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Affordable High-Performance Homes: The 2002 NREL Denver Habitat for Humanity House, A Cold-Climate Case Study

A Project of the U.S. Department of Energy's Building America Program

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Building Technologies Program

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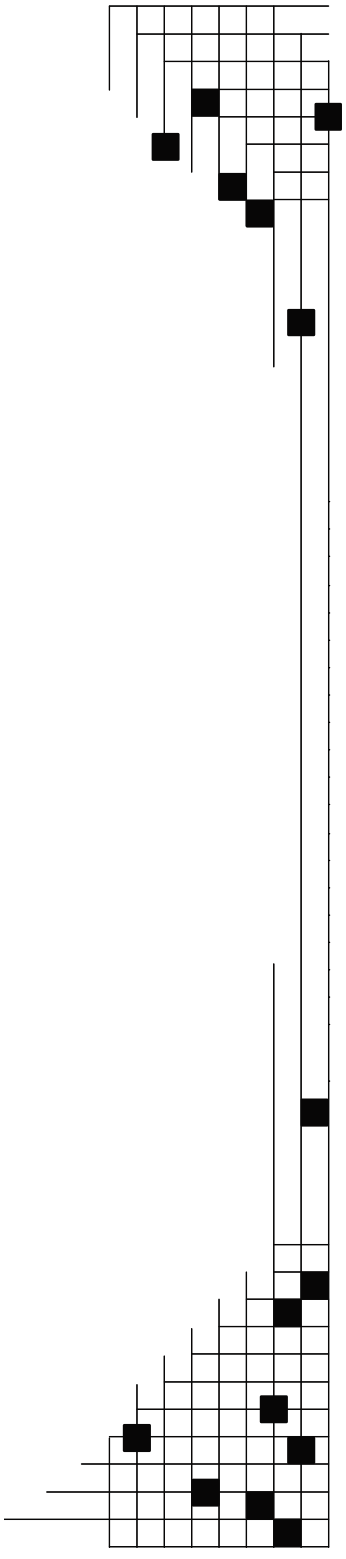

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This report is available on the World Wide Web at http://www.BuildingAmerica.gov.

Introduction

A trend towards "green" building with a focus on energy efficiency is sweeping the United States homebuilding industry. An integrated systems-design approach leads to homes that are more efficient, more comfortable, more affordable, and more durable than homes built with standard practices. Habitat for Humanity affiliates throughout the country are taking the lead on this approach to home building for affordable housing. This approach supports Habitat's goals of supplying quality housing and reducing the energy cost burden on families in Habitat homes—goals that are especially important in these days of increasing energy costs.

How can your local Habitat affiliate begin to incorporate an integrated design approach and advanced building techniques to build more energy -efficient homes? A common approach is to build an Energy Demonstration Home. This home is used to try out a wide range of energy efficient techniques and technologies that may be a good fit with your building style. The experience gained in this process is then used to choose which features of the demonstration house can be used to improve all the homes you build. This process can be repeated periodically to continuously improve your homes.

One Habitat affiliate that has used this approach is Habitat for Humanity of Metro Denver. Through a series of Energy Demonstration Homes built in partnership with the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) and the Building America Program, they have fine-tuned their standard construction to be highly efficient, cost-effective, and volunteer friendly. They are now nationally recognized as energy-efficient building leaders. This report describes their most recent Energy Demonstration Home, built in partnership with NREL in 2002.

Habitat for Humanity of Metro Denver – An Award-Winning Builder

The outstanding work of Habitat for Humanity of Metro Denver has not gone unnoticed. In October 2003, they were awarded an ENERGY STAR® New Millennium Builder Award. This award recognizes builders that have designed, constructed, and marketed top-quality, high-performing homes judged to be the best in the state.

"These builders understand that by constructing homes that use less energy, they are having a positive impact on Colorado's environment and Colorado's future," said Patty Crow, the ENERGY STAR representative for Colorado. "Energy-efficient homes like these are part of the system we are all trying to build to provide benefits to individual home owners and to our communities."

Anatomy of a Well-Built Home

Every house built by Habitat Metro Denver is tight, well-insulated, and energy efficient. Their homes typically receive an ENERGY STAR Colorado energy rating of 88 or higher, when a comparable typical home in Colorado would rate only a 77. Habitat achieved this remarkable quality through a dedication to improvements over many years. Habitat has opened its doors to the DOE through NREL and Building America's Building Science Consortium (BSC).

Through these partnerships, they have developed an integrated approach to home design and construction that combines carefully planned and executed details with high efficiency equipment and appliances. This means that Habitat homeowners spend less of their limited resources on home energy bills

Superior Features are Standard at Habitat Metro Denver

An efficient home design must be responsive to the climatic conditions where it is located. Habitat Metro Denver designs every house they build with this in mind. Each house includes a host of energy-efficient features, including the items listed on the next page.

NREL and Habitat: Energy Efficiency and Renewable Energy Technologies are Key Features of Affordable Housing

NREL's mission is to develop renewable energy and energy efficiency technologies and practices, advance related science and engineering, and transfer knowledge and innovations to address the nation's energy and environmental goals. Habitat for Humanity seeks to eliminate poverty housing and homelessness and to make decent shelter a matter of conscience and action. These goals are a perfect match when it comes to designing and building homes. Habitat homes are an ideal platform for transferring energy efficiency knowledge and technology, thereby reducing the operating cost of the homes for the families that own them.

For nearly 20 years, NREL and Habitat for Humanity have worked together to create durable, comfortable, energy-efficient affordable housing. NREL staff have advised Habitat affiliates nationwide on passive solar design and the use of an integrated design approach, and volunteered their time to participate in several builds, including a Jimmy Carter blitz build.

In 1997, NREL's Exemplary Buildings Program partnered with Habitat for Humanity of Metro Denver to create the *Earth Smart House*. Through the design and building of the *Earth Smart House,* Habitat staff mastered energy-efficient techniques that have become part of every home they build. Habitat of Metro Denver continually strives to improve their homes.

One approach is the building of energy efficient demonstration homes where a plethora of energy efficiency techniques and technologies can be tried out. Those techniques that perform well, are volunteer-friendly, and are cost effective are then propagated into every home they build.

In 2000, Habitat Metro Denver worked with Building Science Corporation under the Building America program to build several demonstration homes that included many techniques now part of Habitat Metro Denver's standard practice.

In 2002 the NREL 20th Anniversary House outlined in this report was Habitat's energy demonstration home. In 2005, NREL and Habitat are partnering again to build a Zero Energy Home – a highly efficient home that produces as much energy as it consumes.

The Valdez Family in front of their Earth Smart Home built by Habitat for Humanity of Denver.

Excellent Cold-Climate Energy Features

A well-insulated building shell

- Walls with 2x6 studs 24-in. on center with R-19[1] cavity insulation and ½-in. XPS foam over one layer of ½-in. OSB[2] sheathing
- Raised heel trusses and R-38 attic insulation
- Low-e[3] vinyl windows
- Header design that allows 2-in. foam insulation in the header space
- 2-in. extruded polystyrene foam (XPS or "blue board") on the interior face of crawlspace walls.

A well-sealed building shell

- Edges of OSB exterior sheathing caulked before being nailed onto walls
- Exterior sheathing seams taped with building tape
- All building envelope penetrations sealed with sill seal, caulk, or spray foam.

Good solar control

- Site and building design to allow maximum solar gain in the winter wherever possible
- 24-in. eave overhangs for shading in the summer

Energy-efficient equipment, appliances, and lighting

- Front-loading washing machine
- Direct-power vent, high-efficiency gas water heater
- Programmable thermostat
- 90%-efficient closed-combustion furnace
- Compact fluorescent lights
- All HVAC duct work sealed and tested
- Continuous ridge and soffit vents.

Developing a similar package of features for the homes you build is an evolutionary process requiring partnership with building energy experts and equipment suppliers. A balanced approach that addresses techniques to make a better building shell with the inclusion of properly sized, efficient equipment and appliances will deliver comfort, durability, and low energy costs to your homeowners.

Dedicated to Improvement: The Energy Demonstration House Approach

How does one learn to build energy efficient homes? By doing it! Habitat Metro Denver works to continuously improve the efficiency of their homes by exploring new techniques and technologies in Energy Demonstration Homes.

Habitat Metro Denver used Building America's integrated design approach to build this award-winning home in Denver, Colorado.

[1] An R value is a measure of resistance to heat loss. The higher the R-Value, the less heat is lost. Its units are $hr \cdot ft^2 \cdot °F/Btu$.

[2] Oriented-strand board

[3] Low-e windows have a low emissivity coating that reduces the heat loss through the window.

The Habitat / NREL Energy Demonstration House

In 2002, Habitat for Humanity of Metro Denver built a home like no other they had ever built. Designed and constructed in partnership with the DOE's National Renewable Energy Laboratory as part of NREL's 25th anniversary celebration, the house featured a well-sealed and insulated shell, high-performance windows, zoned radiant wall heating, high efficiency appliances, solar water heating, and a photovoltaic (PV) solar electric system. The home was evaluated by an independent energy rater and given an E-Star™ Colorado score of 95, making it one of the most efficient homes ever rated by E-Star. During the America Solar Energy Society's National Solar Home Tour in October 2002, visitors were given the opportunity to tour the Habitat /NREL home and gain first-hand experience of a well integrated solar home.

Spray foam insulation

Beginning with Habitat's impressive list of standard efficiency features, a group of NREL's building energy engineers donated their time to review the design and suggest a series of energy upgrades. In consultation with the Habitat construction team and energy committee, this list was evaluated along with other suggestions. To reach consensus on the final design, the evaluators looked at the "volunteer friendliness" of each idea and the availability of materials and expertise.

Placement of the PV

Here is a list of the final design changes:

- Spray foam insulation was used in place of fiberglass batts to improve insulation consistency and air tightness. The spray foam was used in the walls, ceiling, and floor of the home.
- East- and west-facing window areas were reduced and south-facing windows were increased to provide solar tempering.

Solar water-heating collectors

- A 1.8-kW net-metered PV system and a solar water heating system were added to the home.
- A high efficiency boiler and zoned radiant wall system was used in place of a furnace and ductwork.
- The design was made ADA[4] compliant by hanging the floors in the foundation to reduce step-up into house and designing the bathroom for wheelchair use.
- Light-colored roofing shingles and increased attic ventilation were used to reduce attic overheating.
- Compact fluorescent lighting was used throughout the home and a tubular skylight was used for garage lighting.

[4] ADA = Americans with Disabilities Act

High-Performance Comfort

In February 2003, NREL staff of the DOE's Building America Program installed sensors in the home to track its energy performance. They also completed a computer simulation of the home to study the energy performance.

During the summer of 2003, the solar water-heating system provided between 50% and 78% of all the energy used for water heating in the home, lowering the homeowner's energy bills (Figure 1).

The solar electric system is producing an average of about one-third of the electricity used in the home (Figure 2). This simple system has no batteries to take care of; instead, the system feeds electricity into the utility grid when the home is producing more electricity than it needs and pulls electricity from the utility grid when it needs more electricity than it is producing. At times, the electric meter on the home actually runs backward. This arrangement, called "net metering," is now available in most states.

The cost of solar electric systems continues to decrease, but they are currently unable to economically compete with electricity purchased from the grid. Still, there are myriad reasons you may want to consider a solar electric system on your Energy Demonstration Home including the environmental benefits, the demonstration of your commitment to clean energy, and energy bill reductions for your homeowners. In addition, it may lead to press visibility for your local Habitat efforts that can increase sponsorship.

When the energy efficiency features of the home are combined with solar water heating and solar electricity, the home saves about 60% of the total energy that would be used in an identical home built using standard practices. Figure 3 shows how key features of the home contribute to the overall energy savings. The leftmost bar shows the annual energy consumption of the standard practice home. Each color in the bar shows where the energy is being used. The second bar shows that the standard Habitat Metro Denver home uses significantly less energy than the standard home. The remaining bars illustrate how much savings each of the key energy efficiency measures produces, with the rightmost bar illustrating the total energy consumption of the Habitat/NREL home.

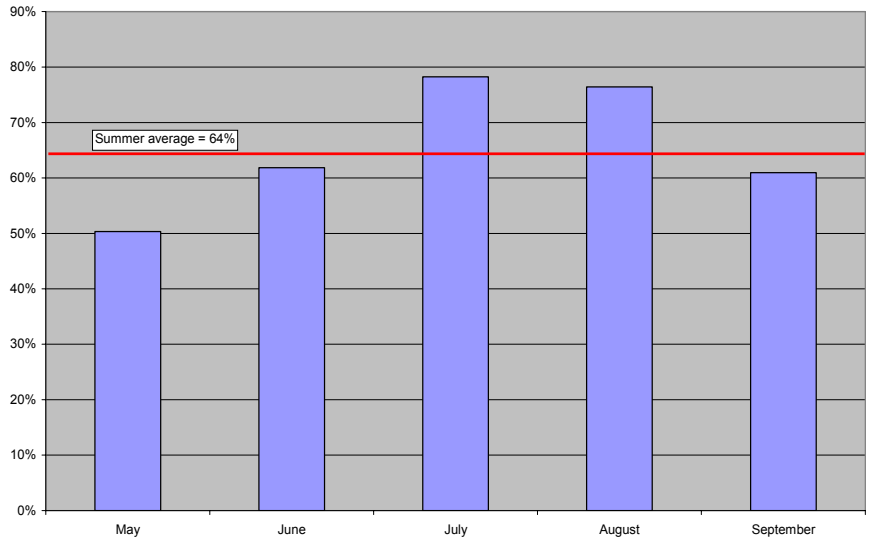

Figure 1. Percentage of Water Heating Energy Supplied by Solar Hot Water System

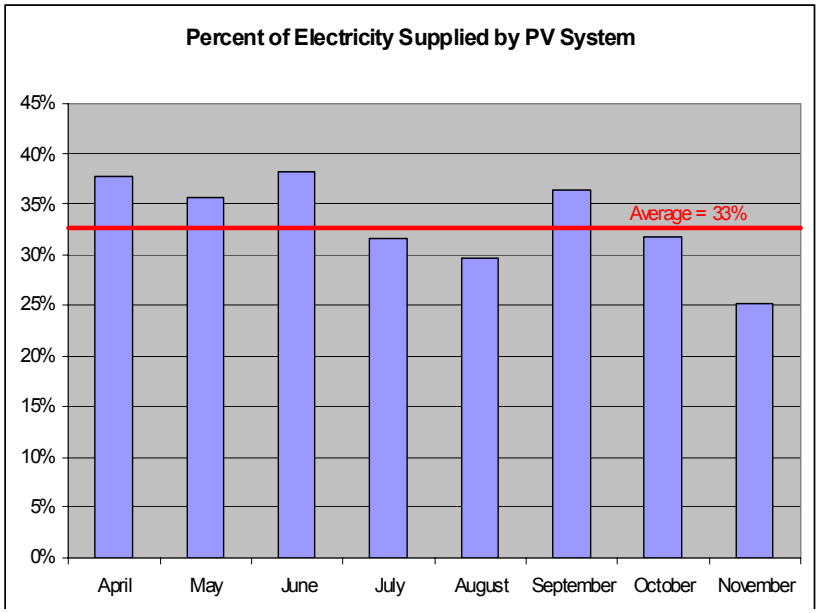

Figure 2. Percentage of Electricity Supplied by PV System

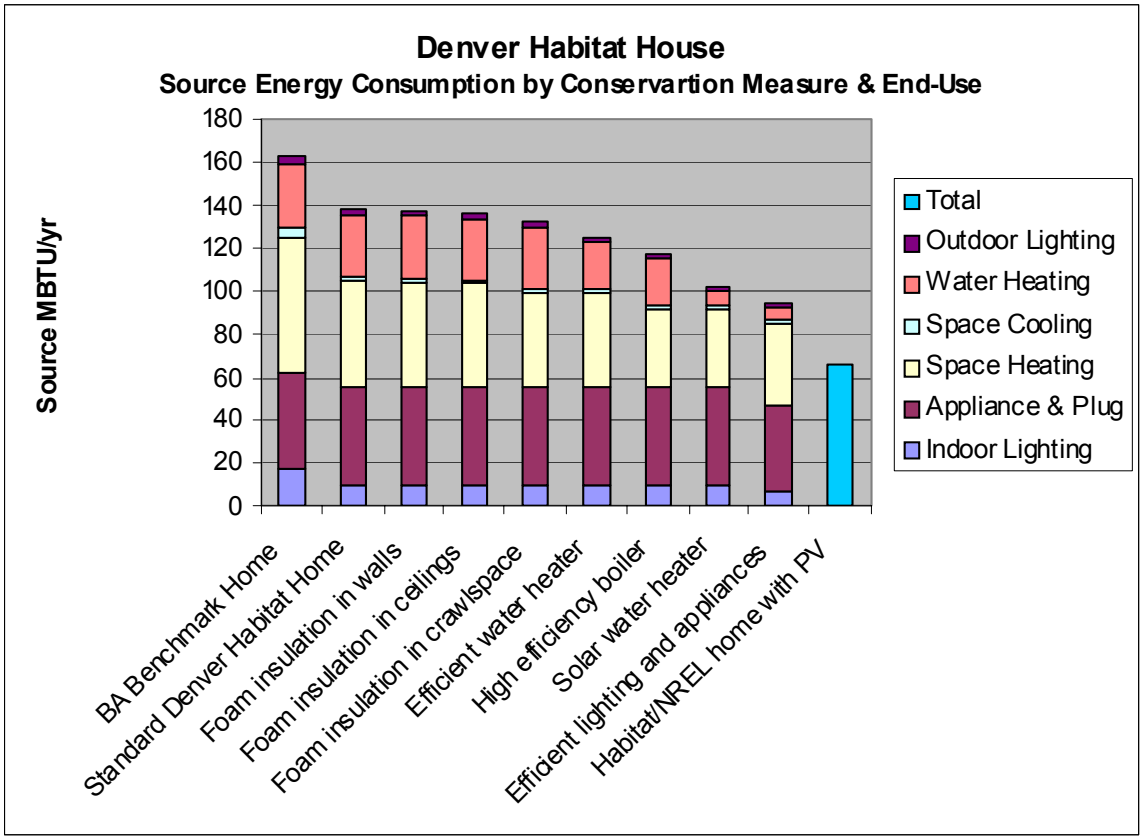

Figure 3. Source energy consumption by conservation measure and end use

Solar Electricity for Habitat Homes Step-By-Step

A grid-connected PV system is the lowest cost of the different types of PV systems. However, it can still be relatively expensive relative to the total house cost and other household systems. The total installed cost of a system can range from $10,000 to $20,000 for a 1- to 2-kW system. The total system cost may be less if there are federal, state, or local rebates.

Step #1. Will the house be located in an area where a utility grid-connection is permitted or available? Is there a local or national supplier willing to donate system components? Check with your local utility company, or check with a local PV system installer who has installed grid-connected systems. PV system costs can be high, so component donations may be a key factor that determines if PV can meet affordability requirements.

Step #1b. Will the homeowner accept responsibility for the system after it is installed? There is some maintenance required, such as periodically checking the installation to see that it is undamaged and operating properly. When the roof needs replacing the homeowner will incur an additional cost because the PV system must be removed and then reinstalled. The type of mounting system will affect this cost.

Step #2. Most utilities are required to buy back the excess PV electricity. The questions are at what price and are there additional charges, liability insurance requirements, or equipment requirements? It may be legally required, yet difficult to implement. In the best cases, the utility pays a higher price for the renewable PV electricity than the homeowner pays for energy from the grid. More commonly, the utility offers "net metering" where the utility pays the same for the PV electricity as it charges for its own electricity. Usually, net metering uses a single meter system that "spins" forward when the home is consuming more electricity than it is producing and backward when producing more than it is consuming. Most homes are on a standard fixed rate – the energy price is the same for every hour of the day. Ask the local utility whether the home could be converted to a time-of-use schedule with net billing. Because the PV system produces power that often closely matched peak demand, it is beneficial to be on a time-of-use schedule where electricity is priced higher during peak demand hours.

Step #3. Make sure the house can accommodate a PV system on the roof. Generally, the roof can support the additional weight of the PV modules, but check with the local building codes and the architect. A sufficiently large, generally south-facing roof is required. The PV system should be installed parallel to the roof, but with a 4-6" separation from the roof.

Several PV mounting systems exist. Many are "retrofit" systems that are installed after the roof is completed. A "retrofit" system will include roof penetrations through the roofing system into the rafters. Care needs to be taken to prevent leaks—follow the manufacturers installation instructions. Other PV mounting systems include mounting posts that are mounted first and then flashed around when the roof is installed. These systems require a slightly greater roofing skill level because there are many more flashings, but are easier when a roof replacement is required.

Solar Electricity for Habitat Homes Step-By-Step (continued)

Step #3b. Make sure there is space for the inverter and disconnects. Most inverters and disconnects can be installed in a 4-ft x 4-ft wall area. Reserve or plan for this space inside the garage or outside by the service entrance. Make sure the area is at a good working height and yet reasonably protected from accidental physical damage. For example, don't place the inverter in the garage where a car or house door could hit it or in the normal people-traffic path. All system displays and indicators should be at eye-level for the homeowner.

The best location for outdoor-rated inverters is outside on the north wall. The worst location is outside on the south wall. While the inverter is outdoor-rated, high temperatures caused by direct sunlight on the inverter will have a negative effect on the performance of the inverter and the lifetime of the inverter. Check the installation requirements for the specific inverters. A location inside a garage may be acceptable, but, again, check the installation instructions because there may be insufficient air flow for some inverters. Read the instructions or have the installer point out the relevant manufacturer installation instructions. In a tactful manner, don't accept an installer's general assertion that he always does it this way, and he's never had any problems. Follow the installation instructions in case there are future warranty claims and to maximize the lifetime beyond the warranty period.

Step #4. Who will install the PV system? People familiar with the PV mounting system, and preferably a licensed electrician or a certified solar installer, should install most PV systems. Check with the local and state codes for installation regulations.

Step #5. Who will pay for the PV system? It's great if you can get someone to donate a system and the installation. Ask around. Someone may donate the system cost, and someone else may sell the system to you at cost. One can ask local installers or contact the manufacturers directly. However, the difficulty of asking manufacturers is that there are several manufacturers for a complete PV system. There are different manufacturers for the PV modules, the mounting structure, the inverter and the miscellaneous switches and boxes. We found a module manufacturer that would also pick up the tab on the other equipment—this may not be available in all cases.

Step #6. Fill out the paperwork. There may be application forms for rebates—check the exact requirements before the system is bought or installed. Coordinate with the local utility on their requirements for the system checkout.

Step #7. Have a system orientation and checkout with the homeowner. Make sure there is a one-page laminated quick instructions and guidelines next to the inverter or closeby that tells how to turn the system on or off and how to tell if it's working okay. Leave a name and phone number for future questions.

Step #8. Follow up with the homeowner in a month or so, to see how the system is working, check for roof leaks, and ask if there are any questions.

Where to from Here?

The NREL Denver Habitat Zero Energy Home

NREL and Habitat Metro Denver are teaming again to push the boundaries of energy efficiency even further. In 2005 we will build a Zero Energy Habitat Home. This home is being designed to produce as much energy as it consumes on an annual basis. The design will be based on the lessons learned from the 2002 Energy Demonstration Home.

Now It's Your Turn!

To start building more comfortable, durable, and energy efficient homes, try these steps:

Make a commitment

Educate yourself

The Internet is a great place to start to come up to speed on energy efficient building practices.

Seek Partners

Connect with local home energy raters (find them at http://www.natresnet.org/dir/raters/default.htm) and ask them about local building energy specialists that may be able to help you.

Design and Build an Energy Demonstration Home

Use the expertise of your new partners to create a home design that incorporates energy-efficient techniques and technologies that fit with your local building style and needs.

Use the experience of the Energy Demonstration Home

Identify the most effective combination of features of your demonstration house and make them standard in every home you build.

Share your experiences with other Habitat affiliates!

So You Want to Build a Better Home?

Here are some World Wide Web pages that will get you started . . .

The Building America Program: www.buildingamerica.gov

The Top 25 Web Sites for Home Builders and Home Buyers of Energy-Efficient Homes

www.eere.energy.gov/buildings/building_america/for_builders_top25.html

EPA's ENERGY STAR™ Homes and appliances: www.energystar.gov

Habitat for Humanity International Construction and Environmental Resources: http://www.habitat.org/env/

Home Energy Magazine: www.homeenergy.org

The Energy and Environmental Building Association: www.eeba.org

ToolBase Green Building site: http://www.toolbase.org/secondaryT.asp?CategoryID=1&TrackID=

If you're in a cold climate, check out Building Science Corporation's Habitat house design for cold climates: http://www.buildingscience.com/about/habitat/default.htm

Superinsulated cold-climate Habitat House designs are also available from the National Affordable Housing Network: http://www.nahn.com/

Examples of energy characteristics for ENERGY STAR Habitat Homes in various climates are available from the Florida Solar Energy Center at http://www.fsec.ucf.edu/bldg/baihp/CASESTUD/Hfh_EStar/index.htm

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Appendix: Let's Do the Numbers

Simulated Performance

The tables below summarize the results of comparing analysis results and performance measurements of the NREL/Habitat home to conventional homes. Details on the analysis procedures used to generate these results can be found on the Building America Web site at http://www.eere.energy.gov/buildings/building_america/pa_resources.html.

	Annual Source Energy			Source Energy Savings of Energy Demonstration Home			
				Percent of End-Use		Percent of Total	
End-Use	Building America Benchmark MBTU/yr	Habitat Metro Denver Standard Home MBTU/yr	Habitat/NREL Energy Demonstration Home MBTU/yr	Compared to Building America Benchmark	Compared to Habitat Standard Home	Compared to Building America Benchmark	Compared to Habitat Standard Home
Space Heating	62	49	38	39%	23%	15%	8%
Space Cooling	5	2	2	68%	1%	2%	0%
DHW	29	29	7	77%	77%	14%	17%
Lighting	18	11	7	60%	33%	7%	3%
Appliances + Plug	45	45	39	11%	11%	3%	4%
OA Ventilation	0	0	0	0%	0%	0%	0%
Total Usage	159	135	93	41%	31%	41%	31%
PV System Generation	0	0	-29			18%	
Net Energy Use	159	135	64	59%		**59%**	

Notes:
The "Percent of End-Use" columns show how effective the prototype building is at reducing energy use 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.

	Site Energy		Source Energy		National Average Energy Cost		Builder Standard (Local Costs) Energy Cost		Measure	Package
Increment	kWh	therms	MBTU	Savings %	$/yr	Savings %	$/yr	Savings %	value ($/yr)	savings $/yr
Building America Benchmark Home	5905	834	158.6		$ 481		$ 1,021			
Habitat Metro Denver Standard Practice Home	5014	713	135.3	15%	$ 408	15%	$ 870			
Habitat Standard Home + Foam Insulation in walls	5011	710	134.9	15%	$ 408	15%	$ 868	0%	$ 2	$ 2
Above features + Foam insulation in ceiling	4964	703	133.6	16%	$ 404	16%	$ 860	1%	$ 8	$ 11
Above features + Crawlspace Foam Insulation	5167	654	129.9	18%	$ 421	12%	$ 844	3%	$ 15	$ 26
Above features + High effiency water heating	5167	594	122.8	23%	$ 421	12%	$ 806	7%	$ 39	$ 65
Above features + High effiency boiler	4619	578	115.3	27%	$ 376	22%	$ 751	14%	$ 55	$ 120
Above features + Solar water heating	4619	447	99.9	37%	$ 376	22%	$ 666	24%	$ 85	$ 205
Above features + Efficient Lighting and appliances	3771	461	92.9	**41%**	$ 307	36%	$ 606	30%	$ 60	$ 264
Site Generation										
Above features + Photovoltiac system	981	461	64.3	**59%**	$ 80		$ 379	56%	$ 227	$ 492

Notes:
"Source Energy Savings %" and "National Average Energy Cost Savings %" compared to the Building America base case, whereas the "Energy Cost Savings %" and the "Package savings $/yr" are compared to the Builder Standard Practice case.

Colorado Average Electric Cost : 0.08 $/kWh (Nov. 2003)
Colorado Average Gas Cost: 0.65 $/therm (Dec. 2003)
(Source: US Energy Information Agency)

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14. ABSTRACT *(Maximum 200 Words)*
A trend towards “green” building with a focus on energy efficiency is sweeping the United States homebuilding industry. An integrated systems-design approach leads to homes that are more efficient, more comfortable, more affordable, and more durable than homes built with standard practices. Habitat for Humanity affiliates throughout the country are taking the lead on this approach to home building for affordable housing. This approach supports Habitat’s goals of supplying quality housing and reducing the energy cost burden on families in Habitat homes—goals that are especially important in these days of increasing energy costs.

15. SUBJECT TERMS
Habitat for Humanity; Affordable Houses; energy efficiency; National Renewable Energy Laboratory; green building; integrated systems-design

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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

Research and Development of Buildings

Our nation's buildings consume more energy than any other sector of the U.S. economy, including transportation and industry. Fortunately, the opportunities to reduce building energy use—and the associated environmental impacts—are significant.

DOE's Building Technologies Program works to improve the energy efficiency of our nation's buildings through innovative new technologies and better building practices. The program focuses on two key areas:

- **Emerging Technologies**
  Research and development of the next generation of energy-efficient components, materials, and equipment
- **Technology Integration**
  Integration of new technologies with innovative building methods to optimize building performance and savings

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