Optimizing Manufactured Housing Energy Use

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OPTIMIZING MANUFACTURED HOUSING ENERGY USE

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ABSTRACT

In partnership with the Florida Solar Energy Center (FSEC), two manufactured homes were located on North Carolina A&T State University's campus in Greensboro, NC and used in a side-by-side energy consumption comparison. One of the homes was built to the basic HUD code standard and the other was constructed with features expected to produce a home that was 50% more energy efficient.

FSEC and NCATSU began monitoring energy performance in both homes. In addition, the performance of each unit was evaluated using a DOE2 based computer energy analysis program developed by FSEC. A comparison of the performance of the units shows a measured energy savings in the more energy efficient unit of 52% for the Heating, cooling, and DHW energy use. This compares well with the energy savings predicted by the FSEC Energy Gauge program of 57%, even when accounting for the warmer than usual winter experienced during the testing period.

1.0 INTRODUCTION

As part of a project funded by the North Carolina Department of Administration - Energy Division, and as Part of the US Dept of Energy's Building America Program, researchers in the Center for Energy Research and Technology (CERT) at North Carolina A & T State University evaluated technologies to improve the energy efficiency of manufactured housing.

The partnership effort described by this report required CERT researchers to monitor the energy use of two side-by-side manufactured housing units on the campus of North Carolina A & T State University in cooperation with the Florida Solar Energy Center (FSEC). One of the units monitored was designed and built to basic HUD code requirements [HUD, 1999] and the other was designed to use at least 50% less energy (Building America compliant).

As part of this study, both units were also analyzed using the FSEC developed ENERGY GAUGE software program. This program predicts building energy consumption using the DOE 2 analysis engine with a user friendly front end that develops DOE2 input files and models that are more appropriate for residential building systems.

In addition, in this second year, modifications were made to the solar hot water heating system in the energy efficient housing unit to help improve the performance of this system. Further, a number of the incandescent light bulbs in the energy unit were replaced with compact fluorescent bulbs. These changes were staged to allow an evaluation of the effect each of these measures had on the energy use in the homes.

The following report summarizes the results of the second year of the effort described above (the first years results were previously reported) [McGinley, 2002].

2.0 STANDARD (HUD CODE) AND ENERGY (ENERGY EFFICIENT) MANUFACTURED HOME DESCRIPTION

Each of the two manufactured homes used in this study have 1,528 ft^2 of living area, 3 bedrooms and 2 baths. Each of the two housing units had identical floor plans. The homes were oriented on the site with the front facing east. Both houses were furnished. Exterior finishes were of medium color, with dark roofs. See Figures 1 through 3.

Each home unoccupied; however incandescent lights on timers were used to simulate occupancy loading. One of the homes was constructed using conventional HUD code provisions and the other was designed to be 50% more energy efficient. Construction differences between the two homes are listed in Table 1.

The Standard housing unit used a perimeter ducting system, while the Energy housing unit used a central trunk line. The higher thermal resistance of the energy home building envelope allows this more efficient central distribution system and a reduction in compressor tonnage, which reduces initial costs and duct losses. See Figures 1 and 2.

It should be noted that the Energy housing unit incorporated the use of a solar hot water heater, with a 66-gallon hot water tank, while the “Standard” home used an electric hot water heater with a 40-gallon tank

Table 1 Summary of Construction of the Two Homes

NCATSU Side-by-Side Study of HUD Code Homes Specifications of Standard and Energy Construction		
Characteristic	**Standard Home**	**Energy Home**
Floor Insulation	R-11	R-22
Wall Insulation	R-11	R-13
Ceiling Insulation	R-20	R-33 roof deck radiant barrier
Windows	Single Pane with Interior Storm Windows	Low-E Thermopane Windows
Exterior Doors	Storm Door on Front door only	Storm Door on All doors
Marriage Wall Seal	Fiberglass Pad	SOF-Seal Gasket
Heating System	Electric Resistance Furnace	Heat Pump HSPF7.5
Cooling System	Central Air Conditioning SEER10 - 3 ton	Central Heat Pump SEER12 - 2.0 ton
Water Heater	Electric Water Heater 40 gallon capacity	Solar Water Heater – 66 gallon capacity
Duct Joints	Industry Standard	Sealed with Mastic
Duct System	Perimeter Duct System	Main Trunk Line
House Leakage	ACH50 = 10	ACH50 = 9

*(Note that the Energy House values for Duct Leakage and House leakage were based on retests done after August 2001 repairs)

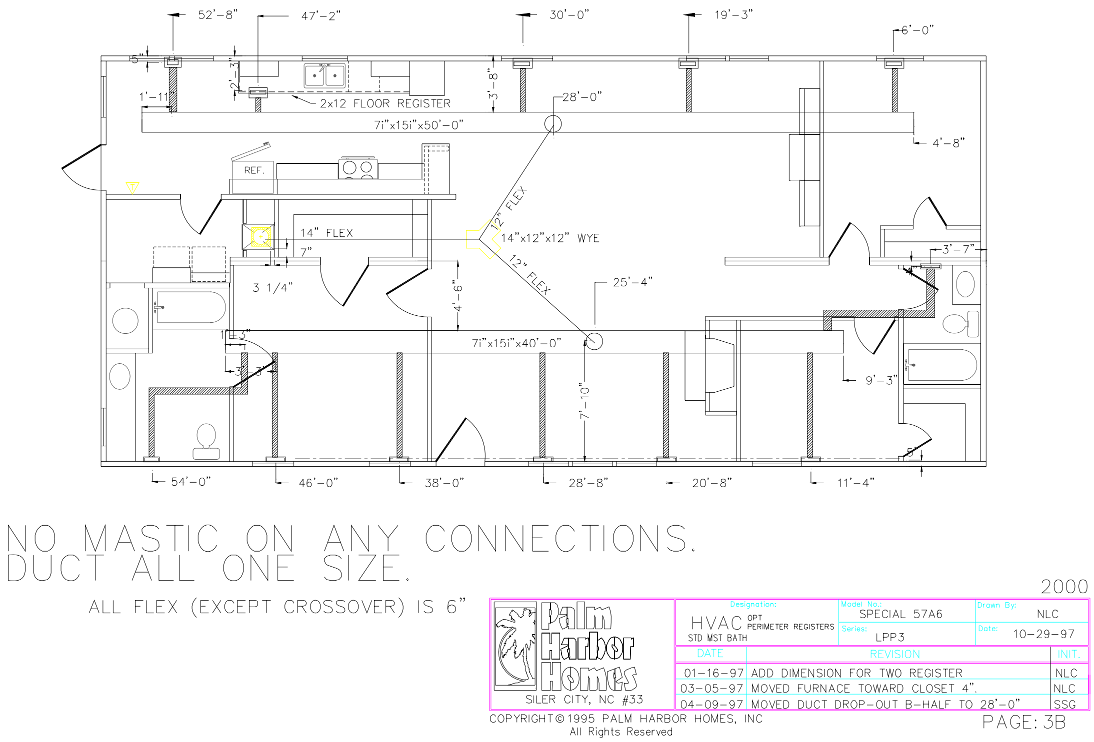

Figure 1 Floor Plan and HVAC layout for the Base HUD Code (Standard) Housing Unit (Courtesy of Palm Harbor Homes)

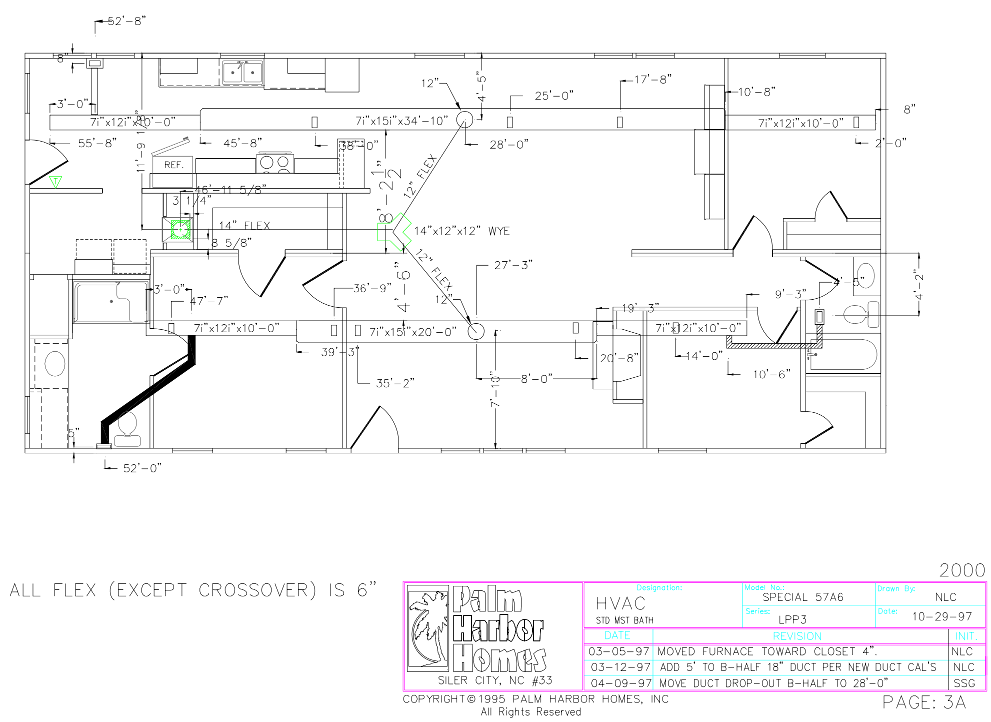

Figure 2 Floor Plan and HVAC Layout for the Energy Efficient (ENERGY) Housing Unit (Courtesy of Palm Harbor Homes)

3.0 MONITORING PROGRAM

A computerized data logging system was used in each house to monitor:

1. The interior temperature and relative humidity.
2. The power consumption of the whole house.
3. The power consumption of the air conditioning/heat pump compressor.
4. The power consumption of the air handler fan.
5. The power consumption of the electric resistance heat (primary heating in the standard house, secondary heating for the energy house).
6. The power consumption of water heater and electric water tank coil.
7. The exterior temperature and relative humidity, solar radiation (both parallel and at the solar panel angle), and wind speed.

The data-loggers were connected to FSEC's mainframe computer via modem, and downloaded automatically. Data were sampled at 6 second intervals and recorded in hourly intervals.

All appliances in the home were unplugged except for the hot water heater, HVAC system and some incandescent lights. There were also a few miscellaneous devices such as the data logger, phones, and controls that show as a minor electrical load. The incandescent lights were used to simulate an occupancy load of 1.5 persons and were run on the following schedule; 500 watts of lights were on 24 hours a day 7 days a week, 500 watts of lights are switched on by timers from 4 pm to 12 pm, 200 watts of lights are switched on by timers from 6 am to 9 am.

In addition, on weekdays, there were two hot water draws of 40 gallons each, one in the morning and one in the late afternoon for each of the houses. This water draw was used to simulate an average weekly water use of a typical residence.

A comparison of the performance of the units over the period from January 2001 to March 2002 was made and reported in the first year report. This report summarized the initial poor performance of the Energy housing unit that resulted from an excessively high air-handler fan speed that significantly reduced the efficiency of the system, a very large duct leak resulting from an improperly set Y-connection coming off the main supply duct trunk line, a supply duct collar failure and a poorly sealed opening around the refrigerant line and drain between the return and supply side of the coil plenum creating a return air bypass around the coil. These items were repaired by September 2001 and "good" data were obtained from September 1, 2001 to August 16, 2002.

Both homes were on cooling only mode from September 1, 2001 through October 26, 2001 at 7:00 pm. After this time, both homes were on heating only mode until, April 16, 2002 at 2:40 pm, where they were switched over to cooling only mode again until October, 2002. It should be noted that one of the critical findings of the first year of the investigation indicated that current manufactured home set up procedures may not be adequate to ensure predicted performance of the energy efficient home units. As a result, Palm Harbor, one of the industry partners in this investigation, has instituted steps to improve installation/setup procedures.

It was also found that the standby losses in the solar hot water heater in the Energy Unit were significant and on long idle periods were sufficient to make the overall efficiency of the solar hot water heater less than the standard electric unit. To help alleviate these stand-by losses, the solar water tank piping insulation was upgraded on March 6, 2002 and its effect on the water system performance was evaluated. The solar hot water tank had a significant amount of copper and plastic tubing exposed in the original installation configuration. Additional pipe insulation was applied to all accessible pipe surfaces and the effects of this upgrade was evaluated.

On May 1, 2002, in an effort to further improve the performance of the solar hot water heater, the solar hot water tank in the energy unit was wrapped with a R5 foil bubble wrap insulating blanket over the sides and most of the top of the tank. Figure 3 shows the tank with the foil insulation and additional pipe insulation applied.

The final modification made to the Energy Housing unit was made on June 4, 2002. At this time, three of the light fixtures that were on evening 4 hour timed duration were changed from 100 watt incandescent lamps to 25 watt compact fluorescent lamps.

Figure 3 The Solar Hot Water Tank with R5 Insulating Blanket and additional Pipe Insulation Located in the Energy Efficient Manufactured Housing Unit

4.0 RESULTS AND DISCUSSION

4.1 Energy Use Results and Discussion

The measured total energy used by each of the housing units for cooling and heating are shown in tables below. Table 2 shows the energy used for heating and cooling the Standard Housing Unit over the period of January through August in 2002. The Standard Unit data logger was struck by lighting in mid August, 2002 and all data after this point was not included since only partial data is available and comparisons of performance were not possible. Table 3 shows a similar summary of the cooling and heating energy used by the Energy Housing Unit.

Tables 4 and 5 show the energy used for domestic hot water production for the Standard and Energy units, respectively for these same periods.

Table 2 Standard Housing Unit Heating and Cooling Energy Use

	C & H ENERGY Measured Values (kWh)											
	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.
2001 values	492	448	649	1741	2495	850	629	384	566	991	853	1066
2002 values					2120	1717	1228	502	438	939	1079	511

Table 3 Energy Housing Unit Heating and Cooling Energy Use

	C & H ENERGY Measured Values (kWh)											
	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.
2001 values	337	206	151	453	1087	473	427	185	528	891	851	672
2002 values					681	537	378	242	312	603	668	627

Table 4 Standard Housing Unit Energy Use for Domestic Hot Water Production

	DHW Measured Values (kWh)											
	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.
2001 values	198	268	250	213	0	0	218	245	258	227	208	214
2002 values					295	281	283	265	280	192	200	85.2

Table 5 Energy Housing Unit Energy Use for Domestic Hot Water Production

	DHW Measured Values (kWh)											
	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.
2001 values	133	176	204	190	0	0	246	184	183	141	152	127
2002 values					251	212	203	146	157	74.8	80.3	83

Also listed in each table are the monthly energy use measured during the first phase of this investigation, January through August (2001). Note that the Energy Housing Unit data prior to August 2001 is suspect due to problems in the ducting and HVAC system, as discussed previously.

Only the cooling and heating energy, and energy used for domestic hot water production, will be discussed in this and subsequent sections since each housing unit was not occupied and was assumed to use essentially the same amount of energy for the occupancy simulation. When the three incandescent bulbs replaced with compact fluoresce bulbs in the energy unit, the reduction in energy use for lighting load was not of concern, what was being evaluated was the impact this change had on the cooling load in the housing unit.

The total cooling energy used by the Standard house from April 2002 to August 16th 2002 was 3468 kW-hrs. The total cooling energy used by the Energy house from April 2002 to August 31st, 2002, was 2451 kW-hrs. If it can be assumed that about 500 kW-hr would be used for the reminder of the August month in the Standard housing unit (~1/2 the 2001 values and about 2 times the 2002 value), then the Energy housing unit used approximately (1- 2451/(3468+500) x 100), or a 38.2 % less energy than the Standard unit for cooling during this time. The totals for the same period in 2001 were 3860 kW-hr (Standard) and 3127 kW-hr (Energy), a 19 % difference. You can see that there is an increased difference in energy efficiency of the two housing units in the second year of monitoring during the cooling season. This may be at least partially due to less waste heat being dumped into the energy unit by the solar hot water heater and compact fluorescent lights. This will be discussed later.

Over the first and second phase of this investigation there was only one complete heating season observed. The total heating energy used by the Standard house from November 2001 to March 2002 was 7454 kW-hrs. The total heating energy used by the Energy house over the same time period was 2199 kW-hr. Over this time, the Energy housing unit used approximately 70 % less heating energy than the Standard unit.

The total heating and cooling energy used by the Standard housing unit from September, 2001 through August, 2002 was 12,365 kW-hr (a sequential heating and cooling season). Over the same period of time, the Energy housing unit used 5194 kW-hr, a 58% reduction.

The total energy used for domestic hot water production from September 1, 2001 to August 16th, 2002 in the Standard unit was 2810 kW-hr. The total energy used for domestic hot water production from September 1, 2001 to August 31, 2002 in the Energy (Solar) unit used 1911 kW-hr of energy. If it is assumed that the Standard unit hot water tank would used about 110 kW-hr for the rest of the August month (about ½ of that used in previous months), the Solar hot water tank in the Energy unit used approximately 34% less energy than the Standard unit.

Combining the energy used for domestic hot water production with that used for heating and cooling produced a total of 15,285 kW-hr of energy used by the Standard housing unit between September 1, 2001 and August 31st, 2002. The Energy housing unit used a total of 7,105 kW-hr over the same period of time. The Energy unit used 53 % less energy than the Standard unit for heating cooling and production of domestic hot water over this period. As will be discussed in the next section, the improvements made on the solar hot water tank and their effects on energy use suggests that the Energy housing unit would use even less energy than the Standard housing unit with these changes in effect over a entire year.

4.2 Effect of Changes in the Solar Hot Tank and the Compact Fluorescent Fixtures

The pipe insulation on the solar hot water tank was upgraded on March 6, 2002. This increase in insulation on the hot water piping appears to have had a significant effect on the performance of the solar hot water system and appears to have reduced the stand-by heat losses in the system.

Since no hot water draws are made on the weekends, it is possible to examine how standby losses are influenced by system changes by looking at this time period specifically. The stand by losses for 18 week end days in the period of March 6 though April 30, 2002 showed that the pipe wrap has cut standby energy losses for the energy house by about 65% (an average of 2.43 kWh/ day (2001) vs. 0.85 kWh/day (2002)) over a similar period last year.

In addition, the reduction of standby losses helped the solar hot water system use less energy than the conventional electric system in the month of March. The Standard Unit used 283 kW-hr and the solar hot water system used 203 kW-hr, a 28.2% reduction. This reduction was further increased in the month of April where the standard system used 265 kW-hr and the Solar system used 146 kW-hr, a 45% reduction. It should be noted that these values represent significant reductions in energy use when they are compared to 2001 values where the solar system actually used more energy than the standard unit in March 2001 and used only 25% less than the standard unit in April 2001.

In an effort to further improve the performance of the solar hot water heater, the water tank was wrapped with a foil bubble wrap insulating blanket over the sides and most of the top of the tank.

Over the month of May, the total energy used for DWH heating was 137.8 kWh for the Energy housing unit and 249.6 kWh for the Standard housing unit. This represents a 45% reduction in energy use for the solar hot water system, about the same as the 45% reduction shown for the month of April.

A comparison of the tank losses over the weekends in months of April, 2002 and May, 2002 give a good indication of actual losses since there are no tank draws on these days. This data shows an average daily week end loss of 2.83 kWh for the Standard home and a 3.08 kWh for the Energy home for the Month of April and an average daily week end loss of 3.92 kWh for the Standard home and a 2.97 kWh for the Energy home for the month of May. There appears to be a little improvement in tank heat loss over the two periods.

The total energy used over the month of June, 2002 for DWH heating was 74.8 kWh for the Energy House and 192.2 kWh for the Standard home. This represents a 63% reduction in energy use with the solar hot water system (compared to the 45% difference for May). This appears to indicate the tank insulation may be having an effect on the losses in the tank. It should be noted that the solar radiation was about the same as the month of May (within 3%) but the water consumption was slightly less. These results suggest that the tank wrap may be reducing some of the heat losses.

The total energy used over the month of July, 2002 for DWH heating was 80.3 kWh for the Energy House and 200.25 kWh for the Standard home. This represents a 60% reduction in energy use with the solar hot water system. This compares well with the June reduction of 63% with about 11% less solar radiation in the month of July. This reduction and those in May and June are significantly greater than the efficiencies observed in 2001 without tank and piping insulation where energy use reductions ranged from 27% to 40%.

The total energy used over the period of August 1, 2002 through August 15, 2002 for DWH heating was 27.13 kWh for the Energy House and 85.18 kWh for the Standard home. This represents a 68% reduction in energy use with the solar hot water system. This compares well with the June and July reductions of 63 and 60%, respectively. These results appear to indicate the tank and pipe insulation is reducing the losses in the tank, particularly the standby losses and improving the efficiency of the solar hot water system.

To look at the impact of improved insulation of the solar hot water system on the cooling energy used in the Energy housing unit, the total cooling energy used for the months of March through August must be examined. To remove the effects of the outside temperature on this evaluation, a comparison of the percentage difference between the cooling energy used by the Standard home and the Energy home will be made. This comparison shows that in the months of March 2002 to August 2002 the Energy housing unit used 29% to 69% less cooling energy than the Standard housing unit. In the same period in 2001, this reduction ranged from only 3% to 48%. This suggests that the improvements in tank insulation may also have had a significant effect on the cooling load within the Energy home. However, the previously described deficiencies in the Energy Unit present in early 2001 make definite conclusions relative to this effect difficult.

In the Energy housing unit, three of the 100 watt incandescent lamps that were on the evening 4 hour timed duration were exchanged for 25 watt compact fluorescent lamps on June 4^{th}, 2002. This change did appear to have a small effect on the cooling load in the Energy housing unit. The relative cooling energy used by each of the housing units from June, 2002 through August 2002 showed a small change. The percentage reduction in cooling energy used by the Energy housing unit increased from about 30% to 38 percent. However, it is difficult to isolate the effects of the improvements in the solar hot water system insulation and the effects of the compact fluorescent bulbs. In any event, these effects appear to be much smaller than that produced by the hot water system changes.

4.3 Energy Analysis

The two housing units described in the previous sections were analyzed using a computer simulation program. The Energy Gauge Program (Version 1.25) developed by the Florida Solar Energy Center was used for the analysis. The Energy Gauge Program uses the basic DOE 2 energy analysis engine to provide an hourly energy use simulation for light commercial and residential structures [Danny Parker, et-al, 1999]. This program was developed to provide a simple to use interface for the DOE2 analysis program that more accurately analyzes the energy use of single and multifamily residences, and light commercial structures.

An analytical model was developed for each of the manufactured home units. These models were essentially the same with differences only in the R-values in the various building envelope components, the duct leakage values, the heating and cooling equipment and the fenestration properties. Figure 4 shows the wire model of the building envelope configuration used for the Standard Home. The Energy Unit model was similar.

The envelope leakage values were measured and these values were used in the analysis (See Table1). Table 1, and Figure 4 also show the window and door U values as well as the HVAC system properties for the unit. In addition, a uniform three-foot crawl space was assumed in the analysis of both houses. The Input Summary Sheets for each of the Energy Gauge runs are shown in Figures 4 and 5.
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It should be noted that the solar hot water heater was not incorporated in the analysis, a standard electrical unit was assumed in both unit's analyses.

The analysis of each of the manufactured housing units was also repeated using the newest version of the Energy Gauge program, Version 2.0. This program was reported to have made changes in the analysis modeling and incorporated a number of "bug fixes". The same input files were used for both set of analyses, Version 1.25 and Version 2.0

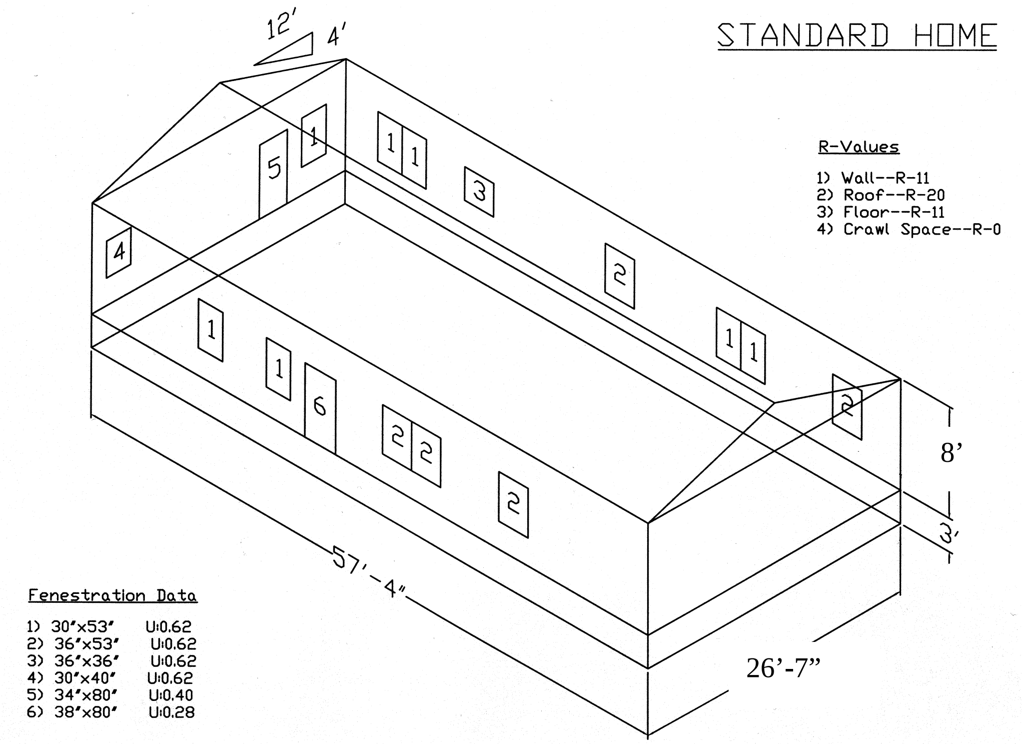

Figure 4 Standard Unit Analysis Model Configuration

Building Input Summary Report

PROJECT

Title:	basehome126	FamilyType:	Single	Adress Type:	Street Address
BuildingType:	Detailed	New/Existing:	New (From Plans)	Lot #	
Owner:		Bedrooms:	3	SubDivision:	
# of Units:	1	Conditioned Area:	1524	PlatBook:	
BuilderName:		Total Stories:	1	Street:	
Permit Office:		Worst Case:	No	County:	
Jurisdiction:		Rotate Angle:	0	City, State, Zip:	, ,

CLIMATE

Design Location	TmySite	Design Temp 2.5 %	Design Temp 97.5 %	Int Design Temp Winter	Int Design Temp Summer	Heating Degree Days	Design Moisture	DailyTemp Range
NC, Greensboro	NC_GREENSBORO	18	91	75	70	3825	30	Medium

UTILITY RATES

Fuel	Unit	UtilityName	Monthly Fixed Cost	$/Unit
Electricity	kWh	Duke Energy Corp	0	0.074
Natural Gas	Therm	North Carolina Average	0	0.869
FuelOil	Gallon	EnergyGauge Default	0	1.1
Propane	Gallon	EnergyGauge Default	0	1.4

SURROUNDINGS

Ornt	Type	Shade Trees Height	Width	Distance	Exist	Adjacent Buildings Height	Width	Distance
N	None	ft	ft	ft		0 ft	ft	ft
NE	None	ft	ft	ft		0 ft	ft	ft
E	Dense Shade Tree	12 ft	30 ft	10 ft		0 ft	ft	ft
SE	None	ft	ft	ft		0 ft	ft	ft
S	None	ft	ft	ft		0 ft	ft	ft
SW	None	ft	ft	ft		0 ft	ft	ft
W	None	ft	ft	ft		0 ft	ft	ft
NW	None	ft	ft	ft		0 ft	ft	ft

FLOORS

#	Floor Type	Exposed Perimeter	Wall Ins. R-Value	Area	Floor Joist R-Value	Tile	Wood	Carpet
1	Crawlspace	168 ft	0	1524.003	11	0	0.2	0.800000

ROOF

#	Roof Type	Materials	Attic Type	Attic Area	Roof Color	Solar Absor.	RBS	Deck Insul.	Attic Vent Ratio (1in)	Pitch
1	Gable or shed	Composition shingles	Full attic	1524 ft²	Dark	0.92	N	0	300	18.4 deg

Figure 4a Standard Housing Unit ENERGY Gauge Input Summary

Building Input Summary Report

CEILING

#	Ceiling Type	R-Value	Area	Framing Frac	Truss Type
1	Under Attic	20	1524 ft²	0.11	Wood

DOORS

#	Door Type	U-Value	Area	Location	Storms	Units
1	Wood	0.28	21.11 ft²	Exterior	Metal	1
2	Wood	0.4	18.89 ft²	Exterior	None	1

WINDOWS

Window orientation below is as entered. Actual orientation is modified by rotate angle shown in "Project" section above.

#	Ornt	Panes	Tint	Coef.	U-Factor	Area	Width	Separation	Int Shade	Storms	Frame	Units
1	N	Single	Clear	0.870000	0.62	44.15999	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	4
2	N	Single	Clear	0.870000	0.62	9 ft²	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	1
3	N	Single	Clear	0.870000	0.62	13.25 ft²	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	1
4	S	Single	Clear	0.870000	0.62	22.08 ft²	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	2
5	S	Single	Clear	0.870000	0.62	53 ft²	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	4
6	W	Single	Clear	0.870000	0.62	11.04 ft²	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	1
7	W	Single	Clear	0.870000	0.62	8.333 ft²	0 ft in	0 ft in	Drapes/blinds	Y	Wood/vin	1

WALLS

#	Wall Type	R-Value	Area	Location	Framing Fraction	Solar Absor.
1	Frame - Wood	11	678.79 ft²	Exterior	0.25	0.5
2	Frame - Wood	11	307.38 ft²	Exterior	0.25	0.5
3	Frame - Wood	11	649.09 ft²	Exterior	0.25	0.5
4	Frame - Wood	11	345.58 ft²	Exterior	0.25	0.5

INFILTRATION & VENTING

Method	CFM 50	ACH 50	ELA	EqLA	--- Forced Ventilation --- Supply CFM	Exhaust CFM	RunTime Fraction	Terrain/Wind Shielding
Estimated ACH(50)	2540	10	139.44	262.24	0 cfm	0 cfm	0	Suburban / Suburban

COOLING SYSTEM

#	System Type	Efficiency	Capacity	Air Flow	SHR	Ceiling Fans	WH Fans	Cross Vent
1	Central Unit	SEER:10	22.5 kBtu/hr	540 cfm	0.75	No		

HOT WATER SYSTEM

#	System Type	EF	Cap	Use	SetPnt	Credits
1	Electric	0.88	50 gal	60 gal	140 deg	None

HEATING SYSTEM

#	System Type	Efficiency	Capacity
1	Electric Strip Heat	HSPF:1	30 kBtu/hr

Figure 4b Standard Housing Unit ENERGY Gauge Input Summary

Building Input Summary Report

DUCTS

#	-- Supply -- Location	R-Value	Area	-- Return -- Location	Area	Leakage Type	Air Handler	Coil Air Flow	CFM 25	Percent Leakage	QN	RLF
1	Crawlspace	8	78 ft²	Interior	0 ft²	Prop. Air Leakage	Interior	792 cfm	90.8 cfm	9.2 %	0.06	0.6

TEMPERATURES

Programable Thermostat: N   Ceiling Fans: N

Cooling	[ ] Jan	[ ] Feb	[ ] Mar	[ ] Apr	[X] May	[X] Jun	[X] Jul	[X] Aug	[X] Sep	[ ] Oct	[ ] Nov	[ ] Dec
Heating	[X] Jan	[X] Feb	[X] Mar	[X] Apr	[ ] May	[ ] Jun	[ ] Jul	[ ] Aug	[ ] Sep	[X] Oct	[X] Nov	[X] Dec
Venting	[ ] Jan	[ ] Feb	[ ] Mar	[ ] Apr	[ ] May	[ ] Jun	[ ] Jul	[ ] Aug	[ ] Sep	[ ] Oct	[ ] Nov	[ ] Dec

Thermostat Schedule: MyFavorite

Schedule Type		1	2	3	4	5	6	7	8	9	10	11	12
Cooling (WD)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73
Cooling (WEH)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73
Heating (WD)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73
Heating (WEH)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73

(Hours)

APPLIANCES & LIGHTING

Appliance Schedule: HERS Reference

Schedule Type		1	2	3	4	5	6	7	8	9	10	11	12
Ceiling Fans (Summer)	AM	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5
% Released: 100	PM	0.5	0.5	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.75
Peak Value: 0 Watts													
Dryer	AM	0.2	0.1	0.05	0.05	0.05	0.075	0.2	0.375	0.5	0.8	0.95	1
% Released: 0	PM	0.875	0.85	0.8	0.625	0.625	0.6	0.575	0.55	0.625	0.7	0.65	0.375
Peak Value: 200 Watts													
Lighting	AM	0.16	0.15	0.16	0.18	0.23	0.45	0.4	0.26	0.19	0.16	0.12	0.11
% Released: 90	PM	0.16	0.17	0.25	0.27	0.34	0.55	0.55	0.88	1	0.86	0.51	0.28
Peak Value: 327 Watts													
Other	AM	0.48	0.47	0.47	0.47	0.47	0.47	0.64	0.71	0.67	0.61	0.55	0.53
% Released: 90	PM	0.52	0.5	0.5	0.5	0.59	0.73	0.79	0.99	1	0.96	0.77	0.55
Peak Value: 435 Watts													
PoolPump	AM	0	0	0	0	0	0	0	0	0	1	1	1
% Released: 0	PM	1	1	1	1	0	0	0	0	0	0	0	0
Peak Value: 0 Watts													
Range	AM	0.057	0.057	0.057	0.057	0.057	0.114	0.171	0.286	0.343	0.343	0.343	0.4
% Released: 100	PM	0.457	0.343	0.286	0.4	0.571	1	0.857	0.429	0.286	0.229	0.171	0.114
Peak Value: 165 Watts													
Refrigeration	AM	0.85	0.78	0.75	0.73	0.73	0.73	0.75	0.75	0.8	0.8	0.8	0.8
% Released: 100	PM	0.88	0.85	0.85	0.83	0.88	0.95	1	0.98	0.95	0.93	0.9	0.85
Peak Value: 140 Watts													
WellPump	AM	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1
% Released: 0.05	PM	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Peak Value: 0 Watts													

(Hours)

Figure 4c Standard Housing Unit ENERGY Gauge Input Summary

Building Input Summary Report

PROJECT

Title:	energyhome126	Family Type:	Single	Adress Type:	StreetAddress
Building Type:	Detailed	New/Existing:	New (From Plans)	Lot #	
Owner:		Bedrooms:	3	SubDivision:	
# of Units:	1	Conditioned Area:	1524	PlatBook:	
Builder Name:		Total Stories:	1	Street:	
Permit Office:		WorstCase:	No	County:	
Jurisdiction:		Rotate Angle:	0	City, State, Zip:	, ,

CLIMATE

Design Location	Tmy Site	Design Temp 2.5 %	Design Temp 97.5 %	Int Design Temp Winter	Int Design Temp Summer	Heating Degree Days	Design Moisture	Daily Temp Range
NC, Greensboro	NC_GREENSBORO	18	91	75	70	3825	30	Medium

UTILITY RATES

Fuel	Unit	Utility Name	Monthly Fixed Cost	$/Unit
Electricity	kWh	Duke Energy Corp	0	0.074
Natural Gas	Therm	North Carolina Average	0	0.869
Fuel Oil	Gallon	EnergyGauge Default	0	1.1
Propane	Gallon	EnergyGauge Default	0	1.4

SURROUNDINGS

Ornt	Type	Shade Trees Height	Width	Distance	Exist	Adjacent Buildings Height	Width	Distance
N	None	ft	ft	ft		0 ft	ft	ft
NE	None	ft	ft	ft		0 ft	ft	ft
E	Dense Shade Tree	12 ft	30 ft	10 ft		0 ft	ft	ft
SE	None	ft	ft	ft		0 ft	ft	ft
S	None	ft	ft	ft		0 ft	ft	ft
SW	None	ft	ft	ft		0 ft	ft	ft
W	None	ft	ft	ft		0 ft	ft	ft
NW	None	ft	ft	ft		0 ft	ft	ft

FLOORS

#	Floor Type	Exposed Perimeter	Wall Ins. R-Value	Area	Floor Joist R-Value	Tile	Wood	Carpet
1	Crawlspace	168 ft	0	1524.003	22	0	0.2	0.800000

ROOF

#	Roof Type	Materials	Attic Type	Attic Area	Roof Color	Solar Absor.	RBS	Deck Insul.	Attic Vent Ratio (1in)	Pitch
1	Gable or shed	Composition shingles	Full attic	1524 ft²	Dark	0.92	Y	0	300	18.4 deg

Figure 5a Energy Housing Unit ENERGY Gauge Input Summary

Building Input Summary Report

CEILING

#	Ceiling Type	R-Value	Area	Framing Frac	Truss Type
1	Under Attic	33	1524 ft²	0.11	Wood

DOORS

#	Door Type	U-Value	Area	Location	Storms	Units
1	Wood	0.28	21.11 ft²	Exterior	Metal	1
2	Wood	0.28	18.89 ft²	Exterior	Metal	1

WINDOWS

Window orientation below is as entered. Actual orientation is modified by rotate angle shownin "Project" section above.

#	Ornt	Panes	Tint	Coef.	U-Factor	Area	Width	Separation	Int Shade	Storms	Frame	Units
1	N	Low-E Double	SHGC[wi	0.48	0.47	44.16 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	4
2	N	Low-E Double	SHGC[wi	0.48	0.47	9 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	1
3	N	Low-E Double	SHGC[wi	0.48	0.47	13.25 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	1
4	S	Low-E Double	SHGC[wi	0.48	0.47	22.08 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	2
5	S	Low-E Double	SHGC[wi	0.48	0.47	53 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	4
6	W	Low-E Double	SHGC[wi	0.48	0.47	11.04 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	1
7	W	Low-E Double	SHGC[wi	0.48	0.47	8.333 ft²	0 ft in	0 ft in	Drapes/blinds	N	Wood/vin	1
8	Skylt	Single	Clear	1	1.17	2 ft²	0 ft in	0 ft in	Drapes/blinds	N	Metal	1

WALLS

#	Wall Type	R-Value	Area	Location	Framing Fraction	Solar Absor.
1	Frame - Wood	13	678.79 ft²	Exterior	0.25	0.5
2	Frame - Wood	13	307.38 ft²	Exterior	0.25	0.5
3	Frame - Wood	13	649.09 ft²	Exterior	0.25	0.5
4	Frame - Wood	13	345.58 ft²	Exterior	0.25	0.5

INFILTRATION & VENTING

Method	CFM 50	ACH 50	ELA	EqLA	---- Forced Ventilation ---- Supply CFM	Exhaust CFM	Run Time Fraction	Terrain/Wind Shielding
Estimated ACH(50)	2286	9	125.5	236.02	0 cfm	0 cfm	0	Suburban / Suburban

COOLING SYSTEM

#	System Type	Efficiency	Capacity	Air Flow	SHR	Ceiling Fans	WH Fans	Cross Vent
1	Central Unit	SEER: 12	18.8 kBtu/hr	564 cfm	0.75	No		

HOT WATER SYSTEM

#	System Type	EF	Cap	Use	SetPnt	Credits
1	Electric	0.88	66 gal	60 gal	140 deg	Solar System

HEATING SYSTEM

#	System Type	Efficiency	Capacity
1	Electric Heat Pump	HSPF: 7.5	32.9 kBtu/hr

Figure 5b Energy Housing Unit ENERGY Gauge Input Summary

Building Input Summary Report

DUCTS

#	---- Supply ---- Location	R-Value	Area	---- Return---- Location	Area	Leakage Type	Air Handler	Coil Air Flow	CFM 25	Percent Leakage	QN	RLF
1	Crawlspace	8	78 ft²	Interior	0 ft²	Prop. Air Leakage	Interior	792 cfm	90.8 cfm	9.2 %	0.06	0.6

TEMPERATURES

Programable Thermostat: N   Ceiling Fans: N

Cooling	[ ] Jan	[ ] Feb	[ ] Mar	[ ] Apr	[X] May	[X] Jun	[X] Jul	[X] Aug	[X] Sep	[ ] Oct	[ ] Nov	[ ] Dec
Heating	[X] Jan	[X] Feb	[X] Mar	[X] Apr	[ ] May	[ ] Jun	[ ] Jul	[ ] Aug	[ ] Sep	[X] Oct	[X] Nov	[X] Dec
Venting	[ ] Jan	[ ] Feb	[ ] Mar	[ ] Apr	[ ] May	[ ] Jun	[ ] Jul	[ ] Aug	[ ] Sep	[ ] Oct	[ ] Nov	[ ] Dec

Thermostat Schedule: MyFavorite

Schedule Type		1	2	3	4	5	6	Hours 7	8	9	10	11	12
Cooling (WD)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73
Cooling (WEH)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73
Heating (WD)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73
Heating (WEH)	AM	73	73	73	73	73	73	73	73	73	73	73	73
	PM	73	73	73	73	73	73	73	73	73	73	73	73

APPLIANCES & LIGHTING

Appliance Schedule: HERS Reference

Schedule Type		1	2	3	4	5	6	Hours 7	8	9	10	11	12
Ceiling Fans (Summer)	AM	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5
% Released: 100	PM	0.5	0.5	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.75
Peak Value: 0 Watts													
Dryer	AM	0.2	0.1	0.05	0.05	0.05	0.075	0.2	0.375	0.5	0.8	0.95	1
% Released: 0	PM	0.875	0.85	0.8	0.625	0.625	0.6	0.575	0.55	0.625	0.7	0.65	0.375
Peak Value: 200 Watts													
Lighting	AM	0.16	0.15	0.16	0.18	0.23	0.45	0.4	0.26	0.19	0.16	0.12	0.11
% Released: 90	PM	0.16	0.17	0.25	0.27	0.34	0.55	0.55	0.88	1	0.86	0.51	0.28
Peak Value: 327 Watts													
Other	AM	0.48	0.47	0.47	0.47	0.47	0.47	0.64	0.71	0.67	0.61	0.55	0.53
% Released: 90	PM	0.52	0.5	0.5	0.5	0.59	0.73	0.79	0.99	1	0.96	0.77	0.55
Peak Value: 435 Watts													
Pool Pump	AM	0	0	0	0	0	0	0	0	0	1	1	1
% Released: 0	PM	1	1	1	1	0	0	0	0	0	0	0	0
Peak Value: 0 Watts													
Range	AM	0.057	0.057	0.057	0.057	0.057	0.114	0.171	0.286	0.343	0.343	0.343	0.4
% Released: 100	PM	0.457	0.343	0.286	0.4	0.571	1	0.857	0.429	0.286	0.229	0.171	0.114
Peak Value: 165 Watts													
Refrigeration	AM	0.85	0.78	0.75	0.73	0.73	0.73	0.75	0.75	0.8	0.8	0.8	0.8
% Released: 100	PM	0.88	0.85	0.85	0.83	0.88	0.95	1	0.98	0.95	0.93	0.9	0.85
Peak Value: 140 Watts													
Well Pump	AM	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1
% Released: 0.05	PM	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Peak Value: 0 Watts													

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Figure 5c Energy Housing Unit ENERGY Gauge Input Summary

Table 6 shows the predicted monthly heating and cooling energy use of the Standard housing unit for September through August (Obtained from both versions of the Energy Gauge program). Also shown in the table is the measured monthly energy use, as well as the percentage difference between the measured and predicted values.

Examination of Table 6, shows that the predicted values ranged from 13 % under the actual usage to 265 % over the actual usage of energy. The analysis model appears to generally underestimate the energy use in the full cooling months and over estimate the energy use in the heating months. Examination of Table 6 also shows that Version 2 of the Energy Gauge program predicts a greater energy use for the Standard housing unit, than Version 1.25. Although there is not good agreement between any of the energy use predictions and the measured values, it appears that the latest version of the program provides a slightly better prediction. The reason for the discrepancy between predicted and measured values relates to the actual weather conditions experienced by the housing units and will be discussed later.

Table 7 shows the predicted heating and cooling energy use for the Energy housing unit for September through August (Obtained from both versions of the Energy Gauge program). Also shown in the table is the measured monthly energy use, for both years as well as the percentage difference between the measured and predicted values.

Table 6 Standard Housing Unit Analysis for Heating and Cooling Energy Use Predicted and Measured

	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.
	Predicted Values (kWh)											
version2.0	430	732	1946	3570	4275	3099	1954	740	287	589	737	694
version1.25	370	652	1757	3209	3825	2772	1762	676	236	509	646	609
	Actual Values (kWh)											
2001 values	492.4	447.6	648.6	1741	2495	849.6	628.8	384	566.3	990.8	852.9	1066
2002 values					2120	1717	**1228**	502	438	939.4	1079	511.2
	Comparison of Values											
EGV2.0 vs M. 01	13%	-64%	-200%	-105%	-71%	-265%	-211%	-93%	49%	41%	14%	35%
EGV2.0 vs M. 02					-102%	-80%	-59%	-47%	34%	37%	32%	-36%
EGV1.25 vs M. 01	25%	-46%	-171%	-84%	-53%	-226%	-180%	-76%	58%	49%	24%	43%
EGV1.25 vs M. 02					-80%	-61%	-44%	-35%	46%	46%	40%	-19%

Table 7 Energy Housing Unit Analysis for Heating and Cooling Energy Use Predicted and Measured

	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.
	Predicted Values (kWh)											
version2.0	329	175	520	1065	1478	997	522	163	219	447	561	528
version1.25	255	172	480	923	1187	823	493	188	158	343	436	414
	Actual Values (kWh)											
2001 values	337.3	205.7	150.8	452.8	1087	472.8	426.9	184.8	528.3	891.5	850.9	671.6
2002 values					680.7	537.1	378.1	241.9	311.8	603	668	626.6
	Comparison of Values											
EGV2.0 vs M. 01	2%	15%	-245%	-135%	-36%	-111%	-22%	12%	59%	50%	34%	21%
EGV2.0 vs M. 02					-117%	-86%	-38%	33%	30%	26%	16%	16%
EGV1.25 vs M. 01	24%	16%	-218%	-104%	-9%	-74%	-15%	-2%	70%	62%	49%	38%
EGV1.25 vs M. 02					-74%	-53%	-30%	22%	49%	43%	35%	34%

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As can be seen by examining Table 7, the predicted values ranged from 2 % under the actual usage to 245% over the actual usage of energy. Even though there were problems with the ducting and HVAC system in the Energy housing unit in early 2001, both analyses appear to generally underestimate the energy use during the cooling (even partially cooling) months, and significantly over estimate the energy use during the heating months for the Energy home.

The results of these analyses also show that Version 2 of the Energy Gauge program predicts a greater energy use for the Energy housing unit, than Version 1.25. Again, there is not good agreement between both programs energy use predictions and the measured values.

If we look at the two sets of analyses we can see a similar trend in the difference between the predicted and measured values. It is likely that a significant amount of this can be attributed to the difference between the actual outside temperatures and those assumed by the analysis program. To evaluate whether this is a significant cause for the inaccuracy of the prediction, a comparison of cooling and heating degree days can be made for both the actual measured outside temperatures and those assumed by the analysis programs.

The average hourly outside temperature measured at the housing units was examined and the heating degree day value (HDD) for each hour was calculated using the following formula:

HDD= (65-T)/24, T=average hourly ambient temperature

These values were added for each 24 hour period, excluding negative values. To calculate the HDD value for the heating months, the HDD values for all the days of that month were added.

A similar procedure was used for calculating the cooling degree day values (CDD), except the following formula was used:

CDD= (T-65)/24, T=average hourly ambient temperature

The predicted HDD and CDD values were also calculated based on the average hourly ambient temperatures listed in energy gauge weather data file.

The results of this analysis are presented in Table 9. Examination of these results indicates that the housing units experienced fewer heating degree days than that assumed by the analysis and experienced greater cooling degree days than assumed by the analysis. This suggests that the analysis will generally over estimate the energy used during the heating season and underestimate the energy used in the cooling season. This pattern is what was observed and suggests that inaccuracies of energy use prediction are, at least in part, weather driven. It should also be noted that the actual home did not use the appliances assumed in the analysis and these will provide some heat loading in the homes not present in the actual homes.

Table 9 Cooling and Heating Degree Day Analysis Results- Both Measured and Assumed

HEATING

	Jan.	Feb.	March	April	Oct.	Nov.	Dec.
Energy Gauge 2.0	985.13	744.04	529.08	237.92	244.71	494.79	825.75
Measured 2001	740.38	484.59	513.78	182.34	156.39	271.54	514.87
Measured 2002	639.76	539.54	421.02	108.18	208.20	458.65	728.69
Percent diff (2001)	-33.06	-53.54	-2.98	-30.48	-56.47	-82.22	-60.38
Percent diff (2002)	-53.98	-37.90	-25.67	-119.93	-17.54	-7.88	-13.32

COOLING

	May	June	July	Aug.	Sept.
Energy Gauge 2.0	104.08	256.63	343.38	317.13	182.13
Measured 2001	191.94	379.66	372.14	455.54	215.06
Measured2002	226.69	451.38	518.42	472.70	285.86
Percent diff (2001)	45.77	32.41	7.73	30.39	15.31
Percent diff (2002)	54.09	43.15	33.77	32.91	36.29

However, if the predicted energy savings is compared to the actual energy savings, a reasonable agreement is achieved. Table 7 shows that the total cooling and heating energy used by the Standard housing unit for the year defined as September 2001 through August 2002 is 12365 kW-hr (adding 500 kW-hr for energy use after Data logger failure). For the same period of time, the Energy housing unit used 5194 kW-hr (Table 8), a 58% difference. The yearly cooling and heating energy use difference between the Standard and Energy housing units predicted by the Energy gauge program is 63% for Version 2.0 and 66% for Version 1.25. This suggests good agreement between predicted and measured energy savings and is similar to that found by others [Parker et-al, 1998].

In addition, the energy savings prediction for cooling, heating and domestic hot water production is approximately as accurate with a predicted savings of 54% (Version 2.0) to 61% and a measured savings of 53%.

It appears that The ENERGY Gauge program gives a reasonably accurate prediction of energy savings and Version 2.0 appears to be slightly more accurate than Version 1.25.

5.0 CONCLUSIONS

Based on the results of the investigation summarized in this report, it can be concluded that

1. The changes in the building envelopes, HVAC systems (increases in efficiency and reduction in tonnage), HVAC ducts, and fenestrations between the HUD code and Energy efficient manufactured homes located on the campus of North Carolina A & T State University appear to be meeting the goal of a 50% reduction in energy consumption. The yearly measured energy savings for heating and cooling energy is 58%, and 53% for heating, cooling and production of domestic hot water.

2. Care needs to be exercised in the setup of the manufactured housing units or relatively minor construction deficiencies can significantly reduce energy efficiency of manufactured housing units. Many of these items are unknown to the homeowner and procedures must be developed to ensure this does not happen in the field.

3. Although the Energy Gauge Energy analysis program did not give an accurate prediction of energy use for typical manufactured housing configurations over the period measured, it did appear to give a reasonably accurate prediction of energy savings. The predicted energy savings for the units evaluated in this investigation ranged from 54% to 63%, while the measure values ranged from 53% to 58%. Version 2.0 of the Energy Gauge Program appeared to provide the more accurate predictions of energy savings.

4. The increase in pipe insulation and an increase in tank insulation increased not only the energy efficiency of the solar hot water heater by reducing stand-by losses but also reduced the cooling load in the manufactured housing unit, significantly increasing the overall energy efficiency of the unit. It appears exposed piping can significantly affect the energy efficiency of the solar hot water heater.

5. Replacement of incandescent lamps with compact fluorescent bulbs not only reduced lighting energy use, but also may have slightly reduced the cooling load in manufactured housing units, while providing essentially the same lighting levels.

6.0 REFERENCES

1. Code of Federal Regulations Housing and Urban Development [HUD], Manufactured Home Construction and Safety Standards, 24, Part 3280, US Government Printing Office, 1999.
2. McGinley, W. M., “Study of Innovative Manufactured Housing Envelope Materials”, Final Report to the Florida Solar Energy Center, Under the Building America Industrialized Housing Partnership, April 2002.
3. Parker, D. et.al., 1999. "Energy Gauge® USA: A Residential Building Energy Simulation Design Tool", Proceedings of Building Simulation ’99. International Building Performance Simulation Association, Organizing Committee for the 6th International IBPSA Conference, Department of Architecture Texas A&M University, TX.

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