SOLAR THERMAL HEATING: ALIVE AND WELL

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ABSTRACT

In 2009, two new, similar homes were being constructed in the Katywil Community in Colrain, MA. These buildings offered an opportunity to compare the energy performance of a Mini-Split heat pump heating system (Home 1), versus a solar thermal heating system with tankless electric backup (Home 2).

Both homes were designed with energy efficiency in mind, but employed two different paradigms with regard to the heating system. The Consortium for Advanced Residential Buildings (CARB) conducted a study of these two homes during the 2009-2010 heating season. The study used energy transducers to monitor electricity consumption in the entire home, while further breaking up that use into relevant subcategories. The analysis revealed that the solar thermal system used much less energy than the mini-split heat pump system. Over the course of the heating season, Home 2 used 84% less overall heating energy from electricity than Home 1.

1. INTRODUCTION

The Katywil Community is located in Colrain, MA a few miles from the Vermont border. The community fomed with the goal of creating a development using no fossil fuels on site. The original design of both homes being discussed in this paper was to use mini-split heat pumps to provide space heat. These active systems, along with passive solar design and ample insulation, will contribute to a very energy efficient overall system design.

The floorplans of the two homes are very similar, consisting of a walk-out basement with two bedrooms on the lower floor. The upper floor contains the main living space, including the kitchen, livingroom and diningroom.

Early on in the project, the possibility of a solar thermal system being installed was discussed. This would provide an opportunity for CARB to conduct a study comparing the energy efficiency of mini-split heat pump heating systems with solar thermal heating systems. Conveniently, both systems use electricity to run various components, so a direct kWh to kWh comparison was possible. The solar thermal heating system cost approximately 15% more than the mini-split heating system. This study is intended to analyze the comparative difference in performance of these systems.

2. SYSTEM DESIGN

The two systems were installed by two different installers. Both had significant experience in installing their respective systems. The design heating load is approximately 22 kBtu/h (6.4 kW) for both homes.

2.1 Home 1

The system installed in Home 1 (seen in Figure 1) is an air-to-water mini-split heat pump with variable refridgerant volume and a nominal heat capacity of 40 kBtu/h (11.7 kW). The heat pump model is a Mitsubishi City Multi with a 2.2 kW compressor. The heat pump is piped to two fan coils, one on each floor. When the outdoor temperature is below 2°F, electric resistance heaters are utilized as backup. The lower floor fan coil is rated with a 1 ton capacity and only services one zone. The upper floor fan coil has a 2 ton

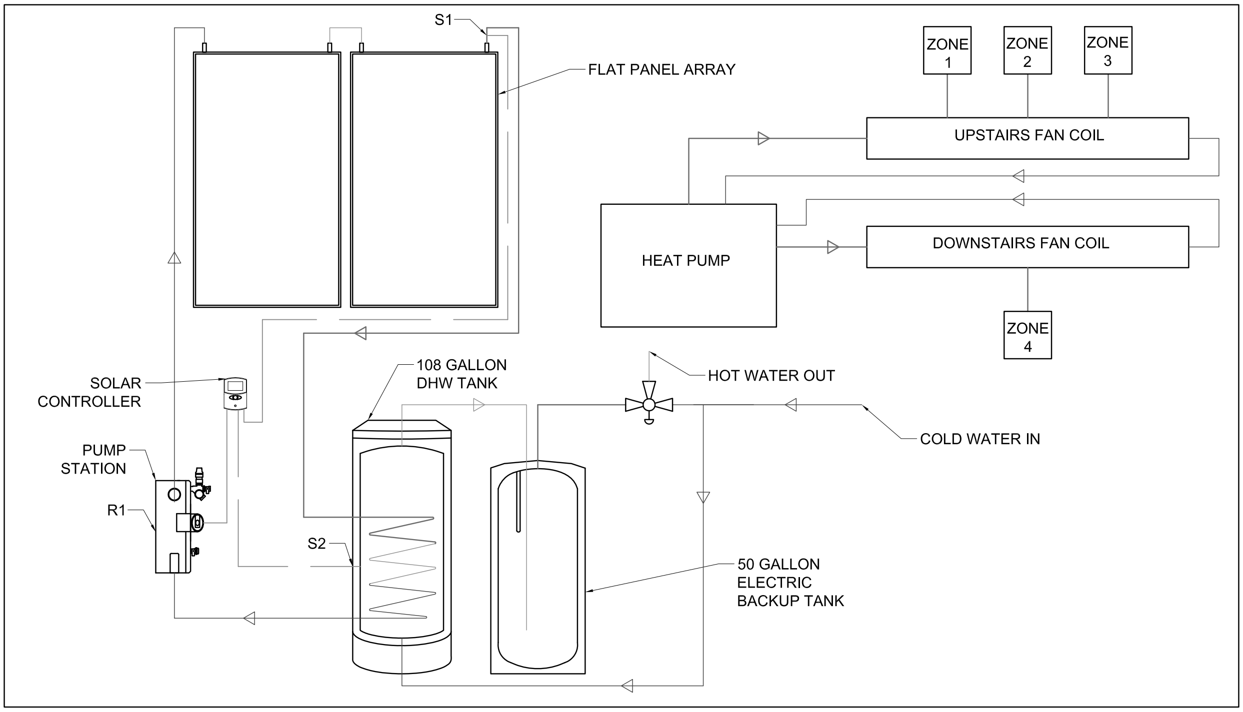

Figure 1: Line drawing of DHW and Heating System installed in Home 1.

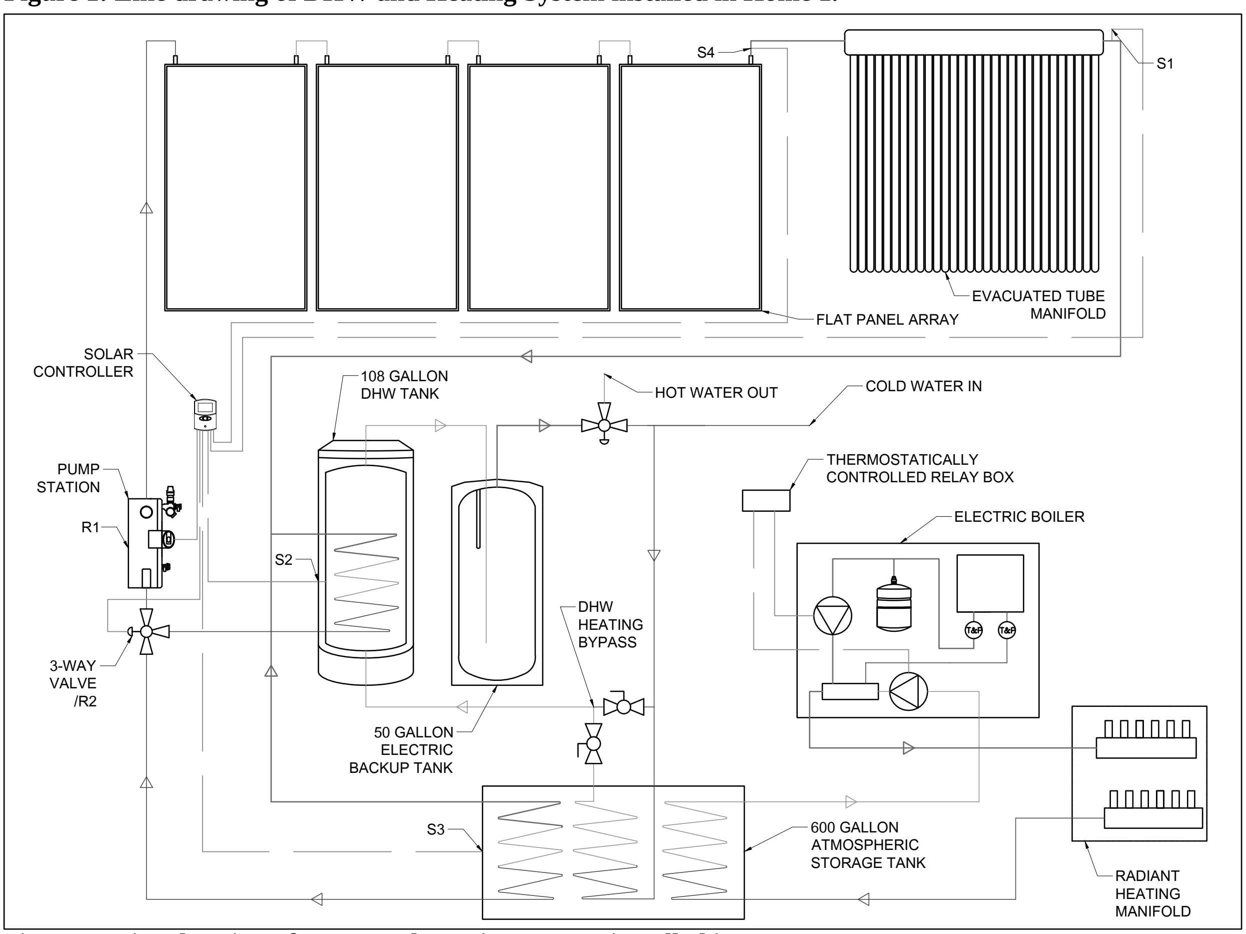

Figure 2: Line drawing of DHW and Heating System installed in Home 2.

capacity and services three zones.

The domestic hot water (DHW) is heated by two Stiebel Eltron SOL 25 Plus flat plate collectors and a 108 gallon tank, backed up by a Rheem 50 gallon 2250 W water heater.

2.2 Home 2

The Home 2 solar thermal system (seen in Figure 2) utilizes 4 Stiebel Eltron SOL 25 Plus flat plate solar collectors angled at 55°. These are connected in series to a Thermomax Mazdon 30 evacuated tube array angled at 70°. This array provides heat to both the DHW system and the heating system.

The array is piped to a 108 gallon tank for DHW, backed up by a Rheem 50 gallon 2250 W water heater. A 3-way diverter valve also connects the solar array to a coil in a 600 gallon STSS thermal mass storage tank. This tank has 3 heat exchange coils: one for solar thermal storage, one for DHW preheating, and another for the heating loop. The DHW pre-warm heating coil, which is used to maximize the solar gain during the warmer months, has a manual bypass valve for the time of year when the heating system is being used. This is an unpressurized tank, so the water in the tank is used only for the transfer and storage of heat. The heating coil is connected to a 20 kW Hydroshark 3 electric boiler which provides heat to a six zone radiant heating system. The zones are split, with three upstairs and three downstairs

In addition to the differences in the heating system, the owners of Home 2 opted to have triple-pane windows installed, which had a lower U-value (.28-.33) as compared to Home 1 (.33). Also, the owner of Home 2 had the screened porch enclosed to increase the passive solar gain.

2.3 Additional Information

Both homes utilize whole-house ventilation with a Fantech HRV unit capable of delivering 60 CFM of fresh air. Both homes also have a wood stove installed for auxiliary heating. Both homes are insulated very well. The basement walls are insulated to R-15. Above grade walls are insulated to R-42. The attic is insulated to R-60, while the cathedral roof is insulated to R-50. All insulation is blown in cellulose.

3. PREDICTIONS

The prediction provided by CARB made estimates about the annual amount of electricity that would be used by each home. They made a prediction that Home 1 would use 16263 kWh per year, and Home 2 would use 15867 kWh per year. The full predictions are provided on the chart below.

Table 1: Predictions of electrical consumption and costs annualy for both homes. The cost assumes an electricity rate of $0.17/kWh. (Source: CARB study)

Modeled Annual Electric Consumption and Cost

	Home 1		Home 2	
Space Heating	6272 kWh	$1,066	6932 kWh	$1,176
Water Heating	904 kWh	$154	0 kWh	$0
Other	9087 kWh	$1,545	8935 kWh	$1,519
Total	16263 kWh	$2,765	15867 kWh	$2,695

4. SYSTEM MONITORING

CARB installed energy monitors on both homes in Mid-November of 2009. The monitors were U30 HOBO dataloggers. The dataloggers measured electrical consumption of the entire home, as well as the individual mechanical units of interest in the study. That data were recorded at 5 minute intervals. The data monitoring occured from December 2009 through September 2010.

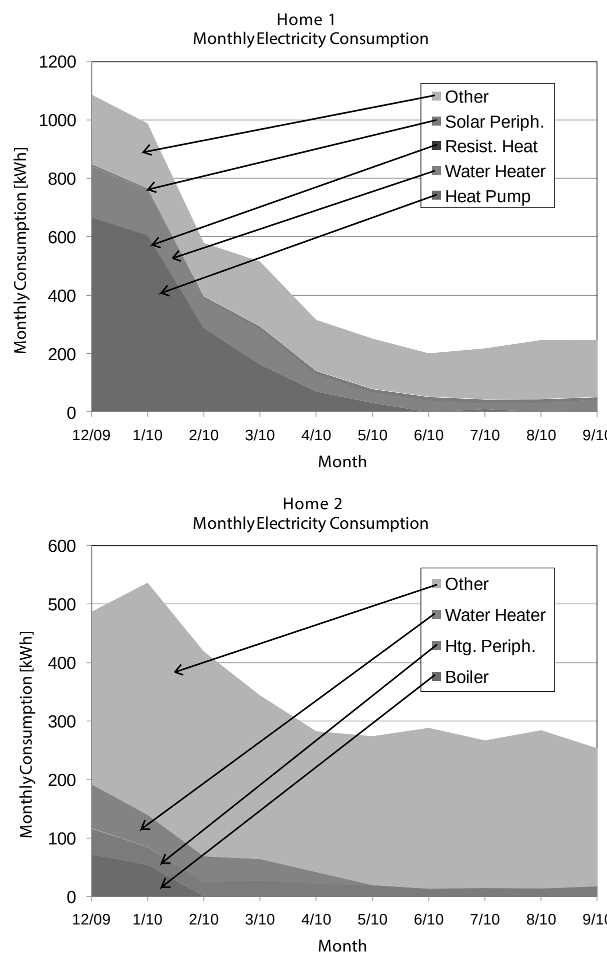

Figure 3: Consumption graphs for each home between December 2009 and September 2010. (Source: CARB study)

5. DATA FINDINGS

The following tables represent the measured electricity consumption of the two homes. The results are published on the following tables and charts. The electrical consumption of Home 2 was 26% lower than the electrical consumption of Home 1. A more dramatic result can be seen when comparing the 2 homes' electrical consumption during the winter months. The heating system in Home 1 consumed 1,667 kWh of electricity, while the heating system of Home 2 used only 280 kWh.

The occupant in Home 1 burned one cord of wood during the monitoring period, while the occupants of Home 2 burned one and a half cords of wood in the same time period. The following table corrects for that difference. Using this correction, the data shows that Home 2 used 84% less heating energy provided by electricity over the course of the winter.

Table 2: Monitored electricity use in the homes from December 2009 through September 2010. (Source: CARB study)

Overall Electricity Use in Home 1

	kWh Used	Fraction	Cost
Heat Pump	1833	39.00%	$312
Water Heater	792	17.00%	$135
Resistance Heat	0	0.00%	$0
Solar Periph.	86	20.00%	$15
Other	1932	42.00%	$328
Total	4643	100.00%	$789

Overall Electricity Use in Home 2

	kWh Used	Fraction	Cost
Boiler	125	4.00%	$21
Heating Periph.	224	7.00%	$38
Water Heater	233	7.00%	$40
Other	2857	83.00%	$486
Total	3440	100.00%	$585

6. ENERGY USAGE PROFILES

The intent of the CARB study was to limit the number of variables between the two homes in order to conduct an accurate quantitative analysis. Fortunately, since both heating sources are powered by electricity, a direct comparison between energy usage could be made.

6.1 Home 1

During the study period, Home 1 was occupied by only one person. The thermostat in the home was kept near 63°F for the majority of the winter. The occupant primarily worked from home, and frequently used the downstairs office. The temperature was kept at 70°F during that time, and at 66°F or lower during the night. At the conclusion of the study, the occupant expressed regret in not installing a heating system like Home 2.

6.2 Home 2

During the study period, Home 2 was occupied by two people, with a third occupant staying there in February. The radiant heating loops in the downstairs master bedroom and the upstairs guest bedroom were not turned turned on during the winter. Night setpoints ranged from 64-66°F while the daytime setpoints ranged from 68-69°F for the living space.

The occupants also occasionally made use of a portable electric resistance heater (see Table 2) and were very involved with the operation of the mechanical systems. The door to the sun room was opened and closed as appropriate to increase the heating gain from passive solar.

Table 3: Comparison of energy use of both homes during the monitoring period. (Source: CARB study)

	Home 1	Home 2	
Modeled Space Heating Load	38.9	23.2	MMBtu
Wood Burned	1	1.5	Cords
Wood Efficiency	65%		
Modeled Load Minus Wood	25.9	3.7	MMBtu
COP/Efficiency of Space Heater	1.8	98.00%	
Modeled Consuption (w/ Wood)	4217	1107	kWh
Measured Electricity Consumption	1870	301	kWh

Figure 4: Image of the solar thermal system installed on Home 2. (Source: CARB study)

6.3 Other Differences

There are a few, notable differences between the two homes' usage profiles that should be noted.

- The difference in window U-values leads to an increase in energy efficiency in Home 2.

- Room temperature comfort settings for each house will be different due to difference in heating type and occupant preference.
- Home 2 temperatures were more variable than Home 1 due to occupant involvement, the quantity of wood burned, and management of additional passive solar gain.

7. CONCLUSIONS

The results of the study clearly show that the solar thermal system used less energy, during the winter months especially. Despite the electric boiler having an equivalent COP of 1 in comparison to the heat pump average a COP of 1.8, the system in Home 2 used significantly less energy.

The reduction in energy use is attributed to the occupants' active participation in saving energy, a solar thermal system providing the bulk of the energy used, and modifications made to Home 2 that reduce the overall heat load. Regardless, both systems saved a significant amount of energy in comparison to an average home on the market, but it is clear that the solar thermal system performed better.

8. REFERENCES

(1) Steven Winter Associates, Inc., Systems Evaluation: Mini-Split Heat Pumps in Cold-Climate Home Katywil Community, Colrain, MA, For the: Consortium for Advanced Residential Buildings Steven Winter Associates, Inc., 2010