Using the standards set in the *2000 Minnesota Energy Code* as a guideline, CARB determined the depressurization of the home in the worst-case scenario. All of the exhaust fans were turned on, the Blower Door was used to exhaust 150 cfm to simulate a clothes dryer, and the water heater was turned on. This resulted in a house depressurization of -19.5 Pa. For a power-vented appliance, the *2000 Minnesota Energy Code* limits the maximum allowable depressurization to 25 Pa. This home falls within those safety guidelines. In addition, CARB used Bacharach Combustion Testing Equipment to verify that there was no spillage of combustion products in the mechanical closet.

Exhaust Fan Airflow Measurements
Using a Balometer, each bathroom exhaust fan was tested and the results are summarized in the table below. The results were consistent with test results of this same fan type installed in prototypes throughout the country. In each case, the fan drew less than 80% of the rated airflow. Also shown in the table is the reduced airflow measured during the CAZ worst-case depressurization test. When the house was depressurized to -28 Pa, with the water heater running and the Blower Door simulating 250 cfm of additional exhaust airflow, the fan flows decreased by an average of 30%. CARB expected a drop in airflow but wanted to verify that the "exhaust-only" ventilation strategy would still work in a tight home. Despite the decrease in airflow, the fans are still able to draw air from the home under extreme conditions.

Bathroom Exhaust Fan Performance

Location	Manuf.	Model	Rated CFM	Measured CFM	CAZ CFM
Main Bath	Broan	S80UE	80	63	45
Master Bath	Broan	S80UE	80	56	37

To minimize roof penetrations, the builder had originally tied the exhaust ducts for both fans into a single termination through the roof. Recognizing the negative impact all the elbows and impingements would have on the fan static pressure, CARB encouraged the builder to provide separate exhaust terminations for each fan. Shown on the right, the builder used a fitting to transition from the 4 inch fan outlet to 6 inch insulated flex duct. The duct was terminated directly out the roof with less than 5 feet of ductwork on each fan. Despite the extra efforts to reduce pressure drop, the fans did not achieve the Manufacturer's rated airflow.

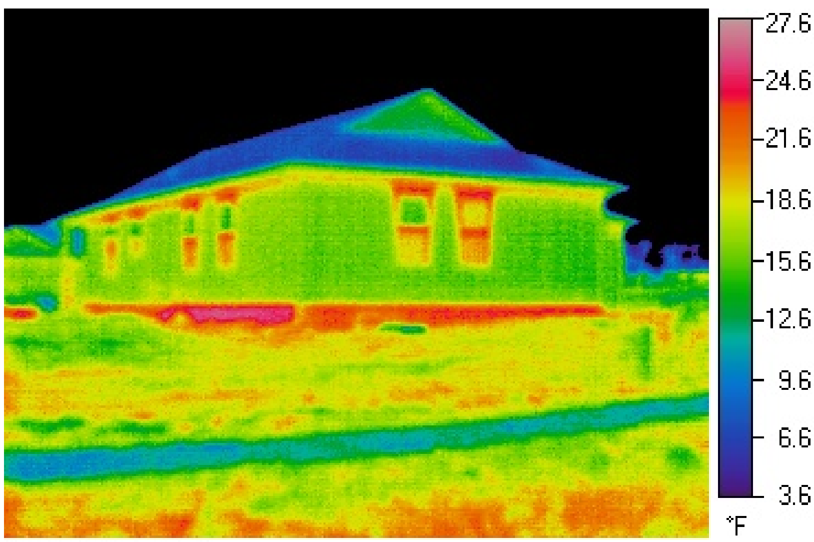
Based on the measured airflow rate of 63 cfm in the Main Bath, CARB calculated the run-time of the fan required to meet the requirements established by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in *Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings.* To meet *Standard 62.2*, an intermittent fan in this home needs to operate for 40 minutes each hour. The pin timer control connected to the Main Bath fan, which can be set for 20 minute intervals, was programmed for this schedule.

Verification of Specifications

CARB performed a detailed audit of the appliances, lighting, equipment, and building specifications in the home. As shown on the right, a Low e Detector was used to verify the low e coating on the windows. During the audit, CARB noticed the stove had a recirculating range hood that did not exhaust to the outside. Although CARB had specified that all exhaust fans be vented to the outside, this is a common mistake. However, after the final testing was complete, the builder went to great lengths to replace the hood and provide proper venting to the outside.

Infrared Camera Photographs

Infrared images are a valuable tool to help visualize the heat loss through the building envelope. The Nebraska Public Power District (NPPD) owns a number of Infrared (IR) Cameras, which are available on loan to interested parties. CARB was able to borrow an IR Camera during the performance testing to take pictures of both the Prototype Home and standard practice construction in the area. On the morning the exterior photographs were taken it was approximately 28º F outside. IR images are shown below.



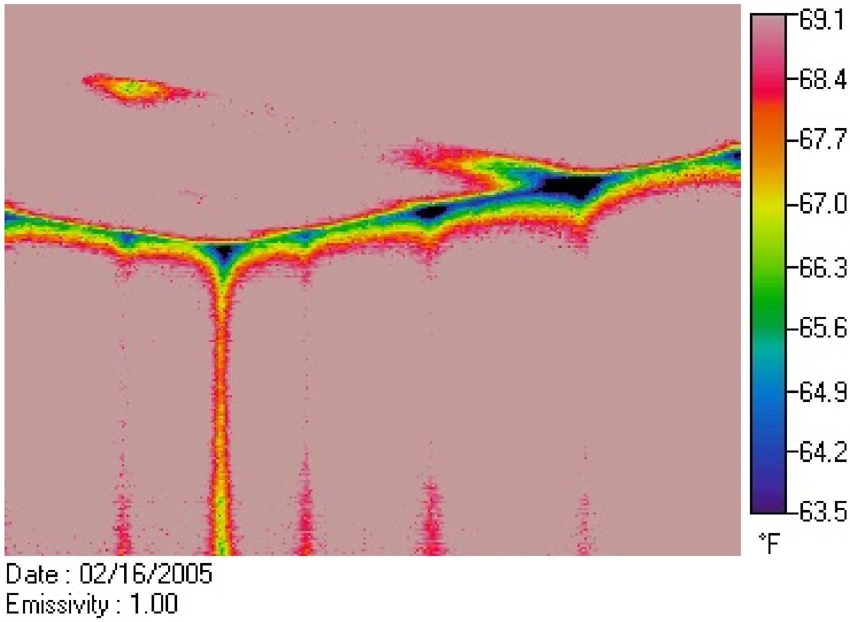
Date : 02/16/2005
Emissivity : 1.00

Prototype Home

Date : 02/16/2005
Emissivity : 1.00

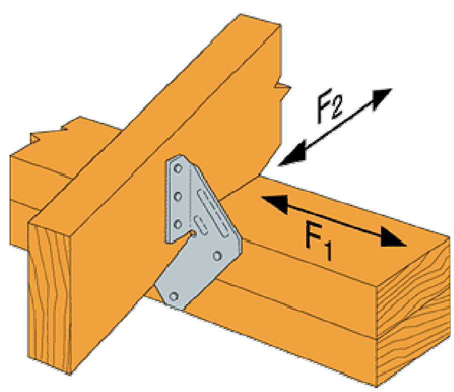
Standard Practice Construction

The IR photographs show that there is less heat loss through the windows of the Prototype Home, a result of high performance glass. The heat loss of the above-grade walls is also greater in the Standard Practice Construction than that of the Prototype.



The IR image above was taken from the interior of the Prototype Home later the same day. It shows two problem areas that are commonly found in framed construction. First is the cold corner. Although this home has open, two-stud corners to allow increased insulation, the extra framing members at the corners increase heat loss. This problem would be much worse in a typical, un-insulated corner.

The major sources of heat loss visible in this photo are the hurricane and seismic clips. These metal clips are placed at the top of wall and attached to each truss. They are designed to resist truss uplift during high winds. As shown on the right, the Manufacturer's Installation Instructions require that the clips be installed on the exterior side of the wall. Unfortunately, it is common practice across the country to install these clips on the interior side of the wall. When improperly installed, the clips do not provide the structural wind resistance for which they were designed. In addition, the metal provides a direct conduction path for cold air when it is contact with the truss plates, as indicated in the IR image and shown below.



Properly Installed Clip

Incorrectly Installed Clip

Many builders are unaware of that these installation practices result in a frame that is both thermally and structurally weaker. It is simply more convenient to install them on the inside because it can be done from a standard ladder. In many cases, these cold spots in the drywall eventually lead to "ghosting", a condition where the drywall blackens at each clip location. CARB continues to educate builders about the proper installation practices.

Short-Term Monitoring
The HVAC system for this home has supply registers that serve the space from overhead. In a heating dominated climate, there were concerns that the hot air would stratify at the ceiling and cause an uncomfortable temperature gradient between the floor and ceiling. To ensure proper mixing of the room air, CARB specified curved-blade registers that are adjustable in three directions. These registers give the occupant more control of the airflow and direct the air down into the living space.

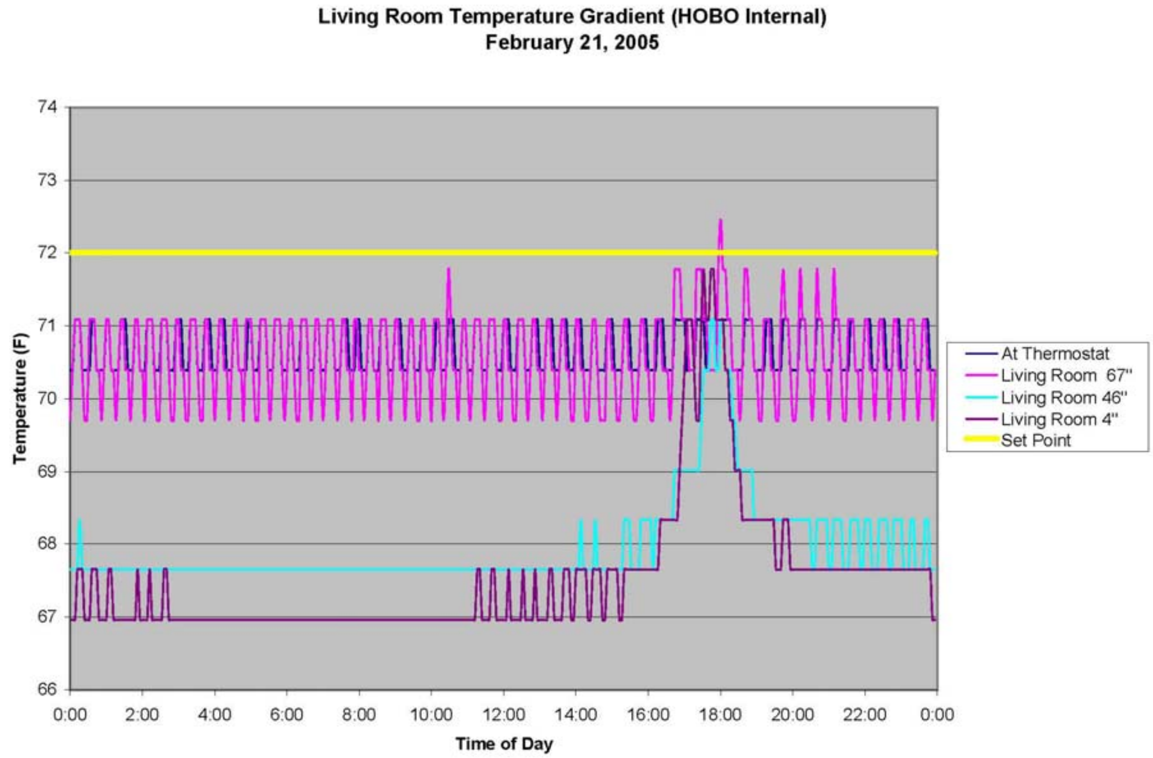
To evaluate the effectiveness of this design strategy, CARB installed seven HOBO temperature sensors in the home. Each sensor scanned the temperature of the space at three minute intervals and logged the temperature data for one week. The test period lasted from February 20-26, 2005. As shown in the photographs below, sensors were installed in two different rooms. The first set of sensors was installed in the main living space at the front of the home, which faces South. The second set of sensors was installed in the Master Bedroom, which is on the North West corner of the home. The last sensor was located next to the thermostat to monitor the overall space temperature.

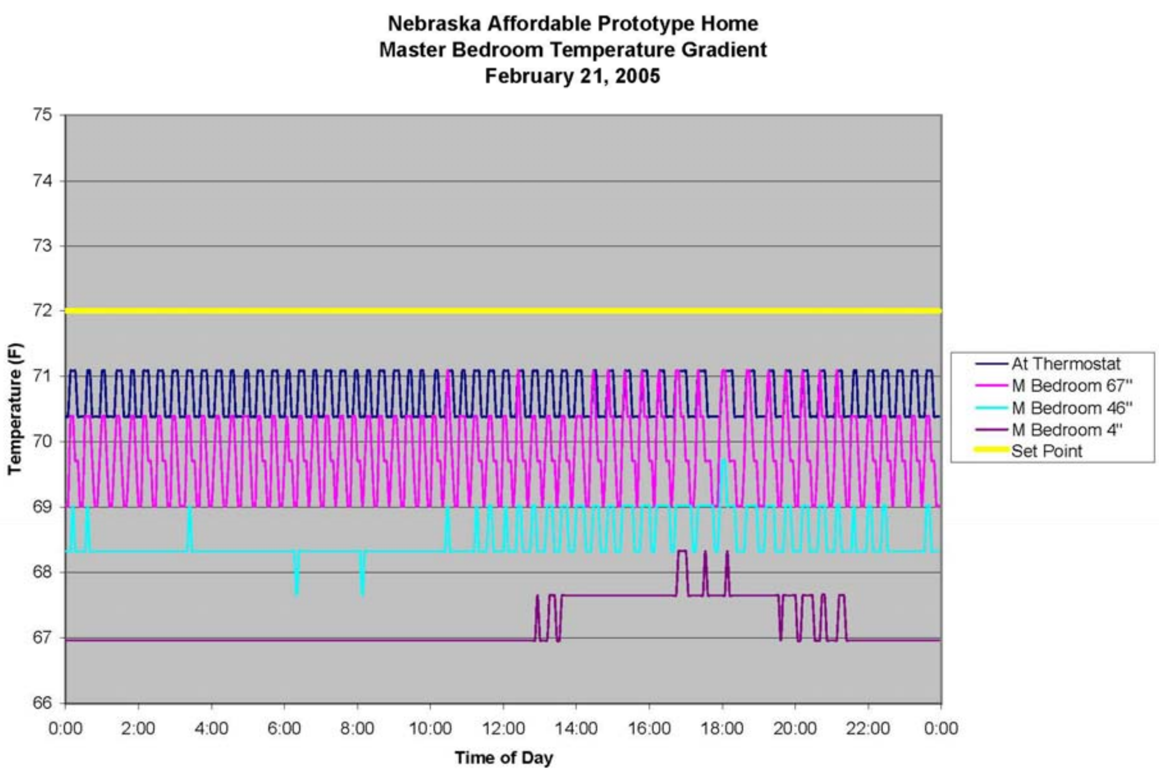
CARB followed the test protocol established in ASHRAE *Standard 55-2004, Thermal Environmental Conditions for Human Occupancy*. The sensors were located near the center of the room and approximately 3 feet from exterior walls or windows. In each room, the air temperature was measured at three heights: 4 inches, 43 inches, and 67 inches from the ground. The thermostat was set for a constant temperature of 72º F for the entire test period.


Living Room Sensors


Master Bedroom Sensors

Test results for a typical day are shown in the two graphs below. In the afternoon, the Living Room temperatures are impacted by solar gains. The temperature at the thermostat stays fairly constant, within 1.5 degrees of the setpoint temperature. The temperature difference between the floor and ceiling is typically 4º F in the Living Room and 3.5º F in the Master Bedroom. These results fall within the acceptable limits defined by *Standard 55-2004*. According to ASHRAE, less than 5% of occupants will be dissatisfied if the vertical temperature difference between the head and ankles is less than 5.4º F.





Appendix A: Energy Modeling

Building America Benchmark/Builder/Prototype Specifications

Project name: Nebraska
Model name: Single-Family
Location: Lincoln, NE

General Description	
Area of living space = 1,175 ft^2	Floors above grade = 1
Glazing Area = 170 ft^2	Attached Garage = 252 ft^2
Basement Area = 1,175 ft^2	TMY site: Omaha, NE

Side-by-Side Study of Homes
Specifications of Standard and Energy Construction

Characteristic	Benchmark Home	Builder Home	Prototype Home
Foundation Construction	full basement - concrete	full basement - concrete	full basement - concrete
Foundation Insulation	U-0.096	R-8 wall insulation	walls: 2" rigid thermax (R-13)
Wall Construction: 1st Floor	2x4 wood framing - 16" o.c.	2x4 wood framing - 16" o.c.	2x6 wood framing - 24" o.c.
Wall Assembly: 1st Floor	U-0.058	R-13 insulation	R-22 blown-in fiberglass
Garage Interior Wall Const.	2x4 wood framing - 16" o.c.	2x4 wood framing - 16" o.c.	2x6 wood framing - 24" o.c.
Garage Interior Wall Assembly	U-0.058	R-13 insulation	R-22 blown-in fiberglass
Ceiling/Roof Construction	pre-engineered wood trusses @ 24" o.c.	pre-engineered wood trusses @ 24" o.c.	plenum trusses @ 24" o.c.
Ceiling Assembly	U-0.026	R-33 insulation	R-40 blown-in fiberglass
Window Type	benchmark	vinyl double pane	vinyl double low-e
Window U-Value	0.397	0.46	0.33
Window SHGC	0.581	0.57	0.32
Interior Shading	interior shading multiplier = 0.7 in cooling season and 0.85 in heating season	drapes/blinds	drapes/blinds
Doors	U-0.20	U-0.4	U-0.4
Infiltration	ELA : 86.8 in^2	0.35 natural ACH	638 cfm_{50} (0.08 natural ACH)
Heating System	NG Furnace 78 AFUE	NG Furnace AFUE 80	NG Furnace, sealed combustion AFUE 93.7
Cooling System	Air Conditioner SEER 10 (SHR 0.7)	Air Conditioner SEER 10 (SHR 0.7)	Air Conditioner SEER 12 (SHR 0.7)
Water Heater	NG Water Heater EF 0.54	NG Water Heater EF 0.54	NG Water Heater EF 0.61
HW Tank Size	40 gal	40 gal	40 gal
Water Heater Location	basement	basement	mechanical closet
Duct R-value	R-5.0	R-4.2	R-0
Supply Duct Area	317 ft^2	317 ft^2	184 ft^2
Return Duct Area	58.5 ft^2	58.5 ft^2	24 ft^2
Supply Duct Location	100% basement	100% basement	100% interior
Return Duct Location	100% basement	100% basement	100% interior
AHU Location	basement	basement	mechanical closet
Duct Leakage	10%	15.0%	25 cfm_{25}
Return Leakage Fraction	30% return / 5% AHU	30% return / 5% AHU	30% return / 5% AHU
mechanical ventilation	(ventilation fan energy only)	--	exhaust only
	--	--	80 cfm / 25 Watts / 66% run-time
Programmable Thermostat?	no	no	yes
Temperature	cooling: 78°F	cooling: 78°F	cooling: 78°F (81°F)
	heating: 68°F	heating: 68°F	heating: 68°F (63°F)
Lighting	10% fluorescents (100 W / 30 W)	0% fluorescents (100 W / 30 W)	70% fluorescents (70 W / 25 W)
Energy Star Appliances	--	--	dishwasher

Benchmark version: Building America Benchmark Definition version 3.1
Software version: Energy Gauge USA - USResRatePro - version 2.3

Builder: **Nebraska**
Model: **Single-Family**
Location: **Lincoln, NE**

2/22/2005

Table 4. Summary of Energy Consumption by End-Use

	Annual Site Energy						Annual Site Cost		
	Benchmark		Builder		Prototype		Benchmark	Builder	Prototype
End-Use	kWh	Therms	kWh	Therms	kWh	Therms	$	$	$
Space Heating	376	532	376	522	292	348	$ 478	$ 469	$ 315
Space Cooling	2129	0	1049	0	675	0	$ 129	$ 64	$ 41
DHW	0	248	0	240	0	216	$ 212	$ 205	$ 185
Lighting	1745		1814		932		$ 106	$ 110	$ 57
Appliances	2419	0	2419	0	2373	0	$ 147	$ 147	$ 144
Plug Load	1962		1962		1962		$ 119	$ 119	$ 119
OA Ventilation	165		0		87		$ 10	$ -	$ 5
Total Usage	8796	780	7620	762	6322	564	$ 1,202	$ 1,115	$ 867
Site Generation					0				
Net Energy Use	8796	780	7620	762	6322	564	$ 1,202	$ 1,115	$ 867

Table 5. Summary of End-Use Source-Energy and Savings

				Source Energy Savings					
	Annual Source Energy			Percent of End-Use		Percent of Total		Component %	
	Benchmark	Builder	Proto	Builder	Prototype	Builder	Prototype	Builder	Prototype
End-Use	MBtu/yr	MBtu/yr	MBtu/yr						
Space Heating	58.3	57.3	38.6	**2%**	**34%**	**1%**	**11%**	**7%**	**40%**
Space Cooling	23.0	11.3	7.3	**51%**	**68%**	**7%**	**9%**	**80%**	**32%**
DHW	25.3	24.5	22.0	**3%**	**13%**	**0%**	**2%**	**6%**	**7%**
Lighting	18.8	19.6	10.1	**-4%**	**47%**	**0%**	**5%**	**-5%**	**18%**
Appliances	26.1	26.1	25.6	**0%**	**2%**	**0%**	**0%**	**0%**	**1%**
Plug Load	21.2	21.2	21.2	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
OA Ventilation*	1.8	0.0	0.9	**100%**	**47%**	**1%**	**0%**	**12%**	**2%**
Total	174.4	159.9	125.7	**8%**	**28%**	**8%**	**28%**	**100%**	**100%**
Site Generation			0.0						
Net Energy Usage	174.4	159.9	125.7	**8%**	**28%**	**8%**	**28%**		

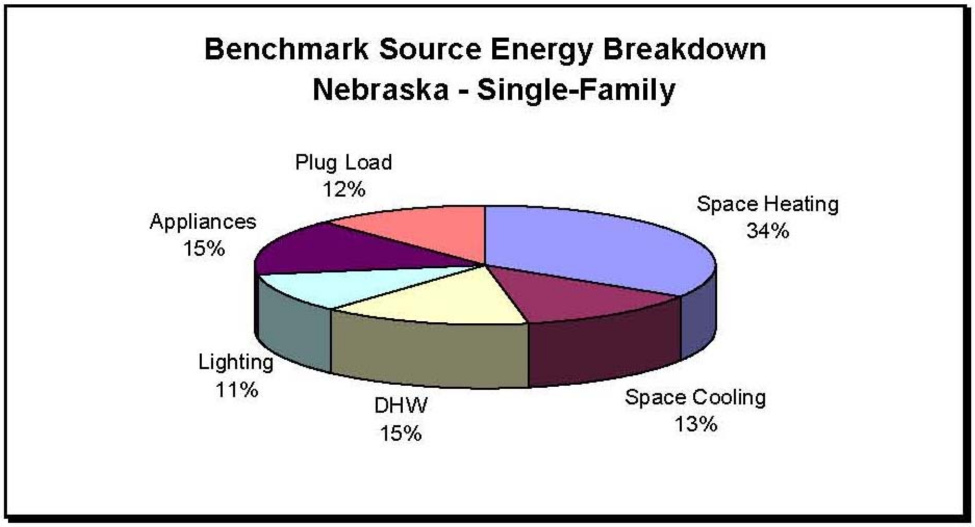
Notes: The "Percent of End-Use" columns show how effective each building is in reducing energy use over the Benchmark in each end-use category.
The "Percent of Total" columns show how the energy reductions in each end-use category contribute to the overall savings.

energy costs	\$0.0608	/kWh for electricity	Lincoln Electric System
	\$0.85	/therm for natural gas	NE gas rate

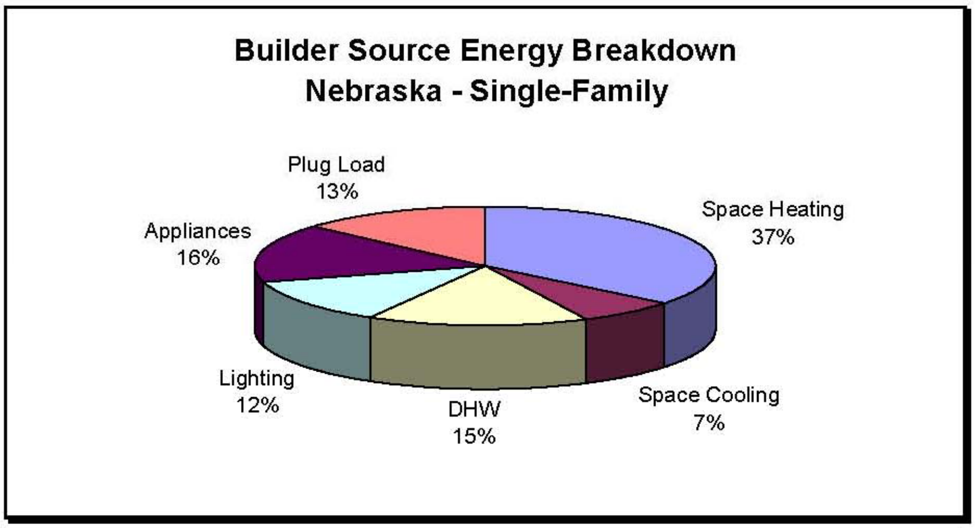
	equipment sizing		
Benchmark	51.6 kBtu/hr for heating		
	27.9 kBtu/hr for sensible cooling	-->	3.5 nominal tons
Builder	46.397 kBtu/hr for heating		
	19.0 kBtu/hr for sensible cooling	-->	2.5 nominal tons
Prototype	30.8 kBtu/hr for heating		
	11.0 kBtu/hr for sensible cooling	-->	1.5 nominal tons

*Sizing of cooling nominal tons is based on a SHR of 0.7, 0.7, 0.7, respectively

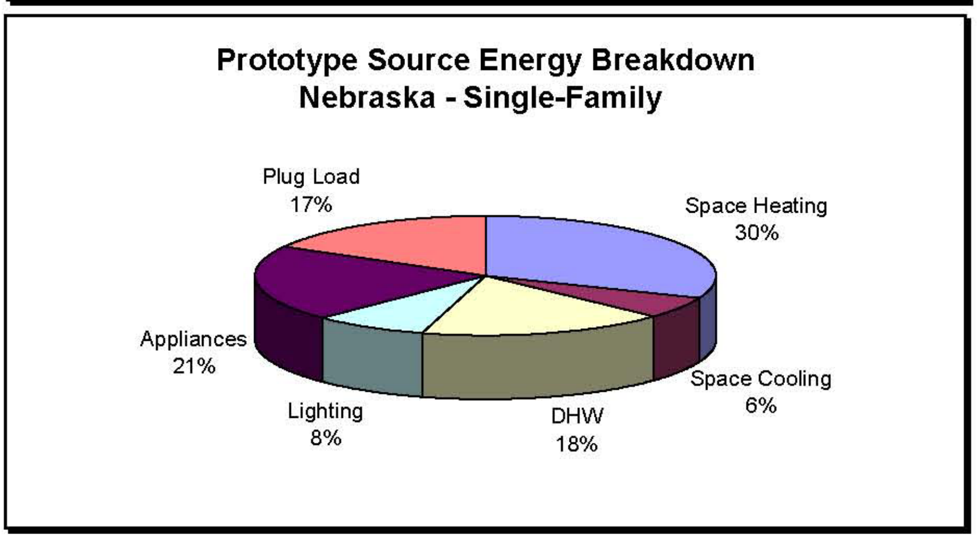
	HERS rating
Benchmark	78.2
Builder	81.0
Prototype	86.9



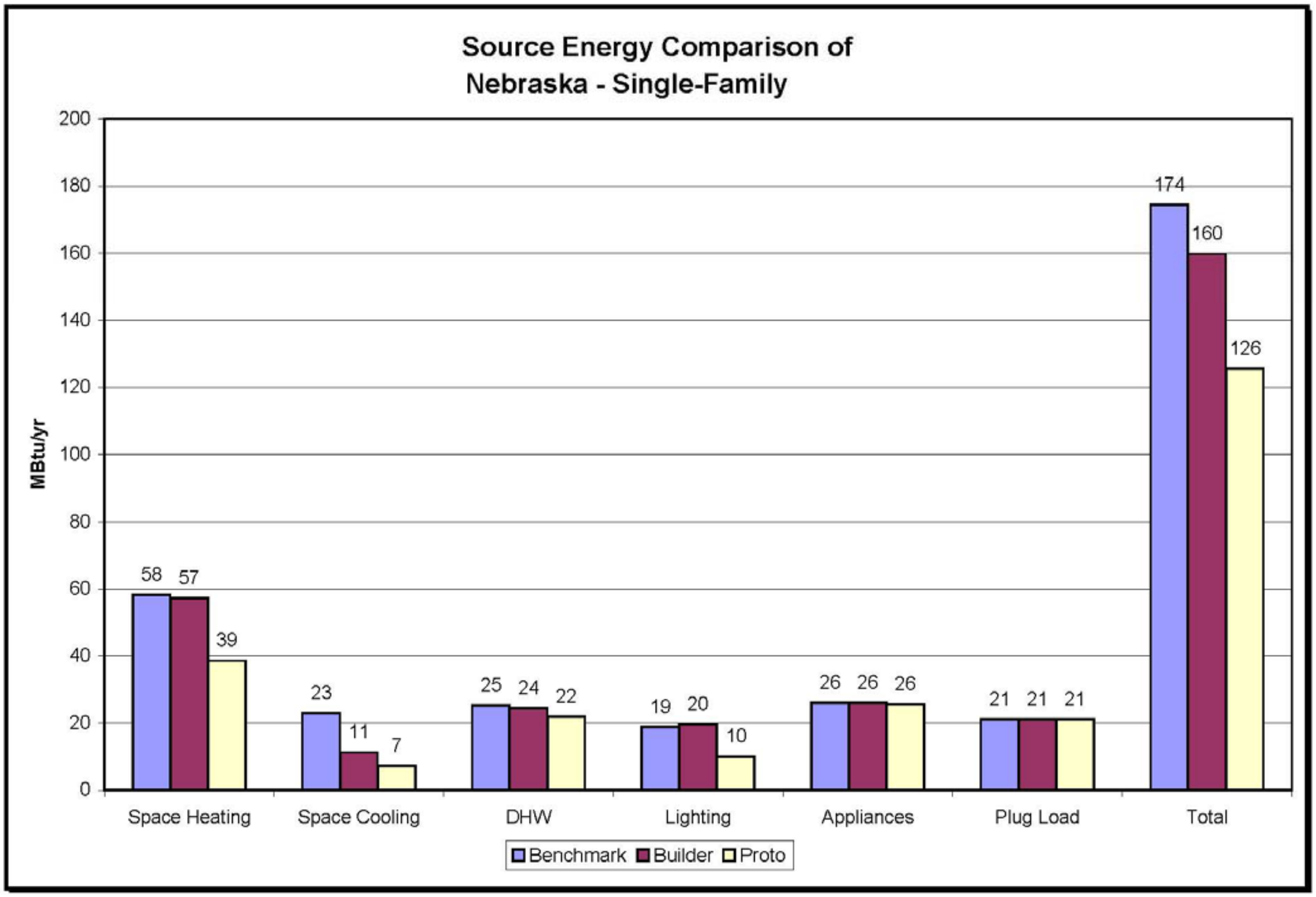
energy consumption
174.4 MBtu/yr



energy consumption
159.9 MBtu/yr



energy consumption
125.7 MBtu/yr



Source Energy Comparison of
Nebraska - Single-Family
MBtu/yr
200
180
160
140
120
100
80
60
40
20
0
58
57
39
23
11
7
25
24
22
19
20
10
26
26
26
21
21
21
174
160
126
Space Heating
Space Cooling
DHW
Lighting
Appliances
Plug Load
Total
Benchmark
Builder
Proto