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Case study of building energy load calculations for a sustainable technology demonstration project

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Abstract

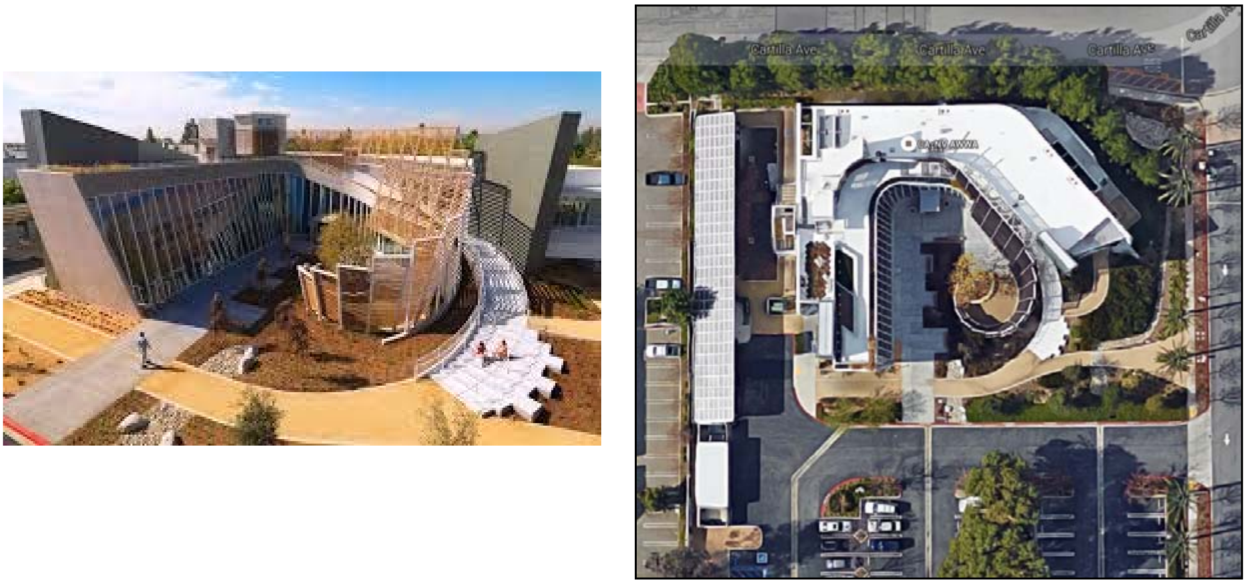
The objective of this paper is to conduct an energy analysis of the Frontier Project using computer-based software and to verify results using load calculation spreadsheets. The Frontier Project is a demonstration of sustainable and renewable energy technologies [1]. The current paper serves to quantify the building energy demands by performing a building energy load calculation on the facility. This is meant to act as a case-study of how energy and the environment can be influenced by using and promoting the correct technologies. The computer-based software selected for use was eQUEST [7] version 3.65. The ASHRAE Bin Method was used to validate the eQUEST computer model. The methods are found to agree with 20% shown that the overall load is 20 tons or 70.34 kW for the 1759.2 m^2 facility.

Keywords: Energy; Sustainability; eQUEST; Load calculations.

1. Introduction

The Frontier Project is a United States Green Building Council LEED Platinum building designed by HMC Architects and completed in 2009 as outlined in [1-4]. The building currently serves as an exhibition/demonstration facility to educate visitors about the most up-to-date building sustainable methods. In order to acquire the LEED Platinum accreditation, the building employs a number of sustainable methods, which include: rain water harvesting, storm management, cool tower and solar chimneys for passive cooling, photovoltaic (PV) panels to generate a portion of electricity consumed onsite, solar hot water collectors tied to terminal unit coil for heating, drought tolerant gardens, pervious concrete in walkways, sun shading wood device to reduce the solar heat gain, green roof to improve the solar reflectance index (SRI), daylight harvesting to eliminate interior lighting, recycled interior finishes.

The Frontier Project is shown in Figure 1. The Frontier Project Foundation, a non-profit established by the Cucamonga Valley Water District, constructed the Frontier Project to demonstrate water and energy conservation strategies. The gross area is 18,936 ft^2 (1759.2 m^2) and the date the project was completed was November 2009. The building reduces water consumption by 50 percent and energy usage by 30 percent compared to one that is similarly sized but relies on standard construction practices. The project includes a 14,000 ft^2 (1300 m^2) resource center, demonstration gardens, and an onsite water retention system. A drainage swale captures excess surface water and directs it to an underground storage cistern for landscape irrigation.



(a) (b)

Figure 1. Frontier Project (a) 3-d image [1], (b) Google maps satellite image [5].

When the cistern is full, water flows into an underground infiltration pit where it percolates into the local groundwater basin. Pervious paving also allows water to replenish the aquifer. A cool tower and two solar chimneys naturally move air through the building without the use of fans. The tower harnesses air and cools it with a highly efficient evaporative cooling system. Metal-paneled solar chimneys generate a stack effect to then pull warm air out of the building. Insulated Concrete Forms (ICF's) were used instead of standard pour-in-place concrete walls; they are made from Styrofoam, or expanded polystyrene, which acts as a thermal mass on either side of the concrete, increasing energy efficiency and improving air quality. Additionally, 230 solar panels provide 40 percent of the building's energy, and a north-facing glass wall provides daylighting while the double-paned glass with a low-E coating reduces radiant heat transfer [6].

A portion of conditioned air served to the spaces is generated by means of a passive cooling system as shown in Figure 2. This system is comprised of a central cool tower, which runs vertically from the Exhibition Room to the main roof and two solar chimneys each located adjacent to the central cool tower. Ambient air is cooled by passing through evaporative cooling pads, and later sent into the building. The solar chimneys work by creating a negative pressure and pulling air out of the building. The building is also served by an energy recovery variable-air-volume (VAV) air-handling unit (AHU) with 100% outside air. The passive cooling system only serves the main exhibition space, and is not intended to condition the building during the winter or when outdoor air quality is poor [1].

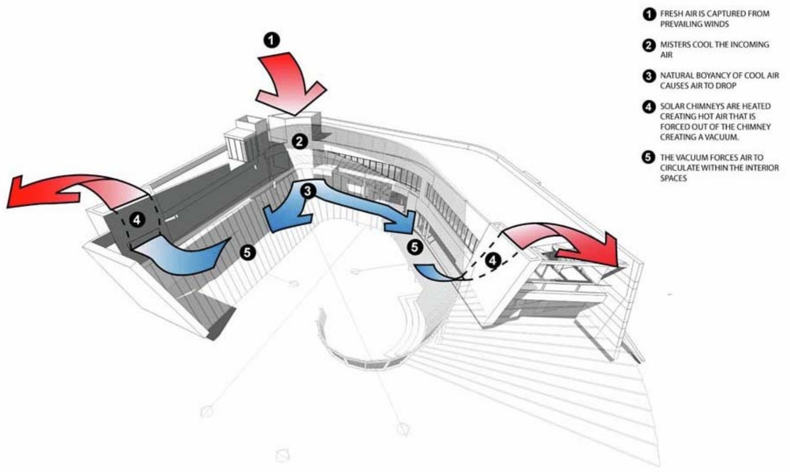


Figure 2. Passive cooling system [1].

The conditioned air is first diverted into an underfloor duct before being introduced into the first floor spaces by means of high velocity floor diffusers. The second floor is served by a high-efficiency DX unit with variable refrigerant flow (VRF) technology and variable-speed compressors, which will modulate to meet the cooling load in the building. All HVAC systems are controlled via an energy management system (EMS). The second system is a custom energy recovery air handler, which provides air to the entire first floor, with the exception of the mechanical/electrical room, data room, and a single private office. This system is best described as a VAV air handler with 100% outside air. The intake air is filtered, and then cooled with both a direct evaporative cooler and an indirect evaporative cooler (which ensures that excessive humidity is not introduced into the spaces served). The third system serves the entire second level, including data, mechanical/electrical room, and a private office on 1st floor. This system has traditional overhead air delivery, but the equipment itself is high efficiency utilizing variable refrigerant flow technology including energy recovery. This system consists of multiple DX fan coils connected via non CFC refrigerant piping to a single rooftop heat pump.

When the ambient conditions deviate from an acceptable range necessary for the passive system operation (such as a humid day), or should the airflow be insufficient to meet minimum OSA requirements (as measured with the CO2 sensor in the space), the active system will be initiated automatically via the Energy Management System (EMS), and a motorized damper will close both the solar chimney and cool tower air paths. The active system can also be manually activated with an override from the operator workstation (EMS) should dusty or windy conditions prevail. The passive system will be the priority system until indoor set-points cannot be met, then the active system shall be activated and the passive system shut down. A building-wide EMS provides full control of all HVAC systems and is based on BACNET open communication protocol [1].

2. Analysis procedure

There are three main categories of loads that will contribute in estimating the total building energy load. The first types of loads are internal loads. These loads are comprised of lighting loads (W/ft^2), equipment loads (W/ft^2) and occupancy loads (W/person). The second types of loads are envelope loads attributed to the thermal properties of construction/roofing insulation materials and windows installed in the building. The third types of loads are infiltration loads, which are a direct result of outside air entering a building through air gaps.

2.1 eQUEST model

An energy model using eQUEST [7] version 3.65 was created to evaluate the building energy loads. The eQUEST software is a sophisticated, yet easy to use building energy use analysis tool which provides professional-level results with an affordable level of effort. This freeware tool was designed to allows engineers to perform detailed analysis of today's state-of-the-art building design technologies using today's most sophisticated building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modeling. This is accomplished by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module with an enhanced DOE-2-derived building energy use simulation program [8]. Data collected from a site visit in conjunction with referencing accepted sources, were used as inputs to evaluate the loads per zone. Figure 3 shows the zone layouts used in the eQUEST model.

To evaluate the lighting loads in the spaces, ASHRAE 90.1 lighting power density (LPD) values were used at the baseline [9]. Note, however, that because this building is LEED Platinum-certified, a 30% reduction over these LPD values was used in the baseline instead. This reduction takes into account the daylight harvesting found onsite, along with the LED lighting. The total heat gain resulting from people was specified at 450 BTU/hr-person (132 W/person). This load is multiplied by a default occupancy profile assigned by eQUEST based on the space type. Table 1 summarizes the ASHRAE 90.1 LPD values and the adjusted values used in the energy model.

To account for envelope loads, insulated concrete was specified as the major material of construction. Added insulation was considered by specifying a more efficient insulation material (R-30). The current version of eQUEST is limited in terms of specifying green roofs. Therefore, the roof’s R-value was improved by specifying added insulation (R-21). This method was used to simulate the improved SRI resulting from having rooftop gardens, which results in higher albedo (solar reflectance) and higher thermal emittance. Lastly, double-pane windows with a ½ inch air gap were specified in the energy model, as confirmed during the site visit.

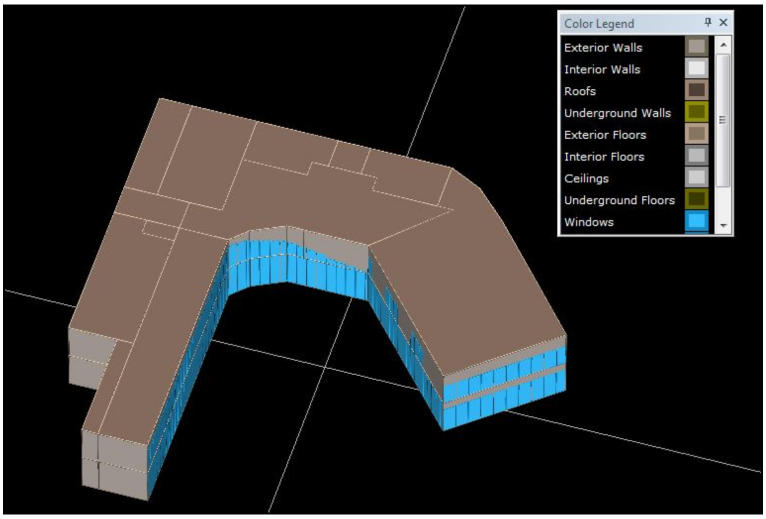


Figure 3. Frontier project eQUEST model

Table 1. ASHRAE 90.1 2013 LPD values and adjusted LPD values

Common Space Type	ASHRAE 90.1 LPD Values (W/ft^2)	Adjusted LPD Values (W/ft^2)
Classroom, Training	1.24	0.87
Conference Room/Meeting/Multipurpose	1.23	0.86
Copy/Print Room	0.72	0.50
Corridor (all other)	0.66	0.46
Electrical/Mechanical Room	0.42	0.29
Lobby (all others)	0.9	0.63
Lounge/Break room (all others)	0.73	0.51
Office (enclosed)	1.11	0.78
Office (open plan)	0.98	0.69
Restroom (all other)	0.98	0.69
Storage Room (>= 50 ft^2, <= 1000 ft^2)	0.63	0.44
Convention Center-Exhibit Space	1.45	1.02
Dining Area (all other)	0.65	0.46

Equipment loads were only specified in mechanical/electrical rooms or in areas where electronics were present. The only mechanical room types found onsite were the elevators. Note that elevators are not conditioned; however, a conservative value of 1 W/ft^2 (10.76 W/m^2) was specified to account for lighting, occupancy, and miscellaneous loads.

Infiltration loads are automatically assigned by eQUEST based on the space types specified. These values range from 0.0010 cfm/ft^2 to 0.1129 cfm/ft^2.

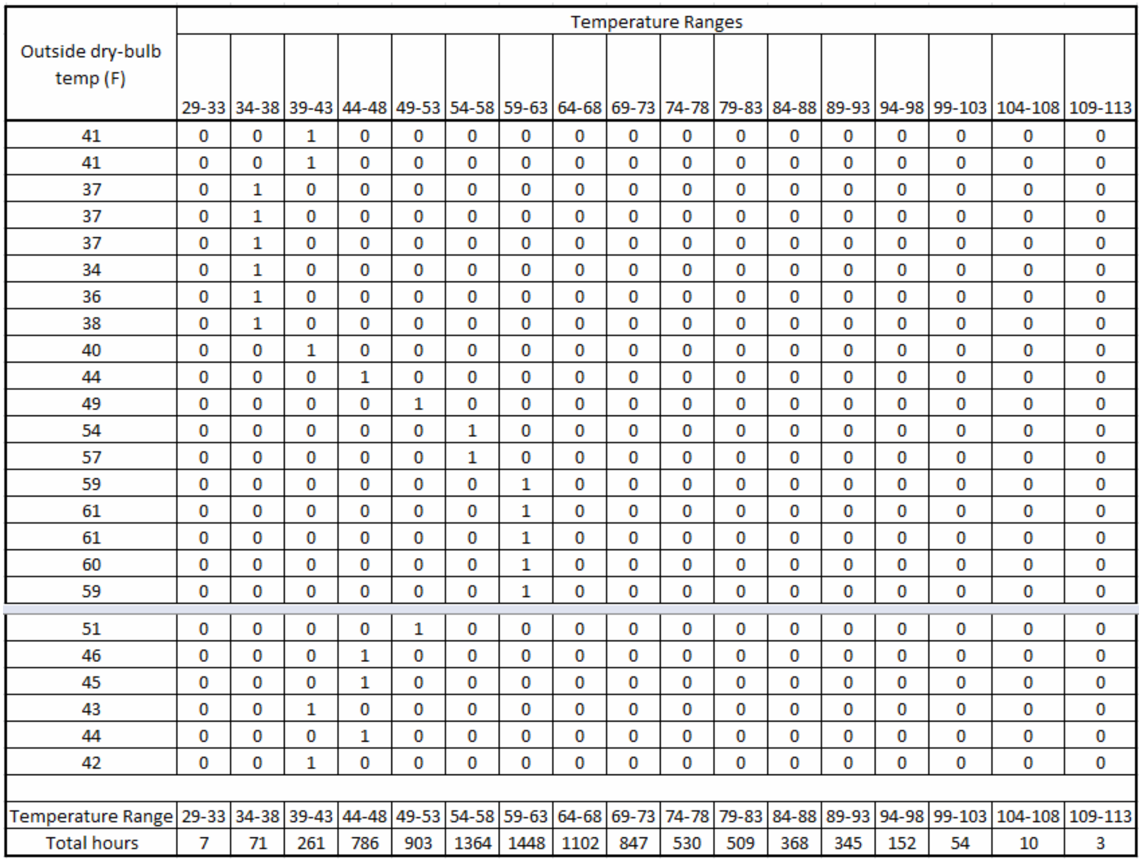
2.2 ASHRAE Bin method

The Bin Method outlined by ASHRAE was used to cross-check the results generated by eQUEST. The Bin Method is primarily dependent on the analysis of weather data and disregards the loads outlined in the previous section. Therefore, there will be a difference in the results estimated by each of these methods. To conduct this analysis, the Climate Zone 10 weather file was exported onto EXCEL, where it was then separated into groups of temperature ranges of four degrees. The total hours at each temperature range was summed for use at the calculation stage. To conduct a building load calculation, it was assumed that the interior set-points are maintained at 72 °F (22.2 °C) cooling and 70 °F (21.1 °C) heating. These are the most common set-points found onsite and are utility-approved values for Southern California Edison (SCE) and Pacific Gas and Electric (PG&E) territories.

The temperature delta (ΔT) can be determined by taking the difference between the set-point temperature and midpoint range temperature. The midpoint range temperature is the halfway point at each of the temperature groups. Lastly, the total building energy load can be calculated using $Q = UA\Delta T$, where the

U-Value is 1/R-Value (BTU/hr-ft^2 or W/m^2) of the building insulation, A is the total building area (ft^2 or m^2), and ΔT (degrees) is the difference between the set-point and midpoint range temperatures outlined previously. When in cooling mode, no cooling is done when temperatures are below 72°F (22.2 °C) and when in heating mode, no heating is done when temperatures are above 70°F (21.1 °C). Thus, when estimating the cooling load and heating load, only applicable ranges are considered. Table 1 and 2 lists the inputs used for the modeling.

Table 2. Climate zone 10 Bin data.



Outside dry-bulb temp (F)	Temperature Ranges																
	29-33	34-38	39-43	44-48	49-53	54-58	59-63	64-68	69-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113
41	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
61	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
51	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature Range	29-33	34-38	39-43	44-48	49-53	54-58	59-63	64-68	69-73	74-78	79-83	84-88	89-93	94-98	99-103	104-108	109-113
Total hours	7	71	261	786	903	1364	1448	1102	847	530	509	368	345	152	54	10	3

3. Results

3.1 eQUEST model results

It is important to note that the eQUEST building energy model was zoned based on floor plans per Figure 4 of this paper. Thus, the eQUEST output results are summarized in a space-by-space format. The total building cooling load determined by the use of eQUEST was approximately 20 tons (70,377 W). The total building heating load was -98,703 Btu/hr (-28,927 W). Note that the passive cooling systems were included in the energy model, however, they have no contribution in either the cooling load or heating load. As expected, the areas with the highest cooling loads are the zones adjacent to window exposures. The areas with the lowest cooling loads are the zones located in the middle of the building, away from window exposures. Additionally, areas with low internal loads, such as corridors and storage rooms, also display the lowest cooling loads. To cross-check the total building cooling load, a typical rule of thumb to use is 2,000 ft^2/3 tons. Using the total building area of 14,000 ft^2, Q= 14,000 ft^2/ (2000 ft^2/3 tons) = 21 tons (73,853 W). Thus, the energy model is +/- 5% from 21 tons (73,853 W). Table 3 lists the results of the eQUEST simulation.

3.2 ASHRAE Bin method results

Table 4 and Table 5 summarize the results of estimating the total building cooling load and heating load by means of the ASHRAE Bin Method. Note that results are reported in BTU/hr to make a direct comparison to eQUEST results.

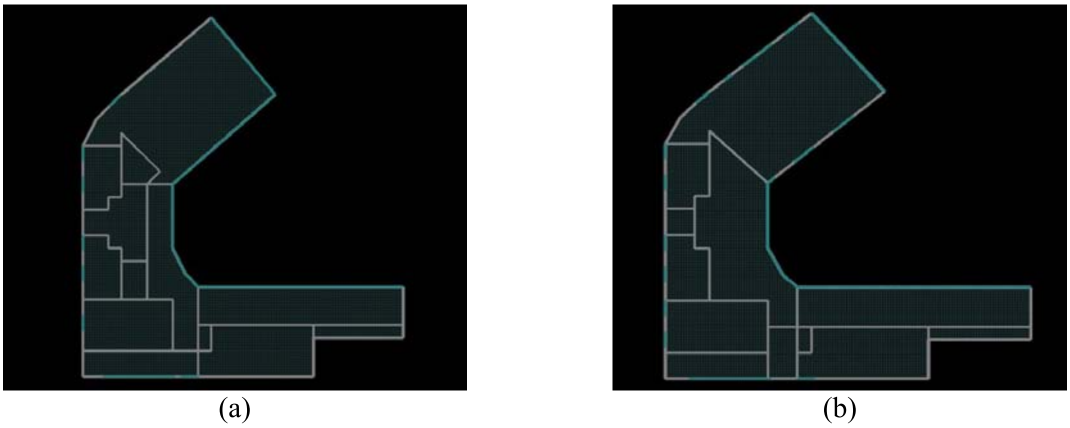

(a) (b)

Figure 4. Frontier project eQUEST model zoning, (a) First floor, (b) Second floor.

Table 3. eQUEST model results.

Space Name	Cooling Load (Btu/hr)	Heating Load (Btu/hr)
1st Floor Solar Chimney	0	0
1st Floor Passive Cooling	0	0
1st Floor Elevator	136	-37
1st Floor Unconditioned	0	0
1st Floor Living Room	5,573	-1,743
1st Floor Exhibition	30,835	-17,074
1st Floor Kitchen	340	-111
1st Floor Men’s RR	4,533	-2,101
1st Floor Women’s RR	4,533	-2,101
1st Floor RR Lobby	1,158	-735
1st Floor Corridor	30,356	-8,866
1st Floor Conference	66,430	-20,383
1st Floor Private Office	421	-128
2nd Floor Exhibition	26,860	-14,914
2nd Floor Conference	6,345	-2,032
2nd Floor Men’s RR	4,636	-2,133
2nd Floor Women’s RR	4,636	-2,133
2nd Floor Elevator	149	-42
2nd Floor Passive Cooling	0	0
2nd Floor Storage	818	-663
2nd Floor Corridor	14,566	-5,807
2nd Floor Open Office	31,130	-16,877
2nd Floor Unconditioned	0	0
2nd Floor Copy Room	1,673	-823
2nd Floor Solar Chimney	0	0
Totals (Btu/hr)	**235,128**	**-98,703**
Total (W)	**68,909**	**-28,927**
Total (tons)	**20**	
Total (W)	**70,377**	**-**

The total building cooling load determined by the use of the ASHRAE Bin Method was approximately 16 tons (56,270 W). Note that this method disregards the three main types of loads previously outlined in section 2. This value is within 20% of the total building cooling load determined by eQUEST. A primary advantage of this method in comparison to an energy model, is the fewer amount of engineering analysis hours invested in estimating preliminary numbers. Therefore, for preliminary sizing of HVAC systems, the ASHRAE Bin Method can help to gain an understanding of the equipment that will be needed in the future. However, because this method is not customized per building, an energy model would predict more accurate results, if properly modeled and calibrated. Thus, the engineering time invested in developing an energy model would theoretically yield more accurate results and optimal HVAC systems sizing. The total building heating load determined by the use of the ASHRAE Bin Method was found to be 195,048 Btu/hr (57,163 W). Similar to the ASHRAE Bin Method for Cooling Load, this method also disregards the three main types of loads previously outlined in this paper. This is apparent in the result, which is nearly double the value estimated by the use of eQUEST. This can be attributed to the fact that the ASHRAE Bin Method disregards the building's shell, sustainable methods, and the effect of weather on the equipment performance. Another critical item to point out is that cooling and heating loads can vary nonlinearly, and this can only be accounted for by means of an energy model.

Table 4. ASHRAE Bin method - cooling load.

T_{db} (°F)	ΔT (hours)	Temperature Range (°F)	ΔT (°F)	q = UAΔT (BTU/hr)
31	7	29-33	-41	N/A
36	71	34-38	-36	N/A
41	261	39-43	-31	N/A
46	786	44-48	-26	N/A
51	903	49-53	-21	N/A
56	1364	54-58	-16	N/A
61	1448	59-63	-11	N/A
66	1102	64-68	-6	N/A
71	847	69-73	-1	N/A
76	530	74-78	4	4,536
81	509	79-83	9	10,206
86	368	84-88	14	15,876
91	345	89-93	19	21,546
96	152	94-98	24	27,216
101	54	99-103	29	32,886
106	10	104-108	34	38,556
111	3	109-113	39	44,226
Total Cooling Load (Btu/hr)				**195,048**
Total Cooling Load (W)				**57,163**
Total Cooling Load (tons)				**16**

Table 5. ASHRAE Bin method heating load.

T_{db} (°F)	ΔT (hours)	Temperature Range (°F)	ΔT (°F)	q = UAΔT (BTU/hr)
31	7	29-33	-39	-44,226
36	71	34-38	-34	-38,556
41	261	39-43	-29	-32,886
46	786	44-48	-24	-27,216
51	903	49-53	-19	-21,546
56	1364	54-58	-14	-15,876
61	1448	59-63	-9	-10,206
66	1102	64-68	-4	-4,536
71	847	69-73	1	N/A
76	530	74-78	6	N/A
81	509	79-83	11	N/A
86	368	84-88	16	N/A
91	345	89-93	21	N/A
96	152	94-98	26	N/A
101	54	99-103	31	N/A
106	10	104-108	36	N/A
111	3	109-113	41	N/A
Total Heating Load (Btu/hr)				**-195,048**
Total Heating Load (W)				**-57,163**

4. Conclusion

This paper has presented a case-study involving a working sustainable renewable energy technology demonstration facility known as the Frontier Project [1]. The goal of this paper is to present a building energy model of the facility in order to demonstrate the energy consumption of such a facility. Developing an energy model and using the ASHRAE Bin Method is a critical steps in determining the total building cooling load and heating load. This ASHRAE model was used to validate a numerical eQUEST building energy load model. Both methodologies work collectively and are critical tools that an energy engineer must become familiar with to have an understanding of how a building works or should be designed. Agreement between the ASHRAE based hand-calculation EXCEL procedure and the more sophisticated eQUEST software was found to be within 20% for an overall load of 70.34 kW for the 1759.2 m^2 facility.

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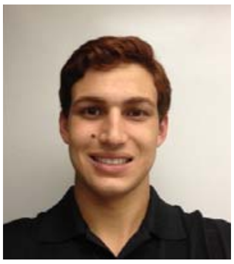

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