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Solar Science A study of the 2002 UMR/RTI competition solar house

Christi Wright

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Abstract

The purpose of this report is show the progress as where it stands for the setting up, collection, and analysis of data on the uses and efficiencies of the 2002 UMR/RTI competition solar house. Sensors were set up and configured to record data every minute on appliance and photovoltaic loads, temperature inside and outside the house, solar radiation, light levels, and net metering information. Temperature stratification, solar panel efficiency, and total house loads are some of the analysis that has been done with this data. I have also used the software donated by Campbell Scientific, Inc. to set up a real time web display of the sensors in the house, which can be viewed at http://solarhouse1.dnsalias.net. The final goal is to make the first of its kind solar house research facility and make the data readily available to the general public.

Introduction

This research originally started to compare the efficiency and comfort level of a forced air heating system versus a radiant floor heating system. The goal was to verify that the radiant floor system that is going to be installed in the 2005 solar house is a better choice by power usage and comfort level. This project has since then gone much further. The National Renewable Energy Laboratory (NREL) has gotten involved and a small team of UMR students received a grant from the Environmental Protection Agency (EPA) to expand this research to analyzing power loads and lighting levels in the house. There were over 20 sensors installed and the now the complete workings of the house are being monitored, recorded, and attempting to be made readily available.

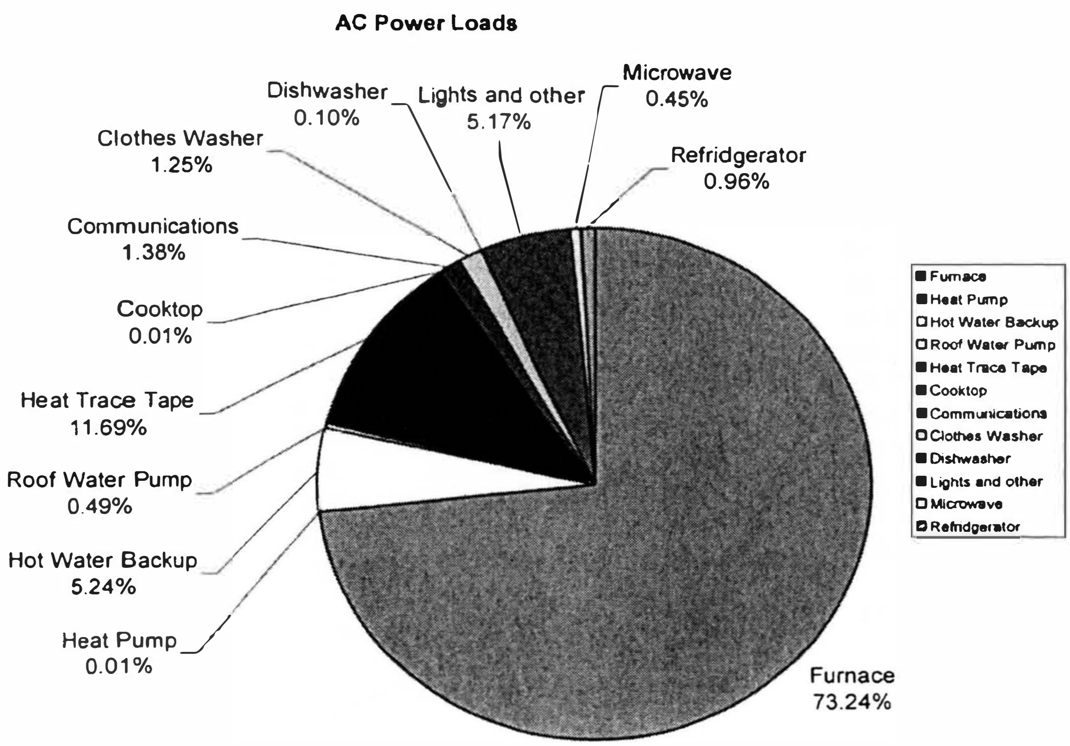
Procedure

The first part of the project was to install the sensors and data logger for the collection of the data. Campbell Scientific, Inc. and Vaisala have generously donated sensors and software used for this project. My advisor and I installed three temperature and humidity sensors inside the house at different height levels for the temperature and humidity stratification of a forced air heating system inside the house. The original idea was to compare this data of the forced air heating system to radiant floor heating system data collected from the 2005 UMR/RTI competition solar house, now being constructed on campus. Due to construction restraints the house is not as far along as originally thought, so data is not able to collected yet. After the sensors were installed the data logger had to be programmed to store the data every so often. By the time we got most of the bugs worked out we had caught the eye of NREL and they donated more sensors for our project and helped with the programming of the datalogger. Now there are 12 watt nodes measuring the AC power loads on the house, 4 temperature and relative humidity sensors measuring inside and outside the house, and 8 sensors measuring the voltage and current of the DC loads on the house. (see Appendix 1 for photos)

Results

The AC loads include the furnace, heat pump, hot water backup, roof circulator pump, heat trace tape, communications, clothes washer, dishwasher, and miscellaneous with a previous collection on the microwave and programming for the home office and cooktop pending the ability to obtain more sensors. The total loads into and out of the house are also being measured to determine the total power bought and total power sold back to the power company. The house sells back the energy it makes over and above what it uses, which is called net-metering. DC loads being measured are the refrigerator, amount of power the solar panels are making, and the power that is used to keep the batteries charged.

LOADS	Total Energy Used (Wh)	# of days/years kWh	38.5722 kWh/day	0.1057 kWh/year	$/yr @ $0.10/kWh
Furnace	1673066.10	1673.07	43.37	15831.84	$1,583.18
Heat Pump	274.50	0.27	0.01	2.60	$0.26
Hot Water Backup	119818.25	119.82	3.11	1133.81	$113.38
Roof Water Pump	11169.38	11.17	0.29	105.69	$10.57
Heat Trace Tape	267131.63	267.13	6.93	2527.80	$252.78
Cooktop	290.25	0.29	0.01	2.75	$0.27
Communications	31591.87	31.59	0.82	298.95	$29.89
Clothes Washer	28628.18	28.63	0.74	270.90	$27.09
Dishwasher	2228.51	2.23	0.06	21.09	$2.11
Lights and other	118151.23	118.15	3.06	1118.04	$111.80
Microwave	10230.34	10.23	0.27	96.81	$9.68
Refridgerator	21878.97	21.88	0.57	207.04	$20.70
TOTAL	2284459.19	2284.46	59.23	21617.31	$2,161.73
TOTAL without communications and heat trace		1985.74	51.48	18790.56	$1,879.06

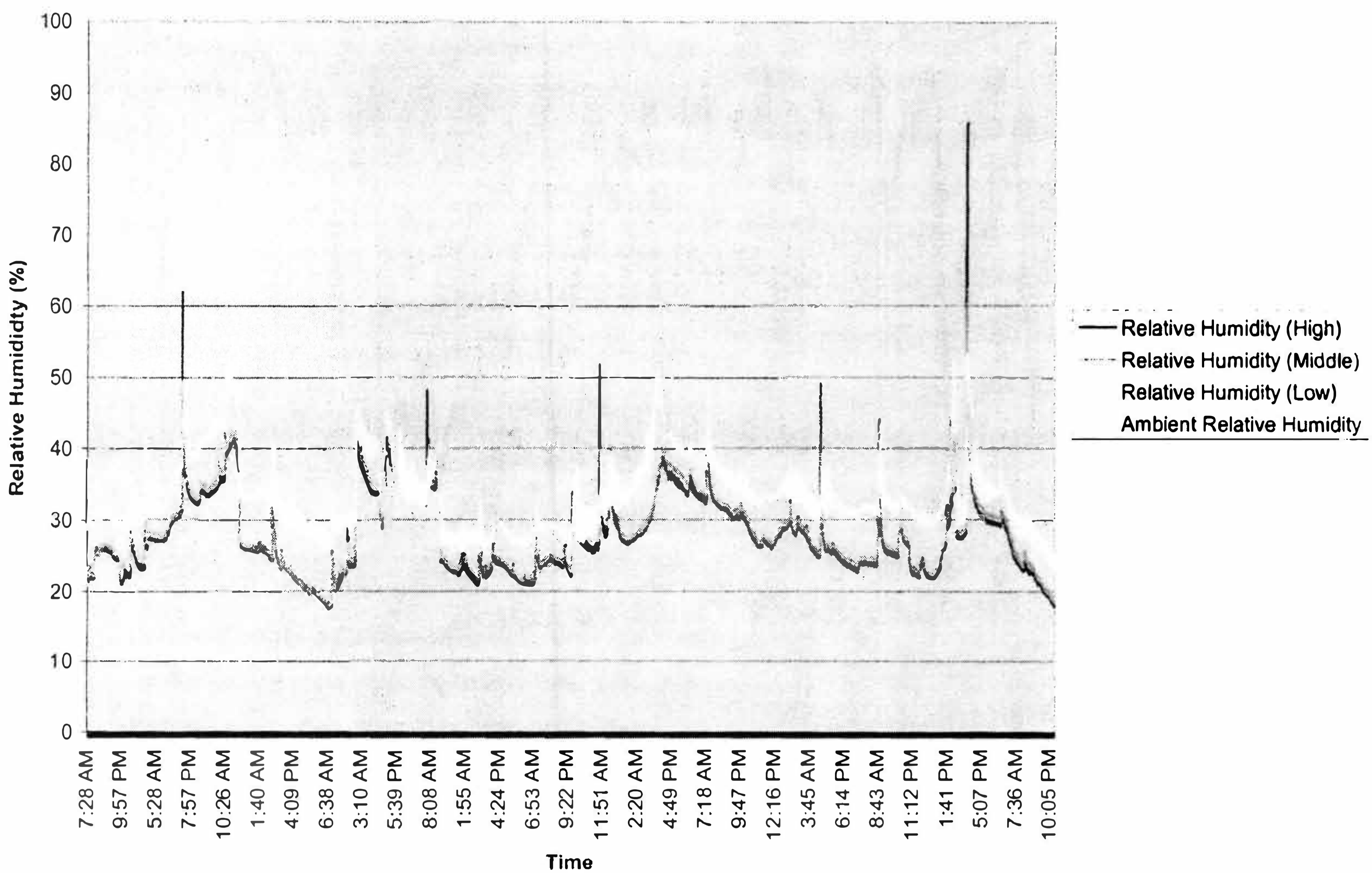


The table above shows the measured total energy used and cost of appliances during the month. of February and March of 2005. The data is not complete in that the total number of minutes of data that has actually been recorded only adds up to 38.5722 days. This is only 65 % of the actual time in the months recorded. The pie chart shows the percentages of the total loads or the whole system. The furnace being over 73% of the entire energy usage is a very costly part of the house. This cannot just be turned off since it is the heat for the residents. The radiant floor heating system that is being installed in the 2005 competition house will not use electricity at all. This system will use hot water to heat the house. This system will greatly reduce the cost of living in the house.

The relative humidity in the house decreases with increasing height from the floor. It is mainly consistant between 20% and 50%. Regulations for the 2005 Solar Decathlon which the UMR/RTI solar house team is competing restricts the humidity to 40% to 55% (http://www.eere.energy.gov/solar_decathlon). While the data was taken during the winter and the outside air is very dry, this comfort zone could be improved. The average change in relative humidity is 2.59% per meter which decreases with height. Below is a sample of the humidity data.

Average inside Relative Humidity	Difference between High and Middle Relative Humidity	0.7620 Relative Humidity change per meter measured between high and middle sensors	Difference between High and Low Relative Humidity	1.9558 Relative Humidity change per meter measured between high and low sensors	Difference between Middle and Low Relative Humidity	1.1938 Relative Humidity change per meter measured between middle and low sensors
40.33	-1.70	-2.23	-7.10	-3.63	-5.40	-4.52
40.50	-1.60	-2.10	-7.40	-3.78	-5.80	-4.86
40.53	-1.70	-2.23	-7.40	-3.78	-5.70	-4.77
40.60	-1.60	-2.10	-7.40	-3.78	-5.80	-4.86
40.53	-1.60	-2.10	-7.50	-3.83	-5.90	-4.94
40.60	-1.50	-1.97	-7.50	-3.83	-6.00	-5.03
40.53	-1.50	-1.97	-7.30	-3.73	-5.80	-4.86
40.47	-1.60	-2.10	-7.30	-3.73	-5.70	-4.77
40.47	-1.60	-2.10	-7.30	-3.73	-5.70	-4.77
40.50	-1.60	-2.10	-7.40	-3.78	-5.80	-4.86
40.53	-1.70	-2.23	-7.40	-3.78	-5.70	-4.77
40.53	-1.70	-2.23	-7.40	-3.78	-5.70	-4.77
40.43	-1.60	-2.10	-7.20	-3.68	-5.60	-4.69
40.47	-1.70	-2.23	-7.20	-3.68	-5.50	-4.61
40.50	-1.50	-1.97	-7.20	-3.68	-5.70	-4.77
40.57	-1.60	-2.10	-7.30	-3.73	-5.70	-4.77
Average	-0.33	-0.43	-5.65	-2.89	-5.32	-4.46
		Average Relative Humidity change per meter:			-2.59	

February Relative Humidity

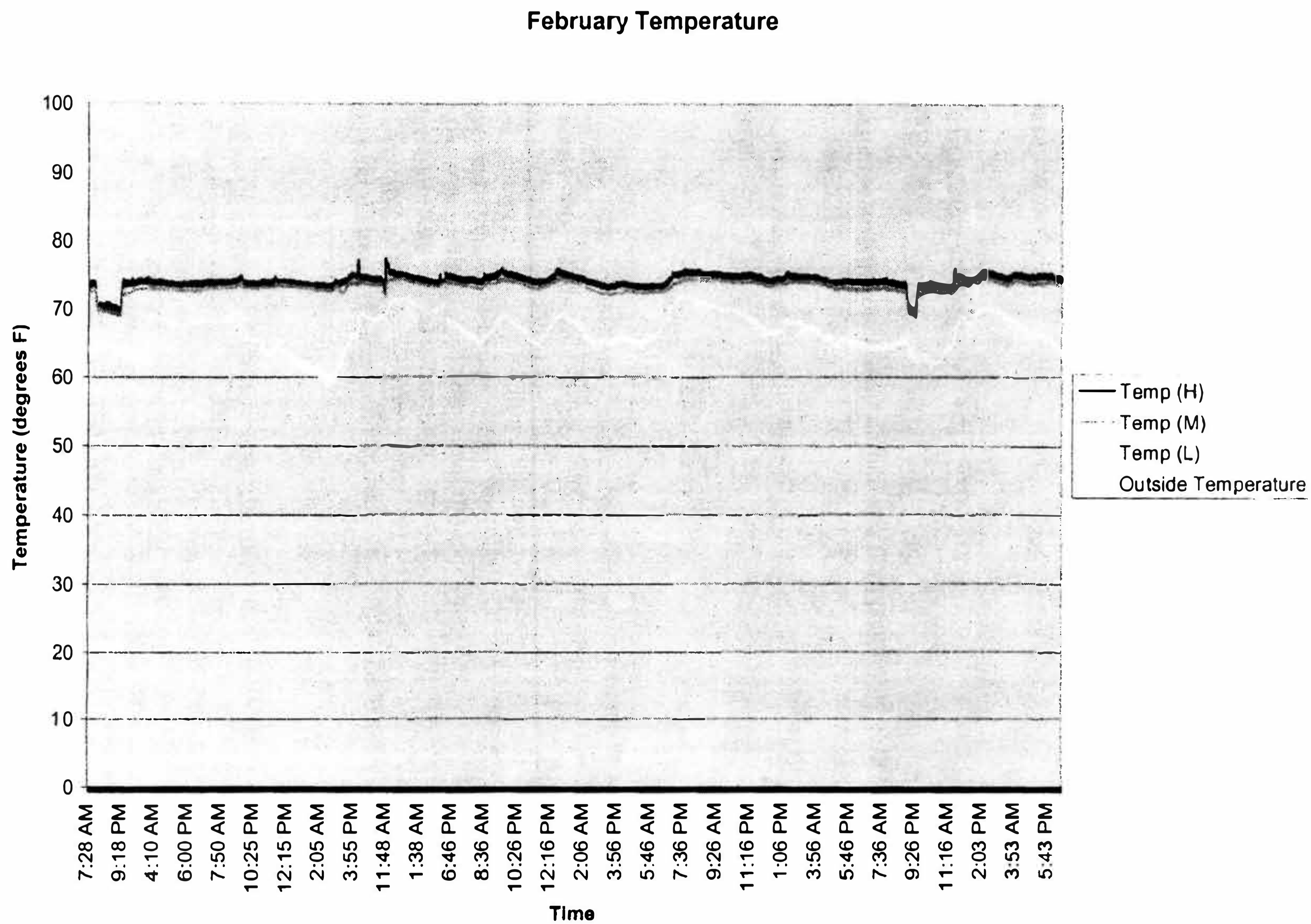


The above graph is the Relative Humidity inside and outside the house during the month of February. The relative humidity inside the house generally increases when the relative humidity outside decreases. This pattern is unexpected since the outside humidity affects inside humidity whenever doors are opened or just by air infiltration. The relationship is probably due to the differences in temperature since it is relative to the amount of vapor the air can hold instead of absolute humidity. Relative humidity is expected to increase with a decreasing air temperature since the amount of water in the air stays the same, but the amount the of water the air can hold decreases.

		0.7620		1.9558		1.1938
Average inside Temperature	Difference between High and Middle Temperature	Degree change per meter measured between high and middle sensors	Difference between High and Low Temperature	Degree change per meter measured between high and low sensors	Difference between Middle and Low Temperature	Degree change per meter measured between middle and low sensors
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.27	1.34	1.75	3.60	1.84	2.60	2.18
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.27	1.34	1.75	3.60	1.84	2.60	2.18
73.33	1.47	1.93	3.60	1.84	2.50	2.09
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.27	1.34	1.75	3.60	1.84	2.60	2.18
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.30	1.34	1.75	3.50	1.79	2.50	2.09
73.27	1.34	1.75	3.60	1.84	2.60	2.18
Average	1.18	1.54	7.68	3.92	6.80	5.70
		Average degree change per meter:		3.72		

This chart is a sample of the analysis of the temperature stratification in the 2002 solar house with the forced air heating system. The average degree change per meter is 3.72 degrees F increasing as the height increases. This value is in error because the spot chosen for the location of the sensors is directly on a seem that joins two modules. This is bad positioning because there is air flow through the floor where the seem is and this affects the reading of the temperature sensors especially the lowest one. The average temperature change in meters is almost 4 or above when it is measured with the low sensor.

The graph below has a relationship between the outside temperature and the inside temperature. As the outside temperature increases the inside temperature has a very subtle change toward the same direction. The reason for this is that temperature is measured on an absolute scale as opposed to relative. As the outside temperature increases the infiltration into the house will bring in a higher temperature than previously and will lessen the load on the heater.


February Temperature
Temperature (degrees F)
100
90
80
70
60
50
40
30
20
10
0
7:28 AM
9:18 PM
4:10 AM
6:00 PM
7:50 AM
10:25 PM
12:15 PM
2:05 AM
3:55 PM
11:48 AM
1:38 AM
6:46 PM
8:36 AM
10:26 PM
12:16 PM
2:06 AM
3:56 PM
5:46 AM
7:36 PM
9:26 AM
11:16 PM
1:06 PM
3:56 AM
5:46 PM
7:36 AM
9:26 PM
11:16 AM
2:03 PM
3:53 AM
5:43 PM
Time
Temp (H)
Temp (M)
Temp (L)
Outside Temperature

The power output from the solar panels is also being measured, but also with error. The solar radiation sensor or pyranometer, which measures the available sunlight, seems to be set up incorrectly. The sensor is on a vertical post on the top of the roof. It is the highest part of the house so that it is never shaded by any other part of the house. The data seems to be getting more negative with the increasing light. It also seems to read -6999 instead of -600. The reference insolation that the data is being compared to is 2820 watts per square meter per day for February and 3520 watts per square meter per day for March which was found on http://Apricus-solar.com. The measured February average is -935.492 which is in absolute terms over 1800 watts difference and the March average is over 5 million off. (see Apendix 1 for data tables)

Conclusions

Some problems I am running into and in the process of working them out is first of all the lack of a radiant floor heating system to compare data. Another is the lack of knowledge about the software and programming and trying to figure out the programming language. There are breaks in the data which was found to be places when the computer did not have an account running. This problem has hopefully been addressed by never logging out of the system. The largest load in the house was found to be the heater in the months of February and March. Without the heater using electricity the power consumed would decrease by more than 70%. This is huge especially when dealing with a solar house attempting complete self-sufficiency. The sensor that measures the available sunlight was found to be configured wrong which shows a percent error of over 1000%.

Acknowledgements

Jeff Birt – Advisor

Helped with the installation, programming, and troubleshooting of the project

Mike Wassmer – NREL

Helped with the installation, programming, and troubleshooting of the project

Campbell Scientific, Inc.

Donation of sensors and software

Vaisala

Donation of sensors

References

http://www.eere.energy.gov/solar_decathlon
http://apricus-solar.com

Appendix 1

Data Tables

Solar Collection

Date	Average Solar Radiation from Apricus-Solar.com (Wh/m^2)	Measured Solar Radiation (Wh/m^2)	Array Area (m^2):	5.004	Array #1 Measured Energy per Area (Wh/m2)	Array #2 Measured Energy per Area (Wh/m2)	Array #1 Efficiency	Array #2 Efficiency	Array #1 Percent Error	Array #2 Percent Error
			Array #1 Energy (Wh)	Array #2 Energy (Wh)						
1-Feb	2820.00	-857.376	6924.939	-1.333	1383.881	-0.266	-161.409	0.031	-50.926	100.009
2-Feb	2820.00	not complete								
3-Feb	2820.00	no data								
4-Feb	2820.00	no data								
5-Feb	2820.00	no data								
6-Feb	2820.00	-1056.456	1622.544	1374.868	324.249	274.754	-30.692	-26.007	-88.502	-90.257
7-Feb	2820.00	not complete								
8-Feb	2820.00	not complete								
9-Feb	2820.00	-705.960	829.008	640.456	165.669	127.989	-23.467	-18.130	-94.125	-95.461
10-Feb	2820.00	not complete								
11-Feb	2820.00	not complete								
12-Feb	2820.00	no data								
13-Feb	2820.00	no data								
14-Feb	2820.00	-2035.584	8790.514	8215.033	1756.698	1641.693	-86.299	-80.650	-37.706	-41.784
15-Feb	2820.00	not complete								
16-Feb	2820.00	not complete								
17-Feb	2820.00	-1298.016	9013.653	9109.306	1801.290	1820.405	-138.773	-140.245	-36.124	-35.447
18-Feb	2820.00	-1283.112	8951.096	8779.547	1788.788	1754.506	-139.410	-136.738	-36.568	-37.783
19-Feb	2820.00	-270.504	1028.240	828.608	205.484	165.589	-75.963	-61.215	-92.713	-94.128
20-Feb	2820.00	-1322.496	6540.405	6479.003	1307.035	1294.765	-98.831	-97.903	-53.651	-54.086
21-Feb	2820.00	-1084.104	2100.704	1803.931	419.805	360.498	-38.724	-33.253	-85.113	-87.216
22-Feb	2820.00	-426.264	3341.766	4465.967	667.819	892.479	-156.668	-209.372	-76.318	-68.352
23-Feb	2820.00	-543.888	153.682	116.502	30.712	23.282	-5.647	-4.281	-98.911	-99.174
24-Feb	2820.00	-173.232	232.846	88.280	46.532	17.642	-26.861	-10.184	-98.350	-99.374
25-Feb	2820.00	not complete								
26-Feb	2820.00	no data								
27-Feb	2820.00	not complete								
28-Feb	2820.00	-1104.408	5288.147	5320.156	1056.784	1063.181	-95.688	-96.267	-62.525	-62.299
February Average	2820.00	**-935.492**	**4216.734**	**3632.333**	**842.673**	**725.886**	**-90.078**	**-77.594**	**-70.118**	**-74.259**
1-Mar	3520.00	-238.320	9481.110	9844.288	1894.706	1967.284	-795.026	-825.480	-46.173	-44.111
2-Mar	3520.00	-156.240	9459.961	9522.821	1890.480	1903.042	########	1218.025	-46.293	-45.936
3-Mar	3520.00	-905.904	9459.067	9032.063	1890.301	1804.969	-208.665	-199.245	-46.298	-48.722
4-Mar	3520.00	not complete								
5-Mar	3520.00	-1859.184	9220.746	9553.475	1842.675	1909.168	-99.112	-102.688	-47.651	-45.762
6-Mar	3520.00	-1232.208	8041.035	8456.476	1606.921	1689.943	-130.410	-137.148	-54.349	-51.990
7-Mar	3520.00	-1600.416	3485.107	2857.957	696.464	571.135	-43.518	-35.687	-80.214	-83.775
8-Mar	3520.00	-674.952	8957.102	8157.217	1789.988	1630.139	-265.202	-241.519	-49.148	-53.689
9-Mar	3520.00	-1237.032	6746.224	7908.855	1348.166	1580.507	-108.984	-127.766	-61.700	-55.099
10-Mar	3520.00	not complete								
11-Mar	3520.00	not complete								

12-Mar	3520.00	not complete								
13-Mar	3520.00	-9206657.640	4384.464	3918.990	876.192	783.171	-0.010	-0.009	-75.108	-77.751
14-Mar	3520.00	not complete								
15-Mar	3520.00	no data								
16-Mar	3520.00	- 50093328.600	9196.290	8389.355	1837.788	1676.530	-0.004	-0.003	-47.790	-52.371
17-Mar	3520.00	not complete								
18-Mar	3520.00	no data								
19-Mar	3520.00	no data								
20-Mar	3520.00	not complete								
21-Mar	3520.00	-4937445.216	5709.000	4653.981	1140.887	930.052	-0.023	-0.019	-67.588	-73.578
22-Mar	3520.00	-1733624.424	1897.333	1603.441	379.163	320.432	-0.022	-0.018	-89.228	-90.897
23-Mar	3520.00	-1149188.712	1298.214	1062.225	259.435	212.275	-0.023	-0.018	-92.630	-93.969
24-Mar	3520.00	- 12246728.112	3797.209	3057.503	758.835	611.012	-0.006	-0.005	-78.442	-82.642
25-Mar	3520.00	-1836443.088	2116.030	1742.353	422.868	348.192	-0.023	-0.019	-87.987	-90.108
26-Mar	3520.00	-1691325.912	1882.412	1572.300	376.181	314.209	-0.022	-0.019	-89.313	-91.074
27-Mar	3520.00	-2012685.360	2212.785	1847.740	442.203	369.253	-0.022	-0.018	-87.437	-89.510
28-Mar	3520.00	- 66602251.560	10633.827	########	2125.065	2199.098	-0.003	-0.003	-39.629	-37.526
29-Mar	3520.00	- 57287404.368	9201.411	8767.573	1838.811	1752.113	-0.003	-0.003	-47.761	-50.224
30-Mar	3520.00	not complete								
31-Mar	3520.00	no data								
March Average	3520.00	**-5414088.003**	**6216.593**	**5984.067**	**1242.325**	**1195.857**	**-0.023**	**-0.022**	**-64.707**	**-66.027**

Minimum, Maximum, Average, and Sum of all Sensors

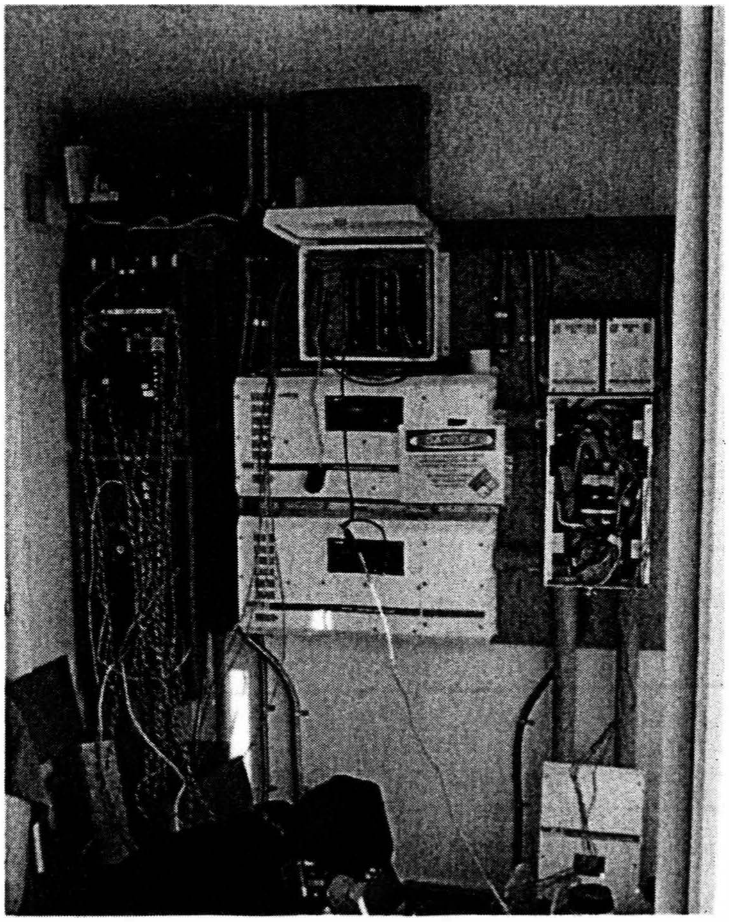
SENSOR	MIN	MAX	AVERAGE	SUM
Relative Humidity				
Relative Humidity (High) (%)	16.20	85.80	26.75	1485755.70
Relative Humidity (Middle) (%)	16.50	62.40	27.08	1503921.60
Relative Humidity (Low) (%)	19.30	53.40	32.40	1799526.00
Outside Relative Humidity (%)	15.00	97.40	67.20	3732327.20
Temperature				
Temperature (High) (degrees F)	69.28	78.90	74.41	4132813.32
Temperature (Middle) (degrees F)	68.63	75.50	73.53	4084179.40
Temperature (Low) (degrees F)	59.02	72.60	66.73	3706501.72
Outside Temperature (degrees F)	18.96	77.80	42.68	2370416.09
Light				
Pyranometer (W/m^2)	-6999.00	0.05	-257.12	-14281379.85
Photometer #1	-6999.00	182.40	-5267.90	-292599992.99
Photometer #2	-6999.00	-1470.00	-6998.64	-388732390.00
Battery				
House Battery Voltage (V)	48.32	58.35	54.02	3000253.43
House Battery Current (A)	-101.50	75.00	0.14	7772.91
House Battery Power (W)	-5020.00	4059.00	7.81	433702.35
House Battery Energy (Wh)	-16.70	10.19	0.73	40808.38
Solar Panels				
Photovotaic Array #1 Current (A)	-0.27	48.17	4.79	266188.41
Photovoltaic Array #2 Current (A)	-0.19	36.39	4.47	248136.29
Photovoltaic Array #1 Power (W)	-15.52	2609.00	258.96	14383787.86
Photovoltaic Array #2 Power (W)	-10.70	1971.00	241.30	13402689.81
Photovoltaic Array #1 Energy (Wh)	-0.26	43.48	4.32	239729.80
Photovoltaic Array #2 Energy (Wh)	-0.18	32.85	4.02	223378.16
DC Fridge				
Fridge Current (A)	-0.85	2.76	0.44	24318.57
Fridge Power (W)	-46.12	147.80	23.63	1312737.98
Refridgerator Energy (Wh)	-0.77	2.46	0.39	21878.97
Appliances				
Furnace Energy (Wh)	0.00	85.00	30.12	1673066.10
Heat Pump Energy (Wh)	0.00	1.50	0.00	274.50
Hot Water Backup Energy (Wh)	0.00	72.80	2.16	119818.25
Hot Water Circulator Energy (Wh)	0.00	0.38	0.20	11169.38
Cooktop Energy (Wh)	0.00	18.00	0.01	290.25
Heat Trace Energy (Wh)	0.00	6.75	4.81	267131.63
Communications Energy (Wh)	0.00	1.13	0.57	31591.87
Clothes Washer Energy (Wh)	0.00	19.50	0.52	28628.18
Dishwasher Energy (Wh)	0.00	10.50	0.04	2228.51
Office Energy (Wh)	0.00	0.00	0.00	0.00
Microwave Energy (Wh)	0.00	24.00	0.18	10230.34

Miscellaneous Critical Loads (Wh)	-2.31	30.32	2.13	118151.23
<u>Datalogger</u>				
Logger Voltage	13.06	13.61	13.30	738876.40
Logger Temp	48.08	93.10	70.38	3908950.91
Reference Temp	47.08	90.10	67.97	3775590.91
<u>Total House Energy</u>				
Critical Load Energy (Wh)	0.00	115.00	5.62	312152.15
Sum of Critical Loads (Wh)	0.00	89.44	3.49	194000.92
Purchased Utility Energy (Wh)	0.00	190.00	37.97	2109045.00
Sold Utility Energy (Wh)	0.00	65.00	3.06	170160.00
Energy In (Wh)	-0.12	204.49	46.28	2531855.49
Energy Out (Wh)	0.66	201.53	44.81	2488839.31

Difference between purchased and sold utility energy (kWh): -1938.89

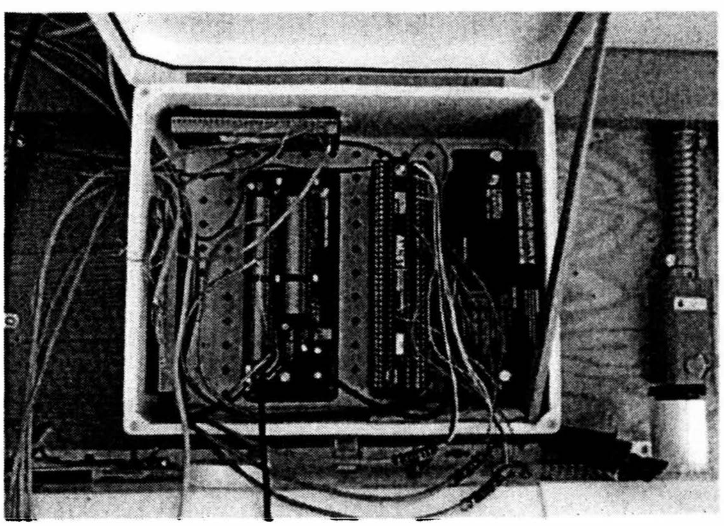
Appendix 2

Photos



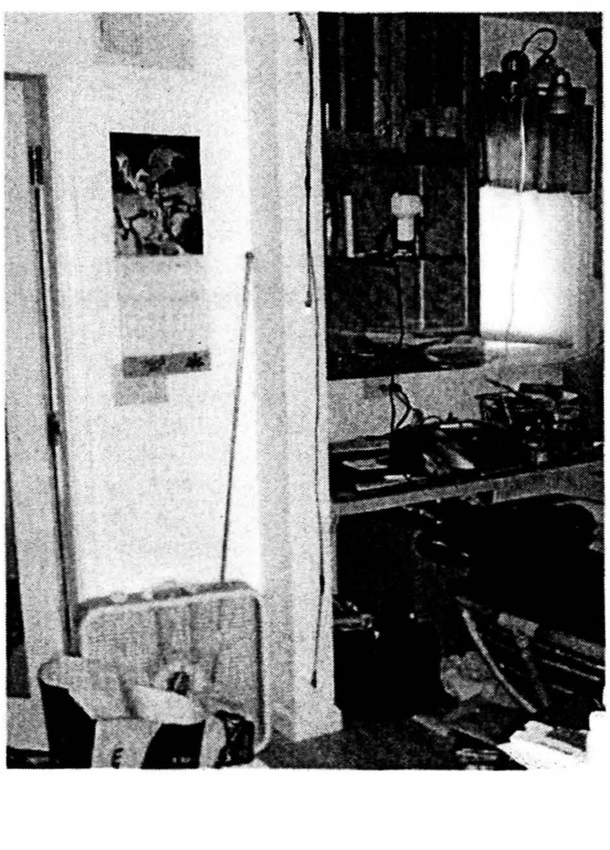
This shows the installation of the sensors. The Campbell Scientific datalogger is in the top center box, the DC load sensors in the right box, and the AC wattnodes are connected in the two electrical panels on the left.

(The NREL representative, Mike Wassmer is in the bottom of the picture)



This is a close up picture of the Campbell Scientific datalogger and multiplexer with all the wires running to it.

This is a photo of the 2002 UMR/RTI competition solar house. The pyranometer is in the middle of the two modules, sticking up above the rest of the house.



These are the temperature and humidity sensors in the 2002 house.