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A Path to Zero Net Energy

(Source: http://autonomecollective.org/ollie/wp-content/uploads/2011/01/domes1.jpg)

Executive Summary:

The Domes is an alternative living community at the University of California, Davis. There are characteristics of the community that make it both an ideal case study for achieving ZNE, and constrain the possibilities of reaching ZNE. This paper examines the feasibility of achieving Zero Net Energy (ZNE) at the Domes.

To assess the viability of ZNE at the Domes, three load reduction/on-site energy production scenarios were examined: 30%, 50%, and 100% ZNE. The first scenario has been achieved and surpassed by this last year's renovation of dome 8, where a load reduction of 35% was achieved by replacing the water heater, the windows and door, and reinsulating the envelope with a soy-based spray foam.

The next tier of reductions is achieved through appliance replacements and new energy efficient alternatives. The remainder of the load was offset with solar PV to achieve a total 100% ZNE. While this goal is possible, and on a moral level recommended, the constraints of the fixed-price utilities does not make this path to ZNE the economically feasible choice.

To apply ZNE to the Domes would be taking on a labor of love, which has probably been the case all along…

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Introduction

Background:

"The Domes" is an alternative housing community at the University of California, Davis. It was built more than 40 years ago by engineering students at the university, and has been connected to both the school and the community of Davis, CA ever since. The property consists of 14 fiberglass dome-like structures (numbered 2 through 15), and a large yurt which acts as a communal space for gatherings and meetings. The utilities for the entire property consist of electrical, water, and sewer.

Every dome, with the exception of Dome 7, houses two university students and is a complete living unit in itself. Each contains a full kitchen with a range and refrigerator (10-12 cu. ft.), a full bathroom with a shower, a common area, and two sleeping areas. There is a 4000 watt in-wall electric heater for thermal comfort and a water heater as well. Currently, the community is at full capacity, housing a total of 26 students.

The exterior of each dome is relatively identical. All have 4 windows and one exterior door. The structures are insulated with ~2" of polyurethane foam, which has been sprayed onto the inside of the envelope. This layer of foam, which is covered in paint, also serves as a finished wall.

As part of a movement to "Save the Domes" from possible demolition, various safety and accessibility upgrades were performed on the property. The largest part of this renovation was the complete gutting and remodel of Domes 7 & 8 on the northeast corner of the property. Both domes were reinsulated with 4" of soy-based spray foam, and all windows and doors were replaced with energy-efficient models. Additionally, all electrical and plumbing was replaced, and both domes were made ADA compliant. Dome 7 has become a "common" dome, with only an open layout and ADA half-bath. Since its renovation was only completed within the last month and has seen no use as of yet, it will be excluded from this study. Dome 8 has the same upgrades as 7, but has remained a living dome, with a loft, full kitchen and bath. Although the heater and range were not replaced, the water heater was upgraded to a heat pump in an effort to reduce the electrical load. The load reduction and energy efficiency upgrades in domes 7 & 8 were completed in conjunction with a previous study of energy use at the domes.

Problem Statement:

The Domes is a well-established community. The question this study will attempt to answer is: Is Zero Net Energy (ZNE) feasible for a community such as the Domes, considering the constraints of the community and the property? For the purposes of this study, three different scenarios will be explored using a combination of load reductions, efficiency improvements, and onsite energy generation to achieve ZNE. The three scenarios will be based on tiers of load reduction. The first scenario will be 30%, the second will be 50% and the final scenario will be a 100% offset in energy usage for the property.

Confirmation of Baseline Energy Use:

A baseline of energy use was established in the previous energy audit report of the domes, but it was necessary to confirm and update this data in order to be able to establish a starting point from which to build from. Billing (and usage) data for the previous year and a half was attained from the Solar Community Housing Association, the Leaser of the property. Initially, this data alone was to be used as the baseline from which to compare from, but after some incongruities in calculations, it became necessary to look into why this was the case. When compared to the energy usage data from the previous study the following results were found:

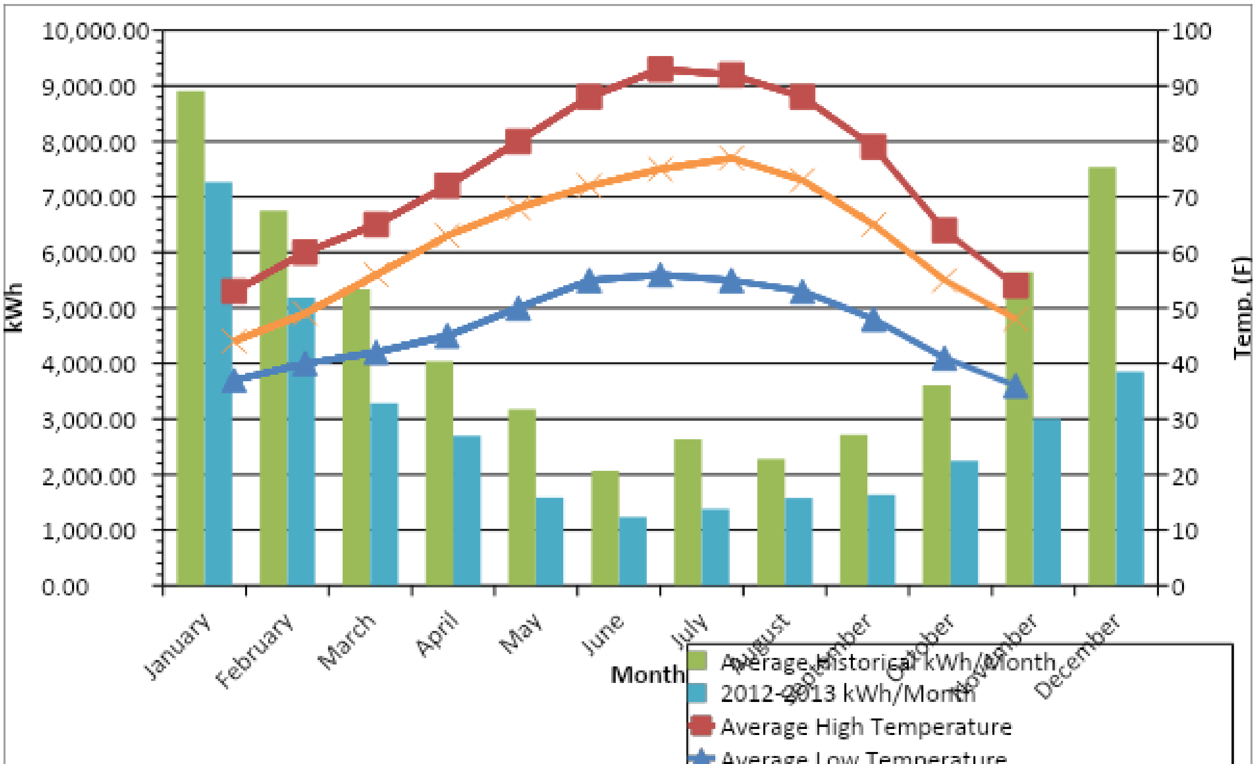


Figure 1: Year average kWh per month: (2012-2013) vs. Yearly Average

Energy use for 2012-2013 accounted for only energy use in 13 domes, but even after the averaged historical data was adjusted to compensate for this 7% difference in per dome energy use, the disparity was significant. Possible reasons for this were explored, including a comparison of average local temperatures with mean temperatures from 2012-2013, but no obvious anomalies were found. It was decided to average all available energy usage data and use the resulting number as a baseline for energy use on the property.

Retrofits were made to Dome 8 following the Energy Audit Report of 2012. To determine the effects of these retrofits, Dome 8 was compared to an average dome without retrofits. Dome 10 was fitted with metering for the electricity entering the dome, and serves as a baseline for a “typical” dome. These domes will also be compared in the on-site generation section of this report.

Methodology:

The methodology in this project aims to approach the problem statement from several angles. Baseline data was established by comparing the historical data from 2006-2011 with the utility billing data from 2012-2013. To address behavior with respect to energy efficiency, an energy usage survey was distributed to the Dome residents. Questions in the survey centered on heating and cooling comfort, electricity usage and allowed for occupant feedback. The Homer Model was used to analyze on-site generation possibilities for the Domes. The different scenarios were analyzed using the variables of solar PV size and cost, and the effect of reducing the primary load. Finally, all of these methods were integrated into creating scenarios for a path to ZNE.

Survey Results

The results of the survey seem to indicate that the behavior of the typical Dome resident (Domie) is not unlike most people outside of the community with certain exceptions. The average American uses 940 kWh/month (U.S. Energy), while the average Domie uses 114 kWh/month.

Space conditioning provides for a large portion of this disparity. There is no air-conditioning in the Domes, and space heating is provided by 4000 watt in-wall electric heaters, most of which are close to 40 years old. The typical Domie will either put a jacket on and/or turn the heater on for a short period of time to warm up a bit. Average use in the morning was 31 minutes and 88 minutes in the evening when needed. Cooling is supplied at the domes through passive ventilation (opening windows and door), or plug-in fan use when needed. No one surveyed owns a portable air-conditioning unit. With this in mind, the heater is a likely source of reduction in energy use.

The surveys indicated that kitchen plug loads were minimal, with only a few people owning coffeemakers, for example. Nearly half own a toaster, but only 4 out of 25 own a microwave. Other plug loads include audio equipment, and almost everyone has a laptop computer of some kind. All hard-installed lighting in the domes have compact fluorescent bulbs, and Domies, for the most part, have replaced them with like technology.

Hot water use in the domes seems to be below the American average as well. There is no dishwasher in any dome, so hand-washing is the norm. The other main use of hot water is for showering. The average shower time, according to the survey, is 5-15 minutes, with a few outliers. The survey indicates that 43% of Domies shower 1-2 times/week, 43% 3-5 times/week, and only 14% shower daily.

Load Reduction

Load Reduction: Appliances, Windows, Insulation

The following results were found in the previous study at the Domes:

Table 1: Existing Appliances in Each Dome (excluding Dome 7 & 8)

Device	Make	Model	Power Rating	Actual Energy Usage per Year (kWh)	% Use
Refrigerator	Avanti/Kenmore	FF1212W/6204	328/350 kWh/year	305	7%
Water Heater	A.O. Smith	EES 30917 (30 gal.)	4500	1202	27%
Space Heater	--	HW4000F	4000	2053	47%
Range	GE	JB503H2WH	9800	469	11%
Other				372	8%

(Source: Brum, 2012)

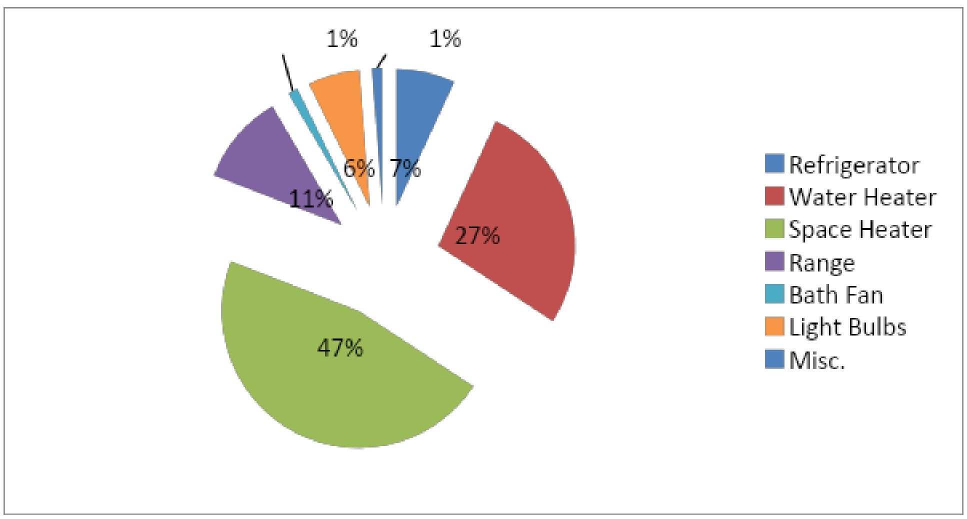


Figure 2: Annual Energy Consumption by Appliance (kWh), based on data above

This data is still pertinent to 12 of the 14 domes. Based on the data taken from the report by Brum et al., the space heater is by far the leading consumer of energy in each dome. Despite having the same numbers as the Brum report, the above chart conflicts with their findings.

The following results were found about load reductions due to the remodel in dome 8, including yearly energy savings and payback period:

Table 2: Load Reduction Scenario 1

				Annual Avg kWh:		54,705	
				Cost per kWh:		$ 0.072	
	Make	Model	Installed Price per dome	12 Domes	Annual Energy Savings (kWh)	Annual Cost Savings	Payback Period (years)
Insulation	Soy-based spray		$ 10,000	$ 120,000	2,735	$ 196.94	609.3
Windows /Doors	Double-paned low-e		$ 4,000	$ 48,000	2,735	$ 196.94	243.7
Water Heater	GE	ECO 18	$ 1,100	$ 13,200	13,676	$ 984.69	13.4
			TOTALS:	$ 181,200		$ 1,378.57	131.4
			TOTAL PAYBACK PERIOD:		131.4	years	

The above scenario accounts for a 35% reduction in annual energy load (based on data collected). This more than covers our first scenario of 30% load reduction outlined in the problem statement, but further reductions in load can be taken into account as well. The space heater is the obvious choice for replacement, but energy-efficient alternatives to the range and refrigerator were also explored. There were many refrigerators to choose from that were energy-star rated, but upon comparison with the existing refrigerator of 305 kWh per unit in the domes now, the only model that was of comparable size (10-12 cu ft) that provided a sizeable reduction in load was the Sunfrost RF-12. With a price of about $2500 per unit, and annual cost savings of only $7.27, however, the payback period was 343 years, which was unrealistic.

With the service at the domes, finding a range that provides a sizeable decrease in load is a challenge. There is no current energy star rating for electric ranges, and power ratings on the various models read as if each unit is a conglomeration of individual loads. Each burner has a rating, as does the oven, and sometimes the broiler as well. On the whole, the options for a low to mid-priced replacement for the existing units did not show sizable reductions in load. An alternate idea was explored to reduce load from this source: replace 6 of the 13 units with an induction cooktop. This involved a reduction in service as well as load, as 6 domes would no longer have an oven, so the question of oven usage in a follow-up survey may have to be posed in order to assess the feasibility of this option in a community sense.

The space heater, although the surveys seem to indicate that usage was relatively low (question 5 in particular), accounted for 47% of energy use in the domes due to appliances. The most plausible option for the size restrictions of each dome is the use of a mini-split ductless heat pump (this was also concluded in the previous study). The Fujitsu 12 RLF was examined as it was the most energy efficient model found. See specifications in the appendix. A unit like this requires purchase and installation by a contractor, and would require re-running an electrical line to the new heat pump location on an exterior wall. Projected energy use per year was calculated with a usage assumption for heating of 4 hours/day, 125 days/year, and a cooling assumption of 4 hours/days for 90 days/year (worst case scenario – every day of the summer). Even with added cooling service in the summer, there was a 75% reduction in load between this model and the existing.

Based on these findings, the following scenario is possible:

Table 3: Load Reduction Scenario 2

				Annual Avg kWh:		54,705	
				Cost per kWh:		$ 0.072	
	Make	Model	Installed Price	12 Domes	Annual Energy Savings (kWh)	Annual Cost Savings	Payback Period (years)
Insulation	Soy-based spray		$ 10,000	$ 120,000	2,735	$ 196.94	609.3
Windows /Doors	Double-paned low-e		$ 4,000	$ 48,000	2,735	$ 196.94	243.7
Water Heater	GE	ECO 18	$ 1,100	$ 13,200	13,676	$ 984.69	13.4
Heater	Fujitsu	12RLF	$ 3,700	$ 44,400	20,059	$ 1,444.25	30.7
Range	Kitchen Aid	KICU569X	$ 2,056	$ 24,672	4,589	$ 330.41	74.7
Refrigerator	Sunfrost	RF-12	$ 2,496	$ 29,952	1,313	$ 94.54	316.8
			TOTALS:	$ 280,224		$ 3,247.76	
		TOTAL PAYBACK PERIOD:			86.3	years	

Although possible, this would probably not be the best scenario as far as cost and payback period is concerned. If this were the only criteria, however, the spray foam, windows and door replacement, and refrigerator would not be viable options for load reduction. For the sake of argument, let's examine a third scenario, which adds only the new heater:

Table 4: Load Reduction Scenario 3

					Annual Avg kWh:		54,705
					Cost per kWh:		$ 0.072
	Make	Model	Installed Price	12 Domes	Annual Energy Savings (kWh)	Annual Cost Savings	Payback Period (years)
Insulation	Soy-based spray foam		$ 10,000	$ 120,000	2,735	$ 196.94	609.3
Windows/ Doors	Double-paned low-e		$ 4,000	$ 48,000	2,735	$ 196.94	243.7
Water Heater	GE	ECO 18	$ 1,100	$ 13,200	13,676	$ 984.69	13.4
Heater	Fujitsu	12RLF	$ 3,700	$ 44,400	20,059	$ 1,444.25	30.7
			TOTALS:	$ 225,600		$ 2,822.81	
		TOTAL PAYBACK PERIOD:			79.9	years	

The payback period has been lowered slightly, and the upfront installed cost to retrofit all of the domes has decreased by about $65,000. For the sake of pure energy reduction, however, we will proceed our analysis with Scenario 2. The resulting energy usage per dome per year would like this:

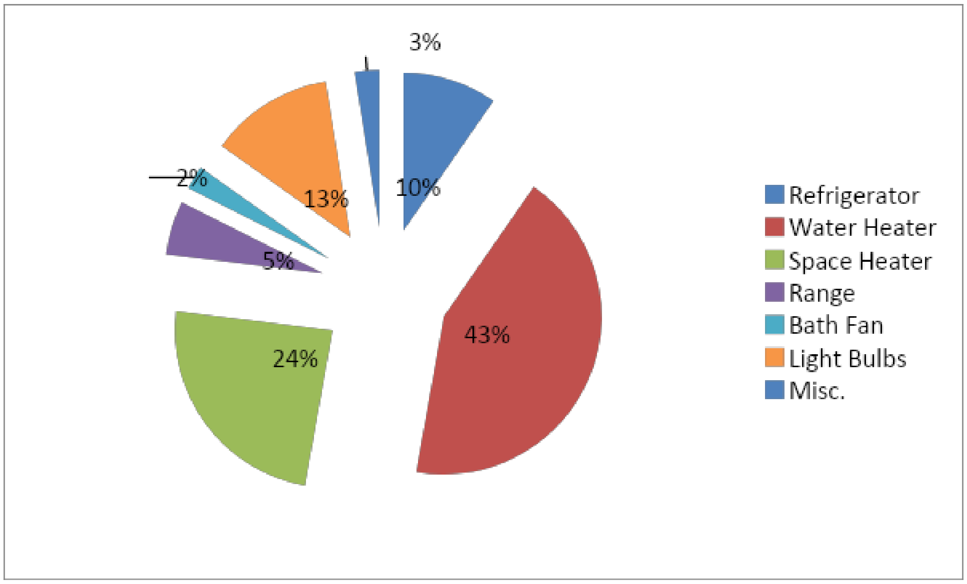


Figure 3: Annual Energy Consumption by Appliance (kWh), with data from Scenario 2

Onsite Generation: Solar PV

Load Reduction & Renewable Generation

Load reduction and renewable generation were examined simultaneously using the Homer Model. For this project, load reduction refers to reductions in the primary load (the water heater and main breakers, for example), consisting of only electricity usages. The primary load was determined directly from Dome 10's metered data for the month of March. Since the Homer Model requires one year of data, entered in hourly increments for one day of each month, h the raw collected data had to be manipulated. The 2006-2011 historical electricity data from a previous study was first averaged to create monthly coefficients. These coefficients were then used to extrapolate the raw data into a representative year of data. Later on in the project, 2012-2013 utility billing data was obtained and used to scale the average kWh per day in the Homer Model (HOMER Energy Modeling Software). The resulting data made up the primary load used in the Homer Model for this project (Table 1 in the Appendix), and represents an average dome on the property. To represent the entire complex, the data was scaled from one dome to 13 domes.

The Homer Model takes inputs such as project lifetime, interest rate, and the price of solar PV to determine the associated size and total net present cost of different solar PV systems. In our model, the project lifetime of 5 years was chosen based on the lease period that SCHA holds on the Domes. The interest rate was set at 6.5%, based on a typical interest rate for residential refinancing (Couchlin and Cory). For the price of electricity bought and sold from the grid, $0.08/kWh was used. This price was set by the Western Area Power Administration (WAPA) for the University of California, Davis. The solar radiation input into the Homer Model was based on the longitude and latitude of Davis, California. A price of $5/Watt was set as the price of installed solar PV, and $1/Watt as the price of the converter (Couchlin and Cory). All of the above inputs to the model were held constant for every version of the model in this project.

A major constraint of solar PV is the amount of solar radiation at the property. Davis, California has an average solar radiation of 4.87kWh/m^2 per day (HOMER Energy Modeling Software). Since sunlight is not a resource that can be controlled, areas were identified on the property that have the most area of south-facing, unobstructed sunlight. This process is described in the following paragraph and illustrated in the image below.

Figure 4: Site map of the Domes property with the three areas of potential solar panel locations highlighted in orange. (Source: http://bagginsend.net/location.html)

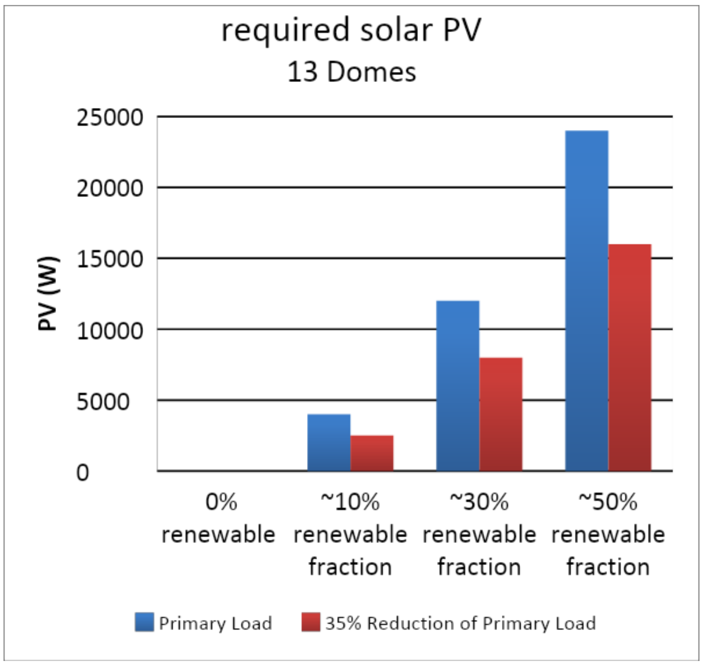
One of the constraints to installing solar PV to reach ZNE at the Domes is the area available for the solar panels. The property was visually inspected and measured for potential areas of solar installation. There were three sites on the property that could serve as future locations for solar panels: two of 1280 square feet and one of 770 square feet. The areas were ranked based on the amount of unobstructed solar radiation and the shade the raised panels could provide to Domies (similar to panels installed to shade vehicle parking). The 1280 square foot area located in the northwest corner of the property was identified to be the best area. This area could support 18kW of solar PV, which would achieve 41% ZNE at the Domes by itself. With all three areas combined, a total of 3,330 square feet could support 47kW of solar PV, and reach 68% ZNE at the Domes (See the table below for a list of all the areas assessed). This 68% ZNE was treated as a maximum percent ZNE achieved through only solar PV application. This area analysis also shaped scenarios in the Homer Model.

Table 5: Possible areas for solar installations.

Max. Available Area	% ZNE	kW of solar PV
1280 sq.ft.	41%	18 kW
2560 sq.ft.	61%	36 kW
3330 sq/ft.	68%	47 kW

The use of the Homer Model was aimed at answering the question: What would it take to get approximately 10%, 30% and 50% of the primary load covered by solar PV? These three scenarios are represented in Homer as a percent renewable fraction, and can also be thought of as percent ZNE achieved through solar PV. Under the inputs described above, the model was run several times. The Homer Model was used to analyze three main project types, each looking at the size and cost of adding solar to the Domes' primary load, a 35% reduction of the primary load (from previous renovation of dome 8), and with incentives to reduce the capital costs of solar PV.

The primary loads of both 1 Dome and 13 Domes were analyzed to determine the size of a solar PV system required to attain 10%, 30% and 50% ZNE. The results were similar because the primary load of 1 Dome was scaled to determine the primary load of 13 Domes. As a higher percent ZNE is achieved, the required PV, total net present cost, and cost of electricity increase. The cost of electricity is defined as the total net present cost per kWh used throughout the project's lifetime.



Primary Load (13 Domes)	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	11	30	50
PV (W)	0	4000	12,000	24,000
Initial Capital	0	24,000	72,000	144,000
O&M	18,187	16,251	12,378	6,568
Salvage	0	-6,350	-19,050	-38,100
Total NPC	18,187	33,901	65,328	112,468
COE	0.080	0.149	0.270	0.384

Figure 5: Required Solar PV for 13 Domes

According to metered data of Dome 8 from February and March, the scenario 1 upgrades outlined in the load reduction section decreased the primary load by 35% (Brum). Based on metered data collection from Dome 10, the Homer Model averaged 11.82kWh per day of electricity consumption. As a result of data corruption in the metering unit at dome 8, the average consumption of Dome 10 was scaled by 35% in the Homer Model to represent consumption in Dome 8. The result was an average 7.68kWh per day consumption for Dome 8.

By comparing Dome 8 to Dome 10, it was found that less solar PV is required to achieve the same % ZNE. Additionally, with less solar PV installed, the total NPC is lower. See the table below for the detailed comparison of Dome 8 and 10.

Table 6: Comparison of Dome 8 &10

	Dome 8		Dome 10	
	PV(W)	Total NPC ($)	PV(W)	Total NPC ($)
~10% renewable fraction	250	$2,005	150	$1,254
~30% renewable fraction	700	$3,773	500	$2,629
~50% renewable fraction	1400	$6,523	1000	4,593

This comparison shows the positive effect of reducing the primary load on the size and cost of a solar PV system. However, these results do not reflect the costs of the completed retrofits to Dome 8, only the costs representing the installation of solar PV. Since Dome 8 is unique in that it is the only Dome with these retrofits, the effects of combining a 35% primary load reduction and solar PV installation into one project were also analyzed. By combining the load reduction and solar installation, the fixed capital costs of the retrofit are included in the resulting total NPC of the model.

The 35% reduction of the primary load was analyzed for both 1 dome and 13 domes. The Homer Model determined the size of a solar PV system required to attain 10%, 30% and 50% ZNE. The results of the model are in the same output terms as the first analysis: PV size, total NPC and cost of electricity. The single dome and 13 dome analysis have similar results for the required PV to reach the 10%, 30% and 50% ZNE scenarios, due to the scaling mentioned previously. Comparing the 35% reduction in primary load to a primary load without any load reduction, there is less solar PV required to reach the same percent ZNE. However, the total NPC of the 35% load reduction and solar PV installation is significantly higher than installing solar PV on a primary load that has not been reduced.

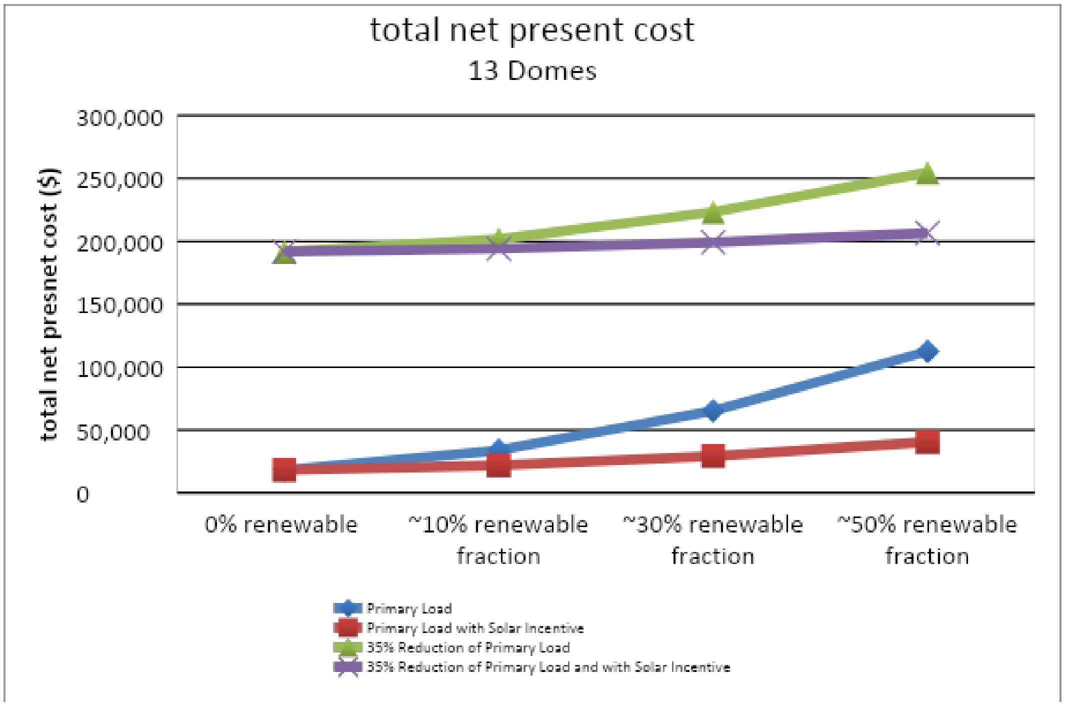


Figure 6: Total Net cost for 13 Domes

The significant increase in costs between adding solar PV to a dome with a primary load and dome with a 35% reduced primary load are in the fixed capital costs of the retrofits. The capital costs of the retrofits to reduce the primary load are included in the model as fixed capital costs, and therefore are added to the dynamic capital costs of the solar PV. Therefore, as the capital costs of the installed solar PV change depending on the percent ZNE achieved, the capital cost of the retrofits is fixed for every % ZNE. The fixed capital costs lead to an increase total NPC, mimicked in the cost of electricity for the 10% and 30% ZNE scenarios. However with the 35% primary load reduction, the cost of electricity decreases for the 50% ZNE scenario. For the combined solar PV and reduced load the cost of electricity to reach 50% ZNE is lower than the cost of electricity to attain a 10% ZNE. This result occurs in the analysis of both 1 Dome and 13 Domes, and reflects the cost effectiveness of investing in more solar PV with simultaneous load reduction.

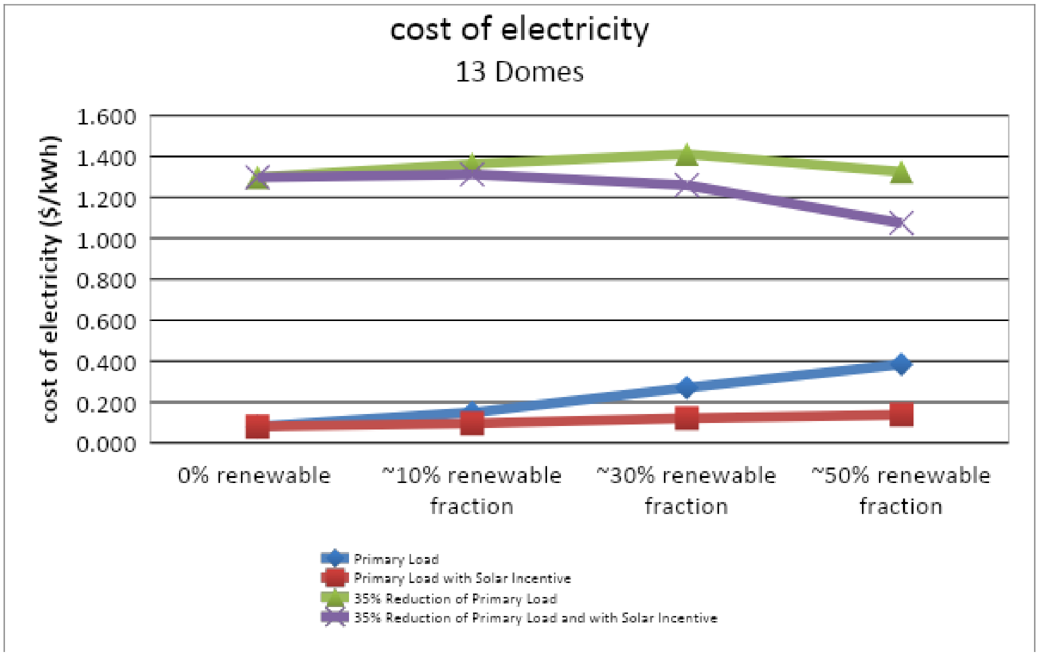
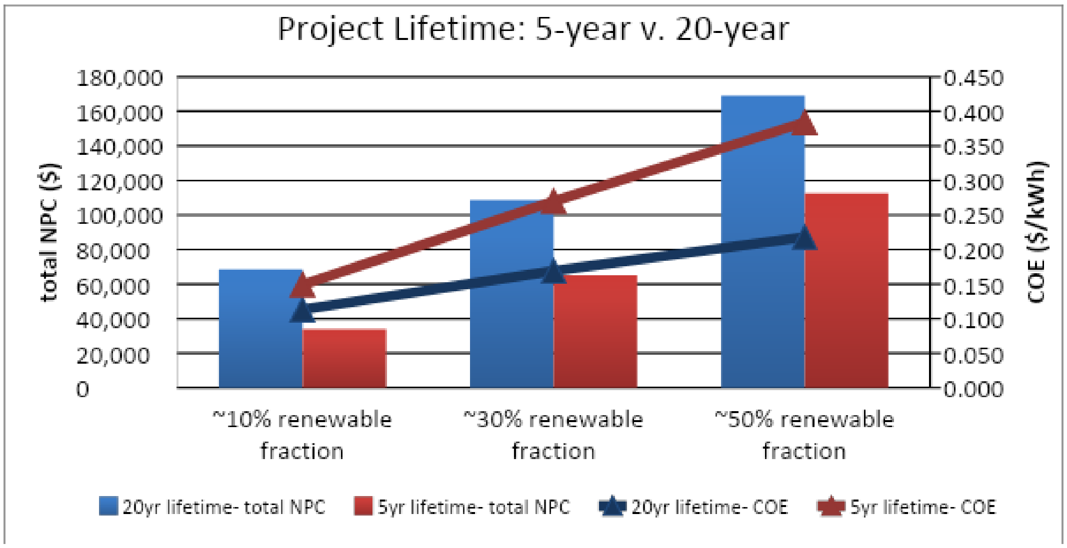


Figure 7: Cost of Electricity for 13 Domes

The last project type analyzed with the Homer Model included incentives for solar PV installations. These incentives can come from the California State Solar Incentive Program, under which PG&E offers rebates for solar installations, the Federal Investment Tax Credit, power purchase agreements, solar leasing programs, and academic grants (PG&E). We examined a scenario in which 50% of the solar PV capital costs would be covered by a combination of the above incentives. With the incentives covering 50% of the capital costs, the total net present costs significantly decreased. The results showed there was a higher decrease in the total net present costs with higher percentages of ZNE attained. For example, the largest difference in total NPC between the primary load and primary load with the solar incentive is at the 50% ZNE scenario. There is a 64% decrease in the total NPC of the primary load and the primary load with solar incentives in the 50% ZNE scenario. This 65% reduction in total NPC occurs in the analysis of 1 and 13 Domes.

With the incentives applied to the 35% primary load reduction project, there is also a reduction in the total NPC. However, the difference between the 35% reduced primary load and the 35% reduced primary load with solar incentives is only 19% at the 50% ZNE scenario. The effect of the incentive is lower in the 35% primary load reduction because the incentive applies only to the capital costs of the solar PV. Therefore, the fixed capital costs required for the 35% load reduction are not affected by the incentives. See the tables in the appendix for more detailed information.

For the purposes of the client, a model to examine different the project lifetimes was conducted using the Homer Model. This evaluation kept the size of solar PV constant, and used a primary load with no reductions/retrofits. The only manipulated variable was the project lifetime, which was changed from 5 to 20 years. With a 20-year project lifetime the total NPC and cost of electricity are higher compared to a 5-year project lifetime. However, the percent increase in total NPC from 11% ZNE to 30% ZNE (achieved through solar PV generation) is lower for a 20 year project lifetime. This result is also true for the total NPC from 30% to 50% ZNE. Attention should be called to the cost of electricity between the two project lifetimes. The cost of electricity is the total NPC divided by the total kWh used throughout the lifetime of the project. On average, the cost of electricity for a 20-year project is 35% lower compared to a 5-year project lifetime. This average was taken from the 11%, 30% and 50% ZNE scenarios for cost of electricity. See the tables below for more details.

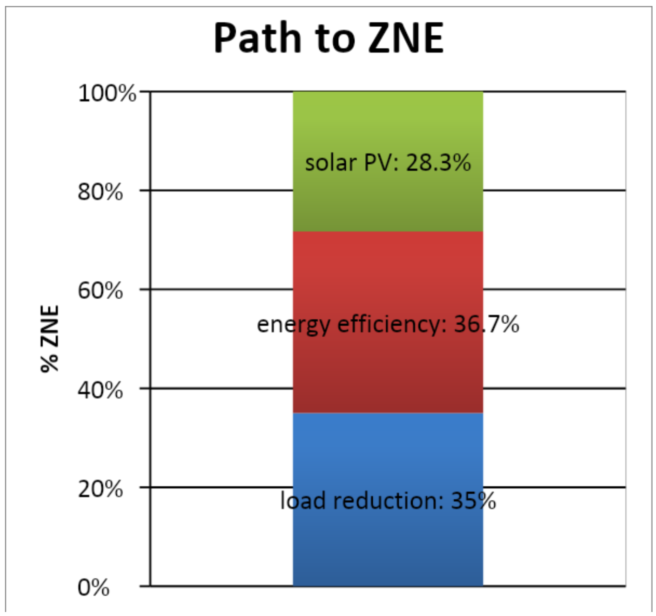


5 v. 20yr project lifetime	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction	Average
COE	24	37	43	35

Figure 8: Comparison of 5 Year and 20 Year Project Lifetimes

Path to ZNE

The final portion of our project was to outline a path to ZNE at the Domes. We used a combination of energy efficiency, load reduction and renewable generation to achieve 100% ZNE. One of our scenarios includes the first 35% ZNE attained through load reductions. This would entail retrofits similar to Dome 8 (a new water heater, windows/doors and insulation). The expected cost of this phase of ZNE is $15,000. The next 36.7% ZNE would be reached with energy efficiency measures, which can include a new heater and more efficient appliances. The predicted cost for this step to ZNE is $48,000. The last 28.3% ZNE would be attained with solar PV generation. This percent ZNE would require 1,100W of PV, determined through the Homer Model with a 5-year project lifetime and resulting total net present cost of $61,399. The methods to reach ZNE are ordered according to price/capital cost, with the cheapest options performed first.



	% of primary load	kWh of primary load	Capital Cost
Load Reduction	35.00	19,146.75kWh	$196,300
Energy Efficiency	36.70	20,059kWh	$107,300
Solar PV	28.30	15,499.25kWh	$61,400

Figure 9: Breakdown of one possible Path to ZNE (for 13 Domes)

Future Work

Our research and assessment of ZNE in the Domes is a continuation of a previous Energy Audit Report performed by Brum et al. Here a few areas of further research are outlined as a possible future extension of our research. Most of these topics are ideas that, due to time limitations, we did not have the chance to research and analyze. The Brainstorming List includes several ideas we wanted to examine, including grouped utilities and itemizing residents' utility bills from the rent to incentivize energy consumption. Our full brainstorming list can be found in the Appendix.

We saw that incentives or grants have large potential in reducing the capital costs of getting to ZNE. If time permitted, we would have explored incentives for solar PV and other renewable generation options.

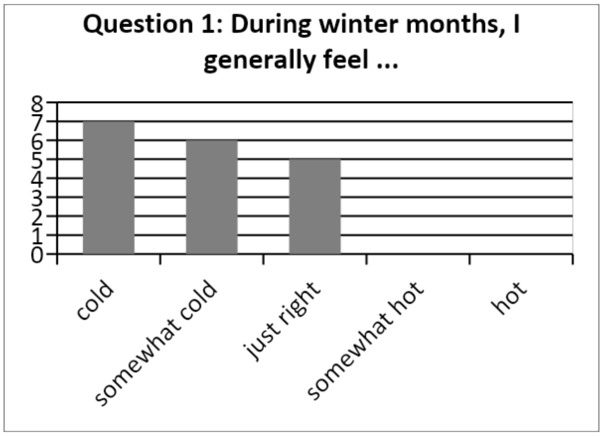
The data we input into Homer was based off of only one month of raw metering data from Dome 10. With a larger period of raw data, we would have been able to make fewer assumptions, and increase the accuracy of our model. Additionally, metered data from Dome 8 was not available at the time of our project due to data corruption, but in the future its use would increase the accuracy of the analysis.

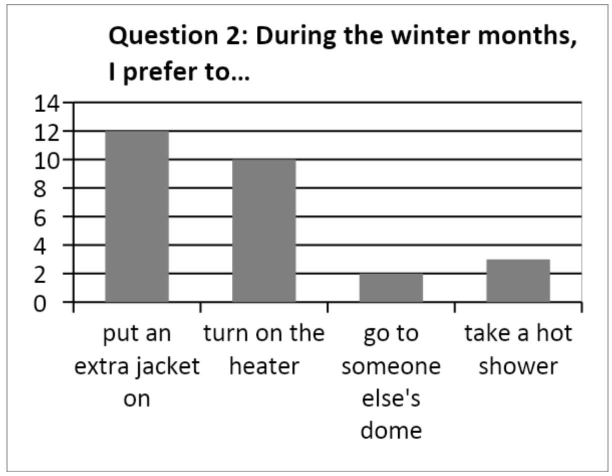
Our project analysis assumed similar living habits among residents and full occupancy of the Domes. However, throughout the project we began to note the different lifestyles of the Dome 8 and Dome 10 occupants. We recognized that the residents in Dome 8 occupied their dome at a much lower frequency than the residents in Dome 10. This difference in occupancy may have affected our interpretation of the data. To account for this difference we would like to utilize another survey to clarify the electricity usage of Dome 8 and 10 residents specifically. The purpose of this survey would be to normalize the data between Dome 8 and 10, thereby eliminating anecdotal information from each of the Dome's two residents. This survey information would insure that one dome is not an anomalous electricity user and would improve the accuracy of analysis and results.

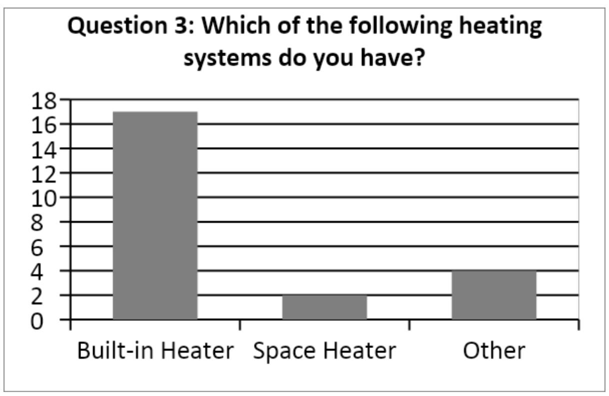
Lastly, we would have liked to conduct interviews with the Dome residents to determine their perspective on a few top scenarios and components to reach ZNE. The results of these interviews would be used to create an evaluative matrix of a path to ZNE components we researched in this project. Potential categories of an evaluative matrix would include sustainability, increase in service, and potential support from the residents. This style of evaluative matrix would approach the problem statement from the point of view of the residents and their quality of life. The next phase of this project would be more service-oriented towards the residents. Ultimately, the matrix would help tailor a path to ZNE to the residents, and ensure its completion and longevity. Our future goal is to integrate our innovative solutions with the community and engage the Domies personally in the path to ZNE.

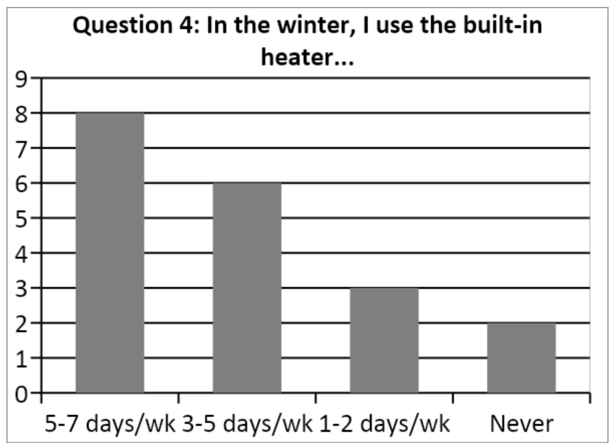
Appendix:

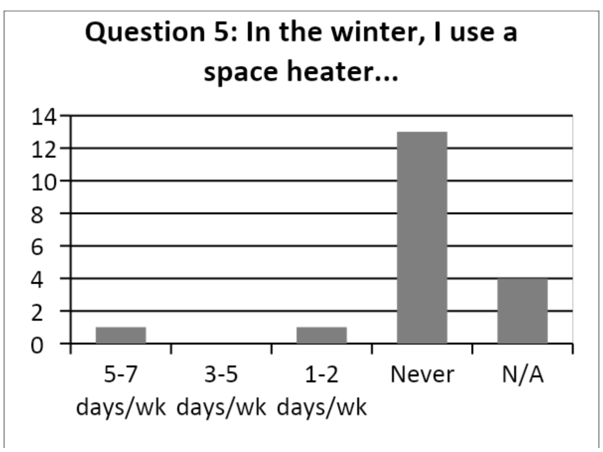
Survey and Results

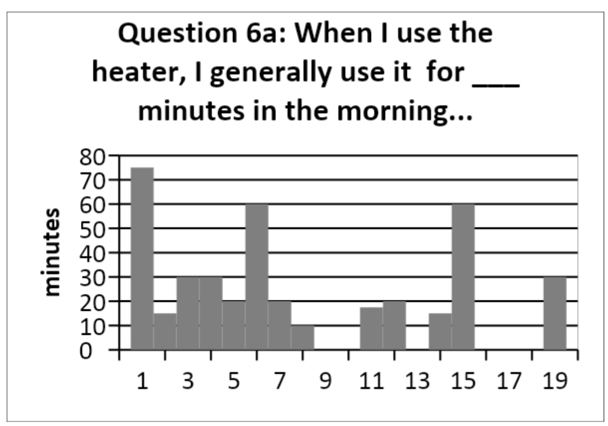


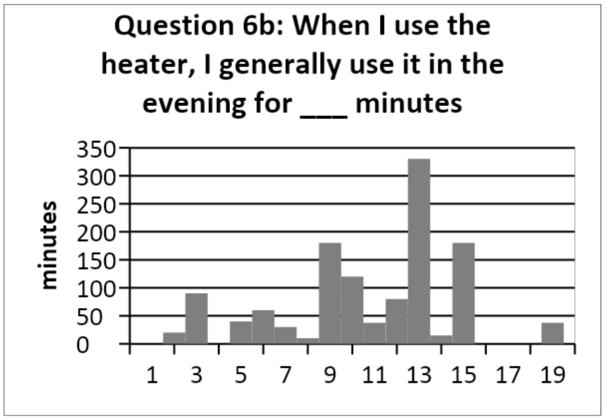


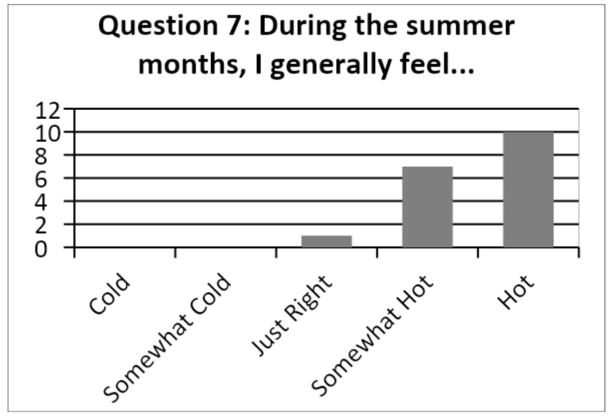


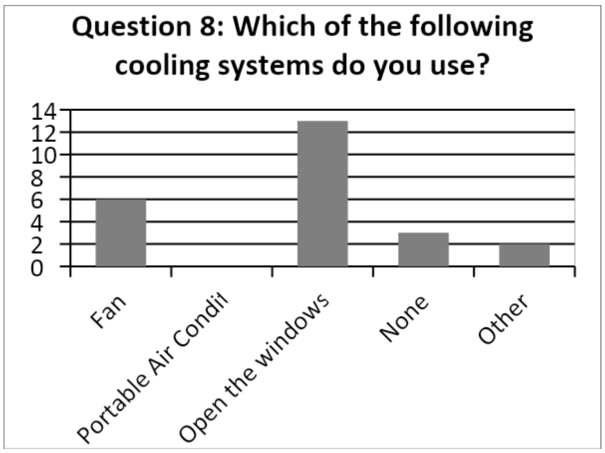


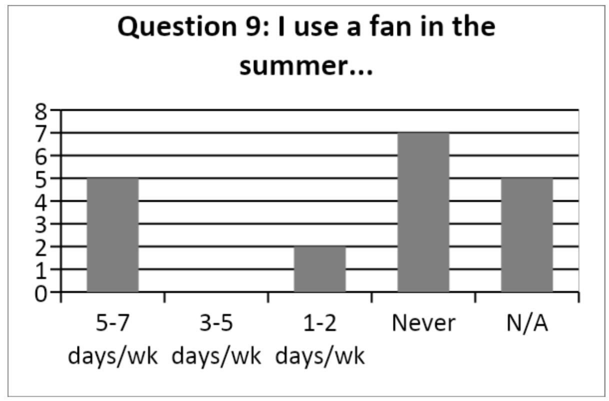


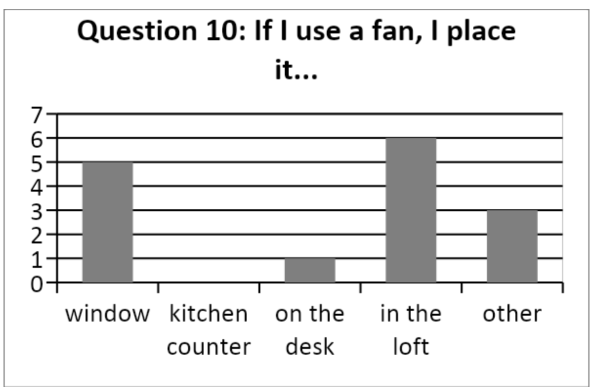


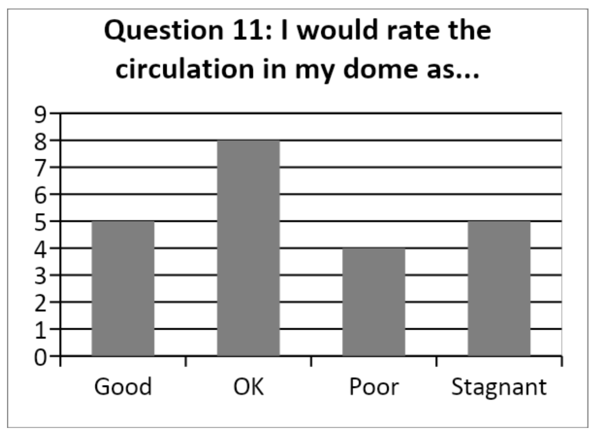

Question 6b: When I use the heater, I generally use it in the evening for ___ minutes
minutes
350
300
250
200
150
100
50
0
1 3 5 7 9 11 13 15 17 19

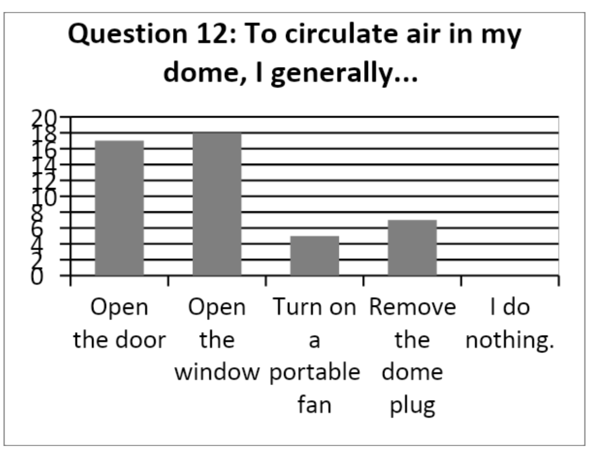

Question 7: During the summer months, I generally feel...
12
10
8
6
4
2
0
Cold
Somewhat Cold
Just Right
Somewhat Hot
Hot

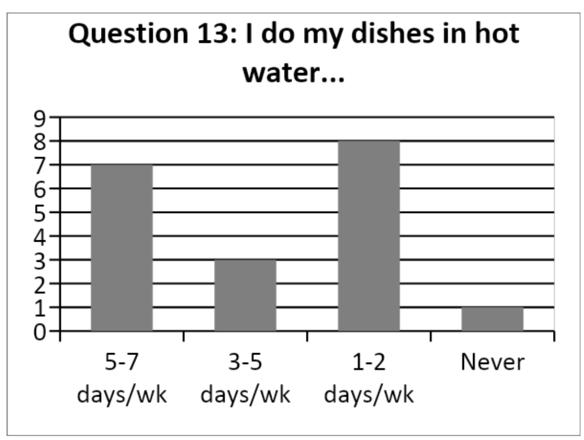

Question 8: Which of the following cooling systems do you use?
14
12
10
8
6
4
2
0
Fan
Portable Air Condit
Open the windows
None
Other

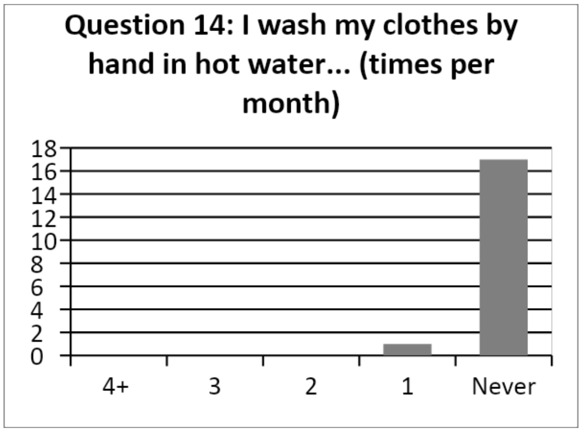

Question 9: I use a fan in the summer...
8
7
6
5
4
3
2
1
0
5-7 days/wk
3-5 days/wk
1-2 days/wk
Never
N/A

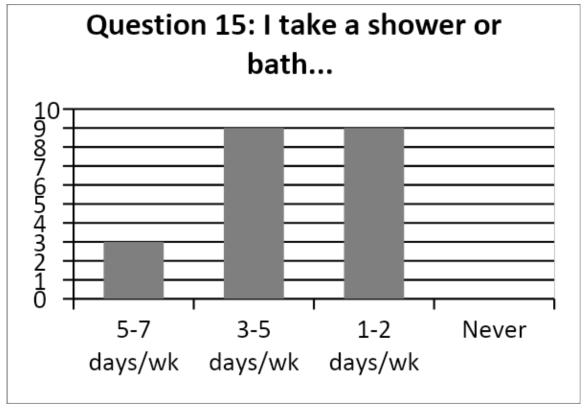

Question 10: If I use a fan, I place it...
7
6
5
4
3
2
1
0
window
kitchen counter
on the desk
in the loft
other

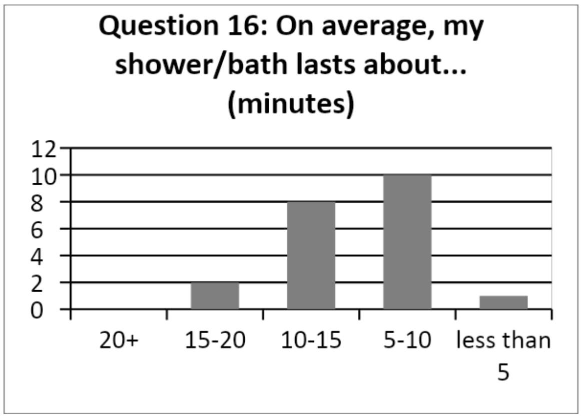

Question 11: I would rate the circulation in my dome as...
9
8
7
6
5
4
3
2
1
0
Good
OK
Poor
Stagnant

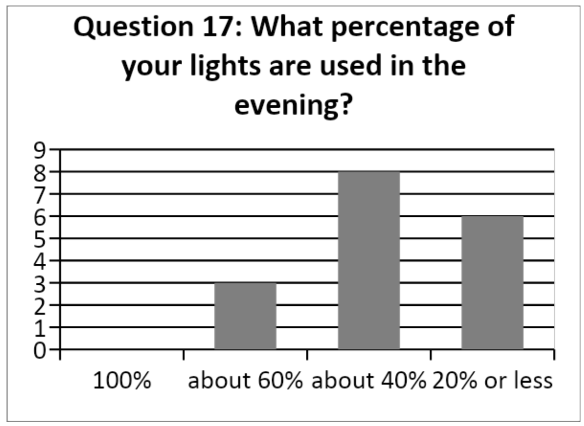

Question 12: To circulate air in my dome, I generally...
Open the door
Open the window
Turn on a portable fan
Remove the dome plug
I do nothing.

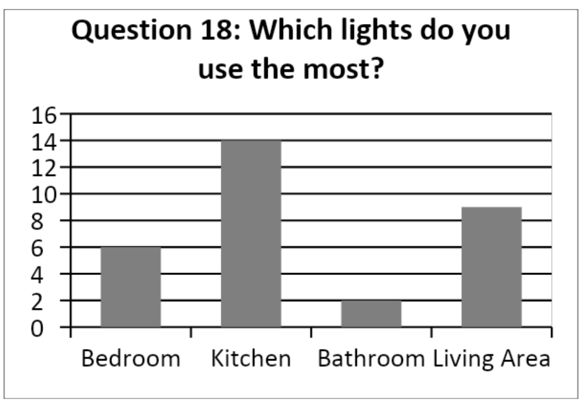

Question 13: I do my dishes in hot water...
9
8
7
6
5
4
3
2
1
0
5-7 days/wk
3-5 days/wk
1-2 days/wk
Never

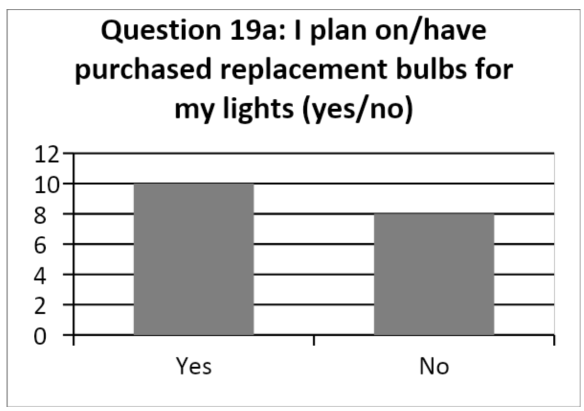

Question 14: I wash my clothes by hand in hot water... (times per month)
0 2 4 6 8 10 12 14 16 18
4+ 3 2 1 Never

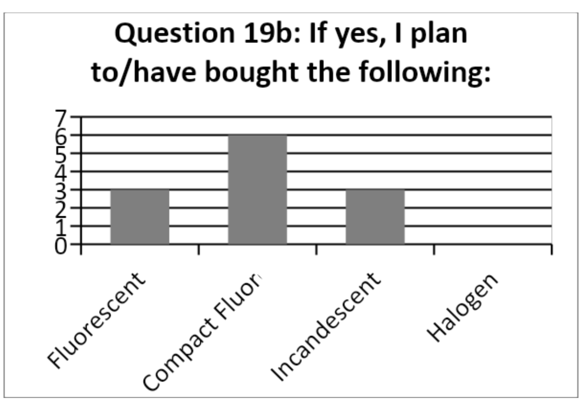

Question 15: I take a shower or bath...
0 1 2 3 4 5 6 7 8 9 10
5-7 days/wk 3-5 days/wk 1-2 days/wk Never

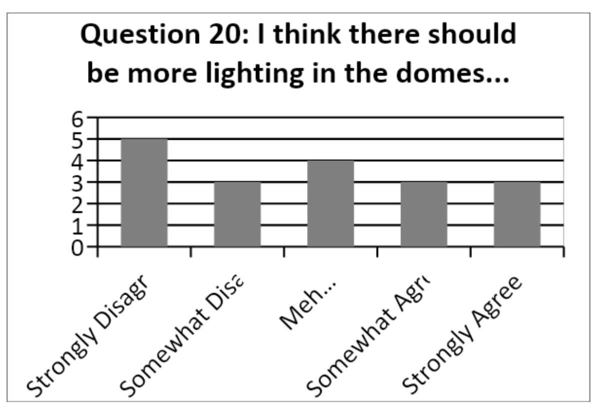

Question 16: On average, my shower/bath lasts about... (minutes)
0 2 4 6 8 10 12
20+ 15-20 10-15 5-10 less than 5

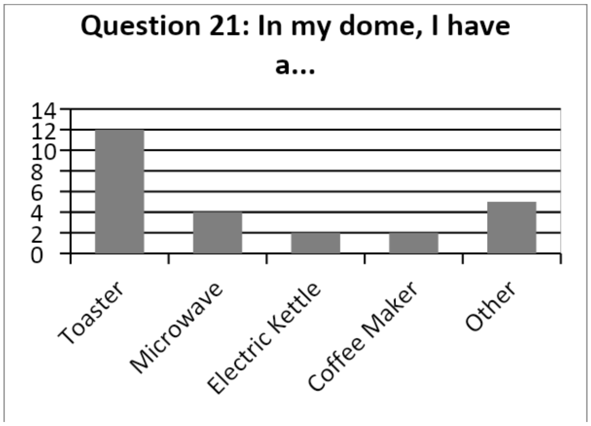

Question 17: What percentage of your lights are used in the evening?
0 1 2 3 4 5 6 7 8 9
100% about 60% about 40% 20% or less

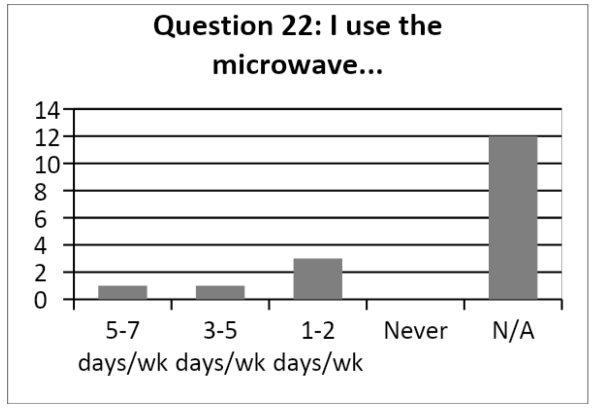

Question 18: Which lights do you use the most?
0 2 4 6 8 10 12 14 16
Bedroom Kitchen Bathroom Living Area

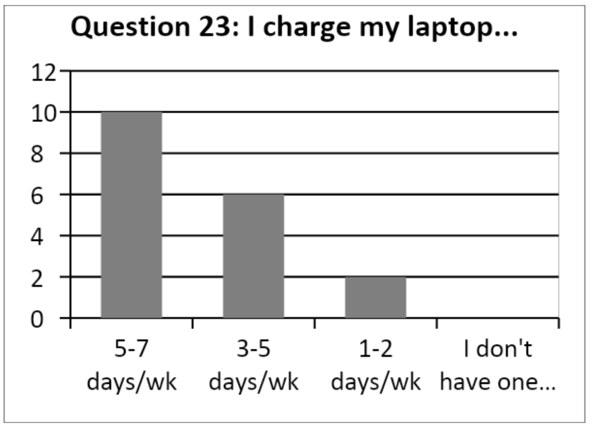

Question 19a: I plan on/have purchased replacement bulbs for my lights (yes/no)
0 2 4 6 8 10 12
Yes No

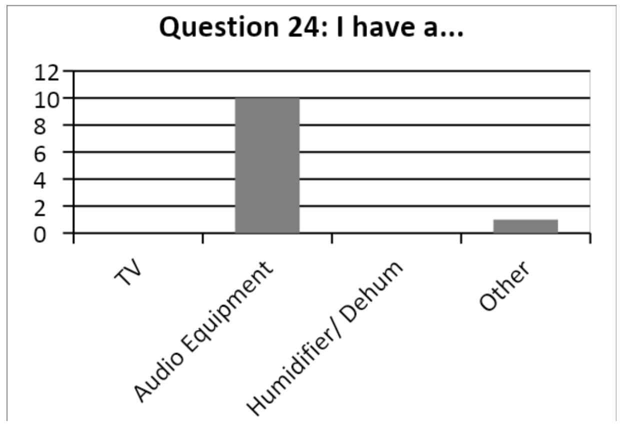

Question 19b: If yes, I plan to/have bought the following:
0 1 2 3 4 5 6 7
Fluorescent
Compact Fluor
Incandescent
Halogen

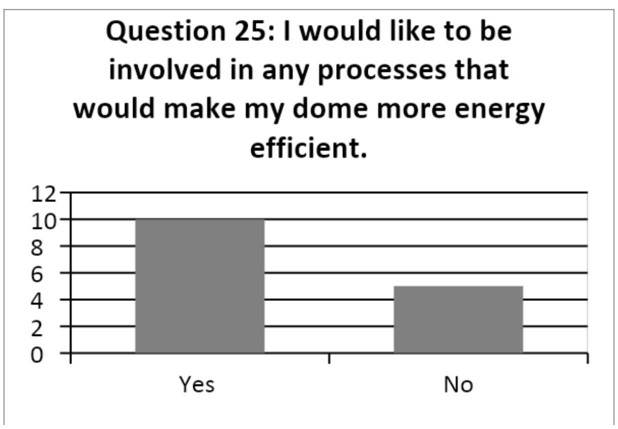

Question 20: I think there should be more lighting in the domes...
0 1 2 3 4 5 6
Strongly Disagr
Somewhat Disa
Meh...
Somewhat Agr
Strongly Agree

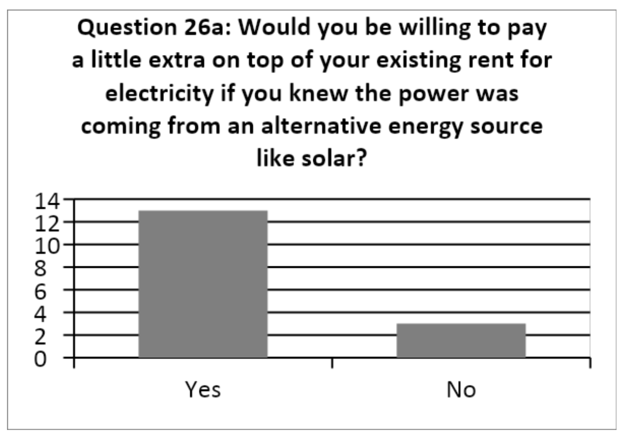

Question 21: In my dome, I have a...
14
12
10
8
6
4
2
0
Toaster
Microwave
Electric Kettle
Coffee Maker
Other

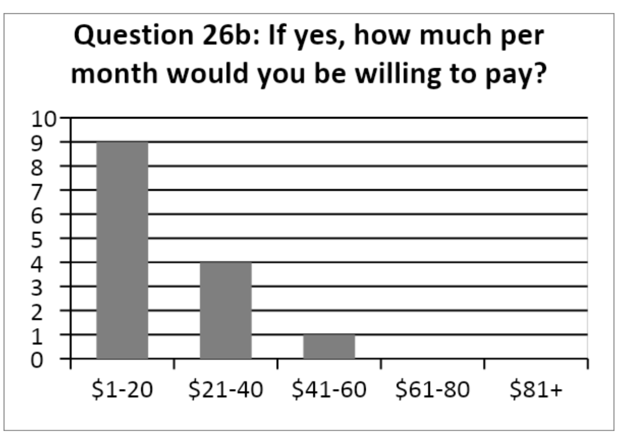

Question 22: I use the microwave...
14
12
10
8
6
4
2
0
5-7 days/wk
3-5 days/wk
1-2 days/wk
Never
N/A

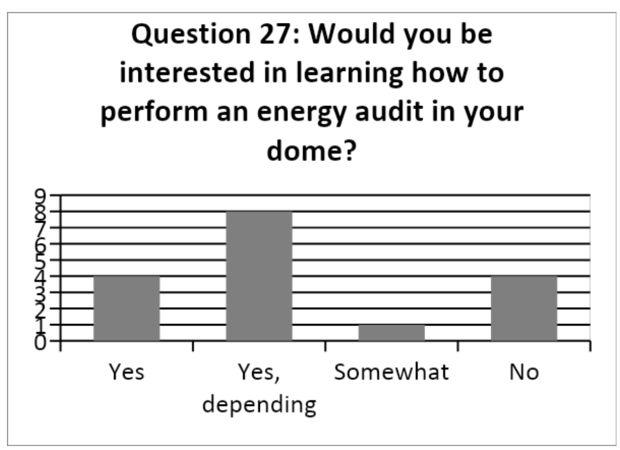

Question 23: I charge my laptop...
12
10
8
6
4
2
0
5-7 days/wk
3-5 days/wk
1-2 days/wk
I don't have one...


Question 24: I have a...
12
10
8
6
4
2
0
TV
Audio Equipment
Humidifier/ Dehum
Other


Question 25: I would like to be involved in any processes that would make my dome more energy efficient.
12
10
8
6
4
2
0
Yes
No


Question 26a: Would you be willing to pay a little extra on top of your existing rent for electricity if you knew the power was coming from an alternative energy source like solar?
14
12
10
8
6
4
2
0
Yes
No


Question 26b: If yes, how much per month would you be willing to pay?
10
9
8
7
6
5
4
3
2
1
0
$1-20
$21-40
$41-60
$61-80
$81+


Question 27: Would you be interested in learning how to perform an energy audit in your dome?
9
8
7
6
5
4
3
2
1
0
Yes
Yes, depending
Somewhat
No

Appliances

Capacities:	
Cooling	12,000 BTU/h
Outdoor Design Temp. *F° DB/WB*	95/75
Heating	16,000 BTU/h
Outdoor Design Temperature *F° DB/WB*	47/43
HSPF	11.0
SEER	22.0
EER *Cooling/Heating*	12.5/12.5
Voltage/Frequency/Phase	208-230/60/1
Indoor Unit:	
Noise Level Cooling *db (A) - H/ M/ L/ Q*	40/ 36/ 30/ 25
Noise Level Heating *db (A) - H/ M/ L/ Q*	40/ 36/ 31/ 25
Weight	18 lbs.
Outdoor Unit:	
Noise Level *Cooling/Heating*	49/49
Recommended Fuse Size	15A
Min. Ampacity	5.9A
Running Current *Cooling*	6.5A
Running Current *Heating*	9.0A
Weight	71 lbs.
Refrigerant Piping:	
Max Ht. Difference	49 ft.
Max Total or Combined Length	66 ft.
Discharge Vapor Line (O.D.)	1/4 in.
Suction (O.D.)	3/8 in.

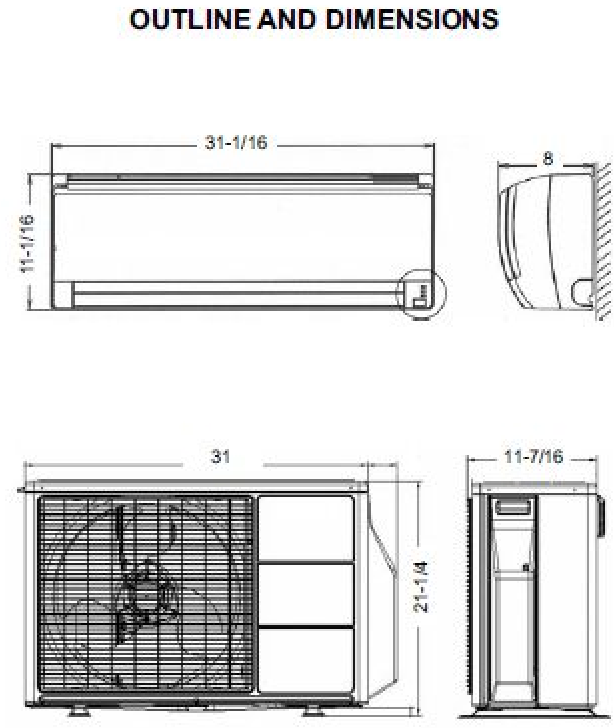


Figure: Specifications for Fujitsu 12RLF (Fujitsu, 2013)

Solar PV

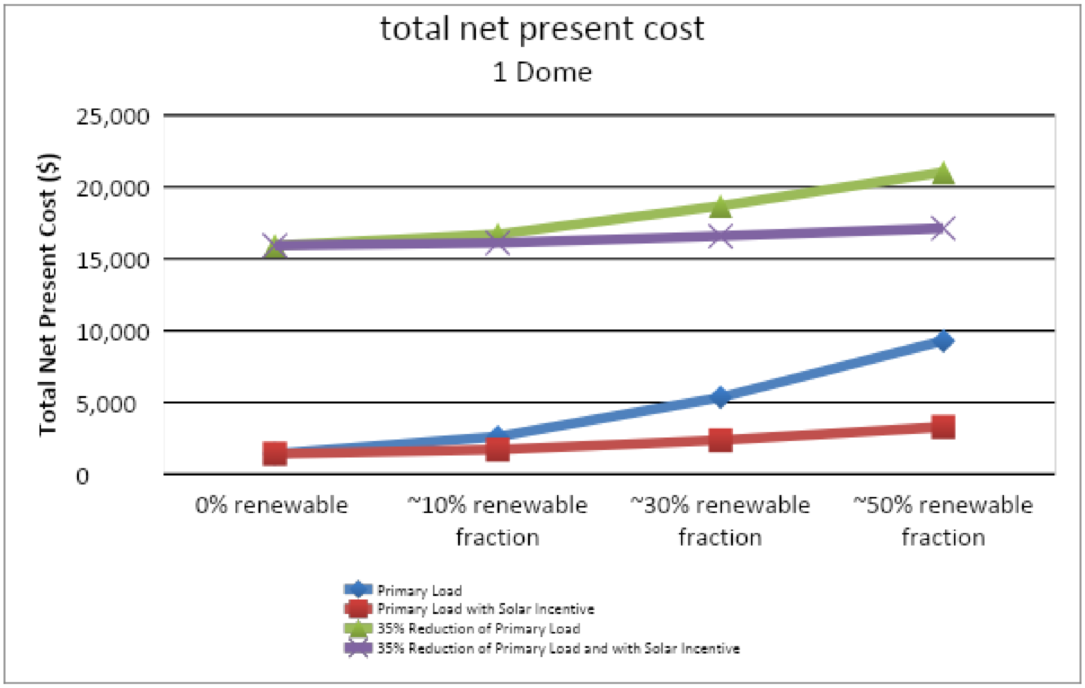
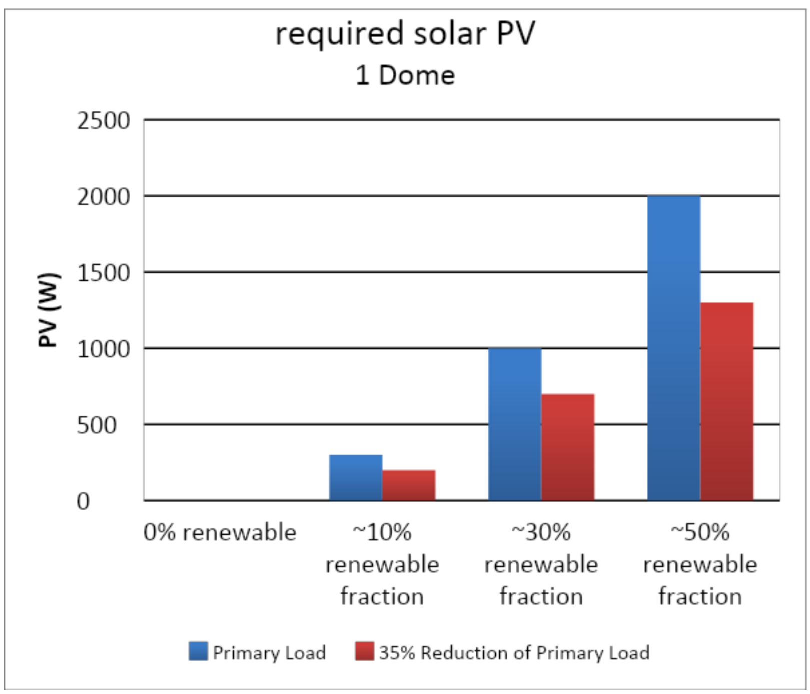


Figure : Total Net Present Cost for One Dome



Primary Load (1 Dome)	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren. Frac.	0	10	31	51
PV (W)	0	300	1000	2000
Initial Capital	0	1,800	6,000	12,000

O&M	1,432	1,287	948	464
Salvage	0	-476	-1,587	-3,175
Total NPC	1,432	2,610	5,360	9,289
COE	0.080	0.146	0.278	0.394

Figure: Required Solar PV for One Dome

Table:

35% Reduction of Primary Load (13 Domes)	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	10	31	50
PV (W)	0	2500	8000	16,000
Initial Capital	180,000	195,000	228,000	276,000
O&M	11,822	10,611	7,948	4,075
Salvage	0	-3,969	-12,700	-25,400
Total NPC	191,822	201,642	223,248	254,675
COE	1.298	1.363	1.412	1.325

Table:

35% Reduction of Primary Load (1 Dome)	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	10	33	51
PV (W)	0	200	700	1300
Initial Capital	15,000	16,200	19,200	22,800
O&M	931	834	592	301
Salvage	0	-317	-1,111	-2,064
Total NPC	15,931	16,716	18,681	21,038
COE	1.369	1.435	1.472	1.372

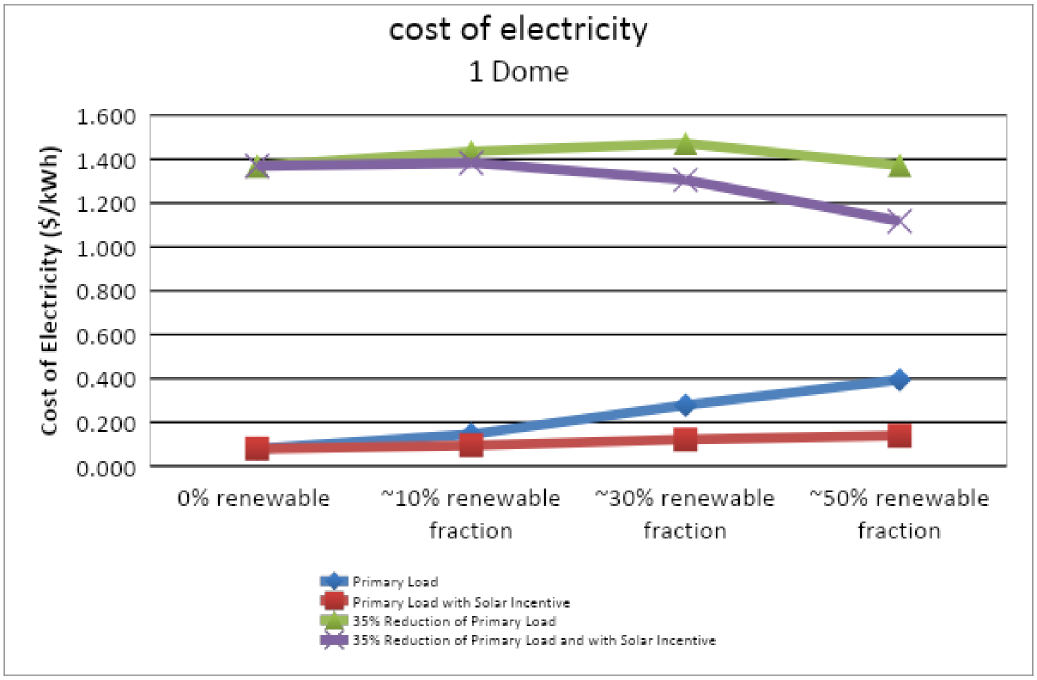


Figure 6: Cost of Electricity for One Dome

Table:

Primary Load w/ Solar Incentive	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	10	31	51
PV (W)	0	300	1000	2000
Initial Capital	0	900	3,000	6,000
O&M	1,432	1,294	955	471
Salvage	0	-476	-1,587	-3,175
Total NPC	1,432	1,718	2,368	3,296
COE	0.080	0.095	0.122	0.139

Table:

Primary Load with Solar Incentive	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	11	30	50
PV (W)	0	4000	12,000	24,000
Initial Capital	0	12,000	36,000	72,000
O&M	18,202	16,265	12,392	6,582
Salvage	0	-6,350	-19,050	-38,100
Total NPC	18,202	21,915	29,342	40,483
COE	0.080	0.096	0.121	0.138

Table:

35% Reduction of Primary Load and with Solar Incentive	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	10	33	51
PV (W)	0	200	700	1300
Initial Capital	15,000	15,600	17,100	18,900
O&M	931	834	592	301
Salvage	0	-317	-1,111	-2,064
Total NPC	15,931	16,116	16,581	17,138
COE	1.369	1.383	1.306	1.117

Table:

35% Reduction of Primary Load and with Solar Incentive	0% renewable fraction	~10% renewable fraction	~30% renewable fraction	~50% renewable fraction
Ren Frac	0	10	31	50
PV (W)	0	2500	8000	16,000
Initial Capital	180,000	187,500	204,000	228,000
O&M	11,822	10,611	7,948	4,075
Salvage	0	-3,969	-12,700	-25,400
Total NPC	191,822	194,142	199,248	206,675
COE	1.298	1.312	1.260	1.075

Table: 5 Year and 20 Year Calculations

5 Year Project Lifetime			
Ren Frac	11	30	50
PV (W)	4000	12,000	24,000
Initial Capital	24,000	72,000	144,000
O&M	16,251	12,378	6,568
Salvage	-6,350	-19,050	-38,100
Total NPC	33,901	65,328	112,468
COE	0.149	0.270	0.384

20 Year Project Lifetime			
Renewable Fraction	11	30	50
PV (W)	4,000	12,000	24,000
Initial Capital	24,000	72,000	144,000
Replacement	1,279	3,836	7,671
O&M	43,126	32,857	17,453
Total NPC	68,405	108,693	169,124
COE	0.113	0.169	0.218

Other Load Reduction Options:

The Power of Working Communally

Each dome currently functions as its own stand-alone house: one refrigerator, one water heater, one space heater, and one stove in each dome, for a total of thirteen of each. There are only two communal buildings: a dome being repurposed into an office, and the Yurt, where communal dinners are held most nights of the week. The focus of the Domes as an intentional community means that residents may be more willing to share resources, such as hot water or refrigerators, and the current state allows plenty of room for consolidation.

Hot Water

The first place to start is hot water. The water heaters consume an estimated one third of the electricity used at the domes (Brum). Survey data (see Appendix) shows that residents at the Domes do not use hot water every day: they take showers and wash dishes on average every other day. This means that at least half the days of the week, the water heater is not being used for its main service, even though it is always maintaining the tank full of hot water.

Hot Water Setups					Total Savings	
	Capital Cost ($)	Energy Savings (kWh/year)	Energy Savings ($/year)	% Dome Energy Reduction	5 years	20 years
ES80H123-45D (x2)	$1,126.00	6082	$486.56	11%	$1,306.80	$8,605.20
Current Setup		0	$0.00	0%	$0.00	$0.00
Remove 1/2 WH		7813	$625.04	14%	$3,125.20	$12,500.80
Remove 1/3 WH		10417	$833.36	19%	$4,166.93	$16,667.73
Solar Thermal	$9,300.00	15626	$1,250.08	29%	-$3,049.60	$15,701.60
Dome Annual Energy Estimate		54704				

The simplest way to reduce the hot water load at the domes would be to remove half of the hot water tanks, and leave every other dome with a hot water heater or even remove one third of the hot water heaters. These measures would reduce the electric load of the domes overall without significant decrease in service, except having to walk out to another dome to take a hot shower. Removing half of the hot water heaters results in a 14% decrease in the electricity used in the Domes community, and removing one third of the water heaters leads to a 19% reduction in load, with no capital costs. Thus the energy savings would translate into monetary savings immediately upon implementation.

Another option is to remove the hot water tanks in each dome and place water heating in a central location. Using estimates from survey data the amount of hot water used at the domes each day is about 180 gallons for showering and another 50 gallons for dishwashing (see Appendix for calculations). At this daily use rate, making available one hundred and fifty gallons of hot water in tanks should sufficiently provide hot water for the whole community since not everyone will be showering simultaneously.

The largest size water heater and tank combinations currently available for residential use are 80 gallons, so two should sufficiently cover the expected hot water load. Using an energy star labeled Whirlpool water heater (ES80H123-45D) with an estimated annual energy usage of 4772 kWh, energy and financial savings were calculated (WhirlpoolWaterHeaters.com). Surprisingly, the monetary and energy savings from taking this measure was significantly less than removing half of the water heaters from The Domes.

Finally, the option of introducing a hot water system maintained by solar thermal panels was explored. Currently, a system is in place that is used to heat the floor of the communal yurt space where dinners are held. With retrofits, it would be possible to use this with a well-insulated tank to provide water for showering or dishwashing. The costs have not yet been analyzed, and should be done at a future time to assess the feasibility of this option. Here, the costs of buying an extra hot water heater system are explored, along with the savings that can be achieved. The system would use two Solar Roofs Skyline3 Systems, each with an 80 gallon hot water tank and 40 square feet of solar collectors at a total cost of around $9300 for two, providing a total of 160 gallons of hot water storage (SolarRoofs.com). This is by far the most expensive system initially. It also has the greatest payback over its lifetime of 20+ years, however. Due to the nature of the system, it also has the greatest grid energy use reduction making it very attractive for achieving Zero Net Energy at the Domes.

Communal Kitchen

Food brings people in the Domes community every step along its process, from planting and weeding the community gardens, to harvesting, cooking, and finally eating together four nights a week. The only part of the process that currently does not occur communally is the cooking process, which each domes resident does individually, even though four to six people cook each night of community meals. As a result, interest has been expressed in creating a communal space for cooking.

Biogas Generation

The use of food waste and manure as a source of methane has recently been gaining traction in the developed nations around the world, though systems have been in place in many developing nations, as a source of energy for rural agricultural homes. Most of the home systems rely on the readily available resource of livestock manure, though the use of plant materials has been researched as a viable alternative, albeit with fewer published case studies.

A biogas digester (also known as an anaerobic digester) allows food to decompose in an airtight space, producing a combination of methane, carbon dioxide, and small amounts of other gases, which can be refined and used as any other natural gas. While this can be used to produce electricity, it is much more efficient to use it directly in producing heat for cooking or water heating. The byproduct of the process is liquid compost that can be used to fertilize any of the many garden spaces around the Domes.

The system explored in calculating energy savings at The Domes here is known as a Fixed Dome digester, for which many case studies and build guides can be found. It can be built by community members, scaled to any size and is easy for any member of the community to use at will.

Use has shown that 0.5 cubic meters of gas is enough to cook on a stove for about one hour (Shaun). Designing a system to offset the cooking that takes place for community dinners, 3 cubic meters (6 cooking hours) of gas would have to be produced each night to handle the load. A system of that size would offset about 15.6 kWh of electricity use at the domes each day, adding up to about $450 every year, a 10% reduction of The Domes electricity load.

These systems have been designed for developing nations, so the cost to gather materials and build them is relatively low: just over $400 for this size. In a year, the digester would pay for itself (Family). The Domes already produces enough feedstock to maintain such a system – humanure from 10-15 people or 6 kg (13.2 lbs) of food waste (Gladstone), – meaning that there would be no cost to produce the gas once the initial investment is made, aside from occasional maintenance. Other costs that would be associated with the system include a food processor to make sure that the feedstock is the correct size to be digested, a ‘scrubber’ that uses water to refine the gas and remove impurities, and a stovetop on which to cook, along with the pipes and valves to transport the gas. These bring the initial cost of the entire system to about $550, the cost of electricity saved in less than 1.2 years of the biogas digester’s projected lifetime. Based on community interest in cooking with such a system, and availability of more feedstock, the digester can be built larger (see appendix K for pricing).

Refrigerator

With a communal kitchen comes the need for food storage in the space. The simplest manner of doing this by installing a large commercial fridge and freezer that might eventually allow the space to be used as a commercial or cooking kitchen for The Domes community and the larger university or Davis community. In the context of Domes energy reduction measures, it is also useful to look at alternative methods that may not necessarily involve the communal kitchen.

Currently, each Domes resident has about five cubic feet of combined refrigerator and freezer space, though there is no data on the amount of space that is actually used. This could be replaced with a 72 cubic foot commercial refrigerator (True TS-72) and a 35 cubic foot commercial freezer (True T-35F), which results in about 4 cubic feet of space available for each resident. Although there will be less space, hopefully having all the residents storing food together will cause residents to buy more food together, and use the space more efficiently. The purchase of the commercial equipment is a relatively expensive, at $4200 for the fridge and $3500 for the freezer (estimated to use 993 kWh/year and 1055 kWh/year respectively) (Restaurant Supplies). Compared to the current setup, the analysis period of 5 years, and even the estimated fridge lifetime of twelve years (Commercial Refrigerators and Freezers) is not economically viable. The main reason to incur such a cost would be to use the space as a commercial teaching kitchen and/or some other Domes-based food business.

	($)	($/year)	(kWh/year)	($/year)	Total Savings		($)
Fridge Model	Initial cost	Maintenance	Annual Energy Savings	Annual Savings	5 year net	12 year net	20 year net
TS-72	$4,214.77	$156.00	-		-	-	-
T-35F	$3,551.13	$156.00	-		-	-	-
			1917	$153.36	-$5,308.96	-$1,869.24	$2,061.86
GEG TZ21GBESS	$1,100.00	$50.00	-		-	-	-
7	$7,700.00	$350.00	1060	$84.80	-$5,776.00	-$3,082.40	-$4.00
5	$5,500.00	$250.00	1890	$151.20	-$2,744.00	$1,114.40	$5,524.00
3	$3,300.00	$150.00	2720	$217.60	$288.00	$5,311.20	$11,052.00
FF1212W (x13)	$0.00	$650.00	0	$0.00	-	-	-

Over a 12 year time period, a consolidation scenario that could pay for itself would be the replacement of the refrigerators with five larger residential units of 21 cubic feet (General Electric GEGTZ21GBESS). This is a lower cost option than a commercial refrigerator and freezer. The advantages of this are the modular nature of the setup – there could be one fridge for every two or three domes, multiple units in one central location, or a combination of the two systems. There are also sizing advantages, which are explored in the chart below. For a size comparable to the commercial setup, the energy usage is comparable. The main difference comes in initial cost – the domestic refrigerators are over $2000 less expensive, leading to a much shorter payback period. Using the same 12 year lifetime, the domestic setup will pay for itself and save the Domes about $1100.

The energy savings of the two systems is relatively small when attempting to achieve zero net energy – changing out the refrigerators leads to a 3% savings in electricity at the Domes, despite cutting half of the load.

Communal Space Scenarios

There are few areas on the property that are deemed viable for building a communal space and/or could house a commercial kitchen and biogas digester. Due to the use of the space, it should not be built very far from the main area of the property where the fourteen domes lie, as each resident needs quick access to the space.

Figure: Possible Areas for Communal Space

Proposed area #1 is an open space between Domes 10 and 15. It has the advantage of being close to the road, for easy access to the community should the space be used for a communal learning kitchen, though it is still set back enough that it can be as private as the two domes on either side. It is very close to seven of the domes on the property, and has access to sunlight should the space be also used for communal hot water. The space might need to be graded to build a biogas digester, and some beautiful open space would be lost. This space also has room to expand should other communal activities be centered on the same location.

The second area proposed is located between the Yurt and the chicken coop, both existing communal spaces, along with the solar water heater that keeps the Yurt warm. If use of those panels was determined to be a viable option, it would be plausible to connect piping from the panels to a shower in a communal building in this area. The proximity to the chicken coop allows chicken manure, a feedstock for the biogas generator, to be easily collected and utilized. Furthermore, the proximity to the Yurt means dinner cooks would be close to the communal dining area when they cook – essentially the space could be an expansion of the Yurt. This space has some room for a larger building, as with the first area proposed, but it is not as close to any of the Domes, compared to the first area which is close to some of the Domes. In spite of this, this space seems like a better choice than location #1 in terms of long term growth potential, and community-mindedness of the space.

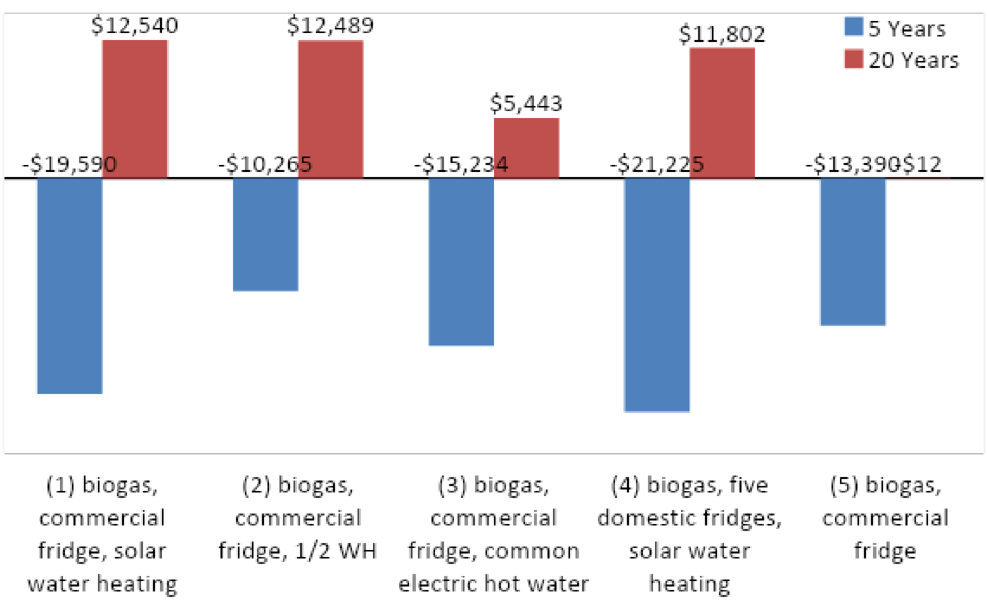


Figure: 5 & 20 Year Net Savings of Some Scenarios

Above are a few scenarios of the net savings over a five and twenty year time period. Along with the net savings of the upgrades, these also include the price of building the minimum size low energy housing for access to the proposed technology. The housing price was estimated to be $150 per square foot, a middle of the road estimate based on the prices for attractive Do-It-Yourself housing kits (Mother Earth News). The sizes for the housing were based on the sizes of the elements inside, plus the minimum space necessary to use them. There are a few assumptions made in the twenty year calculation. With regular maintenance and proper use, commercial and domestic refrigeration units have been known to last twenty years. In this scenario, the units are not expected to be replaced after the twelve year lifetime estimated by Energy Star.

As shown, over a five year period of time, none of the options explored were economically viable to the Domes when the cost of housing for them was included. Over a much longer time period of twenty years, many of the scenarios become economically positive and show the advantages of incorporating such systems.

The first three scenarios focus on changing the water heating situation at the Domes, if installed alongside a kitchen with a biogas stove and commercial refrigeration. If used for five years, a solar installation will cost the Domes nearly twice as much as removing half the water heaters, a process estimated to cost no money. After twenty years, there should be significant energy savings from solar water heating to offset the initial cost, and save the domes slightly more money than just removing the half of the current water heaters. In addition, the Domes will be about 15% closer to Zero Net Energy.

The fourth scenario explores including five twenty-one cubic foot domestic refrigerators in the space, rather than a commercial refrigeration unit in the first scenario. Although the domestic refrigerators cost less to buy than the commercial units, they require much more space than a commercial setup, offsetting any savings in purchase cost. This will ultimately save the Domes less money in both timescales.

The fifth scenario is a minimum community kitchen build that over a twenty year period will end up just barely paying for itself.

Appendix K:

Fridge Data

	($)	kWh/year	($/year)	($/year)	($)	($)	($)
fridge model	initial cost	energy star estimate	cost	maintenance	total (5 years)	total (12 years)	total (20 years)
TS-72	$4,214.77	992.8	$79.42	$156.00	$5,391.89	$7,039.86	$8,923.25
T-35F	$3,551.13	1054.85	$84.39	$156.00	$4,753.07	$6,435.79	$8,358.89
		2047.65			$10,144.96	$13,475.64	$17,282.14
GEGTZ21GBESS	$1,100.00	415	$33.20	$50.00	$1,516.00	$2,098.40	$2,764.00
7	$7,700.00	2905	$232.40	$350.00	$10,612.00	$14,688.80	$19,348.00
5	$5,500.00	2075	$166.00	$250.00	$7,580.00	$10,492.00	$13,820.00
3	$3,300.00	1245	$99.60	$150.00	$4,548.00	$6,295.20	$8,292.00
FF1212W (x13)	$0.00	3965	$317.20	$650.00	$4,836.00	$11,606.40	$19,344.00

	($/kWh)	($/kWh)	($/kWh)	Monetary Savings		($)	Energy Savings		(kWh)
fridge model	5 years	12 years	20 years	5 year net	12 year net	20 year net	5 year net	12 year net	20 year net
TS-72									
T-35F									
	$0.991	$0.548	$0.422	-$5,308.96	-$1,869.24	$2,061.86	-9586.75	-23008.2	-38347
GEGTZ21GBESS									
7	$0.731	$0.421	$0.333	-$5,776.00	-$3,082.40	-$4.00	5300	12720	21200
5				-$2,744.00	$1,114.40	$5,524.00	9450	22680	37800
3				$288.00	$5,311.20	$11,052.00	13600	32640	54400
FF1212W (x13)									

Biogas Digester

	($)	(m^3/day)	(/day)	($/year)	($/5 year)	($/20 year)	($/year)		
	build cost	output	meals	maintenance	NPC	NPC	Electricity Cost Offset	5 year savings	20 year savings
biogas digester	$253.00	1	2	$20.00	$353.00	$653.00	$151.84	$131.20	$1,733.80
	$342.00	2	4	$25.00	$467.00	$842.00	$303.68	$776.40	$4,581.60
	$409.00	3	6	$30.00	$559.00	$1,009.00	$455.52	$1,443.60	$7,451.40
	$495.00	4	8	$35.00	$670.00	$1,195.00	$607.36	$2,091.80	$10,302.20
scrubber	$20.00	-	-	$20.00	$120.00	$420.00			
stove	$50.00	-	-	$5.00	$75.00	$150.00			
food processor	$80.00	-	-	$0.00	$80.00	$80.00			

	(m^3/day)	(kWh/day)	(kWh/year)	(kWh)	(kWh)	
	Output	**Electricity Saved**	**Energy Saved**	**5 years**	**20 years**	**% Domes Energy Reduction**
biogas digester	**1**	5.2	1898	9490	47450	3.47%
	2	10.4	3796	18980	94900	6.94%
	3	15.6	5694	28470	142350	10.41%
	4	20.8	7592	37960	189800	13.88%

Hot Water Setups

	Capital Cost ($)	Mounting Cost ($)	Cost ($/year)	5 year NPC ($)	20 year NPC ($)
ES80H123-45D (x2)	1126	0	$763.52	$4,943.60	$16,396.40
Current Setup			$1,250.08	$6,250.40	$25,001.60
Remove 1/2 WH			$625.04	$3,125.20	$12,500.80
Remove 1/3 WH			$416.69	$2,083.47	$8,333.87
solar thermal	9000	300	0	$9,300.00	$9,300.00

			Monetary Savings		Energy Savings	
	Energy Used (kWh/year)	Domes Energy Reduction (%)	5 years ($)	20 years ($)	5 years (kWh)	20 years (kWh)
ES80H123-45D (x2)	9544	11%	-$1,306.80	-$8,605.20	30410	121640
Current Setup	15626	0%	$0.00	$0.00		
Remove 1/2 WH	7813	14%	-$3,125.20	-$12,500.80		
Remove 1/3 WH	5209	19%	-$4,166.93	-$16,667.73		
solar thermal	0	29%	$3,049.60	-$15,701.60	78130	312520
domes annual energy estimate	54704					

Water Usage Calculations

Showers/ Week/ Resident	# of Residents	Showers/ Week		
6	3	18		
4	9	36		
1.5	9	13.5		
	21	67.5		
	Average Showers/Week/Resident	3.214285714	Total Showers*26 Residents/Day	11.938776
Shower Length/ Shower/ Resident	# of Residents	Shower Length/Shower		
17.5	2	35		
12.5	8	100		
7.5	10	75		
2.5	1	2.5		
	21	212.5		
	Average Shower Length/ Resident/ Shower	10.11904762	Total Shower Length(min)/Day (for all 26 Residents)	120.80904
	*all calculations above made from data collected in surveys for this report	Assuming 1.5 gal/min	Shower Gallons/Day (for all 26 Residents)	181.21
From Brum Report:	Kitchen Faucet Gallons/ Year	17224.83		
	Kitchen Faucet Gallon/Day	47.19		

Communal Space Sizing & Pricing

small house price per square foot	$ 150.00					
			square footage			
w/ commercial		$7,500.00	50			
w/ consolidated		$ 11,400.00	76			
w/ commercial and stove		$9,525.00	63.5			
w/ commercial, stove, shower		$12,675.00	84.5			
w/ consolidated and stove		$14,475.00	96.5			
w/ consolidated, stove, shower		$16,875.00	112.5			
w/ stove		$2,775.00	18.5			
w/ stove and shower		$5,175.00	34.5			
				*consolidated refrigeration		
sizes based on use:			sqft	*7	*5	*3
commercial refrigeration	80x30 + 40x30		25			
consolidated refrigeration	33x33		7.6	53.2	38	22.8
stove and sink	39x24 + 12x24		8.5			
shower	48x48		16			

	Jan 1.6	Feb 1.2	Mar 1.0	Apr 0.8	May 0.6	Jun 0.4	July 0.5	Aug 0.4	Sep 0.4	Oct 0.6	Nov 0.8	Dec 1.3
12 AM	0.465	0.355	0.285	0.215	0.130	0.111	0.142	0.103	0.125	0.172	0.232	0.371
1 AM	0.290	0.221	0.177	0.134	0.081	0.069	0.089	0.064	0.078	0.107	0.144	0.231
2 AM	0.133	0.101	0.081	0.061	0.037	0.032	0.041	0.029	0.035	0.049	0.066	0.106
3 AM	0.315	0.240	0.193	0.145	0.088	0.075	0.096	0.070	0.084	0.117	0.157	0.251
4 AM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 AM	0.250	0.191	0.153	0.115	0.070	0.060	0.076	0.056	0.067	0.093	0.124	0.199
6 AM	0.337	0.257	0.207	0.156	0.094	0.080	0.103	0.075	0.090	0.125	0.168	0.269
7 AM	0.155	0.118	0.095	0.071	0.043	0.037	0.047	0.034	0.041	0.057	0.077	0.123
8 AM	0.266	0.203	0.163	0.123	0.074	0.063	0.081	0.059	0.071	0.098	0.132	0.212
9 AM	0.609	0.464	0.373	0.281	0.169	0.145	0.186	0.135	0.163	0.225	0.303	0.485
10 AM	1.196	0.911	0.732	0.552	0.333	0.285	0.365	0.266	0.320	0.443	0.595	0.953
11 AM	1.399	1.067	0.857	0.646	0.390	0.334	0.428	0.311	0.375	0.518	0.697	1.115
12 PM	1.226	0.935	0.751	0.566	0.341	0.292	0.375	0.273	0.328	0.454	0.611	0.977
1 PM	0.790	0.602	0.483	0.365	0.220	0.188	0.241	0.176	0.211	0.292	0.393	0.629
2 PM	0.908	0.693	0.556	0.419	0.253	0.217	0.278	0.202	0.243	0.336	0.452	0.724
3 PM	0.905	0.690	0.554	0.418	0.252	0.216	0.277	0.201	0.242	0.335	0.451	0.721
4 PM	0.570	0.434	0.349	0.263	0.159	0.136	0.174	0.127	0.152	0.211	0.284	0.454
5 PM	0.744	0.567	0.455	0.343	0.207	0.177	0.227	0.165	0.199	0.275	0.370	0.593
6 PM	1.145	0.873	0.701	0.529	0.319	0.273	0.350	0.255	0.306	0.424	0.570	0.913
7 PM	1.511	1.152	0.925	0.698	0.421	0.360	0.462	0.336	0.405	0.560	0.752	1.205
8 PM	2.022	1.542	1.238	0.934	0.563	0.482	0.618	0.450	0.541	0.749	1.007	1.612
9 PM	1.089	0.830	0.667	0.503	0.303	0.260	0.333	0.242	0.291	0.403	0.542	0.868
10 PM	0.446	0.340	0.273	0.206	0.124	0.106	0.136	0.099	0.119	0.165	0.222	0.356
11 PM	0.576	0.439	0.353	0.266	0.160	0.137	0.176	0.128	0.154	0.213	0.287	0.459
1 representative day for the month (kWh/d)	17.35	13.22	10.62	8.01	4.83	4.14	5.30	3.86	4.64	6.42	8.64	13.82
average for month (kWh/mo.)	537.76	370.27	329.23	240.28	149.71	124.05	164.36	119.59	139.28	199.14	259.06	428.56

Table. The one-month of metered data from Dome 10 extrapolated into one year of data using historical data from 2006-2011. This data is representative of the typical Dome (without retrofits).

Additional Brainstorming List

○ Create a communal kitchen with a biogas generator.

○ Replace 6 of the existing stoves with ranges only (no oven).

○ Solar overhang to provide shading, also integrated with the water heater. The solar panel would preheat the water for the water heater, so the water heater would ultimately use less electricity.

○ Partner with neighboring UC Davis properties to increase available area for solar panels. One potential area is the parking lot to the west of the Domes property. This system would provide shading for the parked cars, while providing electricity for the Domes.

○ Grouped utilities (3-4 domes). Convert every third dome into a kitchen and bath only, and change the occupancy in the remaining domes to 3 residences per dome.

○ Use the existing solar (for the Yurt) to heat water for a communal shower.

○ Incentivize energy conservation by itemizing electricity costs in rent payments. Instead of paying one flat rate for rent, residents would be able to see how much they are paying for electricity each month.

Energy Reduction Ideas:

Options to reduce energy from in-wall heater use:

- Remove all in-wall heaters (no replacement, or replace with plug-in space heaters)
- Replace with more efficient electric in-wall heaters
- Replace entire heating system with alternative heating source. Possibilities include:
    - Biofuel heaters – This is a biofuel burning unit that uses corn husks as fuel. The domes would farm a suitable crop, sell/utilize what can be used, and then dry out and burn the remainder as a heater source. This may not be a viable option depending on local laws regarding burning, however.
    - Biodiesel – Local biodiesel can be sourced (the Silo on campus?) and processed on site.

Options for energy reduction from water heater (WH):

- Replace WH with more energy efficient unit.
- Replace WH with heat pump model. One option is to link this to another system that would capture a lower grade heat so energy required to heat up water for domestic uses would be less. These options will be discussed in other sections.
- Replace WH with instant water heater.
- Build an outdoor shower to be connected with existing solar thermal array near the yurt as an alternative to showering in the domes. Further study would be to be conducted to determine the feasibility of this option.

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