7A7	7.2	-1.7	54	97900	708	1415	274	504	895	56	54000	88500	9600	1420	248	7.2	1	0	24.1	77777				

Figure 10: CSV file outputted from the EnergyPlus weather file converter (illegible)

The CSV then allowed us to easily edit information in the Weather file without causing any formatting issues. After converting to a CSV and editing, the CSV can then be converted back to an EPW and run in EnergyPlus.

4.6 Downloading EnergyPlus Weather Files

Once it was found that EPW weather files were provided on the EnergyPlus website. Our group looked into downloading the weather files for our program to use. We decided that it would be better to keep all of the files locally, so possible errors in writing a code to pull the files off the internet could occur. In addition, having the files locally avoids the problem of no internet connection. Since there were thousands of cities and weather files available, we sought out Matt Mitchell's help, the teaching assistant in our lab. He assisted us in writing a Python script that downloaded and unzipped all of the files available. We then went to work in organizing and renaming all of the files so that they could work seamlessly when called by VB.net and the user.

4.7 Combining Weather Files, EnergyPlus, and VB.NET

Once it was time to combine downloaded weather files, the EnergyPlus input file, and the VB.NET framework, Philip finalized the input file which involved fine-tuning the necessary code and cleaning up the unnecessary code within the input file. He added appropriate comments for future reference. Once the EnergyPlus code was clean and ready to be implemented, it was to the main VB.NET program directory where the file would be called by the VB.NET program. Tests were then run to ensure that the values received through the VB.NET simulation were the same as the values from EPLaunch's simulation. Once the input file and all of the weather files were properly added to the program directory, the EnergyPlus simulation could run without any user contact with EnergyPlus directly.

4.7.1 Downloading Seven Day Hourly Weather Forecast

There were multiple steps that went into downloading the 7 day hourly forecast in the vb.NET program. First, a website had to be found that weather data could be retrieved in an XML format straight from the URL of the website. The team searched several APIs that could return the forecast information needed, but they all had a monthly fee to use them. This was not ideal because we intended this software to be the only application the user would need without the hassle of renewing a subscription as well as reducing the operational cost of the software. The team found a weather.gov website that showed all of the data needed, but it was in the form of a graph which was not the desired XML format. By using trial and error selecting options on the screen, the team found an option to display the weather data in XML format. Second, it was found that the website URL was programmable in that when the latitude and longitude values of the URL were changed, the weather forecast for that location was retrieved. The URL below displays where the latitude and longitude were changed in the URL to retrieve data for different locations.

```
http://forecast.weather.gov/MapClick.php?lat=Latitude&lon=Longitude&
FcstType=digitalDWML
```

Third, the team created a vb.NET sub routine that acted as a web browser to go to the web address and gather the XML data line by line and save it to a text file. Last, once the raw XML

data from the website was obtainable, the weather data could be extracted and implemented into an EnergyPlus weather file format with the aid of the EnergyPlus weather file converter.

4.7.2 Daily Forecast Complications

When working with the daily forecast, there were several complications causing some glitches in this portion of the project. First we had to understand the weather files. After finally understanding the weather files. We were then able to learn how to convert these weather files to a format that could be edited. There were also complications when downloading the XML of the seven day hourly forecast. We had to write code to be able to access the XML data from the internet and get it into a readable file in VB.net. The complications with this area caused several delays in this portion of the project causing us to not be able to get this portion completely finished.

4.8 Testing Software

When testing the software and user interface, Philip provided EnergyPlus insight to Alan, who wrote the VB.NET code that built the framework for the software. Philip checked the outputs from the software as reasonable values using documentation provided by EnergyPlus (EngineeringReference.pdf and InputOutputReference.pdf) and used the documentation to improve the accuracy of the EnergyPlus input file within the VB.NET framework. It was also essential that Philip explain the basic mechanics of EnergyPlus to Alan so he could improve the VB.NET framework accordingly. With Philip's assistance, the optimization routines could then be written in the VB.NET code so that the trailers would be designed with the least amount of solar panels and batteries for a given location. The output values were checked for errors and to determine whether to add a solar panel or a battery for maximum efficiency. The maximum number of solar panels was constrained to 4 due to the limited size of the trailer roof.

4.9 Validations

In order to finish our software, we needed to have confidence in the calculations that were being made in EnergyPlus. Although the validity of EnergyPlus itself has been tested and confirmed thousands of times before us, it was done on different models, meaning that we needed to validate our model and the trailer that we built to ensure that it was built and models accurately in EnergyPlus. We focused on three different areas of our model to compare with hand calculations. The first compared heat transfer rates from the water heater, the second compared cooling times in cold weather, and the third compared the energy collected by the solar panels.

4.9.1 Water Heater Validation

For our first validation we chose to calculate the heat transfer rates from the water heater to the environment in a 24 hour period. We chose a weather file from Chicago airport on January 1st and ran the EnergyPlus simulation to output the heat transfer rate from the water heater. Next, we used a hand calculation to compare and validate. The equation used was $q = kA\Delta T/d$, where q is the heat transfer rate ($W/(m^2 \cdot K)$), A is the surface area (m^2), ΔT is the change in temperature (Celsius), and d is the thickness of insulation (m). Temperatures were taken from the recorded temperatures on the weather file. Below are the values that were used for the calculation.

Material	Thickness L (m)	Thermal Conductivity K (W)/(m*K)	Surface Area A (m ²)	R Value (K/W)
Tank (Polypropylene)	0.0015875	0.009945067	10.59837424	0.01506145
Trailer Insulation (Polystyrene)	0.0254	0.033150222	32.701856	0.023430139
Tank Insulation (Fiberglass)	0.127	0.02882628	8.587117193	0.513059496
R_{total}				0.551551086

Figure 11: Heat Transfer Information

So with all of these values, we then calculated the heat transfer for each hour of the day and found that the numbers didn't match up exactly. This is due to the fact that the calculation done in EnergyPlus is much more in depth and deals with many more variables that were not taken into account with the simple calculation that was done by hand. When we fitted a curve to both the EnergyPlus heat transfer rates and the hand calculations both curves fit very close to the same trend. The graph is shown below.

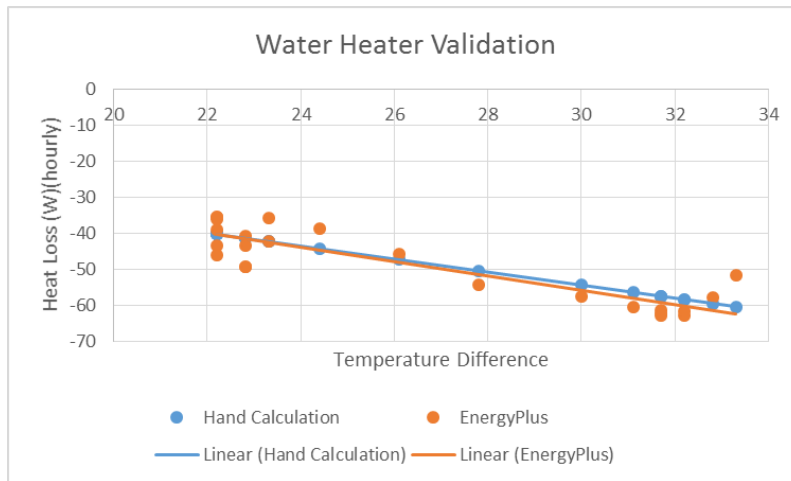


Figure 12: Heat transfer trendlines

Considering the complexity of the EnergyPlus calculation and the simplicity of the hand calculation, it should be expected to see some variation in the numbers, but seeing as the trend is very similar the validation confirms our EnergyPlus model.

4.9.2 Cooling Validation

Taking into consideration the last validation, we decided that it would be best to simplify the EnergyPlus calculation as much as possible in order to match our hand calculations as best we can. So to do this we used a design day with a constant -12 degree Celsius temperature and turned the water heater off. We then ran the trailer for the day and monitored how quickly the water cooled down. On the other hand, our hand calculation used Newton's Law of Cooling, $T(t) = T_a + (T_0 - T_a) e^{-kt}$. Where $T(t)$ is the temperature at time t , T_a is the ambient temperature, T_0 is the temperature at time 0, t is the time, and k is the rate of cooling. By rearranging the equation we can find $k = (-\ln((T(t) - T_a) / (T_0 - T_a))) / t$, and using the first hour in the day with known temperatures the rate of cooling is found.

T(t)	-0.14602 C
Ta	-12.6 C
To	-4.90E-02 C
t	1 hour
$k = \frac{-\ln\left(\frac{T(t) - T_a}{T_0 - T_a}\right)}{t}$	
k	0.007763 per hour

Figure 13: Rate of cooling calculation

Using the cooling rate, we rearranged the equation again to find the time to cool over the next 21 hours in the day, $t = (-\ln\left(\frac{T(t) - T_a}{T_0 - T_a}\right)) / k$.

T(t)	-1.99458 C
Ta	-12.6 C
To	-0.24181 C
k	0.007763 per hour
$t = \frac{-\ln\left(\frac{T(t) - T_a}{T_0 - T_a}\right)}{k}$	
t	19.7039 Hours
t actual	21 Hours
% difference	6.17

Figure 14: Newton's law of cooling

There is a small percent difference of 6.17% over a 21 hour period, which is again due to the fact that the calculation that is done by EnergyPlus is much more complex and variable intensive than a hand calculation can't match exactly. Seeing that the trends are the same and the calculation results are close, proving that our model is still reliable.

4.9.3 Panel Validation

The next step in validating went to comparing the energy collected by the solar panels. For the EnergyPlus calculation we used January 1st in Chicago, covered the entire roof in solar panels, and output the energy collected for the day. The hand calculation used

$Q_{\text{therm}} = A_{\text{surf}} * \eta_{\text{thermal}} * G_{\text{t}} + f_{\text{active}}$ where Q_{therm} is the thermal energy collected (W), A_{surf} is the surface area (m²), η_{thermal} is the efficiency, G_{t} is the direct solar radiation (Wh/m²), f_{active} is the fraction of surface with active solar panels. Below are the calculations done throughout the day.

Date	Time	EnergyPlus Calculation		Hand Calculation		
		(J*s)	Direct Normal Radiation {Wh/m2}	Area	Efficiency	Power (J*s)
1-Jan	1:00	0	0	5.1972	0.2	0
	2:00	0	0			0
	3:00	0	0			0
	4:00	0	0			0
	5:00	0	0			0
	6:00	0	0			0
	7:00	0	0			0
	8:00	22.19824056	22			22.86768
	9:00	134.4250532	397			412.65768
	10:00	267.4471232	587			610.15128
	11:00	362.0038632	688			715.13472
	12:00	358.9872362	521			541.54824
	13:00	241.6385947	151			156.95544
	14:00	180.8883672	54			56.12976
	15:00	114.9082939	93			96.66792
	16:00	46.1242643	36			37.41984
	17:00	3.892242535	0			0
	18:00	0	0			0
	19:00	0	0			0
	20:00	0	0			0
	21:00	0	0			0
	22:00	0	0			0
	23:00	0	0			0
	0:00	0	0			0

Figure 15: Solar panel energy collected

The direct normal radiation was taken from the weather files and the efficiency was matched to the EnergyPlus calculation. Note that the energy collected is zero while the sun is down and it increases and decreases as the sun gets higher in the sky and provides more energy. The calculations don't match exactly again due to the complexity of the solar panel calculations in EnergyPlus and the simplicity of the hand calculations. Seeing that the trends follow closely, and that the data makes sense, we can still trust our model and the EnergyPlus calculations.

5 Detailed Description of Final Design

5.1 Final Design: Main User Interface

The main userform was intended to display all of the active and flagged trailers and also be the link between all of the other userforms. The final design for our main userform is shown below. There is a menu strip along the top of the form with options to exit, add a trailer, and show the archive of trailer options. The active trailer list has options to remove a trailer and to check the weekly forecast for a selected trailer. These functions are all shown in the figure below.

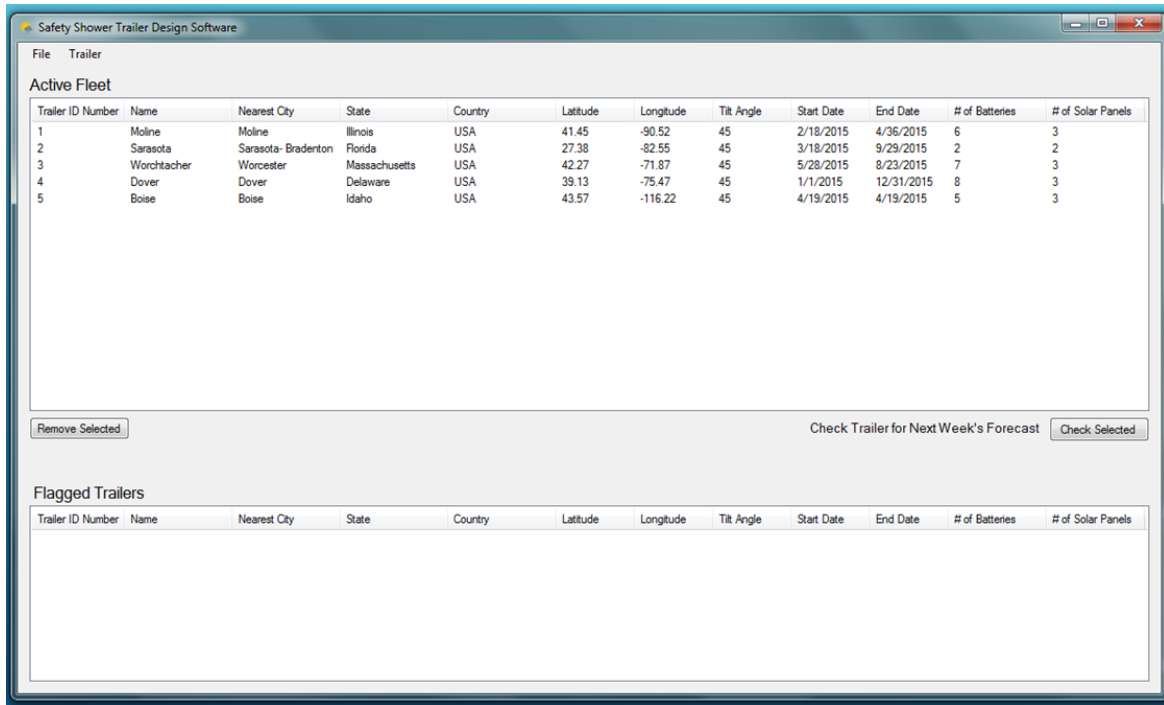


Figure 16: Main userform

5.2 Final Design: Adding a New Trailer

Adding a new trailer is very simple. A visual representation of adding a trailer is shown below:

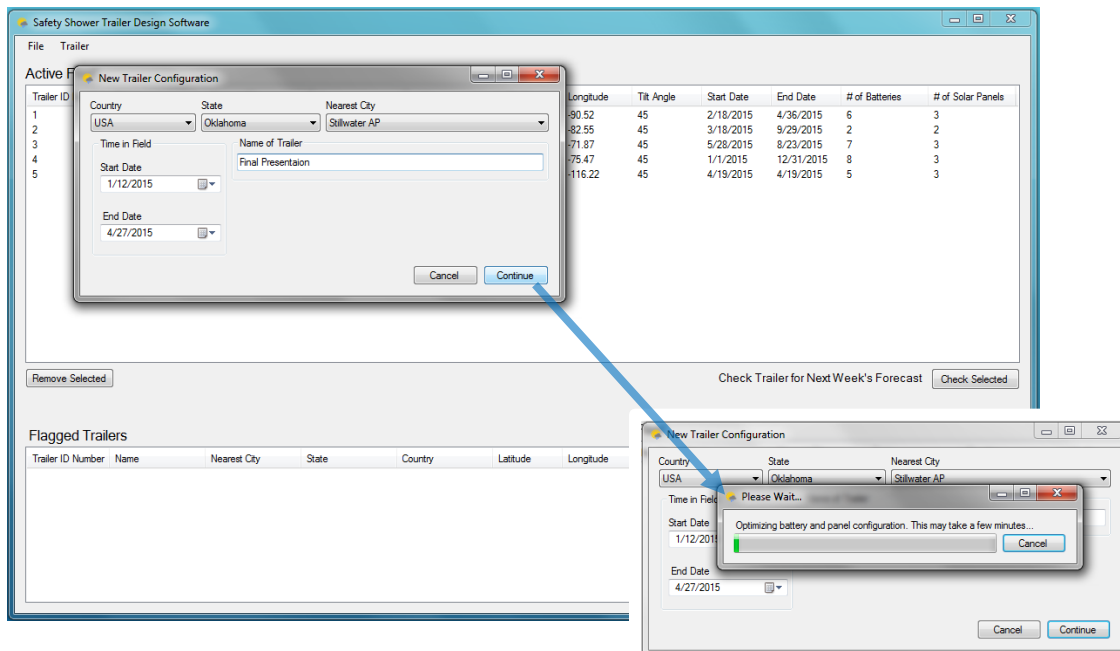


Figure 17: Representation of how to add a trailer

The user selects add a new trailer from the trailer option on the top menu strip and a new form appears. The new form is where the user inputs the country, state, and city location, the start and

end dates of deployment to the field for bookkeeping, as well as a name for bookkeeping of the trailer to be added. The user then clicks continue and the optimizing form appears. This form shows the user a rough progress bar and gives the user the option to exit the optimization routine if changes need to be made. Once the optimization is complete, the details of the trailer are shown and the trailer is added to the list of active trailers on the main userform.

5.3 Final Design: Check Weekly Weather

The Weekly weather forecast is the simplest user control in the entire program. There are three easy steps: Select a trailer in the active trailer fleet list, click the check forecast button on the bottom-right side of the active trailer list, and if the trailer is not adequately equipped then it will display in the flagged trailer list on the bottom of the main form as shown in the figure below.

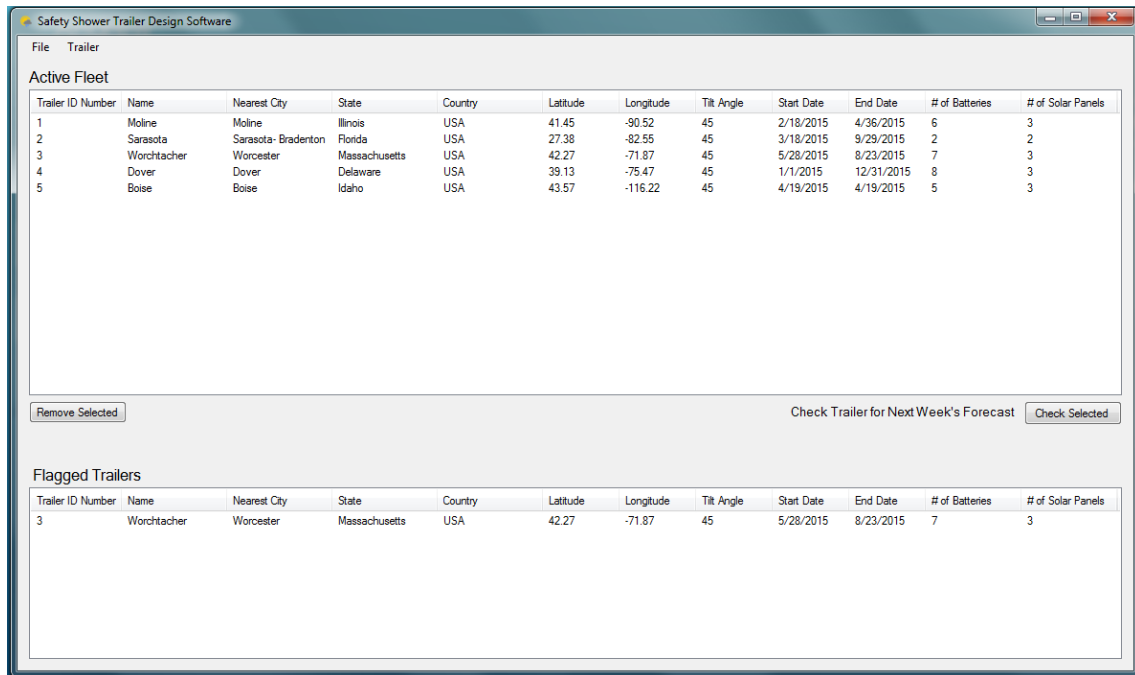


Figure 18: Display of a flagged trailer

5.4 Final Design: Conclusions

The software program that the team wrote successfully integrates EnergyPlus and vb.NET. The EnergyPlus simulation accurately models the emergency shower trailer thermally. The software can store and track numerous different trailers all over the United States. It is complete with a user-friendly interface.

Some aspects of the final design are not ideal. The solar panel to battery behavior seems to be erratic. Much troubleshooting has been done on this issue between the senior design team and Matt Mitchel, the PhD student who has assisted us throughout the project, but there has not been a solution found. The weather files have also proved to be complex which has made it difficult to complete the 7 day forecast check on the active trailers.

6 Evaluation of Final Design

6.1 Deliverables Completed

Configuration software with a user-friendly and GUI has been completed. A user's manual in the form of an informational video has been made. Validation and decision-making documentation has been created. Unfortunately, the configuration software needs further verification and validation due to the problems with the simple battery model in EnergyPlus as well as the strange outputs the team has received when relying on its own VB.NET code to model the battery, rather than EnergyPlus's calculations.

6.2 Deliverables Needing Future Work

The seven day check software on trailers currently in the field needs further work due to the complicated format of EnergyPlus weather files.

6.3 Holistic Assessment

Good: Configuration software has been completed. User interface is easy to use. The team is very confident in thermal calculations by EnergyPlus from our validations

Bad: EnergyPlus's weather files prove to be very complex and difficult to modify. EnergyPlus's simple battery model "is not intended to represent any specific type of storage technology" (according to the EngineeringReference.pdf from EnergyPlus) and has proved to have unpredictable behavior with the PV solar array. If the battery worked properly, we would have a better configuration software running compared to our current VB.NET code that attempts to do a simplified version of the complex mathematics that control the behavior of large capacity batteries.

7 Recommendations for Future Work

- Implement the modification of an EnergyPlus Weather file with the seven day hourly forecast in order to verify that a trailer can make it through the week.
- Create a battery monitoring system so that you can see real time battery levels allowing the configuration software to be more accurate.
- Optimize the VB.net code so that a trailer can be configured more quickly.
- Find a battery for EnergyPlus that is more sophisticated than the simple battery but allows us to maintain the correct construction materials of the trailer to ensure the thermal modeling is correct.

8 Finalized Budget

Our project did not require any expenses. The only tools that our team needed were the EnergyPlus and vb.NET software which are both free to use.

9 Appendices

A 1: EnergyPlus input file code

```
!- Generator IDFEditor 1.44
!- Option SortedOrder
!- NOTE: All comments with '!-' are ignored by the IDFEditor and are generated automatically.
!-   Use '!-' comments if they need to be retained when using the IDFEditor.

!- ===== ALL OBJECTS IN CLASS: VERSION =====

!- Oklahoma State University Capstone Design Spring 2015

!- Building: 1 Zone trailer with opening for 24hr shower access
!-   7ft x 12ft x 7ft high, long side facing N and S
!-   43C Water Set point, 40C Water Safe point
!- Internal: Water Tank, Batteries
!- System: Photovoltaic Solar Generator, Battery Storage, Water Heater Energy Consumption
!- Plant: None.
!- Environment: SafetyFirstDesigns program designated location

Version,8.3;

!- ===== ALL OBJECTS IN CLASS: SIMULATIONCONTROL =====

SimulationControl,
  No,                               !- Do Zone Sizing Calculation
  No,                               !- Do System Sizing Calculation
  No,                               !- Do Plant Sizing Calculation
  No,                               !- Run Simulation for Sizing Periods
  Yes;                              !- Run Simulation for Weather File Run Periods

!- ===== ALL OBJECTS IN CLASS: BUILDING =====

Building,
  Exercise 1A,                       !- Name
  0.0,                               !- North Axis {deg}
  Country,                           !- Terrain
  0.04,                              !- Loads Convergence Tolerance Value
  0.4,                               !- Temperature Convergence Tolerance Value
  {deltaC}
  FullInteriorAndExterior,          !- Solar Distribution
  ,                                  !- Maximum Number of Warmup Days
  6;                                 !- Minimum Number of Warmup Days

!- ===== ALL OBJECTS IN CLASS: SHADOWCALCULATION =====
```

ShadowCalculation,
AverageOverDaysInFrequency,
20;

!- Calculation Method
!- Calculation Frequency

!- ===== ALL OBJECTS IN CLASS: SURFACECONVECTIONALGORITHM:INSIDE =====

SurfaceConvectionAlgorithm:Inside,TARP;

!- ===== ALL OBJECTS IN CLASS: SURFACECONVECTIONALGORITHM:OUTSIDE =====

SurfaceConvectionAlgorithm:Outside,TARP;

!- ===== ALL OBJECTS IN CLASS: HEATBALANCEALGORITHM =====

HeatBalanceAlgorithm,ConductionTransferFunction;

!- ===== ALL OBJECTS IN CLASS: TIMESTEP =====

Timestep,4;

!- ===== ALL OBJECTS IN CLASS: RunPeriod =====

RunPeriod,		
AllDays,	!-Name	
1,		!-Begin
Month		
1,		!-Begin
Day		
12,		!-End
Month		
31,		!-End
Day		
UseWeatherFile,		!-Day of week
for start days		
No,		!-Use
holidays		
Yes,		!-Use DST
designations		
No,		!-Apply
Weekend Holiday Rule		
Yes,		!-Use Weather
File Rain Indicators		
Yes,		!-Use Weather
File Snow Indicators		
1,		!-
Number of Times Runperiod to be Repeated		
No;		!-
Increment Day of Week on Repeat		

!- ===== ALL OBJECTS IN CLASS: SITE:GROUNDTEMPERATURE:BUILDINGSURFACE =====

Site:GroundTemperature:BuildingSurface,18.3,18.2,18.3,18.4,20.1,22.0,22.3,22.5,22.5,20.7,18.9,18.5;

!- ===== ALL OBJECTS IN CLASS: MATERIAL =====

Material,	
Plywood,	!- Name
MediumSmooth,	!- Roughness
0.0254,	!- Thickness {m}
0.12,	!- Conductivity {W/m-K}
545.0000,	!- Density {kg/m3}
1215.00,	!- Specific Heat {J/kg-K}
0.9000,	!- Thermal Absorptance
0.6000,	!- Solar Absorptance
0.6000;	!- Visible Absorptance

Material,	
Aluminum,	!- Name
MediumSmooth,	!- Roughness
0.009525,	!- Thickness {m}
205.00,	!- Conductivity {W/m-K}
2700.0000,	!- Density {kg/m3}
910.00,	!- Specific Heat {J/kg-K}
0.9000,	!- Thermal Absorptance
0.7000,	!- Solar Absorptance
0.3000;	!- Visible Absorptance

!- ===== ALL OBJECTS IN CLASS: CONSTRUCTION =====

Construction,	
LTWALL,	!- Name
Aluminum,	!- Outside Layer
Plywood;	!- Layer 2

Construction,	
LTFLOOR,	!- Name
Plywood;	!- Outside Layer

Construction,	
LTROOF,	!- Name
Aluminum,	!- Outside Layer
Plywood;	!- Layer 2

!- ===== ALL OBJECTS IN CLASS: GLOBALGEOMETRYRULES =====

GlobalGeometryRules,

UpperLeftCorner,
Counterclockwise,
WorldCoordinateSystem;

!- Starting Vertex Position
!- Vertex Entry Direction
!- Coordinate System

!- ===== ALL OBJECTS IN CLASS: ZONE =====

Zone,
ZONE ONE,
0,
0,
0,
0,
1,
1,
2.6000,
13.51;

!- Name
!- Direction of Relative North {deg}
!- X Origin {m}
!- Y Origin {m}
!- Z Origin {m}
!- Type
!- Multiplier
!- Ceiling Height {m}
!- Volume {m3}

ZoneInfiltration:DesignFlowRate,
Main Zone Infiltration,
ZONE ONE,
System Availability Schedule,
Flow/Zone,
0.00,
,
,
,
1.0000,
0.0000,
0.0000,
0.0000;

!- Name
!- Zone or ZoneList Name
!- Schedule Name
!- Design Flow Rate Calculation Method
!- Design Flow Rate {m3/s}
!- Flow per Zone Floor Area {m3/s-m2}
!- Flow per Exterior Surface Area {m3/s-m2}
!- Air Changes per Hour {1/hr}
!- Constant Term Coefficient
!- Temperature Term Coefficient
!- Velocity Term Coefficient
!- Velocity Squared Term Coefficient

!- ===== ALL OBJECTS IN CLASS: BUILDINGSURFACE:DETAILED =====

BuildingSurface:Detailed,
SURFACE NORTH,
Wall,
LTWALL,
ZONE ONE,
Outdoors,
,
SunExposed,
WindExposed,
0.50,
4,
2.44,2.13,2.60,
2.44,2.13,0,
{m}

!- Name
!- Surface Type
!- Construction Name
!- Zone Name
!- Outside Boundary Condition
!- Outside Boundary Condition Object
!- Sun Exposure
!- Wind Exposure
!- View Factor to Ground
!- Number of Vertices
!- X,Y,Z ==> Vertex 1 {m}
!- X,Y,Z ==> Vertex 2

0,2.13,0, {m}	!- X,Y,Z ==> Vertex 3
0,2.13,2.60; {m}	!- X,Y,Z ==> Vertex 4

BuildingSurface:Detailed, ZONE SURFACE EAST, Wall, LTWALL, ZONE ONE, Outdoors, , SunExposed, WindExposed, 0.50, 4, 2.44,0,2.60, {m}	!- Name !- Surface Type !- Construction Name !- Zone Name !- Outside Boundary Condition !- Outside Boundary Condition Object !- Sun Exposure !- Wind Exposure !- View Factor to Ground !- Number of Vertices
2.44,0,0, {m}	!- X,Y,Z ==> Vertex 1
2.44,2.13,0, {m}	!- X,Y,Z ==> Vertex 2
2.44,2.13,2.60; {m}	!- X,Y,Z ==> Vertex 3
	!- X,Y,Z ==> Vertex 4 {m}

BuildingSurface:Detailed, ZONE SURFACE SOUTH, Wall, LTWALL, ZONE ONE, Outdoors, , SunExposed, WindExposed, 0.50, 4, 0,0,2.60, {m}	!- Name !- Surface Type !- Construction Name !- Zone Name !- Outside Boundary Condition !- Outside Boundary Condition Object !- Sun Exposure !- Wind Exposure !- View Factor to Ground !- Number of Vertices
0,0,0, {m}	!- X,Y,Z ==> Vertex 1
2.44,0,0, {m}	!- X,Y,Z ==> Vertex 2
2.44,0,2.60; {m}	!- X,Y,Z ==> Vertex 3
	!- X,Y,Z ==> Vertex 4

BuildingSurface:Detailed, ZONE SURFACE WEST, Wall, LTWALL,	!- Name !- Surface Type !- Construction Name
---	--

ZONE ONE,
 Outdoors,
 ,
 SunExposed,
 WindExposed,
 0.50,
 4,
 0,2.13,2.60,
 {m}
 0,2.13,0,
 {m}
 0,0,0,
 {m}
 0,0,2.60;
 Vertex 4 {m}

!- Zone Name
 !- Outside Boundary Condition
 !- Outside Boundary Condition Object
 !- Sun Exposure
 !- Wind Exposure
 !- View Factor to Ground
 !- Number of Vertices
 !- X,Y,Z ==> Vertex 1
 !- X,Y,Z ==> Vertex 2
 !- X,Y,Z ==> Vertex 3
 !- X,Y,Z ==>

BuildingSurface:Detailed,
 ZONE SURFACE FLOOR,
 Floor,
 LTFLOOR,
 ZONE ONE,
 Ground,
 ,
 NoSun,
 NoWind,
 0,
 4,
 0,0,0,
 {m}
 0,2.13,0,
 {m}
 2.44,2.13,0,
 {m}
 2.44,0,0;
 Vertex 4 {m}

!- Name
 !- Surface Type
 !- Construction Name
 !- Zone Name
 !- Outside Boundary Condition
 !- Outside Boundary Condition Object
 !- Sun Exposure
 !- Wind Exposure
 !- View Factor to Ground
 !- Number of Vertices
 !- X,Y,Z ==> Vertex 1
 !- X,Y,Z ==> Vertex 2
 !- X,Y,Z ==> Vertex 3
 !- X,Y,Z ==>

BuildingSurface:Detailed,
 ZONE SURFACE ROOF,
 Roof,
 LTROOF,
 ZONE ONE,
 Outdoors,
 ,
 SunExposed,
 WindExposed,
 0,
 4,

!- Name
 !- Surface Type
 !- Construction Name
 !- Zone Name
 !- Outside Boundary Condition
 !- Outside Boundary Condition Object
 !- Sun Exposure
 !- Wind Exposure
 !- View Factor to Ground
 !- Number of Vertices

0,2.13,2.60, {m}	!- X,Y,Z ==> Vertex 1
0,0,2.60, {m}	!- X,Y,Z ==> Vertex 2
2.44,0,2.60, {m}	!- X,Y,Z ==> Vertex 3
2.44,2.13,2.60;	!- X,Y,Z ==> Vertex 4 {m}

Roof,	
SolarRoof,	!-Name
LTROOF,	!-Construction Name
ZONE ONE,	!-Zone Name
180,	!-Azimuth Angle
80,	!-Tilt Angle
0,	!-Starting X Coordinate
0,	!-Starting Y Coordinate
4.2,	!-Starting Z Coordinate
3.66,	!-Length (this should be N-S)
2.13;	!-Width (this should be E-W)

!- ===== ALL OBJECTS IN CLASS: SHADING:OVERHANG =====

Shading:Overhang,	
Overhang1,	!-Name
Zone Surface East,	!-Window or Door
Name	
0,	!-
Height above Window or Door (m)	
90,	!-Field Tilt
Angle from Window/Door	
0,	!-Left
Extension from window/door	
0,	!-Right
Extension from windor/door	
1.22;	!-Depth

!- ===== ALL OBJECTS IN CLASS: SHADING:FIN =====

Shading:Fin,	
Fin1,	!-Name
Zone Surface East,	!-Window or Door
Name	
0,	!-Left
Fin Extension from window/door	
0,	!-Left
Fin Distance above top of window/door	

0,	!-Left
Distance Below Bottom of Window/door	
90,	!-Left
Fin Tilt Angle from Window/Door	
1.22,	!-Left Fin Depth
0,	!-Right
Fin Extension from window/door	
0,	!-Right
Fin Distance above window/door	
0,	!-Right
Fin Distance below Bottom of Window/Door	
90,	!-Right
Fin Tilt Angle from Window/Door	
1.22;	!-Right Fin
Depth	

!- ===== ALL OBJECTS IN CLASS: WATERHEATER:MIXED =====

WaterHeater:Mixed,	
Outdoor Electric Tank,	!- Name
0.151,	!- Tank Volume {m3}
Water Heater Setpoint Schedule,	!- Setpoint Temperature Schedule
Name	
5,	!- Deadband Temperature Difference {deltaC}
40,	!- Maximum Temperature Limit {C}
CYCLE,	!- Heater Control Type
38000,	!- Heater Maximum Capacity {W}
,	!- Heater Minimum Capacity {W}
,	!- Heater Ignition Minimum Flow Rate {m3/s}
,	!- Heater Ignition Delay {s}
ELECTRICITY,	!- Heater Fuel Type
1,	!- Heater Thermal Efficiency
,	!- Part Load Factor Curve Name
0,	!- Off Cycle Parasitic Fuel Consumption Rate {W}
ELECTRICITY,	!- Off Cycle Parasitic Fuel Type
0,	!- Off Cycle Parasitic Heat Fraction to Tank
0,	!- On Cycle Parasitic Fuel Consumption Rate {W}
ELECTRICITY,	!- On Cycle Parasitic Fuel Type
0,	!- On Cycle Parasitic Heat Fraction to Tank
Zone,	!- Ambient Temperature Indicator
,	!- Ambient Temperature Schedule Name
ZONE ONE,	!- Ambient Temperature Zone Name
,	!- Ambient Temperature Outdoor Air Node
Name	
1.5,	!- Off Cycle Loss Coefficient to Ambient
Temperature {W/K}	
,	!- Off Cycle Loss Fraction to Zone

1.5,	!- On Cycle Loss Coefficient to Ambient
Temperature {W/K}	
,	!- On Cycle Loss Fraction to Zone
0,	!- Peak Use Flow Rate {m3/s}
Hot Water Demand Schedule,	!- Use Flow Rate Fraction Schedule
Name	
Constant Mains Temp Schedule;	!- Cold Water Supply Temperature
Schedule Name	

!- ===== ALL OBJECTS IN CLASS: SCHEDULETYPELIMITS =====

ScheduleTypeLimits,	
Any Number;	!- Name

!- ===== ALL OBJECTS IN CLASS: SCHEDULE:COMPACT =====

Schedule:Compact,	
System Availability Schedule,	!- Name
Any Number,	!- Schedule Type Limits Name
THROUGH: 12/31,	!- Field 1
FOR: AllDays,	!- Field 2
UNTIL: 24:00,1;	!- Field 3

Schedule:Compact,	
ALWAYS_ON,	!- Name
Any Number,	!- Schedule Type Limits Name
Through: 12/31,	!- Field 1
For: AllDays,	!- Field 2
Until: 24:00,1;	!- Field 3

Schedule:Compact,	
Water Heater Setpoint Schedule,	!- Name
Any Number,	!- Schedule Type Limits Name
Through: 12/31,	!- Field 1
For: AllDays,	!- Field 2
Until: 24:00,22.5;	!- Field 3

Schedule:Compact,	
Hot Water Demand Schedule,	!- Name
Any Number,	!- Schedule Type Limits Name
Through: 12/31,	!- Field 1
For: AllDays,	!- Field 2
Until: 24:00,0;	!- Field 3

Schedule:Compact,	
Constant Mains Temp Schedule,	!- Name
Any Number,	!- Schedule Type Limits Name
Through: 12/31,	!- Field 1

```

For: AllDays,                               !- Field 2
Until: 24:00,15;                            !- Field 3

!- ===== ALL OBJECTS IN CLASS: GENERATOR:PHOTOVOLTAIC =====

Generator:Photovoltaic,
  PV:ZONE SURFACE ROOF,                      !- Name
  SolarRoof,                                 !- Surface Name
  PhotovoltaicPerformance:Simple,           !- Photovoltaic Performance Object
Type
  20percentEffPVhalfArea,                   !- Module Performance Name
  IntegratedSurfaceOutsideFace,             !- Heat Transfer Integration Mode
  1.0,                                       !- Number of Series Strings in Parallel
{dimensionless}
  1.0;                                       !- Number of Modules in Series {dimensionless}

!- ===== ALL OBJECTS IN CLASS: PHOTOVOLTAICPERFORMANCE:SIMPLE =====

PhotovoltaicPerformance:Simple,
  20percentEffPVhalfArea,                   !- Name
  0.25,                                     !- Fraction of Surface Area with Active Solar
Cells {dimensionless}
  Fixed,                                    !- Conversion Efficiency Input Mode
  0.20;                                     !- Value for Cell Eff v3wasdiciency if Fixed

!- ===== ALL OBJECTS IN CLASS: ELECTRICLOADCENTER:GENERATORS =====

ElectricLoadCenter:Generators,
  Generator List,                            !- Name
  PV:ZONE SURFACE ROOF,                     !- Generator 1 Name
  Generator:Photovoltaic,                   !- Generator 1 Object Type
  300,                                       !- Generator 1 Rated Electric Power Output {W}
  ALWAYS_ON,                                !- Generator 1 Availability Schedule
Name
  ;                                          !- Generator 1 Rated Thermal to Electrical
Power Ratio

!- ===== ALL OBJECTS IN CLASS: ELECTRICLOADCENTER:INVERTER:LOOKUPTABLE ===

ElectricLoadCenter:Inverter:Simple,
  Inverter,                                  !- Name
  ALWAYS_ON,                                 !- Schedule
Name
  ZONE ONE,                                  !- Zone Name
  0.0,                                       !- Efficiency
  1.0;                                       !- Efficiency

!- ===== ALL OBJECTS IN CLASS: ELECTRICLOADCENTER:SIMPLE =====

```



```

ElectricLoadCenter:Storage:Simple,
  Battery,
  ALWAYS_ON,
  ZONE ONE,
  0.0,
  1.0,
  1.0,
  17280000,
  67200,
  67200,
  17280000;
!- Name
!- Availability Schedule Name
!- Zone Name
!- Radiative Fraction for Zone Heat Gains
!- Nominal Energetic Efficiency for Charging
!- Nominal Discharging Energetic Efficiency
!- Maximum Storage Capacity {J}
!- Maximum Power for Discharging {W}
!- Maximum Power for Charging {W}
!- Initial State of Charge {J}

```

!- ===== ALL OBJECTS IN CLASS: ELECTRICLOADCENTER:DISTRIBUTION =====

```

ElectricLoadCenter:Distribution,
  PV Array Load Center,
  Generator List,
  DemandLimit,
Type
  0,
Demand Limit {W}
  ,
  ,
Scheme Meter Name
  DirectCurrentWithInverterDCStorage,
  Inverter,
  Battery;
!- Name
!- Generator List Name
!- Generator Operation Scheme
!- Demand Limit Scheme Purchased Electric
!- Track Schedule Name Scheme Schedule Name
!- Track Meter
!- Electrical Buss Type
!- Inverter Object Name
!- Electrical Storage Object Name

```

!- ===== ALL OBJECTS IN CLASS: OUTPUT:VARIABLEDICTIONARY =====

```

Output:VariableDictionary,IDF;

```

!- ===== ALL OBJECTS IN CLASS: OUTPUT:SURFACES:DRAWING =====

```

Output:Surfaces:Drawing,DXF;

```

!- ===== ALL OBJECTS IN CLASS: OUTPUT:CONSTRUCTIONS =====

```

Output:Constructions,Constructions;

```

!- ===== ALL OBJECTS IN CLASS: OUTPUT:VARIABLE =====

```

Output:Variable,*,Generator Produced DC Electric Energy,hourly; !- HVAC Sum [J]
!Output:Variable,*,Generator Produced DC Electric Power,hourly; !- HVAC Sum [J]
Output:Variable,*,Electric Storage Charge State,hourly; !- HVAC Average [J]
Output:Variable,*,Water Heater Tank Temperature,hourly; !- HVAC Average [C]
Output:Variable,*,Water Heater Electric Energy,hourly; !- HVAC Sum [J]

```

!Output:Variable,*,Water Heater Electric Power,hourly; !- HVAC Sum [J]

Output:Diagnostics,DisplayExtraWarnings;

!=====

==