Green & Lean

Designing and Building an Affordable, Resource-efficient Home

GreenHOME

This is the house that Jack and Russ and Peter and Lowell and Margo and Greg and Mark and Ned and Katie and Jane and Brian and Abby and Bambi and Ed and John and Mike and Neha and Lisa and Christie and Maryanne and Scott and Diane and Brett and Jason and Pam and Chaney and Sally and Jake and Alissa and Tate and Tom and Wes and Robert and Jasmine and Sue and Christine and Anne and Sean and Steve and Hillary and Glenn and Rachael and Kim and John and Chris and Melanne and Vicky and Stan and Linda and Kyle and Shelley and Joanne and Ian and Patrick and Tom and Lindell and Renita and Mary and Anne and Glenn and Rachael and Kim and Joe and Kate and Janey and Davon and Marlena and Doug and Veronica and Sharon and Dan and Yvette and Romey and Will and Deborah and Sam and Dana and and George and Carol and Mark **built.**

CAULK IS CHEAP BUT ENERGY ISN'T!

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GreenHOME

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Please feel free to contact GreenHOME to share your green construction experiences or to ask us questions. We continue to accept donations (which are tax deductible) to be used toward our mission of making environmentally responsible homes available to all.

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CONTENTS

We have all seen news stories about multi-million dollar environmentally friendly homes, environmental groups designing sustainable office space, and award-winning prototype energy- and resource-efficient buildings that incorporate technologies of the future. Green building is clearly a luxury reserved for those with the resources and contacts, right? Not anymore, at least not in Washington, DC.

IN 1995, A FEW LOCAL ARCHITECTS, BUILDERS, AND environmental activists in the Washington, DC area founded GreenHOME, an all-volunteer group dedicated to demonstrating that urban housing can be green as well as affordable. GreenHOME committed itself to raise funds, and design and build a home that met these goals in the Historic District of Capitol Hill as an Adopt-A-Home partner with the Washington, DC affiliate of Habitat for Humanity International (DC Habitat for Humanity). We initiated the partnership with DC Habitat for Humanity because we sought to work with a local, affordable homebuilder, and DC Habitat for Humanity's link to Habitat for Humanity International and its 1500 affiliates in North America offered a tremendous opportunity to foster green building nationally and internationally.

The aim of this book is to document our experience in designing and building a green, affordable house in Washington, DC. This first demonstration house incorporates energy- and resource-efficient design features and construction techniques, as well as environmentally-friendly building products and landscaping. Throughout the construction process, environmentally low-impact construction techniques, recycling and reuse were top priorities. GreenHOME also participated in and obtained materials from the deconstruction of homes throughout the metropolitan region. As a result, many high-quality recovered products are featured, such as heart pine floors, salvaged studs in interior wall framing, an antique brick foundation facade, walnut kitchen cabinets, and a cast iron bathtub.

Our first demonstration home has allowed GreenHOME and DC Habitat for Humanity to learn not only about materials and construction techniques, but also about markets and supply issues related to building green in the DC area. With our first home completed, our next job is just beginning, as we share our experiences with a wider building community and help to incorporate some of these principles and materials into the rigorous building program of DC Habitat for Humanity.

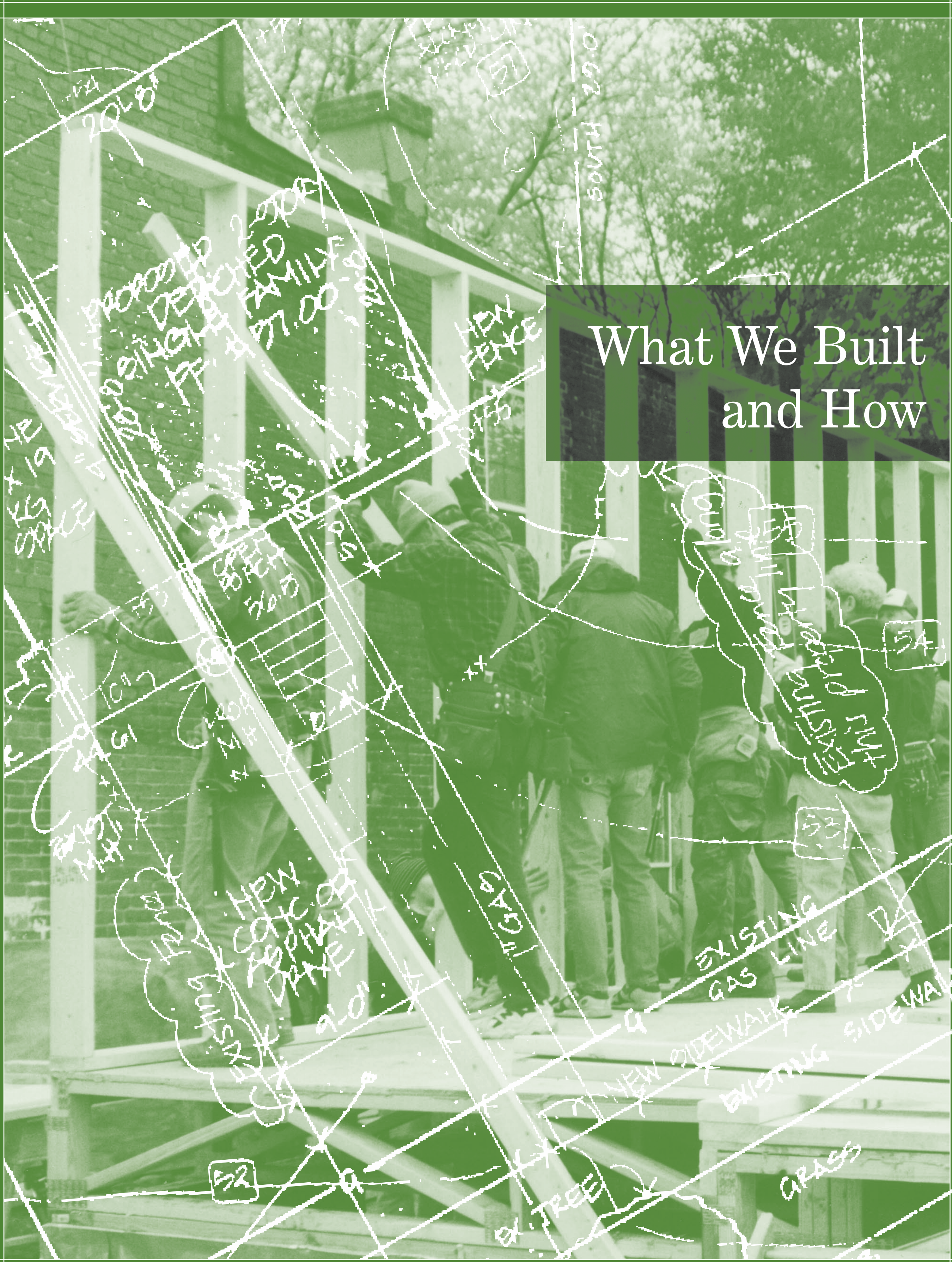
This book is not intended to be a comprehensive listing or evaluation of the available green building materials on the market. New, innovative construction materials are introduced into the market at a very rapid pace; by the time you read this book, there may exist superior choices to some of the materials that we used. Instead, we share details on our materials selection process, including the evaluation criteria that we used and the different options that we considered.

GREENHOME'S GROUNDBREAKING CEREMONY

We invite you to learn with us as we document our experience, building with volunteers using new and unfamiliar products, researching the advantages and disadvantages of various materials and techniques, and uncovering the challenges and opportunities for green, affordable building.

Important Disclaimer: *The product acknowledgements in this book are meant only for informational purposes and are not a commercial endorsement of any one product over another. GreenHOME is committed only to using the most environmentally-sound and affordable products available at the time of construction, and encourages all Habitat for Humanity affiliates and other organizations to conduct their own research on available products, using this book as a preliminary guide.*

What We Built and How



SUMMARY OF THE RESEARCH PROCESS

Materials Selection

The GreenHOME Design Committee met regularly over a two-year period to sort through volumes of information on green building materials, discuss options, and select the materials best suited for the structure. We divided the tasks according to the major component systems of the house, including, among others, the foundation, the framing system, appliances, and roofing. Individuals researched, analyzed, and wrote reports on their findings in each area, and then made recommendations to the committee. The final selections were voted on by the entire committee.

Criteria

The overwhelming flow of information on new construction techniques and building materials sometimes made our choices difficult. To bring order to the process, we agreed upon a set of overall criteria and established a framework, including a checklist, to help sift through the wide range of options.

Our overall criteria were dictated in large part by our commitment to adhere to the guidelines of DC Habitat for Humanity, our partner in this project. We accepted the challenges implied in this partnership—that we had to avoid higher cost technologies and materials, as well as those that would be difficult for volunteers to work with, even if they might be more “cutting edge” or more energy efficient. These criteria rendered solar collectors and photovoltaic technologies, for example, beyond our reach. Our overall criteria were:

- Environmental friendliness
- Affordability (our total cost-of-materials could not exceed $65,000)
- Volunteer friendliness (i.e., installation by mostly non-skilled labor)
- Consistency with zoning and building permit requirements, and the standards of the local historic district commission.

We also established a common checklist for our materials research in each area to bring consistency to the gathering and presenting of information, and to make certain our evaluation of the options was comprehensive. Underlying the checklist was the notion of ‘life-cycle’ or ‘cradle-to-grave’ analysis of the impacts of using a particular material. Life-cycle phases we adapted to our process were:

- The material’s source. Was habitat destroyed? What were the other environmental impacts of the extraction of raw materials and/or production of the item? Did production of the item expose workers or others to hazardous materials?
- Embodied energy, or the amount of energy consumed in producing an item. For example, steel and aluminum products, unless composed of recycled materials, require high levels of energy to make. Some building materials publications routinely include data on embodied energy.
- Recycled content.
- Distance from the site, and mode of transport.
- Toxins and pollutants released in construction and residential use. For example, off-gassing from certain resins in lumber and from paints with high levels of volatile organic compounds can affect indoor air quality.

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- Contribution to the energy efficiency of the completed structure.
- Contribution to comfort and convenience of the owner/occupant of the finished home.
- Maintenance requirements and durability of materials in the finished home.
- Recyclability or re-usability of both used and unused materials.
- Cost and availability.

Not all of the categories were applicable to all options under consideration. Moreover, while these categories were intended to be weighed equally, we occasionally would make trade-offs to highlight a specific material, either for its particularly good performance in one category, or as an alternative to the typical construction method. We realized that our final evaluation on some materials would have to await actual installation, and in some instances, would require monitoring over time.

Evaluation and Decision Process

For most categories, the assigned committee member prepared a set of Material Evaluation Sheets in spreadsheet form, applying the relevant criteria to the options under consideration. Along with several pages of text, these evaluation sheets were incorporated into a written report summarizing findings and offering recommendations to the Committee. The entire Design Committee then considered the report, and usually returned initial drafts for further work. Decisions on materials were reached primarily by consensus, after varying amounts of discussion and debate, with the occasional difficult choice subjected to majority vote.

The decisions in each category by the Design Committee were summarized on a single page and presented for review to the GreenHOME steering committee, and in some instances to persons outside GreenHOME, including Washington, DC Habitat for Humanity's construction manager. A representative from the Energy Efficiency Building Association (EEBA) reviewed all of our decisions and made many significant recommendations. The steering committee then ratified the final decisions, which were then incorporated, as needed, into the building plans and submitted to the Washington, DC government for zoning review and permitting.

Whole House Issues

Apart from the selection of individual materials, the Design Committee also looked at issues in the construction of the house and sought to project how the entire structure, once completed, would perform against established criteria for energy efficiency. Our goal was to reduce energy use and cost by over 30 percent compared to the minimum allowed by building codes, to qualify for the US EPA Energy Star performance rating, and to reduce the monthly cost of home ownership (mortgage plus utilities, including energy cost). With these goals in mind, the Design Committee deliberated on several additional concerns, including:

- Overall building envelope including insulation, moisture control and air infiltration prevention
- Contribution of windows to an energy efficient structure
- Heating, ventilation, and air conditioning (HVAC) system
- Indoor air quality

We submitted our revised plans to an organization that conducted a computer simulation of the energy performance of the planned house, as detailed in the Energy Analysis section, immediately following.

Landscape Design

Finally, the Design Committee enlisted the help of a landscape architect to produce a landscape design that would emphasize suitable drainage, the use of pervious surfaces, native species, low maintenance plantings, and would have a low impact on the local environment.

More detailed information on decisions and criteria for specific component systems of the house can be found in subsequent chapters of this book.

Energy Analysis Summary

An energy analysis takes the details of a house's construction features and estimates the annual energy usage, including the heating and cooling bills for the house. Input variables for this type of analysis include specifications for the construction materials discussed in this book, as well as air infiltration, the local climate, and the house's orientation. We used this methodology to determine how different construction materials affect the house's utility bills. This information was then used to determine whether the material choices were cost-effective. For example, once the house was numerically modeled, we were able to explore the effect of using extra insulation in the exterior walls and to evaluate whether the decrease in utility bills justified the insulation's extra cost.

John Spears of the Sustainable Design Group performed an energy analysis using a software package entitled REM/Design. (There are other energy analysis programs available as well.) This software package estimates costs for the heating, cooling, and domestic hot water consumption based on a description of the home's features, information on the local climate, and local energy cost data. The features considered by the software include wall, attic, and basement insulation materials and construction, window type and placement, infiltration amounts, efficiency of heating, ventilation, and air conditioning (HVAC) components, house layout, and any active solar heating system. REM/Design's analysis incorporates estimated values for factors such as weather patterns, number of occupants, and thermostat settings that can effect the overall energy usage of the house. The software also calculates heating and cooling design loads that can be used to accurately size heating and cooling equipment. The version of the software that we used did not account for the additional energy usage from lights and appliances other than the HVAC system.

The first step in the analysis was to create an energy usage model of a house with the same layout as this demonstration house, but designed to the minimum building standard as defined by the 1992 Model Energy Code (MEC). The MEC, created by the Council of American Building Officials (CABO), contains energy related building requirements. The specific requirements of this code vary by climate and focus on insulating and sealing the building envelope. Several states have adopted the MEC as their residential energy code. The parameters that we used to create a model of a house constructed to the MEC are listed in *Table 1* in the column labeled MEC base house.

We then experimented with different construction techniques for the model and compared the estimated energy usage with the MEC base house to determine cost savings. The final parameters that we used for the model are shown in the last column of *Table 1*. The energy analysis was created during the initial home design and material selection process, so some of the specifics that were changed later were not included in this analysis. The only significant changes from the model listed in *Table 1* to our actual construction were the installation of a novel heating system that relies on the hot water heater as its heating source (see the Mechanical System section), and the addition of R-1 rigid insulation to the R-19 insulation used under the frame floors.

The extra R-1 of rigid insulation listed for the frame walls corresponds to the sheathing material we installed. We used the national average for infiltration (air leakage) in new home construction of 0.75 ACH (air changes per hour) for the base home and estimated that we could achieve an infiltration level of around 0.30 ACH by using a very carefully constructed exterior wall system for our house. (A later test, as documented in the Testing the Construction section, found that the constructed house had an infiltration value of only 0.16 ACH.) The SEER 10 (Seasonal Energy Efficiency Ratio, see page 38) air conditioner listed for the base home is a standard value for air conditioners, while the SEER 12 unit used on this house is a higher efficiency unit. We selected a medium-efficiency hot water heater, while the unit used in the base home model is a typical low-efficiency unit.

Table 1. Parameters used in the energy analysis

Component	*MEC base home*	*GreenHOME*
Ceiling insulation	R-19	R-38
Frame Walls	R-11	R-19 + R-1 rigid
Doors	R-5	R-5
Window type, frame	Double, wood	Double, low E, argon filled, wood frame
Frame floors	R-11 batt	R-19 rolls
Infiltration, estimated	0.75 ACH	0.30 ACH
Heating system	Gas, AFUE=80%	Gas, AFUE=80%
Cooling system	Electric A/C, SEER 10	Electric A/C, SEER 12
Water heater	Gas, AFUE=70%	Gas, AFUE=80%

Table 2. Summary of predicted energy costs

Component	*Base home*	*GreenHOME*	*GreenHOME's savings*
Heating	$425	$264	38%
Cooling	$111	$71	36%
Water Heating	$159	$100	37%
TOTAL	*$695*	*$435*	*37%*

Table 3. Predicted annual energy costs by component

	Component	*Energy cost for base home*	*Energy cost for GreenHOME*	*Annual energy savings over base home*
Heating	Infiltration	$148	$59	60%
	Frame walls	$144	$85	41%
	Mechanical Ventilation	$93	$93	0%
	Frame floors	$42	$28	32%
	Windows	$26	$15	41%
	Roof	$24	$13	44%
Cooling	Windows	$84	$58	31%
	Internal gains	$35	$19	47%
	Frame walls	$9	$4	55%
	Roof	$8	$3	58%

Table 4. Predicted peak loads

	Peak Loads (kBtu/hr)		
	Base home	*GreenHOME*	*GreenHOME's savings*
Heating	26.6 kBtu/hr	17.0 kBtu/hr	36%
Cooling	25.5 kBtu/hr	18.6 kBtu/hr	27%

Table 2 summarizes the annual energy costs predicted by the REM/Design software using the construction details listed above, data on the Washington, DC climate, and some information on the house's layout. *Table 3* then details the major energy costs of the modeled building on a component basis. These energy costs do not include the costs from running appliances in the house except the HVAC system. The cooling internal gains listed in *Table 3* refer to the heat generated inside the house by people, lights, appliances, and anything else that releases heat, which can result in a substantial amount of heat that needs to be removed in the summer.

The REM/Design software also estimates the predicted peak loads for the mechanical system, which are used when sizing the heating and cooling equipment and shown in *Table 4*. The peak loads correspond to how much capacity the equipment must have in order to maintain the temperature of the house at a comfortable setting during the typical hottest and coldest days in the house's climate. The heating load is calculated by assuming an overcast winter day (no passive heating from sunlight), when the house is unoccupied and all appliances are off. The cooling load is determined for a hot, sunny summer day, when all of the home's residents are in the home and all appliances are running. The following table shows that our design required substantially smaller heating and cooling equipment, which saves energy and money.

As shown in *Table 2*, our energy analysis predicted that our demonstration house would have energy cost savings of 37 percent ($260 annually, or $7806 over the 30-year mortgage), when compared to a typical house built to the MEC code. In addition, the design saved money by requiring smaller HVAC equipment. If the added energy features of this house cost $4,112 more than a typical DC Habitat for Humanity house (with a cost of $65,000) at the standard Habitat for Humanity zero-interest, 30-year mortgage, monthly mortgage payments would increase by $11, but the monthly energy savings would save $22 monthly, which creates a net monthly savings of $11. Thus, although this house cost more to build, the home-owner will actually save money each month, while living in a house that will use fewer natural resources. (Savings shown are for heating and cooling only, and do not include the effect of the energy efficient appliances and lighting, nor does it take into account energy cost increases and inflation, which if anything should make this house even more affordable.) We intend to confirm the predictions of our energy analysis through a monitoring plan, outlined in the Testing the Construction section on page 58.

Energy analysis performed by:

Sustainable Design Group
22923 Wildcat Rd.
Gaithersburg, MD 20882
301-428-1040
www.sustainabledesign.com

Cost Summary

Great care was taken in the design of the house so that costs would be kept to a minimum. The total cost of the house, not including salvaged materials, was $75,054.

Table 5 details the expenses for GreenHOME's first demonstration house. The net expenses listed in the final column are what we calculate it would cost to build the same house again. This does not include the costs of reclaimed materials, which can be obtained free with volunteer labor, but does include the cost of donated items, which we cannot assume would be donated again. (Net expenses are out of pocket expenses plus donated values.)

Some notes on the category definitions:

- Site Work includes stormwater and drainage (including a $4,343 charge to connect to the city's water and sewer lines), site excavation, landscaping, fencing, and a retaining wall.
- Masonry/Foundation includes costs for the foundation and footings, the concrete porches, and brick work.

Table 5. Cost summary

	GROSS EXPENSES			*NET EXPENSE*
Category	*(A) Out-of-pocket expense*	*(B) Estimated value of donated items*	*(C) Estimated value of salvaged items*	*(A + B)*
Site Work	$11,064	$1,781	$200	***$12,846***
Masonry / Foundation	$3,339	$477	$1,250	***$3,816***
Framing	$6,655	-	$250	***$6,655***
Roofing	$1,464	-	-	***$1,464***
Stairs	$1,087	-	-	***$1,087***
Gutters	$136	-	-	***$136***
Doors	$773	-	$455	***$773***
Windows	-	$4,555	-	***$4,555***
Siding	$2,524	-	-	***$2,524***
Wall sheathing	$2,664	-	-	***$2,664***
Insulation / Sealants	$2,090	$154	-	***$2,243***
HVAC / Hot water	$3,714	$3,100	-	***$6,814***
Plumbing	$6,810	-	-	***$6,810***
Electrical	$3,609	-	-	***$3,609***
Trim	$1,362	-	-	***$1,362***
Flooring	$3,030	$1,191	$3,510	***$4,221***
Appliances	$1,909	$800	-	***$2,709***
Bathroom accessories	$186	$130	$200	***$316***
Paint	$520	$1,921	-	***$2,441***
Cabinets & Countertops	$201	-	$2,000	***$201***
Punchout—Finish Hardware/General	$7,576	$234	-	***$7,810***
Grand Total	***$60,711***	***$14,543***	***$7,865***	***$75,054***

- HVAC includes the air conditioner compressor, ventilation unit, and installation costs. This category also includes the hot water heater, which provides the heat source for the house.
- Electrical includes all of the wiring and switches in the house, as well as the lighting fixtures.
- Framing includes the subfloor, flooring framework, wall framing, roof framing, and drywall.
- Punch out–Finish Hardware/General is a miscellaneous category which includes finishing hardware (such as railings), survey fees, soil testing, temporary utilities, tools, site security, and a DC Habitat for Humanity administrative fee.

The total cost of the home shown in *Table 5* would be reduced by 10 percent if we were to apply Habitat for Humanity cost rules. Under these rules, many items we included in our total are considered owner options, and would be paid for by the owner, if they exceed the allowance for such items of the local Habitat for Humanity affiliate ($1000 in DC). The air conditioning equipment, the dishwasher, the sideyard and backyard wood fencing, and the clothes washer, which totaled $4037, would typically be deemed owner options. In addition, we classified several expenditures as site-specific costs, i.e., costs that might not be incurred if we were to build the same house again on a different lot. These included the retaining wall (required due to the steep gradient from the neighboring plot of land) and the wrought iron fence and brick facing above the foundation (both needed to meet Historical District requirements), for a total cost of $3,553. The total net cost of the house without these two categories was $67,465.

Figure 1. Gross expenditures breakdown

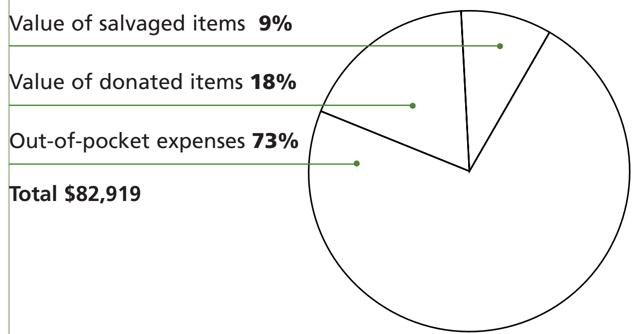


Figure 2. Net expenditures breakdown

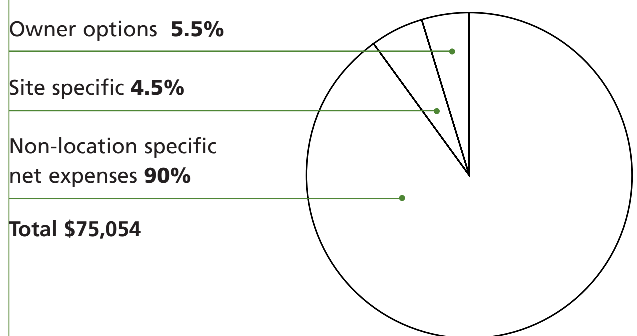
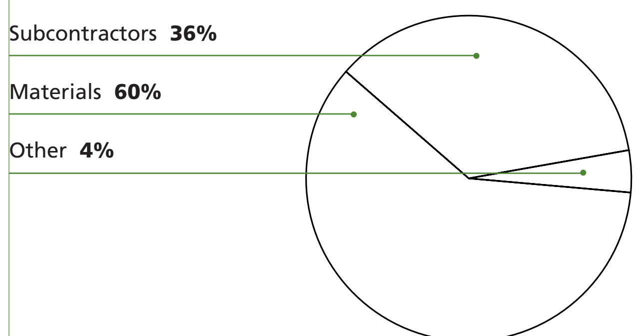


Figure 3. Materials and labor breakdown of expenditures



OVERALL HOUSE DESIGN

Design Features

Green building principles governed the overall design and layout of GreenHOME's demonstration house. We created a large living room/dining room with an open kitchen, to maximize the flow of passive lighting from the first floor's south-facing windows. The front of the house faces the southeast, which is the best orientation in this climate to maximize passive solar lighting and winter heat gain. Therefore, we placed large southeast facing windows for maximum winter heat gain and minimized the number of north facing windows, which receive no direct sunlight in the winter and are large heat loss sites. We also maximized the proportion of usable space by decreasing the size of areas like hallways. Since plywood and other sheathing materials normally come in 4 foot by 8 foot sheets, we designed the house on 24 inch increments to minimize the construction waste of these materials.

The house area totals 1186 square feet, divided into three bedrooms, one full bathroom, a kitchen, a utility room, and a combined living room and dining room area. The house has a crawl space foundation system, and no basement. However, the attic was designed to contain some storage space for the homeowner. The landscaping includes a driveway, a back patio, a flagstone front walkway, and several planting beds.

Integrated System Concept

The house was designed as an integrated system by considering how particular building component selections affected other choices and the overall design. For example, we found that while choosing energy efficient windows might cost more, they also reduced the heating and cooling loads of the house and increased its energy efficiency. Also, as a result of increasing the house's energy efficiency by reducing the air leakage (infiltration) of the house and increasing insulation values, a mechanical ventilation system had to be included in the house. (See the Exterior Wall and Mechanical System sections for more details.)

Historical District Requirements

The house's location in an historical district of Washington, DC, placed some aesthetic and material requirements on the design. The house had to be a two-story building located a specific distance away from the street and using certain proportions. The first floor ceiling was required to be nine feet high, which made it more difficult to reduce the waste of lumber because dimensional lumber comes only in even lengths. However, the extra height of the nine foot first floor helped with natural air flow within the house. To fit within the neighborhood's style, we incorporated some brick into the façade and selected a lap siding. We also had to use a wrought iron fence in front of the house and use a dark roofing material.

Location of HVAC System, Ductwork and Piping

Our design placed the utility room inside the conditioned space of the house (the part of the house which is heated and cooled by the HVAC system), so that the heating and cooling system would not lose heat in the winter by being exposed to cold air in the unconditioned attic or crawl space and similarly, not gain heat from hot, unconditioned air in the summer. We then ran all of the ductwork through the trusses supporting the second floor, so that the ducts would not lose heat in unconditioned spaces. To accommodate the ducts, we used an open truss system that allowed plenty of room for ducts without requiring us to cut holes

Figure 4a. Floorplans, first floor

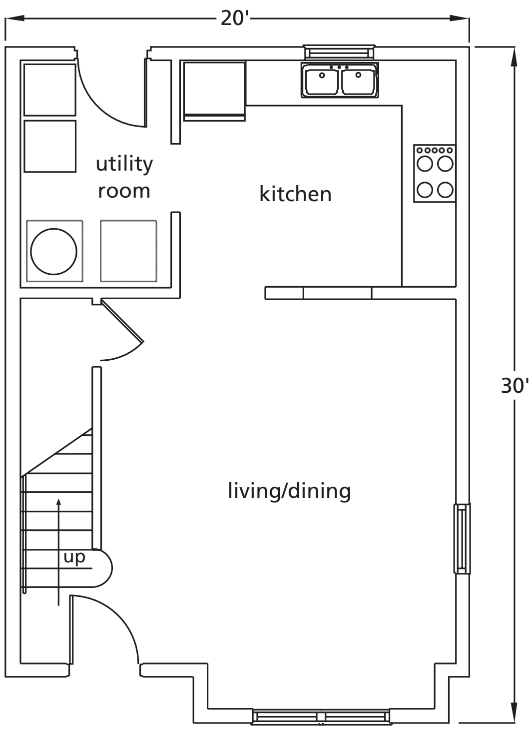
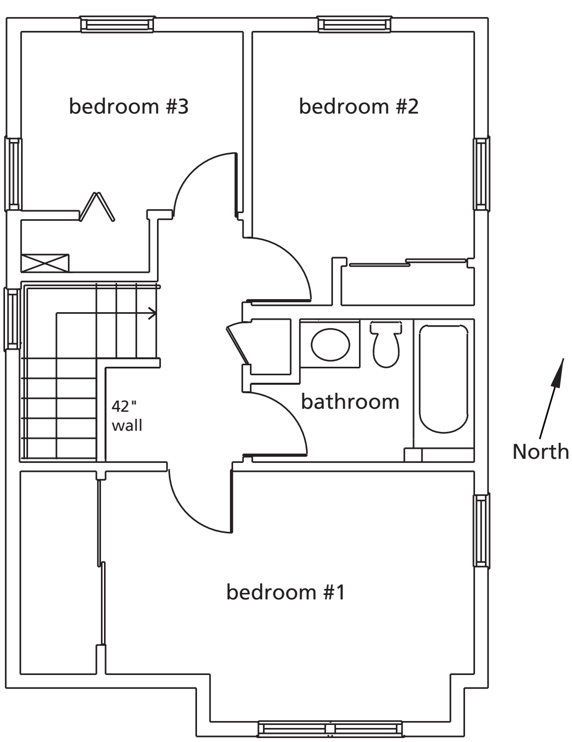


Figure 4b. Floorplans, second floor



in the truss webbing. Most of the plumbing is located in the interior walls, within the conditioned space of the house. This was done so that the plumbing would not displace the insulation in the exterior walls, and the hot water would not lose heat to the outside cold air. However, late in the design process we selected our HVAC system, which required an air handler to be located next to the hot water heater. The only location left in the utility room for the dryer and washing machine was along an exterior wall, which meant that we placed the required plumbing for these appliances through a short length of the external wall. Also, we used a low flow toilet, a low flow shower head, and sink aerators to reduce water consumption.

THE COMPLETED HOUSE

MATERIALS RESEARCH AND CONSTRUCTION

Foundation

FOUNDATION AT A GLANCE

Systems evaluated
- Slab-on-grade
- Frost protected shallow
- Crawl space
- Basement

Important criteria
- Cost
- Suitability to house site
- Volunteer friendliness
- Environmental impact

Selected system
- Crawl space, using concrete with a mix of 50% newcem/50% cement and a plastic vapor barrier

The primary function of a house's foundation is, of course, to provide structural support for the house. The foundation also controls heat and moisture flow from the ground through any crawl space or basement into the conditioned space of the house (i.e., space that is heated and cooled by the house's HVAC system). Installation of insulation below any concrete slab or (in a crawl space system) below the first floor will minimize heat loss from the house through the foundation system. Any unconditioned crawl space should also be well sealed from the conditioned living space to limit any unintentional airflow (infiltration) into the house. In addition, foundations need to be waterproofed and dampproofed to protect basements and crawl spaces from moisture.

Table 6. Foundation costs

Category	*Cost*
Excavation—backhoe	$3,250
Footings/foundation	$1,982
Radon pipes and equipment	$80
Porches—concrete and brickwork	* $3,084

** Includes a value of $1250 assigned to salvaged bricks*

Figure 5a. Crawl space system

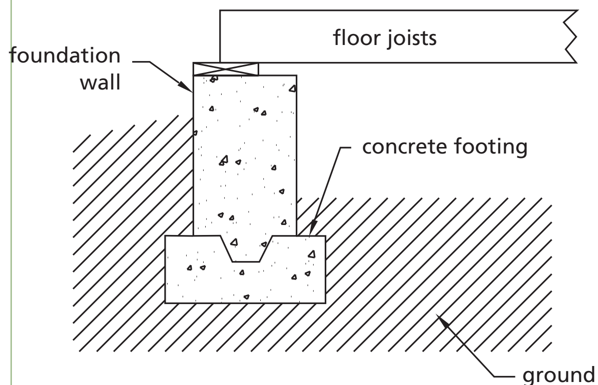


Figure 5b. Slab-on-grade system

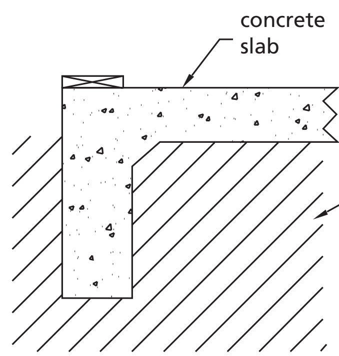
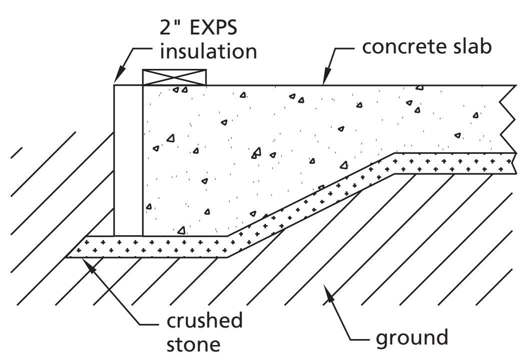


Figure 5C. Concrete shallow system



We evaluated three possible foundation systems (*Figures 5A–5C*): a slab-on-grade construction, a frost-protected shallow system, and a crawl space system. Specific details, such as insulation, drainage and radon pipes, are not shown.

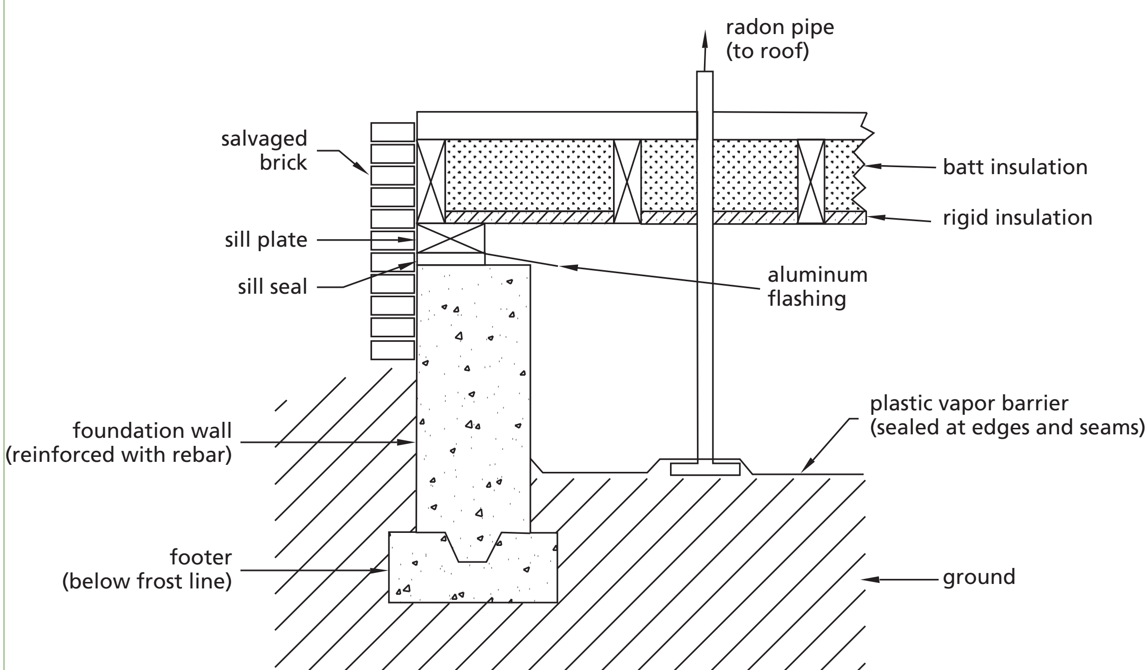
We chose the crawl space foundation system. The shallow concrete foundation system intrigued us, but in the end we deemed it inappropriate for our lot. This system uses strategically placed insulation to redirect heat from the house into the soil, which locally raises the frost line above the insulation. The shallow foundation system has been successfully used for over fifty years in areas in Europe, but is currently not permitted under Washington, DC building codes. This foundation system requires less concrete, and therefore less cost, than a conventional slab-on-grade system. A conventional slab-on-grade system was not feasible, mainly because of the Historic District's requirement that the first floor be elevated four to five feet above grade.

We did not seriously consider including a basement into the foundation system, because of the additional costs and limited green benefits. A basement system would have called for additional concrete and required us to consider the costs of insulating the basement walls and floors. We also would have had to add stairs to the first floor of the house, and find a way to keep moisture out of the basement. Instead, the attic was designed to expand the storage space available to the home's occupants. (Refer to the following Framing section for details on the attic.)

The crawl space foundation system that we used is diagrammed below. We used a footing (two feet wide by one foot high) reinforced with two #4 rebars, and then added four foot high, poured-in-place, foundation stem walls. A 2 x 4 sill plate, which is a pressure treated wood stud that connects the framing system to the foundation, was attached using anchor/sill straps embedded in the foundation wall. Usually a 2 x 6 or 2 x 8 is used as a sill plate, but we used the 2 x 4 because structurally our floor trusses only had to bear on a three-inch wide base, thus saving on wood. We considered using anchor bolts, but sill straps are more commonly used in construction and were deemed easier to use. The metal straps were bent around the sill plate and nailed in place to firmly hold the sill plate.

A closed cell foam sill seal (or sill gasket) was placed on top of the foundation wall to close any gaps that might occur due to variations in the height of the foundation wall. Aluminum flashing was placed on top of the foundation

Figure 6. Detailed sketch of foundation system



wall and sill seal as a termite shield, and was bent down along the sill seal. The aluminum flashing does not actually shield away termites, but exposes them so a quick annual inspection by the house occupant will reveal any infestation problem. Caulk was applied to the top of the flashing before installing the 2 x 4 sill plate.

We debated whether to use a concrete block or poured concrete stem wall system. A poured in place system was judged easier to do, because a block installation would have required skilled labor. Since both systems possessed similar embodied energies, we selected the poured stem wall system.

The concrete mixture that we used contained a 50 percent cement, 50 percent newcem mix, in lieu of the standard cement mix. Newcem, a type of slag, is a byproduct of Baltimore steel mills which is ground up and added to the concrete. This addition increases the concrete's strength, decreases its permeability, increases its workability, and requires the use of less cement. Using a mix of cement and newcem, or other similar additive, is becoming more common; in fact, this mix is standard for many concrete suppliers, and many homebuilders may be using it without realizing it. We looked into using flyash (a waste product from coal-fired power plants) for filler, which is a popular system used in the Midwest and West, but no local sources could be located. No installation differences were observed from using this newcem-cement mixture versus conventional concrete.

We installed a four-inch perforated drain pipe around the inside perimeter of the crawl space, dug a hole under the footing, and ran the drain pipe to an old well just north of the foundation to drain water that collected inside the foundation before the roof cover was in place. We did not install an exterior drainage system. For details, see the Landscaping section.

Toward the completion of the construction process, we took steps to keep moisture out of the crawl space, to prevent moisture from damaging the insulation in the first floor truss system and migrating into the house. The two sources of concern were moisture from the ground and from humid summer air. Volunteers raked the ground in the crawl space clean of rocks and debris, then placed a six mil (one mil = 0.001 inches) plastic vapor barrier on the ground space floor to stop ground moisture from entering the crawl space. The seams were overlapped one foot and run up the stem wall one foot. Volunteers then caulked and sealed all of the plastic's seams and edges. In addition, the foundation was dampproofed on the outside with a parge coat of Portland cement (1:1 cement to sand mix), in lieu of using tar. A four inch PVC pipe was run directly from the soil level in the crawl space, where the pipe had a "T" fitting, to above the roof (with no openings in between) to vent any radon buildup. We installed foundation vents to allow limited ventilation through the crawl space, so if moisture were to collect inside then it could be dried out.

POURED FOUNDATION

The exterior of the foundation was faced with salvaged bricks from three local sources: an historic garage in Alexandria, VA, an historic garage in Washington, DC (both garages were deemed unrestorable), and a building being demolished during site clearing for a new downtown convention center in Washington, DC. We found that cleaning off the old mortar from the bricks was labor intensive and time consuming; however, this was more than offset by the bricks being a reused material that we were able to obtain for free. We formed the stem wall with a four inch ledge on which to lay the bricks.

Framing

FRAMING AT A GLANCE

Important criteria
- Minimize amount of new lumber
- Maximize insulation values
- Cost
- Minimize embodied energy
- Ease of installation
- Reliability

Wall framing systems considered
- 2 x 6s on 24-inch centers, using OVE
- SIPs
- Strawbales
- Steel studs

Wall framing system selected
- 2 x 6s on 24-inch centers, using OVE
- Salvaged lumber for interior walls
- Drywall clips

Floor and roof framing systems considered
- 2 x 12 joists
- Trusses
- TJIs

Floor and roof framing systems selected
- Open web floor trusses
- Roof support trusses

Selection Criteria

The availability of inexpensive lumber has often encouraged its wasteful use in conventional home building, where closely spaced (on 16 inch centers) dimensional lumber (2 x 4s, 2 x 10s, etc.) remains the standard. GreenHOME sought to move away from this standard, both in the framing design and selection of framing materials.

We sought a frame design that would provide a strong structure using the least possible amount of new lumber and thicker exterior walls to allow additional depth for insulation. We also wanted to avoid materials with high embodied energy, toxic adhesives, or subject to delamination from moisture exposure. Our frame design was also influenced by the local Historic District regulations, which required that the first floor have nine foot ceilings and be placed several feet above grade.

Table 7. Framing costs

Category	*Cost*
Subfloor	$ 73
Floor framing	$ 2,389
Wall framing	* $ 5,014
Roof framing	$ 1,785

** Includes a value of $250 assigned to salvaged lumber*

Selected Framing Design: Stack Framing, Salvaged Wood, and Drywall Clips

To meet these objectives, we opted for a framing system dependent primarily on conventional lumber but arranged in a more efficient manner: 2 x 6s spaced 24 inches apart, aligned vertically from floor to floor, or “stacked.” (Stack framing involves the alignment of roof trusses, wall studs, and floor framing with each other.) The 2 x 6 framing system uses roughly the same volume of wood as the more conventional 2 x 4s on 16 inch centers, but requires approximately 30 percent fewer wood pieces, and thus reduces installation time. The 2 x 6 framing also allows two additional inches of insulation depth over a 2 x 4 system. Additionally, the stacked aspect of the design saves more wood by requiring only a single top plate, since framing members line up and transfer loads directly to the foundation. (Double top plates are required to transmit loads effectively if studs, joists, and rafters do not line up.)

A few other techniques spared more wood in our framing system. During construction, wherever possible we used reclaimed lumber for framing interior walls instead of new lumber. To reduce wood use, we eliminated window and door headers in non-load-bearing situations and used steel header braces instead of jack studs (also referred to as trimmers or deadman studs). Window openings were located against a normally placed stud, to eliminate the need for additional studs to define these openings.

In place of conventional three-stud corners, we saved additional wood by using two-stud corners and drywall clips to mount interior drywall panels. This also allowed insulation to reach further into the corners of the house. We ordered drywall clips from a non-local source. Alternatively, scrap wood could have been substituted for the drywall clips.

STACKED FRAMING SYSTEM

Figure 7. Examples of optimum value engineering (OVE)

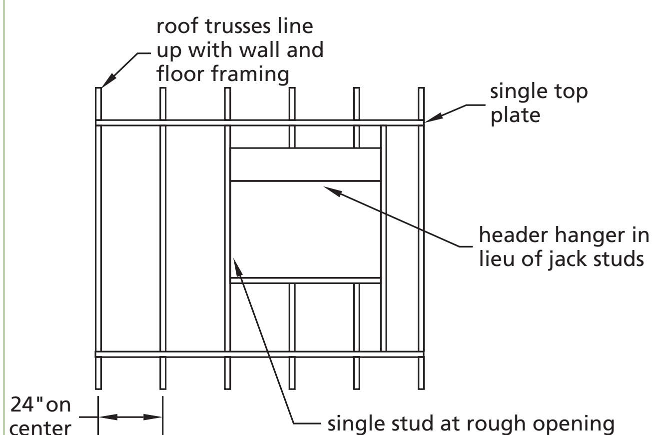
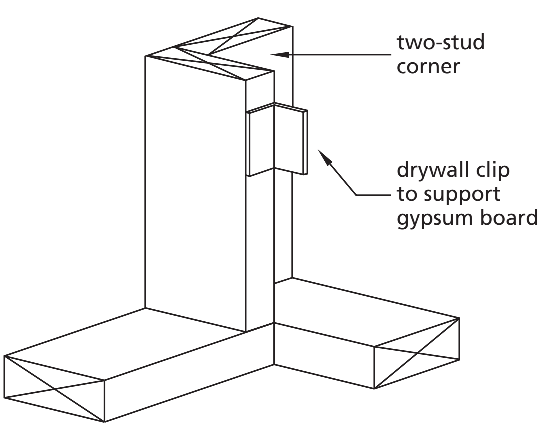


Figure 8. Diagram of 2-stud corners and drywall clips



In designing the framing, we followed the precepts of optimum value engineering (OVE)—a set of practices that saves builders money by reducing the amount of material and time used in construction. OVE includes framing 24 inches on center, stack framing, aligning openings with stud spacing, and eliminating unnecessary framing at intersections. (See reference section on page 72 for more on OVE.)

We selected open-web floor and roof support trusses as shown in *Figure 9* (in place of conventional 2 x 12 joists and rafters) to minimize the use of long lengths of dimensional lumber which would have to be cut from old growth trees and shipped across the country from the Pacific Northwest. The open-web floor truss system allows for simpler and less expensive installation of plumbing, electrical work, and ductwork within the trusses than with the conventional floor joists, and does not cost significantly more. (Contractors typically have to cut holes in joist systems for these installations, place them in unconditioned spaces, or run heating ducts under floor joists, which reduces headroom clearance.) We installed raised heel roof trusses to permit a full thickness of attic insulation all the way out to the eaves and to allow maximum attic storage for the homeowner. This roof system costs slightly more and uses more wood than a conventional system, but in our view this was outweighed by the associated benefits.

Because of warnings that an oriented strand board (OSB) subfloor would not hold up well with the extra nailing required to install our recycled hardwood flooring, we used surplus tongue and groove 4 x 8 foot sheets of plywood subflooring donated by DC Habitat for Humanity.

RAISE HIGH THE ROOF TRUSSES

OPEN-WEB FLOOR TRUSS

Figure 9b. Raised-heel roof truss

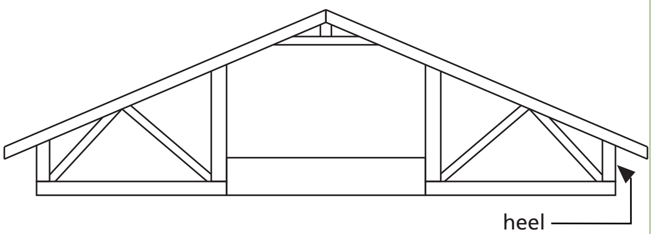


Figure 9a. Open-web floor truss

Other Framing Options Considered

We considered, but decided against, structural insulating panels (SIPs), despite their high promise in meeting our criteria, because they pushed the technical envelope a little too much in the Habitat for Humanity context. SIPs typically consist of a sheet of OSB on either side of an insulating core, are used in place of the conventional structural lumber frame, and come in sizes from 4 x 8 to 8 x 24 feet. SIPs offer high R-values and low infiltration values, as there are fewer seams to seal. The big advantage of using SIPs is the reduction in dimensional wood (i.e., 2 x 4s, 2 x 6s, etc.) used in a house; one source found a 50 percent reduction in the dimensional lumber by using SIPs. On the negative side, they currently cost about 15 percent more than building with lumber and have a learning curve associated with installing them.

Several of us urged the use of straw bales for exterior walls, given the proximity of an impressive model straw bale building. Straw bales are made out of an agricultural waste product, which is often burned in the fields. The straw bale construction system offers the benefits of the use of little or no lumber, volunteer friendliness, and high insulation values. Packed straw is also fire resistant, but is very moisture sensitive before interior and exterior coverings are applied. Straw bales are typically 18 to 24 inches wide, so they might not be feasible on some urban areas with small plots of land. We also anticipated a range of potential problems using straw bales in an urban historic district, including difficulty in obtaining building permits.

We decided against a steel stud system, even though their use would have helped save trees, because of steel's high embodied energy, high thermal transmission, and DC Habitat for Humanity's mixed experienced with steel studs in two other homes. In particular, DC Habitat for Humanity found that building with the steel studs took twice as long due to a steep learning curve for volunteers in mastering the use of self-tapping screws and screw guns.

We also investigated the use of TJIs (engineered lumber truss joists shaped as wood I-beams) for the floor framing system. TJIs consist of webs of OSB or plywood and top and bottom bands of either continuous blocks of solid sawn or laminated strips, and thus are more resource-efficient than solid dimensional lumber. However, TJIs with plywood webs proved too expensive, and we heard reports about TJIs with OSB webs delaminating and disintegrating after long term water exposure (such as might be encountered from a plumbing leak).

A Reality Check: Availability

We sought, but could not locate, a supply of lumber from "certified sustainable" sources, which are forests that are managed to protect biodiversity and ensure a supply for future generations. Engineered finger-jointed stud lumber available elsewhere was not available locally. However, our deconstruction of an old house yielded a good supply of solid, if ancient, 2 x 4s, and we used this wood for framing almost all of the interior walls.

Our Framing Experience

Aside from our initial errors interpreting the truss manufacturer's installation instructions, stack framing proved quite manageable, even amidst the chaos of a "blitz build" swarming with volunteers. Using the reclaimed 2 x 4 studs was challenging, as our volunteers spent much time denailing and preparing this lumber. The studs were also wider and thicker (an actual 2 by 4 inches instead of the 1½ by 3½ inches of today's nominal 2 x 4s) and required constant recalculation to ensure proper lengths. This size difference also necessitated the use of 20d nails instead of the usual 16d nails to join the studs. Their width and breadth varied from piece to piece, and defects in individual pieces not originally apparent (e.g., insect borings that hollowed out several pieces) required us to replace some. Still, we fell in love with these oldies but goodies, and would use them again.

What We Would Do Differently Next Time

We would not change many things, actually. In the future, it may be easier to find lumber from certified sustainable sources, as such programs are new, yet growing in acceptance. We might look again at structural panels or straw bales in a future house designed to push the green envelope more aggressively than this, our first effort. We especially recommend scouting creatively for recycled and recoverable framing materials. It is amazing what is available for little more than the effort to gather it.

Exterior Walls

EXTERIOR WALLS AT A GLANCE

Selected Air Sealing
- Caulk
- Great Stuff sealant

Vapor Barrier Considered
- Builder's foil
- Polyethylene sheet
- Low-permeability primer

Selected Vapor Barrier
- Low-permeability primer

Airsealing: Caulk is Cheap

We took care to seal the house as tightly as possible to prevent air infiltration. In traditional construction, infiltration occurs through gaps and cracks in the building shell. Excess infiltration of cold air in the winter and hot humid air during the summer can raise heating and cooling bills by 30 percent and also create uncomfortable drafts. By decreasing air infiltration, the size and cost of the HVAC system can be significantly decreased. Adding an air handler system (see the Mechanical System section), regulates the ventilation so the indoor air temperature is predictable, controllable, and comfortable.

A small investment in sealants can yield a large reduction in heating and cooling utility bills. Airsealing does not require expensive materials or highly skilled labor, and can lead to significant energy savings. In fact, we spent less than $200 for caulk and other sealants while reducing the air infiltration in the house by more than 350 percent compared to a typical house (from 0.75 ACH to 0.16 ACH—refer to the section on Testing the Construction). Caulk is cheap, but energy isn't.

The sealing materials used must last the lifetime of the home or be easy for the homeowner to re-apply. Sheathing and finish materials are the primary air barriers, while insulation materials, such as batts or loose-fill materials, do not seal against air leakage. We carefully sealed all holes and seams in the sheathing and finishing materials with caulks, gaskets, and foam sealants.

Table 8. Exterior wall costs

Category	*Cost*
Blown-in insulation	* $ 1,583
Sheathing	$ 2,664
Siding	$ 2,524
Vapor barrier primer	$ 215
Caulk/sealants	$ 194

• Includes cost for attic insulation

We used caulk to seal small gaps (typically less than 1/4 inch) and an expanding spray foam to fill large cracks and small holes. Expanding foam sealants generally use HCFCs as a blowing agent. While this is a major improvement over the older sealants that used CFC-11, some reports indicate that HCFCs damage the stratospheric ozone layer. A few foam sealants available use ozone-safe blowing agents, such as propane and isobutane (which are hydrocarbons produced from natural gas that do not affect the ozone and are not greenhouse gases), and HFCs (which pose no risk to the ozone layer, but may contribute to global warming). We used Great Stuff sealant, produced by Flexible Products, which uses a blend of propane and isobutane.

KEEPING THE OUTSIDE OUT AND THE INSIDE IN

Airsealing must be done throughout the construction process—during framing, prior to insulating and drywalling, after installation of fixtures, and as part of the final construction punchout. Our sealing process included:

- Sealing between termite shield and sill plate with sill seal
- Sealing subfloors to floor joists with adhesive
- Applying two beads of caulk on bottom plate before erecting exterior walls, caulking along the joint between the inside of the bottom plate and the subfloor after frame walls were up
- When setting exterior doors and frames, caulking generously under thresholds
- Sealing around trim and flashing of siding
- Sealing around bath tub framing with thermo-ply (or any impermeable material like plastic) before tub was installed
- Sealing perimeter of windows and exterior doors with caulk or sill seal
- Sealing electrical wire, HVAC duct work and lines, and plumbing penetrations at top plates and through ceilings and floors before installation of drywall
- Sealing electrical outlets and switchboxes, telephone boxes, and cable TV boxes by installing foam gaskets under cover plates
- Sealing bath ventilation fan to drywall, sealing air duct vents to floor or drywall, sealing around kitchen exhaust vent, gas water heater vent, air handler intake, and output vents
- Sealing all duct work joints with mastic
- Sealing exterior penetrations, such as light fixtures, phone and electrical service openings with caulk or foam
- Sealing drywall to wall framing (top plates, bottom plates and stud framing)
- Caulking and foaming all ceiling, wall, and floor penetrations, such as the frame gap at the attic pull-down stairs
- Sealing exterior wall sheathing to wall framing with adhesive on studs and caulking between sheathing joints.

Vapor Barrier

Vapor barriers are typically installed in temperate climates where moisture can condense from diurnal (daily) temperature fluctuations. The exterior wall is particularly susceptible, as it separates warmer interior spaces from the cooler outdoors (and vice versa in the summer), providing ample opportunity for condensation to occur. During winter, when the inside of the house is warmer than outdoor air, moisture (generated in the house by cooking, bathing, cleaning, and breathing) tends to pass through the interior wall and condense on the colder outside wall (and vice versa during the summer), potentially damaging the insulation and causing the framing to rot.

Common choices for vapor barriers are builder's foil (aluminum foil faced over a paper substrate, which provides reflectance of radiant heat) and polyethylene sheets. Instead, we installed a low permeability primer directly on the drywall. This primer has a low permeability latex formulation, which reduces the passage of moisture into and out of the house through the walls. We selected the primer as our moisture barrier in lieu of the more typical plastic sheet vapor barrier, which requires a large amount of plastic.

Before painting, the interior walls facing the house's perimeter were primed with Glidden Insul-Aid Vapor Barrier Primer-Sealer #5116. Unfortunately, this primer has a high solvent content (about 51.5 percent by weight). Several volunteers complained of eye irritation while applying this paint. Our experience suggests that adequate ventilation is essential applying this primer. We would recommend finding a less irritating primer or using another vapor barrier method and a zero VOC primer.

Insulation

INSULATION AT A GLANCE

Important criteria
- Cost
- R-value
- Recycled content
- Environmental impact
- Ease of installation

Insulation types considered
- Fiberglass
- Rigid foam
- Foam-in-place
- Air-krete
- Cotton
- Cellulose

Selected insulation
- Walls: wet-blown cellulose (recycled newspaper and phone books)
- Attic: dry-blown cellulose
- Crawl space: Fiberglass rolls

Selection Criteria

In our evaluation of the many different types and brands of insulation, the primary criteria included cost, availability, environmental impact, and, of course, a high insulation or R-value. Stability of placement (to reduce sag or displacement) of vertically installed insulation was also a criterion, as was ease of installation by volunteers. The environmental considerations of our insulation selection included issues such as resource conservation and minimization of waste in the process of both production and installation. We also evaluated the possible health effects of various materials.

Materials Considered

Taking all of the above factors into consideration, we eliminated most of the commercially available forms of insulation. Even though fiberglass is thermally effective and durable, blown fiberglass and fiberglass batts were rejected because of reported concerns about health impacts from exposure to loose glass fibers and from the use of formaldehyde. Specially made, encapsulated fiberglass batts do reduce these problems, but at a significant increase in cost. (Encapsulated R-19 batts cost $0.40/ft^2 while more typical kraft-paper faced batts cost $0.33/ft^2.)

We found that most rigid foam insulation materials, such as XPS (extruded polystyrene) require the use of CFCs or HCFCs during production. EPS (expanded polystyrene) is an alternative rigid foam that does not uses CFCs and has high R-values. However, all of these insulation types have relatively high embodied energy, poor recyclability, and high waste production.

We rejected most foam-in-place insulation materials because of the use of CFC and HCFC gasses in their production and potential shrinkage over time. There is an alternative foam-in-place insulation called Icyene that has no toxic emissions. However, all foam-in-place insulations require trained installers, who are generally costly. Thus, these insulations are not conducive to use by a volunteer workforce.

Air-Krete insulation is an inorganic material made from magnesium oxide, which comes from sea water. Air-Krete is foamed-in-place, uses no CFC or HCFCs, has low VOC emissions, and is non-combustible. Unfortunately, it is also relatively expensive.

Table 9. Insulation comparison

Insulation type	*R-value per inch*	*Cost*	*Environmental impact*
Fiberglass batts	2.2–4.0	$0.33/ft^2	Irritants from fiberglass fibers
Encapsulated fiberglass batts	2.2–4.0	$0.40/ft^2	No major concerns
Rigid foam (XPS)	5.0	Medium	CFCs/HCFCs used in manufacturing, high embodied energy, high waste production
Rigid EPS	3.6–4.4	Medium	High embodied energy, high waste production
Foam-in-place	4.3	High	Most use CFCs/HCFCs in manufacturing
Air-Krete	3.9	$2.00/ft^2	No major concerns
Cotton batts	3.0–3.7	$0.37/ft^2	Made from recycled materials
Cellulose insulation	3.0–3.7	$0.30/ft^2 (wet) $0.20/ft^2 (dry)	Made from recycled materials, low embodied energy

Cotton batts would have been preferable to all of these insulations. However, production problems at the local manufacturer limited GreenHOME's access to this material. Cotton insulation is made from recycled cotton from textile plants and is treated with borates to provide fire and insect resistance. Cotton batts have similar performance to fiberglass, but without the irritation from fiberglass fibers.

Selected Wall Insulation: Wet-blown Cellulose

We selected wet-blown cellulose insulation, which is produced from recycled newsprint and telephone books and contains no toxins, carcinogens or petrochemicals. Most cellulose insulation is approximately 80 percent recycled material by weight; the remainder is borates or ammonium sulfates (which are added for fire and insect resistance) and acrylic binders, added to hold the insulation in place once installed. The choice of cellulose insulation was based on its thermal performance, safe composition, low cost, use of recycled materials, and lowest embodied energy of all of the insulation materials that were considered.

The cellulose can be installed dry (loose) or wet blown. The wet-blown method of installation was selected because it provides for better adhesion of the material within the wall cavity to better fill gaps and therefore provide more effective insulation. The wet-blown insulation is also more stable than other methods of installation and has added binder agents to prevent the material from sagging over time within the wall cavity. Dry cellulose is often used in horizontal surfaces such as attic floors. A 1990 Colorado University study compared cellulose and fiberglass batts insulation in two otherwise identical houses, and found that wet-blown cellulose reduced heating costs by about 26 percent over the fiberglass insulation. The wet-blown cellulose needs ventilation after installation to dry out and prevent mildew and rotting conditions.

Even though it could be installed by volunteers, GreenHOME opted to have the wet blown insulation professionally installed due to the low cost involved in obtaining this service. This type of insulation more than satisfied the criteria set by the selection committee. The wet blown material adhered to the wall cavity while simultaneously filling spaces that would have been difficult to fill completely using other methods. Observation to date has not

INSTALLING WET-BLOWN CELLULOSE INSULATION

revealed any sagging of material that would reduce its insulation value. Given the success of this type of insulation we would recommend using it again in subsequent homes.

Crawl Space Insulation: Fiberglass

We placed R19 fiberglass roll floor insulation in the cavities between the trusses on the underside of the first floor subfloor. (Blown in insulation would have required more time and money for this specific application, as we would have had to create a structure to hold the insulation in place.) We then applied one inch thick, rigid R-4 insulation (extruded polystyrene T&G foam) to the underside of the floor trusses to provide further insulation and to keep the insulation rolls in place. All seams were taped and sealed to try to keep any residual crawl space moisture from damaging the fiberglass insulation.

Attic Insulation: Dry-blown Cellulose

We had dry cellulose insulation blown into the attic, taking care to blow the insulation all the way into the attic corners. This insulation was blown to an 11 to 16 inch deep depth for an insulation value of R-38. The raised heal truss attic design allowed insulation to be blown to this same depth to the attic eaves. We then sealed the attic door with a sealing gasket. (A recent study found that an attic with blown-in insulation that did not fully cover all corners and did not have a sealed attic door had a 30 percent reduction in effective insulation value.)

Exterior Wall Sheathing

SHEATHING AT A GLANCE

Important criteria
- Environmental impact
- Cost
- Volunteer friendliness
- Durability

Sheathing materials considered
- Rigid insulation
- Plywood
- OSB
- Composite wood-cement
- Compressed wood board
- Recycled wood fiber

Selected sheathing
- Homasote (recycled wood fiber)

Selection Criteria

Selection of a sheathing material required consideration of several factors. Sheathing should be a low to no-maintenance material that provides structural reinforcement, good nailability, and additional insulation. Because the expense of sheathing for a small house is relatively low, cost was not a significant consideration by contrast with other green materials. The environmental impact of different forms of sheathing options was a significant factor in our selection process, as most products satisfied our performance requirements.

Materials Considered

We considered rigid insulating sheathing, which typically consists of foam insulation between kraft paper facings, is generally durable and a good thermal performer. However, this product can be expensive and its production usually requires the use of CFCs or HCFCs.

We do not recommend bare plywood sheathing due to potential delamination problems upon exposure to moisture. Oriented strand board (OSB) is widely used, but it can deteriorate when exposed to moisture. While both of these materials are easy to install and customarily available, they need to be protected from the elements by the use of a house wrap.

Composite wood-cement sheathing, which is made of wood fiber strands combined with portland cement, boasts superior performance over wood. However, its production consumes excessive resources and energy, and it is relatively expensive.

Compressed wood board was the most promising sheathing choice. This material is made from several continuous plys of wood fiber, which are 100 percent recycled from post-consumer waste and mill waste, and joined by non-hazardous phenolic resin adhesives. Compressed wood board has a low embodied energy and is lightweight and durable. Unfortunately, this sheathing material has poor nailability, making it potentially difficult for volunteers to install.

Table 10. Sheathing comparison

Sheathing material	*Cost for 4 x 8 panels*	*Durability*	*Volunteer friendliness*	*Environmental considerations*
Rigid insulation	High	High	Good	CFCs/HCFCs used in manufacturing, high embodied energy
Plywood (1/2” thick)	$10.50	Medium–High	Good	Higher embodied energy than OSB
OSB (1/2” thick)	$7.50	Medium–High	Good waste wood	Made from wood chips and other
Composite wood-cement	$27.00	High	Medium	High embodied energy
Compressed wood board	$7.00	Good	Medium	Made from 100% recycled waste
Recycled wood fiber (Homasote)	$15.00	Medium	Good	Made from 100% recycled newsprint

INSTALLING HOMASOTE SHEATHING

Selected Sheathing: Homasote, a Recycled Wood Fiber

Homasote 440 sheathing, 5/8 inch thick, was finally selected for this GreenHOME project based on its nailability, thermal insulation value, and recycled content. Homasote is a recycled wood fiber sheathing whose primary ingredient is 100 percent recycled newsprint, and it contains a low embodied energy. Homasote is also lightweight and serves as an adequate nailbase. It is higher in cost than most sheathing options, so savings from other material selections were applied to purchase this sheathing because of its known environmental benefits. This product also provides good sound absorption and is resistant to termites and fungus. While it is easy to cut, lots of dust is generated in the process. Volunteers wore filter masks when cutting this sheathing product.

The use of Homasote as a structural panel depends on a very tight nailing schedule. Since its shear strength is effected by exposure to the elements, it may not be appropriate for use as a structural panel where strong wind and severe weather conditions are prevalent. (See *Table 10*.)

Our experience with Homasote sheathing

The Homasote was easy to cut and easy for volunteers to install. Sheathing was attached to each stud with adhesive, and nailed with 8d ring shank nails spaced 4 to 6 inches apart along panel edges and 10 to 12 inches apart at intermediate framing.

Unfortunately, we found that the Homasote absorbed much more moisture than we expected, causing expansion. Almost 20 percent of the sheathing area buckled, which created an uneven surface across the exterior walls, making it difficult to install the siding evenly. This may be due in part to our not consistently leaving the recommended 1/2-inch gap between sheet edges, to allow for the large expansion of the material. Even so, we observed significant buckling even where we included the recommended gaps between sheets.

In retrospect, we should have:

- installed the panels vertically so that the length-wise edges were fully nailed down,
- installed cross blocking at horizontal joints to provide a solid nail base for the sheet edges,
- left a consistent spacing at joints, and
- consistently nailed from the center of the sheet and worked outward to the edges.

We also did not install siding immediately over the sheathing (which would have protected the sheathing from moisture), even though we did install 15lb felt paper to help protect the Homasote from the weather.

We would not recommend using Homasote for sheathing. The magnitude of the buckling problems that we experienced suggests we would have encountered problems even if we had avoided the mistakes noted above. Perhaps Homasote would work as sheathing for 16 inches on center framing, but ours were 24 inches. Other sheathing materials are readily available.

Siding

SIDING AT A GLANCE

Important criteria
- Cost
- Maintenance requirements
- Durability
- Environmental impact
- Ease of installation

Siding materials considered
- Vinyl
- Conventional wood
- Sustainable wood
- Wood fiberboard
- Engineered wood lap
- Recycled aluminum
- Composite fiber-cement

Selected siding
- Hardi-Plank (fiber-cement composite)

Selection Criteria

The selection of siding material was predicated by the location of the GreenHOME project within the Capitol Hill Historic District, which required lap siding. However, this still allowed for a wide range of choices in the types of materials and suppliers. The choice of an exterior siding was one of our most difficult selections, since every available material had some negative aspects. Our siding evaluation focused on cost, maintainability, availability, environmental impact, and volunteer friendliness.

Options Considered

We rejected vinyl siding, despite its low maintenance and low cost, because of the petrochemicals usage, high embodied energy, and pollutants created in its production. Vinyl also off-gasses potentially toxic chemicals and releases high levels of toxic chemicals when burned.

Sustainably forested wood siding offered the lowest environmental impact and cost. However, we could not pursue this option because we were unable to purchase this type of wood locally, and our project was too small to justify purchasing a truckload of siding from a certified sustainable source, at a great distance from Washington, DC. Conventional wood siding remained an option—except for redwood or cedar possibly sourced from the ancient forests of California and the Pacific Northwest—but would require high transportation energy usage and costs.

We also considered compressed wood fiberboard siding (composed of wood chips and fibers heated under pressure with phenolic and natural adhesives) and engineered wood lap siding (essentially OSB, produced from wood chips and resinous adhesives). While both use less virgin wood and are volunteer friendly, we rejected these materials due to their high maintenance and lower durabilities than the other considered sidings.

Table 11. Siding comparison

Siding material	*Cost (per linear foot, based on 8-foot lengths)*	*Volunteer friendliness*	*Durability*	*Maintenance requirement*	*Environmental considerations*
Vinyl	$0.80-$1.10	Good	Good	Low	Concerns about pollution and chemicals during manufacturing, high embodied energy
Conventional wood	$0.78-$1.95*	Good	Good	Medium	Uses a lot of virgin wood, low embodied energy
Sustainable wood	$0.78-$1.95*	Good	Good	Medium	Low embodied energy
Wood fiberboard	$0.85	Medium/High	Good	Medium	Low embodied energy
Engineered wood lap	$0.85	Medium/HIgh	Good	Medium	Low embodied energy
Recycled aluminum	$1.50	Medium/Low	Good	Low	Medium embodied energy
Composite siding (Hardi-Plank)	$0.55	Medium	Good	Low	High embodied energy

** Varies with market and grade*

Recycled aluminum siding was yet another option that we considered. Despite its very low maintenance requirements, it can be difficult to find certified recycled aluminum siding. In addition, installation requires trained personnel, and was discouraged by the Historic District.

Selected Siding: Hardi-Plank, a Fiber-cement Composite

As the materials were evaluated, cost of purchase and maintenance over the long term emerged as the foremost practical concerns. As a result, a composition cement and wood siding was selected. This material is very durable, uses less wood than conventional wood siding, is inexpensive, and is highly resistant to moisture and humidity once it has been properly sealed. This selection was made despite the greater amount of energy used in its production and transport (it uses especially long wood fibers typically imported from New Zealand). In addition, composite siding is heavier than wood and can be difficult to cut.

Composite siding, also known as fiber-cement siding, is composed of portland cement that is combined with long wood fiber strands that are pressed and heated together. Few companies produced this kind of siding at the time of the material research, but since that time more have begun production. One manufacturer, Hardi-Plank, also produces trim boards to go with the siding. We selected Hardi-Plank because we believed that those products would help to maintain consistency across the exterior of the house by having all materials weathering at approximately the same rate. All current manufacturers offer fifty-year warranties on fiber-cement siding.

We primed the Hardi-Plank on all sides and edges to reduce moisture absorption that can cause damage through expansion and warping, particularly in colder and temperate climates. We attached the siding to furring strips, installed vertically on the exterior walls, which provided an air space between the siding and the wall sheathing to permit the backside of the Hardi-Plank to breathe. The air space provides natural ventilation, allowing moisture behind the siding to dissipate. The furring strips were one of the many salvaged materials used in the house—lath taken from a building scheduled for demolition.

VOLUNTEERS INSTALLING SIDING

One environmental and maintenance advantage of composite siding over wood is that it requires less frequent painting. However, specific paints are required in order to not void the siding's warranty (see the Paint section). We estimate that the siding will require painting every 15 to 20 years, compared to every 5 to 10 years for wood siding in the Washington, DC climate. Since exterior paints are noted for their negative environmental impacts, this is a genuine long-term environmental benefit.

Our Experience With Hardi-Plank

Composite siding proved to be somewhat more difficult to install than was anticipated. The carbide tooth saw blades which we used to cut the boards to their proper lengths had to be replaced frequently. A large amount of dust was created during the cutting process, necessitating the use of filtration masks by the volunteer cutters. Special tools do exist to easily cut Hardi-Plank, creating less dust, but these tools are expensive.

The high degree of density of the siding made it more difficult than wood to nail into place. Cuts had to be primed after sawing and before installation. Nails had to be driven carefully, so that the nail heads would not break the surface of the Hardi-Plank, which would have voided the warranty. To be on the safe side, volunteers painted over all the nail heads after installation. As our construction crews also learned, the siding boards had to be handled with a moderate degree of care and could not be allowed to bend excessively because of the danger that the boards would break. Overall though, these problems were minor and acceptable.

Windows

WINDOWS AT A GLANCE

Important considerations
- Energy ratings: U-factor, SHGC, VLT, ALR
- Glazing type and coating
- Frame material
- Frame type
- Geographical location and orientation

Selected windows
- Double pane, argon filled, low-e coating, vinyl-clad wood

Selection Criteria

Windows are a key determinant of the energy efficiency of a house, accounting for up to 25 percent of heating and cooling losses. They are equally crucial to a home's livability, as they directly effect internal lighting, external appearances, security, emergency egress, and intake and fresh air and humidity. While high performance windows cost more, they result in significantly reduced energy bills and can lower heating and cooling loads enough so that smaller, cheaper heating and cooling equipment may be utilized.

We selected windows based on their performance ratings, frame materials and type, and cost. In arriving at window performance criteria, we took into account each window's orientation on the house and the amount of shading that it received. Because of the many trade-offs involved in the window selection process, we recommend using a computer energy analysis program to find the exact effect of different windows on the energy consumption of the house.

A ROOM WITH A VIEW

Window Ratings

Many windows now have labels developed by the National Fenestration Rating Council (NFRC) that list four major energy ratings that can be used to compare window performance. We list general recommended values for these ratings, but specific choices depend upon your house's climate, window orientations, and window shading.

U-factor: The U-factor is a measure of how good an insulator a window is, with lower values indicating better insulating windows. Generally, windows with U-factors of 0.40 BTU/hr ft^2 °F or less are recommended.

Solar heat gain coefficient (SHGC): This indicates the fraction of solar radiation that passes through a window, which is basically the shading ability of the window. Values range from 0 to 1, with lower numbers indicating better shading. While windows with low SHGC values will reduce summer overheating, they also will reduce the solar heat gain in the winter. Therefore, these values need to be chosen carefully, and may vary according to the window's orientation on the house. In general, in climates where a substantial use of air conditioning is needed, use SHGC values of 0.40 or less, while in more temperate climates values of 0.55 or less are recommended.

Visible Light Transmittance (VLT): Ranging from 0 to 1, VLT indicates the fraction of daylight that is transmitted through a window, including its framing. Select VLT values of 0.50 or more to allow more light into the house.

Air Leakage Ratio (ALR): ALR measures the air infiltration through cracks in a window frame in the presence of a strong wind, with lower values indicating less leakage and better airtightness. Select values of 0.30 cfm/ft^2 or less. (CFM stands for cubic feet per minute.)

Glazing (glass)

High performance windows generally consist of two or three panes of glass. In addition, the space between the glass panes is often filled with a gas, such as argon and krypton, to reduce the heat transfer through the window. Low emissivity (low-e) coatings—extremely thin and invisible layers of metal or metal oxide—often are applied to reduce the amount of heat and ultraviolet light passing through a window without effecting the passage of visible light.

Frame Materials

There are several options available for window frame materials. Our review of the literature strongly suggests that when choosing an environmentally preferable window, performance should be given top priority over other factors (e.g., embodied energy, recycled content or toxicity of frame materials), because the amount of energy that can pass through residential windows is so great, particularly over a product life span of 50 years or more, that other considerations pale in comparison.

Wood: Wood is a relatively good insulator, but requires owner maintenance.

Aluminum: Aluminum provides low maintenance, but is a very poor insulator, and should not be used as a window frame unless thermal breaks are designed in the window frame system.

Vinyl: Vinyl is also a low maintenance material, but is not as structurally strong as aluminum or wood, and presents some environmental concerns as a result of chlorine and other chemicals used in its production.

Fiberglass: Stronger and more expensive than vinyl, fiberglass presents some of the same environmental concerns during its production, except that chlorine is not used.

Vinyl-clad and aluminum-clad wood: These frames combine the advantages of wood as an insulator with the low maintenance attributes of vinyl or aluminum.

Frame Types

Fixed pane windows: While airtight and inexpensive, these windows cannot be opened and thus offer no ventilation.

Casement windows (windows that open out): These windows are moderately airtight and offer good ventilation. However, typically they are more expensive than double-hung windows, complicate the placement of security bars, and may not be acceptable in a historic district.

Double-hung windows: These leak more air than casement windows and offer less ventilation when fully open.

As a comparison on the airtightness of the last two window types, Andersen's Double Hung Narrowline windows are rated with an ALR of 0.14, while Andersen's Casement windows have an ALR of 0.05.

Geographic Location and Orientation

The orientation and climate in which a window is installed will dictate the performance criteria. In cold climates or north facing windows in temperate climates, maximum insulation and airtightness values are the most important criteria. In warmer regions, and east and west facing windows, minimum SHGCs are most important.

Houses should be designed to optimize window locations. The major glass areas in the house should be placed on the south side of the house, as south facing windows receive the maximum amount of solar heating from sunlight in the winter yet little heat gain, when properly shaded, in the summer. East and west facing windows get the most sun in the summer and little in the winter, so these windows should be minimized unless properly shaded. North facing windows receive little direct solar gain.

Solar shade screens, roof overhangs, awnings and trees can be used to provide shade to windows. Deciduous trees are a great natural shading device, blocking sun in the summer when in full leaf, yet allowing sun through during the winter when devoid of leaves. Solar shades can block up to 70 percent of direct sunlight, while allowing ventilation and light pass, and typically the cost is minimal ($0.40-$0.70 per square foot).

Table 12. Window u-factors and solar heat gain
Representative coefficients based on 3 x 5-foot windows

Window type	*U-factor*	*SHGC**
Single pane, aluminum	1.30	0.74
Double pane, wood or vinyl	0.48	0.60
Double pane, wood or vinyl, low-e coating	0.38	0.54
Double pane, wood or vinyl, low-e coating, argon filled	0.34	0.54
Triple pane, wood or vinyl, low-e coating, argon filled	0.23	0.45

Table 13. Window glazing types
Energy usage and cost comparison

Type	*Additional cost (dollars/ft^2)*	*Additional annual energy savings (dollars/ft^2)*
Single pane w/storm window	1.50–4.00	0.40–0.70
Double-pane	0.50–2.00	0.40–0.70
Double pane, low-e	3.50–5.50	0.80–1.05
Double pane, gas filled	4.00–6.00	0.90–1.20

**Solar Heat Gain Coefficient*

Table 13 gives approximate values for the additional purchase price as well as the annual energy savings relative to single pane, aluminum windows using various glazing techniques. A calculation using data from this table shows that purchasing ten of the higher quality, double-pane, gas filled, 3 x 5 windows would cost approximately $750 more than the single pane windows. These high efficiency windows would save approximately $3150 in energy bills over a 20 year period, for a net savings of $2400.

Selected Windows: Double-pane, Argon Filled, Low-e coating, Vinyl-clad Wood

In keeping with the Historic District requirements of our demonstration house, we selected double hung windows to best fit the neighborhood style. When we were about to make our final selection, we were approached by Andersen Windows with a donation offer of a complete set of Tilt-Wash windows, which met all our criteria and thus were selected. These windows are double-pane and argon filled, have a low-e coating, are constructed out of vinyl-clad wood, and retail for $264 each. Their energy ratings are a U-value of 0.32, ALR of 0.20, SHGC of 0.51, and VLT of 0.73.

When we installed the windows, we applied caulk and sill seal around each window to ensure an airtight seal. The windows on the west side of the home are shaded by the neighboring two-story home and a large deciduous tree. We were not permitted to place a roof overhang or awning to shade the south facing windows in the summer, due to Historic District requirements. We would therefore advise the homeowner to purchase sun screens (which cost approximately $25) for these windows if summer overheating proves to be a problem, as the trees that we planted will take many years before they supply adequate shading. The east side windows are similarly unshaded, but because of their east-northeast orientation they should require less extensive shading.

Doors

DOORS AT A GLANCE

Important criteria
- Cost
- Ease of installation
- Insulation (for exterior doors)

Selected doors
- Exterior: Metal-clad insulated doors
- Interior: Salvaged, hollow core, wood doors

Selection Criteria

The main qualities that we looked for in selecting doors were capacity to insulate (for exterior doors), cost, availability, ease of installation, and maintainability.

Table 14. Door costs

Category	*Cost*
Exterior doors	$ 366.00
Interior doors	$ 861.72*

** Includes a value of $455.00 assigned to salvaged doors and hardware.*

Exterior doors

Although wood is the standard material used for doors, its ability to resist heatflow (R-value) is low, and as a result, it is a poor insulator compared to other door materials. On the other hand, metal-clad insulated doors are inexpensive and provide better insulation. A solid wood door has an R-value of approximately R-2.5, while metal clad doors typically have values around R-7.5. Both wood and metal doors are easy to install and maintain. Thus, insulated metal-clad doors were installed and finished with two coats of enamel paint. We estimate that these doors cost about half of what the same-sized solid wood door cost. Sill seal and caulking were placed around the door frames to reduce air infiltration through gaps.

Interior doors

We used hollow-core, wooden doors for all the interior rooms, obtained free from a salvage and deconstruction effort of a house in Potomac, MD. Installing these salvaged doors required significant time and skill. Standard interior doors come pre-hung on a frame with pre-built molding attached. We spent two to three hours on each salvaged door, because we had to construct all of the interior frames and molding and install door casings, door stops, latch holes, etc. separately, which would come standard on pre-hung doors. The additional time and skill that this required leads us to recommend using standard interior doors.

EXTERIOR DOOR INSTALLED

Roofing

ROOFING AT A GLANCE

Important criteria
- Durability
- Cost
- Weight
- Recycled content
- Reflectivity (color)

Roofing materials considered
- New asphalt
- Salvaged asphalt
- Recycled aluminum
- Recycled steel
- Clay tile
- Fiber cement
- Concrete tile
- Slate

Selected roofing material
- 100% recycled aluminum shingles

Selection Criteria

Roofing provides an excellent opportunity to select alternative, environmentally-preferable materials while minimizing the homeowner's long-term maintenance burden and costs. Roofing components can be expensive to repair or replace. The roof also protects the other materials and systems in the house.

For the selection of an affordable, sustainable roofing system, our primary criteria were durability and reliability. We also considered compatibility with the roof framing system, enhanced cooling of the attic space by the incorporation of a ridge vent, materials with high heat reflectivity, materials with high recycled content, and potential recyclability of the roofing material.

Options Considered

We considered a wide range of roofing systems and products. In order of preference after aluminum roofing, these were recycled steel roofing, fiberglass, organic systems such as wood or paper, inorganic fiber, asphalt shingles from a nearby salvaged product warehouse, organic asphalt shingles (new, not salvaged) with high recycled content, and Ondura corrugated roofing (with high recycled content).

Recycled steel roofing is nearly as durable as aluminum but heavier and less rust resistant. Also, steel is likely to have less recycled content and is less likely to be recycled if removed. These products were deemed superior to fiberglass shingles, asphalt shingles, and corrugated roofing because of their higher durability. Also, corrugated roofing was not consistent with the Capitol Hill Historic District requirements. In future projects, we would reconsider all of these various products, depending upon site-specific criteria and product availability.

Although they offered very high performance and environmental friendliness, we rejected products such as slate, clay, cedar shakes, and composite cement due to their high cost. We also rejected composite cement roofing both because of its high cost and its potential to freeze and crack in the Washington, DC climate.

Selected Roofing: Recycled Aluminum Shingles

We selected a shingle made from 100-percent recycled aluminum produced by Zappone Manufacturing (Spokane, Washington). This product provides multiple benefits, including 100 percent recycled content and the light weight and durability of aluminum. Aluminium is very durable, commonly lasting more than 50 years, and requires little maintenance. A light-colored aluminum roof is highly reflective, which helps keep the house cool. In addition, aluminum has a very high value as a recyclable product, if later removed in deconstruction.

We used a darker shingle to match the surroundings of the neighborhood. The dark color also reduced the potential heat reflective properties of this product, but the low thermal mass of aluminum ensured that very little heat will re-radiate from the roof into the house. To maximize the reflective properties of aluminum shingles, a lighter color is preferred.

Despite the moderate purchase price and the steep learning curve associated with volunteer installation, we were encouraged by the positive review of this product by the Sacramento affiliate of Habitat for Humanity International.

Table 15. Roofing comparison

Roofing material	*Durability*	*Color*	*Recycled content*	*Cost*	*Weight*
Organic asphalt shingles	Medium-low	Light colors available	Potentially high	Low	Moderate
Recycled aluminum	High	Light colors available	100%	Moderate	Low
Recycled steel	Medium-high	Light colors available	Lower than aluminum	Moderate	Moderate
Clay tile	High	Mainly dark colors	None	High	Heavy
Fiber cement	Medium	Light colors available	Waste cellulose fibers may be used	Moderate	Heavy
Concrete tile	Medium	Light colors available	None	High	Heavy
Slate	Very high	No light colors available	None	High	Very heavy

Roof Vents

We incorporated soffit and ridge vents into the roof design, which provide continuous intake and outlet vents to form a fully ventilated cavity. The resulting air movement removes attic heat, reducing summer heat buildup and helping to prevent condensation on the attic side of the sheathing and within the insulation. As a result, energy costs are reduced and roof life is extended.

Our Experience With Aluminum Roofing Shingles

We used one half inch OSB sheathing covered with 15 pound roofing felt, and then installed the roofing shingles directly onto the sheathing. Though many problems were encountered during their installation, most were related to the use of unskilled volunteer labor.

One challenging feature of metal roofing shingles is their absolute regularity, which allows virtually no room for any installation error. During installation, some volunteers were not careful to maintain flush, parallel rows with their shingle placements. The minimal margin for error required more experienced volunteers to reinstall parts of the roof, creating significantly more work.

We also encountered difficulties in the roof valleys and roof trim points. It was necessary to bend the roofing material to fit it into valleys. However, the material is difficult to bend accurately into specific shapes and requires a crimping tool. Incorrectly bent pieces resulted in increased waste. (Note that the cost of wasted pieces can be offset by selling the material for recycling.) To better fit the neighborhood's style, the design of our roof incorporated more valleys than in standard Habitat for Humanity designs. Roof designs with minimal valleys may result in a greater ease of use of these shingles. In some locations, where sections of the roof had to be reinstalled, the underlaying tar paper was penetrated. There was some leakage in these areas, and the necessity of correction added to the cost and overall workload of the project.

In summary, the aluminum roof shingles clearly met our criteria of recycled content, durability, and recyclability. However, we encountered many problems during installation. We strongly recommend careful training of volunteers when using this product and experienced volunteers double checking installation throughout the process. We recommend choosing this product only for simple roof designs.

Mechanical System

MECHANICAL SYSTEM AT A GLANCE

Important considerations
- cost
- energy efficiency
- mechanical ventilation
- correct system sizing

Selected system
- Nutech Lifebreath air handler (uses hot water for source of heat)
- 80% efficient direct vent hot water heater
- 2.5 ton, SEER 12 air handler
- Equipment, ducts located in conditioned space in house

Heating and Ventilation

This house's mechanical system needed a hot air source (typically a furnace), an air conditioner, a ventilation system, and a hot water heater. With the special attention we gave to insulation, and our efforts to limit air infiltration (see the insulation and exterior wall sections), selecting the heating, ventilation, and air conditioning (HVAC) system required more attention than is typical in a more conventional house. In particular, our demonstration house required smaller (and less expensive) air conditioning and heating equipment, thanks to the reduced heating and cooling loads associated with our design. However, the home's airtightness also required supplemental ventilation to supply sufficient input and circulation of fresh air.

Table 16. Cost of the major mechanical equipment

Equipment	*Cost*
Nutech Lifebreath Air Handler	$ 1,100
PRV50-NBDS Water Heater	$ 449
Air Conditioner Compressor	$ 2,000

Mechanical ventilation

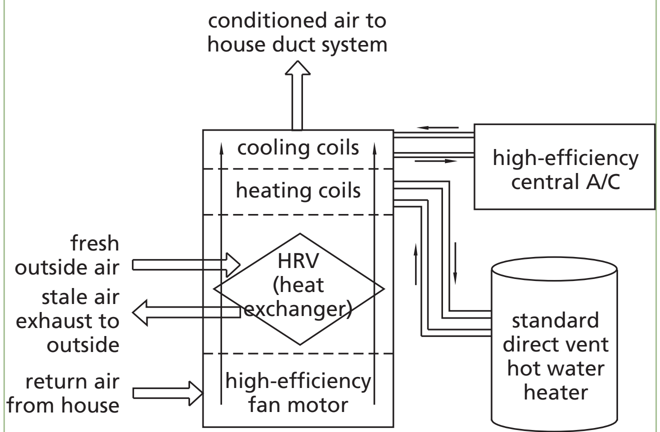
All homes require some ventilation to provide fresh air and to remove household pollutants, which may come from such sources as combustion appliances, pets, household cleansers, and aerosol sprays.

With traditional home construction, natural ventilation of fresh air is supplied through cracks and gaps in the building envelope. The amount of ventilation depends upon the outside wind speed and temperature, which can result in cold drafts in the winter and correspondingly high heating costs, as the mechanical system must heat all of the influx of cold air. Conversely, in the summer, the mechanical system must cool the infiltrating warm air. (See the Exterior Wall section for more details on why relying on ventilation through cracks in the house is not energy or cost efficient.)

In a tightly sealed house the builder must supply some type of mechanical ventilation system to continually clear the inside air. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) standard for natural infiltration (to avoid indoor air pollution) is 0.35 ACH; since the demonstration house has 0.16 ACH, the mechanical ventilation system must supply the 0.19 ACH difference in fresh outside air. Mechanical ventilation can also help control the indoor humidity levels.

We selected a mechanical ventilation system that included a heat recovery ventilation (HRV) system. This type of system has a built in heat exchanger that transfers heat during the winter from the stale exhaust air to the fresh air entering the house, and removes heat from incoming air during the summer. HRV systems typically can recover 60 to 75 percent of the heat from the exhaust air and transfer this energy to the incoming fresh air. This ensures that ventilation air is neither uncomfortably hot nor cold. HRV systems also typically filter dust and pollutants from the incoming air, and generally they are very quiet. We also installed localized exhaust fans above the kitchen stove and in the bathroom to remove pollutants and excess moisture.

Figure 10. Diagram of the mechanical system



Selected Heating and Ventilation System: Nutech Lifebreath Air Handler

We chose a Nutech Lifebreath air handler unit, which contains an integrated HRV system. This air handler heats the house by distributing ventilation air which is heated by being blown over coils heated with hot water piped from the hot water heater (see *Figure 10*). The greatest advantage of the Nutech system is that we were able to eliminate the furnace, which resulted in reduced costs, reduced system complexity and ductwork, and conserved space in the utility room. Additionally, during the winter, the system saves the standby energy that would have been wasted in heating water which may not be needed for use for hours or days. The elimination of the separate furnace can also improve indoor air quality, because more air particulates are created when dust particles fry in a normal furnace due to the very hot air.

The Lifebreath system has an integrated HRV unit that is 70 percent efficient in transferring heat from exhaust air to the incoming fresh air. The 60,000 BTU Lifebreath air handler that we installed is capable of providing ventilation airflow of 100 cubic feet per minute (CFM). We installed a conventional, high efficiency air conditioning unit for summer cooling, which connects directly into the Lifebreath system. The system has two fan speeds: a lower speed for continuous fresh air ventilation, and a higher speed for heating and cooling. A night setback thermostat automatically controls fan speed, heating, and cooling. The system is very quiet and is barely audible during operation in the low-speed ventilation mode. Ironically, the first system problem was noise from a loose screw in the housing, but this was fixed with ease.

More efficient alternatives than the Nutech Lifebreath air handler / hot water heater system exist. However, this home's low heating and cooling loads meant that other systems would not provide substantial energy savings, and the alternative equipment was far more costly. For example, our analysis (see Energy Analysis) predicted annual heating costs of $260. The additional 15 percent efficiency (as measured by the AFUE rating) provided by a higher efficiency furnace system would have saved only $39 per year but the purchase price would have been at least $600 more.

Hot water heater

We selected an 80 percent efficient direct vent hot water heater with a 50 gallon storage tank, powered by natural gas with an electric ignition (Model PRV50-NBDS). This appliance does not use a flue (chimney) but instead uses a triple-walled concentric "direct vent" pipe that passes through the exterior wall directly above the unit itself to serve both as an exhaust vent and as an intake of combustion air from outside the house. In a tightly sealed house, inside air is not advisable for combustion appliances because there is a danger of backdrafting. The hot water heater is no larger than typically required for a home of this size. Higher efficiency hot water heaters are available at about twice the cost, which was not warranted due to the small potential savings.

Equipment and duct-work placement

The utility room by the kitchen contains the hot water heater and the air handler so that both are located in a conditioned space and will have low heat losses to outside air. We ran all the ducts through the open web second floor joist system (which was specifically chosen for this purpose), so that all ducts are in a conditioned space, with no ducts in the crawl space or attic. As a result, any duct leaks will contribute to heating or cooling the house and will not be lost to outside air. Studies have shown that air leakage from poorly sealed ductwork in unconditioned spaces (attics or crawl spaces) can waste more than 30 percent of a home's heating and cooling energy. The duct placement in the second floor joists required shorter runs compared to routing the duct through the attic or crawl space, because very few vertical runs were required.

All duct joints were sealed with a special mastic to leakproof the joints. (Cloth duct tape and silver metal tape should never be used to seal ducts, as they have been shown to allow leaks to develop after several heating and cooling cycles.) Pipes into and out of the air handler were insulated with wrap-around foam.

Installation of the Lifebreath air handler
The subcontractors who installed this novel HVAC system were a little wary at first, since this was their first installation of this type of system. Initially, we lacked a system manual, requiring the installers to make educated guesses about system setup. After we received the manual, the installers had to modify several aspects of the installation. However, now that they have installed one of these systems, they believe that they could install this combined hot water heater-ventilation setup in a typical house with no more time or effort than a normal air handling system. Of course, it may be difficult to find HVAC installers who are as open to installing new system types as the company that we used.

Air Conditioning

Air conditioning is one of the largest single sources of home energy consumption in the United States, with residential air conditioners accounting for five percent of total electricity consumption. As such, selecting an energy-efficient air conditioning unit can have a large impact on limiting a home's energy consumption. Key features to consider include a fan-only option, a check-filter light, and an automatic delay switch for the fan (which keeps the fan on a few minutes longer than the compressor, and thus blows air over the already chilled coils). A related feature is a programmable thermostat that can automatically control the use of the air conditioner, turning it on at pre-set times during the day. Another key aspect is the size or cooling capacity of the unit. A common mistake is selecting an overly large unit.

An oversized air conditioner will short cycle (cycle on and off for short periods of time) even during extremely hot weather. Air conditioners are more efficient at cooling and dehumidification the longer they cycle. Short cycles result in cool, but humid air blowing into the house. Oversized air conditioners cost more, are less efficient due to short cycles, may be loud, and will result in cool but uncomfortably damp air, especially inappropriate for high humidity areas like Washington, DC.

When sizing an air conditioner, standard rules of thumb with respect to square footage estimates are not reliable because they fail to account for insulation levels, infiltration amounts, house layout, window type, window area, and window orientation. Instead, we advise using energy analysis software, Manual J from the Air Conditioning Contractors Association of America (ACCA), or similar methods that account for the unique features of a building's design.

The energy efficiency of central air conditioners is determined by dividing their cooling output by their power input, for a typical U.S. climate. This value is known as a Seasonal Energy Efficiency Ratio (SEER). Higher SEER numbers indicate higher efficiency units, because they indicate higher cooling outputs per unit of energy consumed. The national standard for central air conditioners is a SEER of 10. On average, using an air-conditioner with a SEER of 12 will save $50 annually compared to a unit with a SEER of 10. Typically, air conditioners with SEER ratings beyond 12 are expensive and may require substantially longer payback periods.

The low infiltration of this house technically allowed us to downsize the air conditioning unit by about 40 percent, from 2.5 to 1.5 tons. However, we did not have the flexibility to install such a smaller unit because our system was generously provided by Sears, which donated a 2.5 ton cooling capacity Kenmore Super High Efficiency 9000 (model #CA9026VKD2). Though the unit is oversized, the SEER rating is 12, making it more efficient than the standard models.

Appliances

APPLIANCES AT A GLANCE

Important considerations
- Cost
- Energy efficiency
- Ease of use features
- Correct sizing for homeowners

Selected appliances
- GE Potscrubber dishwasher
- Maytag 18.5 ft3, freezer-on-top, EnergyStar rated refrigerator
- GE gas range
- Front loading, EnergyStar rated Frigidaire clothes washer
- Gas powered Frigidaire clothes dryer with automatic shut-off

Selection Criteria

Our goals were to select appliances that were energy efficient, had all of the homeowner's desired features, were readily available at local appliance stores, and, most importantly, would save the homeowner money in the long term. We calculated the homeowner's savings by considering the cost of the appliances and their estimated annual energy costs. We found a large amount of detailed information on energy usage of the different appliance options. For example, the yellow EnergyGuide labels that are required on most appliances indicate the estimated annual energy usage. Other helpful resources include magazines like *Consumer Reports* and the EPA Energy Star website: *www.energystar.gov*. (See the Energy Star section for more details on this program and its rating methodology.) In addition, many utility companies provide technical and financial assistance for purchasing energy-efficient appliances.

Table 17. Costs of appliances

Item	*Cost*
Gas stove and oven	$ 500
Range hood	$ 31
Refrigerator	$ 850
Dishwasher	$ 300
Clothes washer	$ 700
Gas dryer	$ 328
TOTAL	**$ 2,709**

Dishwasher

The two major factors for evaluating dishwashers should be water use and energy use. Water use is determined by how much water is required per cycle. Energy use is affected by many variables: water use (typically, 80 percent of a dishwasher's energy consumption is used to heat water); use of a booster heater (which allows consumers to turn-down their home water heater to a lower temperature); and drying options (electric heat uses more energy than fan drying). Flexible wash cycles that vary the washing time can save both water and energy.

A private citizen kindly donated the dishwasher used in this house, a GE Potscrubber (model GSD2230Z0 1 WW). This unit has flexible wash cycles and an air-drying option which, when used consistently, can reduce water and energy use. While it does not qualify as an Energy Star model, the unit is rated as 11 percent more efficient than required by federal law per the National Appliance Energy Conservation Act (NAECA). At present, Energy Star qualifying dishwashers must surpass the NAECA standard by at least 13 percent. The 11 percent energy savings corresponds to 78.7 kilowatt-hours (kWh) savings per year for an annual savings of $7.87.

Refrigerator

Four factors affect refrigerator energy use: (1) size (with all features equal, energy use increases with size); (2) freezer placement (top-mounted freezers use considerably less energy; for example, an average 20 cubic foot model with freezer on-top uses 20 percent less energy than the same size side-by-side refrigerator); (3) defrost option (manual uses less energy than automatic); and (4) other added features, such as an automatic ice-maker (which increases energy use). In addition to affordability and homeowner expectations, we considered the energy efficiency of numerous models to determine the optimal balance of amenities, cost, and environmental benefits.

Table 18. Refrigerator comparison

Refrigerator	*Cost*	*Annual energy usage*	*Cost to own and operate*	
			For 10 years	*For 20 years*
Maytag MTB1956BE (used in this house)	$800	527 kWh/year	$1327	$1854
Typical freezer-on-top (White-Westinghouse MRT18PNE)	$600	697 kWh/year	$1297	$1994
Typical side-by-side (Whirlpool ED20TXFN)	$800	785 kWh/year	$1585	$2370

We selected a Maytag 18.5 cubic foot refrigerator (MTB1956BE), which is an Energy Star qualified unit. This refrigerator uses approximately 527 kWh per year (measured without the automatic icemaker). Other models of comparable size use as much as 705 kWh per year (the NAECA standard). This model will save approximately 25 percent in electricity over a similar standard refrigerator, without any sacrifice in performance.

We considered, but ruled out, a smaller model, which could have saved more energy but which would have inconvenienced the homeowner and her family, in part because a smaller unit would have required more frequent shopping trips. Similarly, we ruled out larger size units, which are generally much less energy-efficient. We did install an automatic icemaker, which slightly increases energy consumption, but was requested by the family.

With respect to life-cycle costs/savings, we compared this model to a typical freezer-on-top model and side-by-side refrigerator in the table above (which assumes electricity rates of $0.10/kWh.). Based on a 20-year life, the nominal (undiscounted for the time value of money) savings total $140 ($340 in energy savings minus $200 in additional up-front costs) versus the standard freezer on top model and $516 versus the side-by-side model.

Range

Stoves and ovens are not currently rated under the DOE/EPA Energy Star system. However, there are several key features that can be used to determine the relative energy efficiency of different options. Overall, gas-powered units are more efficient than electric units. A key feature of gas-powered units is an electronic pilotless ignition, which uses 30 percent less fuel than a pilot light that operates continuously. Notably, a gas oven with an electronic ignition is less than 50 percent as costly to operate than an electric unit. For electric stovetops (ranges), induction elements are the most energy efficient and use only half the energy of typical electric coil elements. However, these are currently very expensive and work only with non-aluminum cookware. To ensure good indoor air quality, gas ovens require the installation of an outdoor venting range hood and good indoor air circulation.

The typical annual energy cost of a gas-powered range with electronic ignition is $11, compared to $23 for its electric-powered counterpart. For a gas-powered oven, the annual costs are approximately $13, while the electric version costs $27. Thus, the total annual savings for using a gas oven and range versus an electric appliance are approximately $26.

Self-cleaning ovens generally have higher insulation levels than normal ovens, and so cost less to operate (sometimes up to 20 percent more energy-efficient). However, regular use of the self-cleaning option will ultimately cost more than is saved by the extra insulation, because the self-cleaning mode uses a large amount of energy to get the oven hot enough to clean off all surfaces.

A private citizen kindly donated a new gas range, a General Electric model GEXL44 (with electronic ignition) which met all of our requirements. We also installed an outdoor venting range hood.

Clothes Washer

In evaluating clothes washers, we considered the following: (1) capacity (a smaller unit requires more frequent use, while a larger capacity unit, *if used at full capacity*, will save energy and water); (2) water level controls (adjusting to meet load sizes will lower water use up to 50 percent as well as save energy when using heated water); (3) cold water rinse cycle (hot or even warm water is not always needed for washing and never for rinsing—this can save energy with every load, approximately 20 cents per load in Washington, DC); (4) high spin speed (spinning is much more energy efficient than air drying); and (5) horizontal axis operation, i.e., front loader, uses up to one-third less water than traditional vertical axis machines, and usually has faster spin cycles and greater capacity. Of these factors, the horizontal axis is most important, followed by water level control.

We selected a Frigidaire front loading clotheswasher, model FWT449GFS, which costs $700 (after $100 manufacturer's rebate). This is one of the most environmentally friendly units available and features all five of the options noted above. Estimated energy use is 275 kWh per year, versus 885 kWh per year for comparable vertical axis units, which typically cost around $360. The maximum water use for this model is 33 gallons per load, by contrast with 40 to 43 gallons for a typical top loading washer. Several energy companies and local governments offer incentives to buy front loading washers.

Take caution when comparing the yellow EnergyGuide labels on washers, as there is a different scale for front-loading and top-loading labels. As a result, direct comparisons may cause confusion. We recommend comparing the numbers for energy use when comparing front and top loading washers, rather than comparing the scale chart.

Table 19. Clothes washer comparison

Clothes washer model	*Cost*	*Annual energy cost*	*Total cost to own and operate for 10 years*
Typical top-loader	$360	$114	$1500
Frigidaire FWT449GFS (front loader)	$700	$51	$1210
Whirlpool LSW9245EQ (top loader)	$550	$54	$1090

We utilized the Energy Star washing machine comparison calculator (located at *www.energystar.gov/products/clotheswashers/calculator.phtml*) to evaluate the horizontal loading Frigidaire unit with a typical top loading washing machine. In addition, we also examined the energy use of the new Whirlpool Resource Saver washer, which is the first Energy Star qualified top loading washer. (This washer was not available when we selected our unit.)
We employed an electricity rate of 10¢ per kWh, the local water rate of 0.5468¢ per gallon, and an estimated five loads per week. The results are summarized in the below table. The annual energy cost includes electricity and water costs, and the total 10-year cost adds the price of the washer to the operating cost over a decade. *Table 19* shows that both Energy Star washers save considerable money (at least $290) during a decade of use.

Clothes Dryer

We considered three key energy efficiency features when evaluating a clothes dryer: (1) type of automatic shut-off; (2) gas versus electric operation; and (3) cool-down/fluff cycle (which reduces the need for ironing and hence reduces energy use). Unlike most other residential appliances, different models of dryers showed little variation in energy use.

The automatic shutoff feature is the most important feature for energy efficiency. Dryers now are required to have at least one cycle that will automatically shut off once the machine detects that the clothes are dry. The more traditional dryers measure exhaust air temperature air to gauge clothes' dryness. Recently several manufacturers have introduced dryers which actually measure the residual moisture in the clothes, which provides more accurate readings and can save considerable energy (as well as extend clothing lifetime by avoiding excessive drying). Dryers with moisture sensors typically are at least $150 more expensive than the more conventional thermostat controlled dryers.

Another important factor is the energy source (electricity or natural gas) used in operating a dryer. Natural gas generally is less polluting, with the exception (rarely available) of electricity generated from renewable sources such as wind or sun. Gas dryers typically cost $30 to $50 more than electric dryers. However, gas dryers cost about $0.15 to $0.25 to run per load, while electric dryers cost about $0.30 to $0.40 per load. Thus, gas dryers actually are the cheaper long term alternative. For example, after 250 cycles, the total costs (initial purchase cost plus operating costs) of electric and gas dryers nearly equivalent, while after 500 cycles gas dryers save approximately $50 over electric units. Using a clothesline (a so-called solar clothes dryer), either inside or outside, obviously is the most environmentally sound option.

We selected a Frigidaire clothes dryer, model FDG546RES. This unit is gas-powered, has an automatic shut-off and uses an exhaust sensor and a cool-down cycle. No affordable dryers with moisture sensors were readily available when we purchased this appliance, although now they may be more widely available. In addition, the homeowner is considering using a clothesline during the summer.

Lighting

LIGHTING AT A GLANCE

Important criteria
- Life-cycle costs
- Energy efficiency

Selected lighting
- General indoors: Dedicated 13-watt compact fluorescents
- Kitchen: T-8 linear fluorescent tube
- Outdoors: Incandescents (with motion sensors and photocells)

Indoor Lighting

Two main options exist for indoor lighting: incandescent and compact fluorescent. Incandescent lighting is the traditional form of lighting, which is very inefficient since only 10 percent of the electricity used contributes to producing light and the remainder is converted into heat. This has the effect of raising air conditioning needs in the summer and heating up the house inefficiently during the winter. On the other hand, compact fluorescent lighting (CFL), a miniature version of the standard overhead fluorescent light, uses ¼ to ⅓ as much electricity as incandescent lighting and lasts up to nine times longer. In most cases, the light from these fluorescents is comparable in quality to the conventional incandescents.

Table 20. Costs of indoor lighting

Type	*# purchased*	*Total cost*
Compact fluorescent fixtures	7	$150
Linear fluorescent fixture	1	$70
13 watt, compact fluorescent bulbs	20	$80
T-8 linear fluorescent tube	1	$10

** All lighting was purchased from EnergyWise Lighting for a reduced cost*

Table 21. Incandescent vs. compact fluorescents

Bulb Type	*Initial cost*	*Rated life (hours)*	*Lumens (light output)*	*Cost to run for 5 years**	*Bulbs needed per 5 years*
60 watt incandescent	$0.77	1000	870	$45	9
13 watt CFL	$13	9000	720	$22	1

** Based on lights burning for five hours per day, includes electricity costs and purchase price of bulbs*

Table 22. Comparison of halogen and fluorescent torchieres

Torchiere type	*Purchase price*	*Annual energy cost*	*Operating cost for five years*
Halogen	$20	$35	$195
Fluorescent	At least $40	$7	$75

While the CFL bulbs cost more to buy, they quickly become cost-effective by saved electricity costs and longer lifetimes (see *Table 21*). In addition, using CFLs result in less landfill waste as each bulb lasts for the equivalent of nine incandescent bulb lifetimes. Based on these facts, 13-watt compact fluorescent twin tube lighting was installed in every room in the house except for the kitchen. We selected dedicated fluorescent fixtures, which will accept only CFLs and will not allow the homeowner to install incandescent bulbs. The table below compares CFL and incandescent bulbs with similar light outputs.

Compact fluorescents usually are rated to last approximately 10,000 hours, at three hours per start. Due to the comparatively higher energy expenditure when turning on a fluorescent light, incandescent bulbs should be selected in situations where lights will be turned on for short periods of time, such as closet lights and outdoor floodlights operating on sensors.

We installed a T-8 (the 8 refers to the diameter of the tube in 1/8 inch increments) linear fluorescent lamp in the kitchen instead of the standard T-12 lamp. The T-8 renders better color than the T-12, uses approximately 30 percent less energy for the same output, loses less light as it ages, and only costs a few dollars more than a T-12 bulb. The ballast that is used to power the T-8 is electronic, starts the lamp instantly, and has no flicker or hum. Both of these fluorescent types are rated to last 20,000 hours at three hours per start, which is 20 times the life of an incandescent.

Outdoor Lighting

To provide adequate lighting outdoors we installed incandescent lights in the front, back, and west side of the house. The side and back lamps are attached to motion sensors and photocells, which results in lower energy use (since they are turned on only at night when detecting motion) and a safer environment for the owner. We selected incandescent bulbs for these lights since the lights potentially will be turned on and off frequently by the motion detectors.

A Note on Halogen Torchieres

Halogen torchieres have become popular as an inexpensive method to light homes. However, these lamps are fire hazards and are extremely energy inefficient as a result of the intense and concentrated wasted heat they generate. Several compact fluorescent torchieres recently have been introduced which are much more efficient that their halogen counterparts. We highly recommend choosing fluorescents over halogen lamps.

Paint

PAINT AT A GLANCE

Important criteria
- VOC content
- Durability
- Cost

Selected paints
- Interior: Glidden Spred 2000, a non-VOC paint
- Exterior: Benjamin Moore latex primer and paint

Selection Criteria

Conventional paints contain a variety of chemicals that adversely affect both human health and the environment. Chief among these chemicals are volatile organic compounds (VOCs) such as solvents and other additives, which readily evaporate at room temperatures and are inhaled during paint application and drying. VOCs contribute to indoor air pollution and can induce headaches, nausea and respiratory problems. In addition, VOCs contribute to the formation of ground-level ozone. Oil-based paints tend to have a larger VOC content and lower recyclability than water-based (latex) formulations. Conventional latex paint contains seven to nine percent petroleum-based solvents, while oil-based paints contain 50 percent solvents and are considered to be household hazardous waste.

Paint and coatings manufacturers have been increasingly responsive both to stricter emission regulations and consumer demand for safer, user-friendly products. A number of options were available for interior and exterior paint that would fulfill our low-VOC formulation paint requirement. Glidden donated some of its Spred 2000 paint, which we used for the interior of the home. Introduced in 1994, this paint was the first non-VOC paint on the market, contains no organic solvents, and is available in flat and semi-gloss interior formulations. However, this paint is available only in a limited number of pre-mixed white and off-white colors. Tints may be added to achieve darker colors but these contain VOCs. Non-VOC tint base paints are not yet available.

Table 23. Paint costs

Category	*Cost*
Exterior paint	$1,437
Interior paint	$1,004

Table 24. Interior paint

Paint type	*Solvent content*	*Price*
Typical latex	7%–9%	$15–25
Glidden Spred 2000 (flat or semi-gloss)	0% (not including tint)	$21

Some published tests suggest that the Spred 2000 paint is comparable in quality to most flat latex paints, in terms of hiding power, whiteness, and spatter resistance. However, the paint performed poorly in a scrub resistance test, which involves the use of a highly abrasive brush on the paint. The Spred 2000 paint did perform well against washing as opposed to the heavy scrubbing.

Our volunteer painters reported that the major difference in using the non-VOC paint was the absence of the normal paint smell. In addition, the paint seemed to dry faster than regular paints, cleaned up easily with water, and appeared to cover well in one coat.

An increasing number of manufacturers offer paints with low-VOC or no-VOC formulations, including Duron, AFM, and NonToxiCA. Consumers are advised to check locally for the availability of these and other comparable products. Other environmentally-friendly alternatives include casein (or milk-based) paints and the “natural” paints made in Germany (one brand available in the United States is Auro). Because these latter options are relatively costly and can be somewhat more difficult to use, they were not considered appropriate for an affordable housing project.

The Hardi-Plank siding was primed with Benjamin Moore Fresh Start latex exterior primer, then painted with Benjamin Moore Life Exterior Latex. These paints were not selected for any environmental consideration, but were selected because these were among the few paints that would preserve the siding manufacturer's guarantee. For exterior paints, the level of VOCs is not considered to be as important a consideration, because the solvents will not be evaporating into an enclosed space. However, paints with higher levels of VOCs will contribute to ozone smog generation, and thus may affect our future evaluations in the potential use of Hardi-Plank. We primed both sides of the Hardi-Plank before applying the paint to control moisture absorption into the siding. Where the initial paint layer could be scratched or damaged (approximately 20 percent of the surface area), we applied two coats.

VOLUNTEER PAINTING HOUSE INTERIOR

Flooring

FLOORING AT A GLANCE

Important criteria
- Effect on indoor air quality
- Resource efficiency of the source materials
- End of life recyclability and reuse options
- Cost
- Ease of maintenance
- Durability

Flooring options considered
- General spaces: new wood, salvaged wood, vinyl
- Kitchen: natural linoleum, vinyl
- Bathroom: standard tiles, tiles with recycled content

Selected flooring
- General: salvaged wood floors
- Kitchen: natural linoleum
- Bathroom: tiles with recycled content

Selection Criteria

The house's design called for three types of floors: (1) the general living spaces (including bedrooms and living room); (2) the kitchen and utility room; and (3) the bathroom. The wide variety of different types of flooring and products available provided an ideal opportunity to maximize the use of recycled and environmentally-friendly materials.

Our flooring material selection criteria included: the resource efficiency of the source materials, the impact on indoor air quality of the flooring and any installation or finishing materials, the options for disposal, recycling or reuse of the material selected, and cost. Ease of maintenance and durability were also important factors in flooring selection.

Table 25. Flooring costs

Category	*Cost*
Hardwood	$5,399*
Tile	$1,550
Linoleum	$781

** Includes a value of $1,191 assigned to salvaged wood flooring.*

Table 26. Flooring comparison for general living spaces

Flooring type	*Cost*	*Durability*	*Volunteer friendliness*	*Recycled content*	*Environmental Impact*
New wood	Expensive	Lasts the lifetime of the house	Difficult, requires expert	None	Destruction of trees
Salvaged wood	Moderate	Lasts the lifetime of the house	Difficult, requires expert	100%	No significant impact
Carpet	Moderate, depending on the quality and fiber type.	Usually 15–20 years	Moderate–difficult	Usually minimal	Offgassing from the latex or PVC backing

General Living Spaces

Tongue and groove heart pine flooring salvaged from a local residential deconstruction project was used for all general living spaces. (Refer to the Deconstruction section). Wood flooring provides an extremely durable, hard wearing floor surface and is more aesthetically pleasing than most other flooring options. Wood flooring is manufactured from a natural and renewable resource, and is significantly less energy-intensive or polluting to produce than products of the petroleum industry. The drawbacks involved in using a wood flooring system are the increased expense and the labor intensive installation.

We achieved significant cost savings by using salvaged wood flooring. Salvaged wood flooring also has the advantages of not using additional living trees, not contributing to existing landfills, and, since it was obtained locally, minimizing the energy used for transportation. (We estimate that this salvaged wood floor has a value of $3,510.) Our only expense was paying a contractor to install the floor. The hardwood floor was finished using a locally purchased water based polyurethane (Aqua Zar). The use of a water-based acrylic has the benefit of drying faster and greatly reduces the level of released toxic fumes.

We also considered a synthetic fiber carpet for the general living space, since it is typically used in homes built by the local affiliate of Habitat for Humanity International. In general, carpet manufacturing is highly energy intensive and utilizes non-renewable fossil fuels. Carpet also can be a major source of indoor air quality problems due to offgassing of its component materials and by acting as a sink, absorbing various pollutants, which can often be a source of allergens. Depending upon the quality, carpet has a relatively short useful life, and contributes to landfill problems when disposed. The carpet manufacturing industry has begun to address these issues and better choices are becoming available, such as a polyester carpet made from recycled plastic (PET). This would make a suitable choice in the absence of a recycled or salvaged wood floor. However, we recommend searching for suitable deconstruction projects to supply salvaged wood flooring.

Our Experience With Salvaged Wood Flooring

Collecting the wood floor was a labor intensive process that was carried out exclusively with volunteer labor. It involved salvaging the floor at the deconstruction site and denailing and cleaning each piece of wood. No part of this project posed a problem for an unskilled volunteer work force, and therefore it is ideally suited to a Habitat for Humanity or other volunteer project. The major challenge encountered with this deconstruction project was the storage required for the floor during the time between collection and installation. The need to store the floor created extra work transporting the wood between the salvage site, the storage facility, and the building site.

Proper installation of salvaged hardwood flooring requires a highly skilled craftsman, and therefore we used a contractor to install the wood floor. The floor was installed directly onto the subfloor, which was first covered with a layer of tar paper. The contractor reported no major problems with the installation of the floor and commented that it was no more difficult than using new materials. One minor problem encountered was that some of the board grooves required cleaning out so that the tongue of the adjacent board would fit correctly. This problem could be easily overcome by paying more attention to the cleaning of the floor during the salvaging process.

SALVAGED WOOD FLOORING (BEFORE)

SALVAGED WOOD FLOORING (AFTER)

Overall, the use of a salvaged material has resulted in an aesthetically pleasing, hard wearing, and cost effective floor covering throughout the general living spaces of the house. We would highly recommend this approach in the construction of an affordable, environmentally sustainable house.

Kitchen and Utility Room Flooring

We selected natural linoleum as the floor covering for the kitchen and utility room. Linoleum is non-toxic and made primarily from plentiful and renewable materials such as linseed oil, cork dust, sawdust, pine resins, limestone, and jute. Therefore, linoleum is also readily biodegradable and extremely durable. Linoleum continues to get stronger over time and has an expected life span of 30-40 years. Natural linoleum is a low maintenance product and does not require regular waxing. Drawbacks of linoleum include a relatively high amount of embodied energy and the production of volatile organic compounds during its manufacture and as it ages. Linoleum produces more VOCs as it ages than vinyl flooring—the chemicals produced are not harmful, but can have a strong smell. Linoleum is more costly in comparison to most sheet vinyl flooring and is imported from Europe. (At the time of this writing, linoleum was not being manufactured in the USA.) The adhesive used for the installation of the linoleum flooring was a non-toxic, low VOC, water based adhesive that contains rubber. This adhesive is different from those used for vinyl flooring, which generally do not bond well to linoleum.

The main alternative to linoleum that we considered was sheet vinyl flooring. Vinyl was rejected as a flooring option since it contains petroleum based products, plasticizers and chlorine based chemicals. Also, the manufacturing of vinyl flooring contributes to air pollution.

The cost of two millimeter thick residential linoleum flooring is $2 per square foot installed. This is only slightly more expensive than vinyl products, which cost approximately $1.50 per square foot installed, making linoleum a financially viable option. The linoleum and adhesives used were supplied free of charge by a local Forbo representative.

Table 27. Flooring comparison for kitchen and utility room

Flooring type	*Cost*	*Durability/ Maintenance*	*Embodied energy*	*Installation*	*Environmental impact (production)*	*Indoor air quality effect*
Linoleum	High	High durability (lifetime of 30-40 years). Very low maintenance.	Moderate	Moderate	Made from all natural materials and other than the acrylic topcoat linoleum is biodegradable.	Offgassing of VOCs as the linseed oil oxidizes.
Vinyl Flooring	Moderate	Moderate to high depending on quality. Lower quality vinyl requires regular waxing treatment.	High	Easy	Has many chlorine based organic compounds and contains plasticizers. Difficult to dispose of.	Offgassing as material ages, but not as high as linoleum.

Table 28. Flooring comparison for bathroom

Tile type	*Cost*	*Recycled content*	*Ease of installation*
Terra Green Ceramic	Medium (comparable to impervious standard tiles)	77%	Medium
Summitville	Medium (comparable to impervious standard tiles)	90%	Medium
Standard Tiles	Low (though higher quality can be expensive)	No recycled content	Medium

Before installing the linoleum, volunteers used a patch compound to fill all holes and fix some uneven edges in the subfloor to ensure an even surface. We also leveled bumps and high spots to prevent imperfections in the subflooring from eventually showing through to the surface and to the linoleum.

Two different approaches were tested when the linoleum was installed. The first was to lay the linoleum over the surface to be covered, and then to cut the flooring in place. The alternative, and clearly superior method in our case, was to prepare a paper template of the area to be covered, and to use this template to cut the linoleum.

Linoleum is more brittle than standard vinyl flooring (due to the lack of plasticizing compounds), and the brittle nature of the linoleum made it more difficult to cut in place, especially for unskilled volunteers.

We would recommend taking the time to prepare a paper template of the area to be covered, which makes the job of cutting the material easier and results in a more accurate cut. Overall, the installation of linoleum was not intrinsically different from the process of installing vinyl flooring, and therefore, linoleum can be a viable alternative to vinyl flooring in any construction project which relies on volunteer labor.

Bathroom Flooring

The bathroom floor and tub surround were covered with ceramic tiles made from 55 percent post-consumer and 22 percent post-industrial glass. Terra Green Ceramics incorporate post-consumer recycled material (glass) in their tiles, with recycled windshield glass being one of the major recycled materials. Post-consumer waste is more difficult to incorporate into new products, so maximizing its use is important in any product made from recycled materials. The Terra Green tiles have comparable costs to other quality tiles, but they are more expensive than standard tiles. GreenHOME received a reduced price on Terra Green Ceramic products from their DC/Baltimore supplier (RE-Creative, DC/Baltimore). A water based, thin-set mortar, as recommended by the supplier, was used to set the tiles.

We also considered a tile manufactured by Summitville, which uses a high percentage of post-industrial waste. Ninety percent of the raw materials used in their manufacturing process consists of tailings from feldspar mining. Other tile manufacturers were considered, but were rejected because their tiles contain only small amounts of post-industrial waste, rather than the combination of post-industrial and post-consumer waste.

The subfloor was reinforced with 3/16 inch Condura fiberglass mesh reinforced cement sheeting, which was recommended by the tile manufacturers. We applied a standard grouting, as recommended by the manufacturer.

The Terra Green tiles were more difficult to cut than standard tiles. Each tile needed to be scored multiple times before breaking and even then they did not always break along a straight edge. This difficulty of cutting the tiles resulted in a higher quantity of waste than otherwise might be expected, adding to the cost of a product that already is more expensive than standard tiles. Other than the difficulties encountered in cutting, the installation does not differ from any other tile product. More effort is needed to minimize waste when using this product, but due to the high recycled glass content we would recommend these tiles for future projects.

Landscaping

LANDSCAPING AT A GLANCE

Important considerations
- Use indigenous plants
- Use plants which provide habitat to urban wildlife
- Maximize permeable surfaces
- Minimize cost
- Maximize use of salvaged and recycled materials

Selected landscaping
- Indigenous plants
- Salvaged bricks to define planting beds and in driveway
- Concrete parking pad
- Trees planted to eventually shade house in summer
- Salvaged flagstone walkway
- Mortar-free Keystone retaining wall
- Privacy fences

Selection Criteria

We created a landscape design which incorporated sustainable design concepts, such as recycling, efficient energy use, local materials, and low costs, and combined these with concepts generally associated with the outdoor environment. The overall design is shown in *Figure 11*. Our landscape standards include:

- The use of native plants that are indigenous to the area and that require less irrigation and fertilization.
- The planting of species which would provide habitat, shelter, moisture, and food to urban wildlife.
- Where possible, the use of permeable surfaces, which allow water to soak into the ground and reduce urban runoff which flows to local rivers and lakes.

Table 29. Landscaping costs

Category	*Cost*
Stormwater/drainage	$108
Retaining wall (donated)	$1,160
Sidewalks and brick driveway (brick/flagstone donated)	$585
Trees/plants/shrubs (some donated)	$769
Side and back wood fences	$985
Wrought iron fence	$1,480
TOTAL	$5086

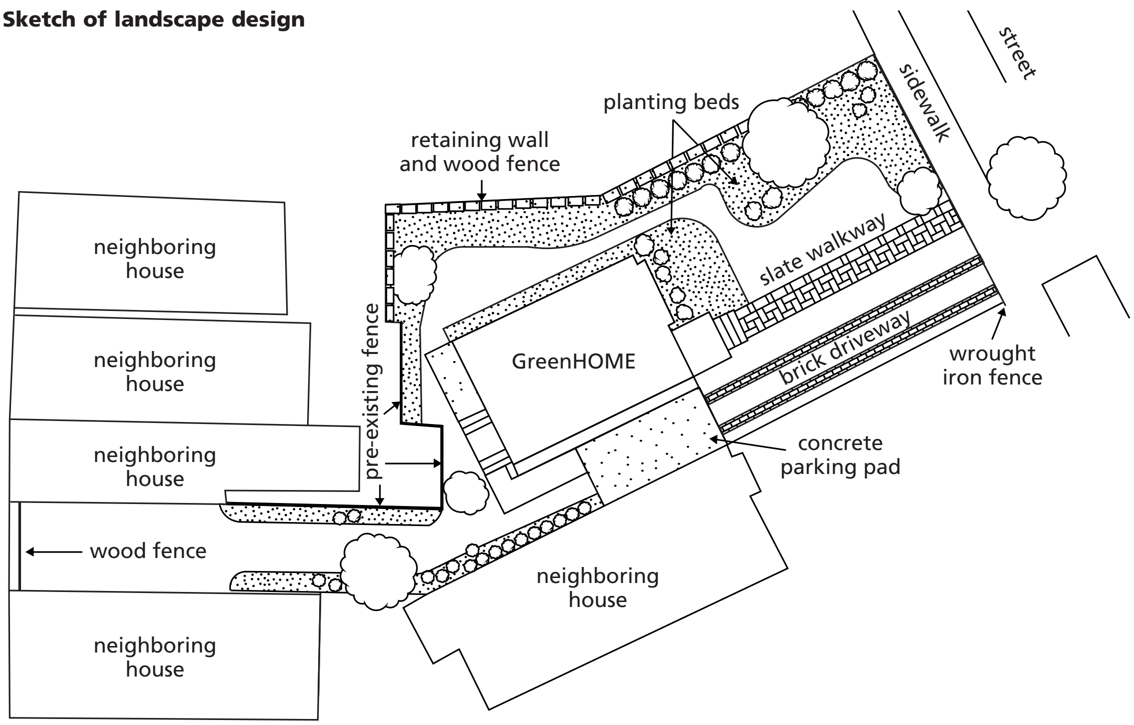
EDAW, an internationally renowned sustainable landscape design firm, served as a member of GreenHOME's Advisory Board and contributed countless volunteer hours to the planning, design, and installation of the grading and landscaping of the yard. EDAW was also instrumental in coordinating with our partner organizations, the National Wildlife Federation (NWF) and the Alliance for the Chesapeake Bay (ACB) to develop a landscaping design which utilized recycled materials, native plants, and permeable surfaces. The homeowner, community members, GreenHOME volunteers, and DC Habitat for Humanity homeowner candidates all participated in a day-long landscape design charrette which produced five different landscaping plans. These plans focused on types of plants—evergreen shrubs, flowering shrubs, and shade trees—rather than selecting specific plants. We then worked with the homeowner to create a final landscaping plan which combined her favorite parts of the several original plans. Once the design was completed, NWF and ACB worked together to establish the final list of native plants. From this list, we selected plants that fit the desired plant type, and applied them to the design. Finally, ACB contacted nurseries to secure donations or discounts, and collected the plants. Some of the plant selections had to be changed due to lack of availability.

Plants

All of the plants used at GreenHOME's first demonstration house are indigenous to the area and provide habitat, shelter, or food to urban wildlife in the area. Most of the plants were donated by nurseries and were very young. After an initial period, these plants will not require the irrigation, fertilization, or pesticides that many exotic plants require. We used salvaged bricks that were broken up by volunteers to line the planting bed areas, which were designed to create habitat for urban wildlife and respond to microclimate conditions surrounding the house. The yard includes both planting beds and seeded grass areas. During the design process, we emphasized the need to reduce grass areas in order to limit maintenance and grass care. However, the homeowner requested some grass areas in which her son could play.

We began the plant selection process by developing a list of perennials, trees, and shrubs that are native to Washington, DC. Native plants were chosen since they are adapted to local conditions, require little watering and maintenance, and provide the best habitat value for local birds, butterflies, and other wildlife.

Figure 11. Sketch of landscape design



Because of the owner's interest in a low maintenance landscape, the landscape includes numerous easy-care shrubs that will provide food and cover for wildlife, especially resident and migratory birds. For example, chokeberry, bayberry, and winterberry will provide berries for birds at various times of the year.

We chose perennials that provide nectar and seeds, and then planted these densely in order to crowd out unwanted weeds and provide cover for ground foraging birds. Examples of these perennials include: bee balm (monarda didyma), which is an excellent nectar source for the ruby-throated hummingbird, and purple coneflower (echinacea pupurea) and blazing star (liatris), both of which provide nectar to butterflies and seeds to birds, such as the goldfinch. We planted butterfly weed (asclepias tuberosa) to provide a food source for monarch caterpillars.

We also included a birdbath to act as a water supply for birds and wildlife, in order to supplement the habitat values of the plants. A small birdfeeder was also installed.

Trees and Shading

There were several existing trees on the lot before the house was built. Some of these trees were invasive species growing along the foundation of the neighboring houses or along the fence lines. None were located in areas that would benefit the energy efficiency of the house; however, some did have habitat and aesthetic value. Several of these trees were removed from the site.

During the site analysis, we analyzed the orientation of the house, and determined which parts of the house would be exposed to northern winds and to summer sun. To increase the energy efficiency of a house, deciduous shade trees should be planted to the south (in this case, the front) to reduce summer heat with their shade, and to warm the house in the winter with the sunlight which passes through their bare branches. Wind breaks, such as hedges, should be planted to the north and east of the house to reduce cold winter winds.

The house site was irregularly shaped and bordered on a series of row houses to the north and west. These houses protect the site from severe winter winds, but also cast shade on areas behind the house that would be better open to the sun. The southern side of the house contained one street tree, but no trees on the parcel. We planted two major trees in the landscape (although they will not immediately improve the energy efficiency of the house until they grow larger). The first we planted approximately 20 feet to the south of the house. Volunteers planted the second tree approximately 15 feet to the east of the house to help break the northeastern winter winds and provide visual screening from the neighboring houses to the northeast.

Soil

The soil on the house site is typical of urban soil. Over the years, it has been compacted, dug up, compacted again, and had trash and other wastes dumped on it. During the site clean up and construction process, volunteers found numerous items typically associated with urban soil, such as old bricks, construction materials, litter, and discarded drug paraphernalia.

We dealt with our urban soil by adding composted leaf material to the planting beds to enrich it with organic material, and tilling and raking almost the entire yard to help aerate it. We augmented the soil in areas slated for grass with a trailer load of steaming compost, comprised entirely of recycled materials: ground-up wood, restaurant vegetable waste, and horse manure from a local race track.

We tested for lead contamination by taking soil samples in five places in the yard where a child might be exposed to soil while playing. All of the samples tested positive for lead; however, only two were considered dangerous for exposure. These two areas were heavily planted with shrubs to discourage people from walking through them. Lead soil contamination is very common in urban areas throughout the country; it is often impossible to remove or mitigate the contaminated soils. Often, the best solution is to reduce access to the area and to educate homeowners, parents, and children on ways to reduce lead exposure, such as washing hands and toys and taking off shoes before entering the house.

Walks and Driveway

We used flagstones (slate) obtained from the deconstruction of a house in Maryland to create the main walkway from the front sidewalk to the front steps of the house. The flagstones were laid on a bed of packed sand. The back walkway from the driveway to the backdoor is a salvaged brick sidewalk, which is similarly laid on a bed of packed sand. The setting of these walkways in sand, rather than mortar, enables water to drain off of the stones through the sand directly into the ground where it can recharge the soils. Our volunteers found that it was difficult to lay the flagstones level, due to old mortar on the bottoms of the stones. They also had trouble placing the salvaged bricks in consistent patterns, due to their irregular sizes.

The driveway is made up of two parts: a concrete pad for parking and two brick tracks leading from the street to the parking pad. Although the concrete pad is impervious, it contributes to the outdoor living space of the house because it is located in a spot that can be used as a patio and possibly as a basketball court. In order to limit the amount of impervious surface, the two brick treads were laid on a deep bed of sand. A mesh fabric was placed beneath the bricks to prevent weed growth. Therefore, a car can access the parking pad on a hard surface while the driveway is only a minimal element in the front yard. We had to remove an older, cracked concrete parking pad, which we broke up and re-used as backfill behind the retaining wall, and also to anchor fence posts.

Drainage and Retaining Wall

Early in the landscaping process, we established a high point on the property to the northwest of the house, and drove in a stake at this location. Volunteers then placed strings to set up the proper gradient in each direction, and sloped all of the land away from this high point. We also sloped the soil slightly away from the house, so that water would always flow toward the street, either in front or in back of the house. Slight channels were created to properly guide any runoff water. We used the strings as a guide when pouring the concrete parking pad.

SIDEYARD LANDSCAPE DESIGN

We connected the downspouts from the roof gutters into a four inch drain pipe that drained to an underground dry well in the front of the property, which we created by digging a large hole, and then filling it with loose rock. We decided that it was unnecessary to install an exterior perimeter drain around the foundation, because all of the water from the gutters was directed into the dry well, and we did not have a basement to worry about flooding.

Volunteers installed a retaining wall along the eastern property line to prevent water from running onto our lot from the steep gradient of the neighboring vacant lot. We dug trenches, leveled them, then placed sand and bricks. We had to repeat this process a few times because of the learning curve for volunteers to get the bricks to lie flat and create a straight enough trench. We then placed a mortar-free, keystone interlocking block wall, donated by Betco, Inc. of Bethesda, Maryland, consisting of approximately 90 blocks (weighing nearly 100 pounds each) and 25 cap pieces. We used recycled slag, bricks broken up by volunteers, and small stones to backfill behind the retaining wall.

DECONSTRUCTION, SALVAGE AND REUSE

Salvaging involves removing materials of value from a building prior to its demolition. Deconstruction is a more comprehensive form of salvaging materials from a building, which involves taking part or all of a building apart in the reverse order from which it was put together in order to try and reclaim more materials. Both salvaging and deconstruction require a substantial amount of labor, technical expertise, and storage area until the materials are needed. However, for organizations like GreenHOME and DC Habitat for Humanity with a large volunteer workforce, salvaging and deconstruction present an opportunity to obtain quality construction materials for free, while reducing the volume of demolition waste that will be hauled to a landfill.

Reusing existing materials instead of buying new materials generally is more environmentally desirable, except when the material has associated low energy efficiency or contains toxic or otherwise hazardous ingredients. An example of items which may not be desirable for reuse include older, higher-flow toilets which can use up to 4.5 more gallons per flush than the newer, low-flow toilets. Use of old and leaky single-pane windows may result in much higher heating or cooling energy costs compared to using newer and more energy-efficient double-pane windows. Thus, evaluating whether or not to reuse a particular material takes forethought to weigh the environmental, economic, and logistical (storage and installation) costs and benefits.

Timing is one of the greatest challenges to salvage or deconstruction. Often, bad planning or developer inflexibility allows only a small window of opportunity to deconstruct or salvage materials from a building slated for demolition. This leaves little time to mobilize the resources needed to perform the job and identify adequate storage space if it is not readily available. The rest of this section will discuss our experience with salvage and deconstruction. Other, more detailed reports have been written on this subject, some of which are listed in the references section beginning on page 72.

Our Deconstruction Experiences

We undertook deconstruction and salvage activities at various points over a two-year period prior to construction for the purpose of reclaiming and reusing materials. These activities resulted in the reuse of many building materials and fixtures which otherwise would had to have been purchased new. These captured materials would have otherwise been landfilled.

GreenHOME volunteers deconstructed four houses in the Washington, DC area, and one bathroom which was being gutted and renovated. We estimate that we saved $7,865 from the materials that we salvaged and used on the house, even after accounting for our costs to transport these materials.

Table 30. Value of salvaged materials

Material	*Estimated value*
Heart pine wood flooring	$ 3,510
Kitchen cabinets	$ 2,000
Bricks	$ 1,250
Interior doors and hardware	$ 455
Flagstones	$ 200
Bathtub	$ 200
Lathing/furring strips	$ 160
Dimensional lumber	$ 90
TOTAL	**$ 7,865**

VOLUNTEERS DECONSTRUCTING A HOUSE

We found that the owners of the deconstructed buildings also benefited from the process. They avoided having to pay some of the costs that would have been associated with demolition and saved a substantial portion of the costs that would have resulted from material disposal.

Free volunteer labor and storage facilitated the deconstruction and salvage activities undertaken by GreenHOME. All materials salvaged prior to construction were transported to and stored on a farm near Annapolis, MD, 20 miles from Washington, DC. The environmental impacts of transporting these materials was minimal compared to the impacts of transportation that would have been required to dispose of the materials plus the transportation required for the delivery of new materials.

We salvaged a few thousand bricks from the houses, and found many uses for them in our construction and landscaping. Most were used as brick facing around the base of the foundation and for the front porch. We also used whole bricks in the construction of the driveway and back walkway. We found innovative applications for broken bricks: some were used to create planting beds, while other brick pieces were broken up into smaller, gravel-sized pieces and used to fill a dry well constructed near the front of the yard, and as backfill for the retaining wall. (Refer to the Landscaping section for more details on our use of these salvaged bricks.)

CORNER DETAIL OF SALVAGED BRICK

We used some of the structural lumber from one deconstruction site in all of the non-plumbing interior walls. Additional salvaged lumber we used for blocking, sheetrock "Ts" used during installation, temporary ramp construction, and bracing. We reused lathing as shims and furring strips under the siding, which allowed for air circulation between the siding and the exterior wall.

A sink, toilet, and tub were diverted from the landfill and donated to GreenHOME during a bathroom renovation job. Only the tub ended up being used in the demonstration house as the toilet cracked from freezing water during its outdoor storage prior to construction, and the sink was deemed too small. The sink will likely be reused by one of the volunteers.

Other materials that we deconstructed and used include the hardwood flooring, walnut kitchen cabinets, slate for outdoor walkways, and most of the interior doors and hardware.

We found that one difficulty associated with deconstruction is preparing the salvaged materials for new construction. For example, volunteers had to clean off the old mortar from bricks and slate, and remove all of the old nails from the reused lumber. Floorboards had to be very carefully cleaned before they could be used. These tasks are most feasible when a volunteer work force is available, and are well worth the extra effort for the financial and environmental returns they provide.

WASTE MANAGEMENT

Waste management is usually an afterthought or just a budget line item for a dumpster somewhere along the way in the planning for the construction of a building. Rarely is much thought given to how waste disposal can be minimized to save money and/or to save landfill space. It has been estimated that 25 percent of waste dumped at municipal landfills comes from construction sites, and about 90 percent of construction waste could be recycled. A compelling argument for the contractor is that waste management has the potential to save money. It usually is cheaper to recycle many materials than to dump them at a landfill. Some materials, like cardboard and rubble, can be recycled for free, and recyclers will pay cash for several materials, such as aluminum, copper, scrap steel, and piping.

Waste management is an important component of a green building project and must be given thought early in the planning process. The National Association of Home Builders (NAHB) Research Center produced a tremendously helpful document entitled *Residential Construction Waste Management: A Builder's Field Guide—How to Save Money and Landfill Space* which discusses how to plan and carry out greener waste management practices. We recommend obtaining this guide (available at www.nahbrc.com or 301-249-3000) and using it to develop a plan for your specific needs and local conditions. We consulted the guide and will share our experiences below.

A good waste management program consists of the following elements:

- Reduce the amount of waste generated through good building design, good construction, and event planning, proper materials handling, storage and education.
- Reuse as many materials as possible in other applications directly or indirectly related to the construction of the building.
- Recycle and compost those wastes that can not be reused.
- Properly dispose of the unavoidable waste generated. Where available, processing plants that convert waste into energy are generally preferable over landfills.

Pre-Construction Site Preparation

We built on a site that was donated to DC Habitat for Humanity and had long been a vacant lot on the end of a row of older urban row houses. Volunteers cleared this site of miscellaneous debris and vegetation before beginning the construction process. All of the larger trees (none were thicker than six inches in diameter) and small branches were cut up into fireplace-sized lengths and donated to a neighbor for household heating use. We rented a chipper to chip the brush removed from site. These chips were used at a different building site where they were spread on the wet ground to minimize erosion. We separated out recyclable containers (such as beverage cans and bottles) and recycled these at a local drop-off collection site. Volunteers placed metals into a separate pile, which then went to a metal recycler. We brought pieces of concrete and asphalt to a local construction and demolition debris recycler for recycling into road construction materials. We transported several loads of waste lumber (excluding pressure treated lumber) to a compost manufacturing facility where it was ground up and mixed with restaurant vegetable waste and horse manure. We then used a large load of this mixture to augment the soil in areas slated for grass. We eventually reused most of the bricks and natural stones found on the site as part of the landscaping. Finally, all remaining non-recyclable and non-compostable materials were accepted for disposal by a local business.

ON-SITE WASTE MANAGEMENT AREA MAKES RECYCLING EASY

Construction Waste Management

Prior to construction, we set up a waste management area in a vacant lot adjacent to our building site. Labels were hung along a pre-existing chain link fence to designate the specific area to which each waste material would be segregated. These categories included cardboard and paperboard, compostable non-food vegetation, bricks, stones, concrete and asphalt debris, mixed metals, mixed untreated wood (unpainted, no glue), mixed treated wood, Hardi-plank, and Homasote. No dumpster was used on site during construction for the disposal of materials. Three 90-gallon toters were donated to GreenHOME by BFI, Inc. for use in recycling and waste management.

Volunteers separated all recyclable and compostable materials throughout the course of the project. These materials were kept for possible reuse, until being ultimately recycled or disposed of properly in a few cases where a local recycling option was unavailable. The following list shows how we disposed of the various construction waste types that were generated.

Reused, Recycled or Otherwise Not Landfilled Waste

- *Land clearing debris:* Recycled at a composting operation for approximately $30 per 9 yard trailer load.
- *Lumber* (with and without nails): Some of the longer scraps were used for construction purposes; other scraps were used onsite as stakes, and volunteers took some home for use as kindling. The remainder were hauled to the composter.
- *Engineered wood* (plywood and OSB): Most of it was hauled to the composter, but some was used on muddy ground to facilitate foot traffic.
- *Drywall:* We encapsulated almost half of the waste in the interior walls as an alternative method of disposal, called “cavity storage.” Though the benefits have not been scientifically researched and agreed upon, cavity storage lowers the amount of material sent to the landfill, and may provide increased sound insulation, fire retardance and thermal mass. The remainder of the drywall went to the composter.
- *Homasote:* Almost half of the waste went into cavity storage, with the remainder going to the composter.
- *Rubble* (brick, block, and stone): Some of the concrete and brick was used on-site as beneficial fill and most of the stone was used for landscaping. The remainder (approximately 80 to 85 percent of the total amount) was recycled for free at a concrete recycling/mixing company.

- *Metals:* Mixed ferrous and non-ferrous metals were sold to a scrap metal recycler for $6. It would have brought in slightly more if the two types had been separated.
- *Chain link fence:* This was not accepted by the metal recycler, but we did use two rolls as concrete reinforcement in the parking pad.
- *Cardboard:* Most was taken to a drop-off recycling site. The cardboard that was left on site and rained on became dirty and unrecyclable.
- *Recyclable containers* (mostly volunteer generated, including glass bottles and jars, plastic bottles, and aluminum cans): These were recycled periodically at a local drop-off center or with a volunteer's curbside recycling.

NOTE: We were lucky to have a wood and yard debris compost producer who was flexible with the materials he accepted.

Landfilled

- *Miscellaneous garbage* (includes caulk and adhesive tubes, styrofoam packaging, broken glass found on site, plastic bags and other non-recyclable plastic packaging, empty paint cans, felt cans, etc.): Dumped for landfill disposal.
- *Hardi-plank:* A small amount was accepted by the composter, but most went into dumpster.
- Scraps of pressure treated wood.
- Chain link fence.

We estimate that 62 percent of the waste that was generated during the construction of this house was diverted from the landfill and reused, recycled or composted. Since there were no standardized containers used for the recyclables, we were unable to keep accurate measurements and had to instead rely on estimates.

GreenHOME did save some money by recycling. For instance, rubble cost nothing to recycle except for our own negligible transportation costs. Compostables cost only slightly less to recycle ($30/load) than to landfill ($38/load average in this area). Although our data is not accurate enough for quantitative analysis, the results are positive. We accomplished the waste management goals of our mission while saving some money.

It is important to note that the Washington, DC area has two extremely large barriers to construction recycling success: very low tipping fees at landfills and few recycling companies which accept the high volume components of construction waste—lumber, engineered wood and drywall. Higher tipping fees and the presence of more construction material recyclers would make green waste management a much more economically and logistically viable option. The dynamics also would have been vastly different if a larger site with multiple houses were involved—larger quantities of waste materials being generated at a faster rate are more likely to be viewed as a useful commodity by large waste haulers. We did, in fact, find one local company which offered discounted rates for clean loads of recyclables. Using such a service would also provide for an accurate accounting of quantities and costs, making it possible to reliably document the results.

Lessons Learned

Organization and neatness in the recycling area promotes ease of reuse and final recycling. More clearly separated bins with prominent signs would have helped our recycling effort. We found that continuous worker education of new volunteers is an essential element to a recycling program's success. We strongly recommend that an on-site waste management coordinator be designated for each day. This could be the same person (or several people) who knows the drill and reports to a team leader. This point-person would not have to manage the waste all day long, but would pay attention to and educate volunteers on how the waste management area works before each workday begins. This recommendation comes specifically from our experience on the final site clearance before construction, where some recyclable materials were thrown away because the volunteers were unfamiliar with our waste management plan and goals. The waste management coordinator would also log any disposal activity so that a more accurate estimate could be kept. Using dumpsters or other methods for measuring material volume would be very helpful for gathering useful data.

TESTING THE CONSTRUCTION

When building an energy efficient home, testing the construction will allow you to determine the effectiveness of the materials selected and to check how well the house is actually sealed from infiltration.

The air leakage (infiltration) of a house usually is measured using a blower door test, where a fan in the front door pressurizes the house by forcing in air. The amount of air that the fan has to blow into the space in order to maintain a constant pressure is recorded and used to determine the number of air changes per hour (ACH) for the house. Better sealed houses will have lower ACHs. This number corresponds to how often the volume of air inside the building is replaced by outside air due to air infiltration. The ASHRAE standard for natural infiltration, to avoid indoor air pollution, is 0.35 ACH; houses with lower infiltration values require a mechanical ventilation system to provide regular fresh air.

We performed a preliminary blower door test during construction to try to find potential air leakage sites. We pressurized the house, and then placed smoke near areas where we thought cracks or seams might exist. If the smoke disappeared, then we knew that it must have leaked through the wall, and so we applied additional caulk and sealing to those areas.

After the house was completed, a final blower door test was performed on the house. A typical house has about 0.75 ACH; our demonstration house was tested to have 0.16 ACH. We also used the blower door test to pinpoint the major leaks in the house. Taping the opening around the pull-down attic stairs reduced the measured infiltration by about 3 percent, and taping the bathroom vent lowered the infiltration by another 3 percent. Feeling the air movement, we noticed that most of the house's infiltration seemed to occur in between the tops of the upper window sashes and the window frames. However, since the blower door fan is situated in the front doorway, the test did not take into account what may be the largest source of infiltration—the mail slot in the front door.

BLOWER DOOR TEST IN PROGRESS

The leakage of the ductwork was tested using a duct blaster test, which is very similar conceptually to the blower door test. We sealed all of the duct registers, and then pressurized the ducts using a small fan called a duct blaster. The duct leakage in cubic feet per minute (CFM) was then recorded. Unfortunately, this test was not conclusive because the monitoring system was being installed at the same time in the mechanical equipment, which prevented the duct system from being well sealed.

We were fortunate that the Oak Ridge National Laboratory funded the Sustainable Design Group to monitor the house's performance. Data logging devices are installed at 36 locations throughout the house and will record temperature, humidity, and air quality. These are placed not only in the living space, but also in the attic and crawl space to fully measure how much heat is gained and lost through these areas. Monitoring devices were installed on all of the major components of the HVAC system to measure energy usage, and also on the house's electricity and gas meters. A year's worth of data, collected from each of the 36 data points, is being fed into an on-site computer, and from there transmitted to sustainable Design Group and then to Oak Ridge National Laboratory for analysis. They will then analyze this data to detail the energy savings effectiveness of the house's construction. The data transmission required an additional phone line located in the utility room.

ENERGY STAR® PROGRAM

GreenHOME's first demonstration house has become Energy Star certified, since the results from the blower door test confirmed our expectations for the house's air tightness. ENERGY STAR® Homes is a joint program of the DOE (U.S. Department of Energy) and the EPA (Environmental Protection Agency), and recognizes houses built with high-energy efficiencies.

To qualify for this certification, a house must have energy consumption reduced by at least 30 percent of that required under the 1993 Model Energy Code (MEC), which is equivalent to a Home Energy Rating System (HERS) rating of at least 86. More than 700 U.S. builders are currently constructing ENERGY STAR® houses.

ENERGY STAR® qualification does not require any specific construction technique or materials; houses are qualified as long as the home achieves the required energy usage performance, as measured by one of several software packages and a blower door test to check airtightness. Typical ENERGY STAR® homes have extra insulation, tight construction, high-performance windows, and high efficiency heating and cooling systems.

The homeowner receives many benefits when purchasing an ENERGY STAR® home, in addition to the reduced energy usage. ENERGY STAR® homeowners are eligible for Energy Efficient Mortgages (EEM), for which the lending institution will take into account the lower monthly energy costs and increase the monthly payment limit that a homebuyer can afford. The combined cost of the mortgage and monthly utilities is usually reduced (although the house may cost more initially). In addition, a recent EPA study found that a house's market value increases $20 for every $1 reduction in average utility bills.

Builders of ENERGY STAR® homes also receive benefits. An ENERGY STAR® rating can be a great selling point for a new house, due to an increasing recognition of the program through a nationwide promotion program. The ENERGY STAR® program offers certified homebuilders sales training, marketing assistance, and technical aid through their publications (such as the *Home Builder Guide*) and individual technical help, as needed. In addition, it sometimes is possible to save costs in energy-efficient construction, as we have shown throughout this book. An example of this is needing smaller HVAC equipment (due to the increased insulation and better airtightness).

The ENERGY STAR® program also certifies a range of products. These include some large home appliances (such as clothes washers, refrigerators, and dishwashers), some home electronics, lighting, heating and cooling equipment, and windows. Currently, the program does not include clothes dryers, ovens, ranges, and water heaters. A product can achieve ENERGY STAR® certification if it is significantly more energy-efficient than the government minimum standard. The exact amount by which the product must exceed the standard depends upon the specific product type, and the available technology. While ENERGY STAR® certified products may have higher purchase costs, their life cycle cost (initial cost plus annual energy costs) is often less. Purchasing ENERGY STAR® qualified appliances ensures that the homeowner has one of the more energy efficient appliances available.

Fund Raising and Donors

FUND RAISING

Thanks to our Adopt-A-Home partnership with the Washington, DC affiliate of Habitat for Humanity International, we had an outstanding success rate in bringing in donations for GreenHOME's first demonstration house. Out of four full proposals submitted, we were fully funded on three of them. A few additional local fund- raising efforts helped us reach our goal of $65,000, which is the maximum allowable cost for a DC Habitat for Humanity house.

Our major funders each took a different approach.

- Our first major donor, the Beekhuis Foundation ($5,000), focuses on local, start-up initiatives. GreenHOME offered this aspect to the long-established presence of DC Habitat for Humanity and brought in this local foundation to support our green building initiative. Beekhuis awarded us $2,000 and offered up to $3,000 more if we could match it, which we did through local fundraising efforts.
- Another funder, the Hechinger Foundation ($5,000), is associated with a local home maintenance retail operation and wanted to support environmental building and maintenance with local homeowners and homebuilders.
- The third and largest funder, the North American Fund for Environmental Cooperation ($52,000), considered the GreenHOME/DC Habitat for Humanity partnership an opportunity to support a highly replicable project as an example for the other 1,500+ North American affiliates of Habitat for Humanity International.

Foundation Strategy

We found that our Advisory Board's personal contacts provided us with the entrée to both local foundations. These contacts were key to getting meetings that led to brief proposals and immediate funding.

With the North American Fund for Environmental Cooperation (NAFEC), we were fortunate (because of a volunteer active in environmental issues) to have learned about their international call for two-page pre-proposals. Realizing the minimal effort required to pull together two pages highlighting NAFEC's interests in facilitating environmental cooperation and innovation at the local level, we submitted a preproposal. It was not accepted in the first round, but a call to NAFEC to get feedback on the preproposal led us to refine it for the next round three months later. Based on that submission in September 1996, we were invited to submit a full proposal in December that was fully funded at $52,000.

In all three cases, GreenHOME volunteers prepared the proposals and presented the initiative directly to funders with full collaboration and proposal review by DC Habitat for Humanity. On each proposal document, and with all donations, DC Habitat for Humanity was the incorporated fiscal entity which received each grant, and all funds were dedicated to the GreenHOME building effort.

Diversified Fund Raising

In addition to foundations, GreenHOME brought in funds from other sources through events, sponsorships, product sales, and individual contributions. We organized several live band parties and a Valentine's Day Silent Auction to tap into the broad network of our volunteers' young environmental friends and colleagues. These events brought in a few hundred to several thousand dollars. While these results fell short of our targets, these events produced a valuable side benefit—within months, GreenHOME was recognized throughout the Washington, DC area by environmental professionals and local social activists, which resulted in broad ongoing support and enthusiastic volunteers at the ready.

Our most successful strategy, in terms of its efficiency, was to have another organization hold a benefit on our behalf. The Human Resources Staff of the World Bank, for example, donated $1,000 to GreenHOME/DC Habitat for Humanity collected at a staff happy hour. We also held a fund raiser at the home of John Hunting—a Capitol Hill residence noted for its cutting-edge environmentally-responsible design. Another friend asked for donations at a high-profile birthday party.

We also participated in two DC Habitat for Humanity fund-raising events: Hexagon (a benefit musical production) and the Down Home Ball (a down-to-earth, "up-scale" party). These ended up being less lucrative for GreenHOME's efforts simply because a few groups were all sharing in the proceeds.

Finally, we made an effort to both promote GreenHOME and bring in funds by selling t-shirts and historic bricks from the United States Capitol steps that were donated to us after renovations. While these kept a steady trickle of funds coming in, they never produced significant revenue and were very difficult to coordinate. The absence of easy storage, accessible distribution, and a streamlined inventory procedure further reduced them as strong fund-raising options. We also routinely enclosed in outgoing correspondence a GreenHOME brochure, resulting in occasional donations.

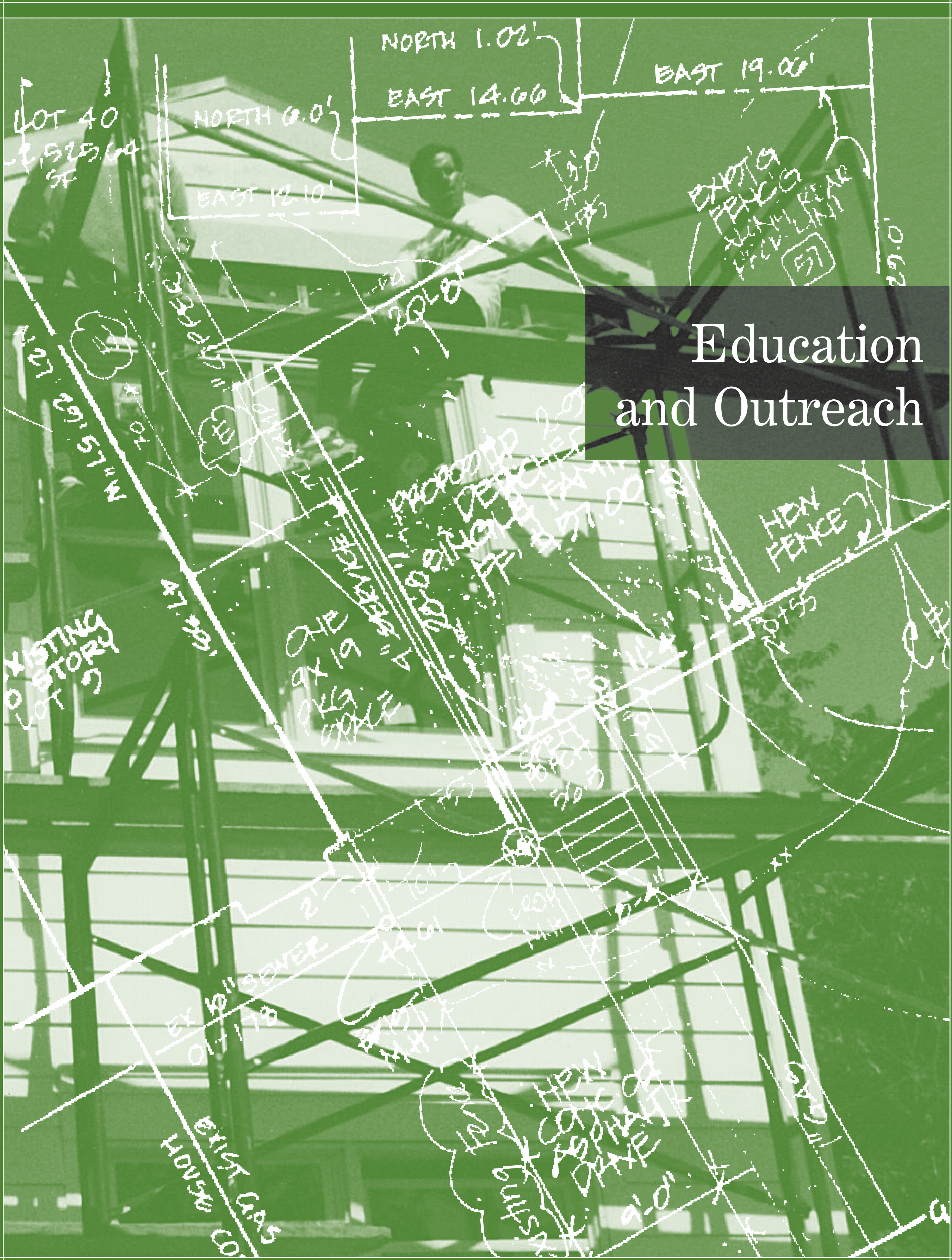
ON-SITE SIGN LISTING MAJOR DONORS

Lessons for the Future

As many nonprofits quickly learn, certain fund-raising strategies are more efficient for raising significant funds than others, but varied strategies also serve various purposes. Foundation proposals will probably always remain as the principal thrust of our fund raising. However, a diversified fund-raising strategy helps build recognition, serves as publicity, establishes the presence of the organization over time, and provides a communication tool with constituents. Smaller donations also provide ongoing income for the organization. Ultimately, we realized we had to be careful not to expend too much time, effort, or energy on lower pay-off fund-raising efforts.

Creating new partnerships to meet shared goals can truly open up new funding sources and enhance the ability of an organization such as the Washington, DC affiliate of Habitat for Humanity to accomplish its mission of building affordable housing, while innovating with alternative construction principles, products and systems.

Education and Outreach



HOMEOWNER EDUCATION

While we can build a house with the best energy and resource efficiency available, a critical aspect of an environmentally sustainable household is how the homeowner maintains and lives in the home. For example, if a homeowner sets the thermostat to 65°F for the entire summer, large amounts of energy would be wasted regardless of the house's energy efficiency. We therefore instituted a program to try to educate the homeowner on how to properly maintain her house and to save money in the process by decreasing her utility bills.

During the research and design phase of the first demonstration house, volunteers on GreenHOME's Education and Outreach Committee attended DC Habitat's Family Partnership Committee meetings and made several presentations to homeowner candidates. Homeowner workshops on sustainable living were also incorporated into the Family Partnership Committee's homeowner education series. These workshops included "Saving Energy and Saving Money" and "Backyard Gardening."

Shortly after the completion of GreenHOME's first prototype house, our Education and Outreach Committee began planning for a series of homeowner training sessions. The purpose of the training was to prepare homeowners for adapting to a sustainable way of life while benefiting from the reduced costs of green living. Each of the training sessions addressed a new area which assisted homeowners exploring the opportunities and challenges that arise with sustainable living. These areas included:

- Energy Efficiency (utilizing appliances and utilities/air tests)
- Atmosphere and Toxicity (Radon testing and cleaning products)
- Pesticides (groceries)
- Solid Waste (recycling, buying bulk)
- Landscaping (erosion protection and gardening)

Our winter training sessions focused on minimizing energy usage with home appliances and utilities, by identifying energy and cost saving tips for utilizing the stove, oven, washer, dryer, refrigerator, dishwasher, and lighting. This session also explained how the energy efficient features in the house operated, how the heating and hot water systems function, and how energy savings (in terms of energy use and costs) can be tracked.

During the spring sessions, we gathered research materials on environmentally-friendly landscaping practices as well as non-toxic indoor cleaning alternatives. The summer training discussed "Keeping Cool and Saving Money," as well as indoor air quality concerns such as radon. The training sessions ended in the fall with a workshop on waste management design, which presented options for minimizing the solid waste flow going in and out of the house, by emphasizing recycling, reuse of materials, and reduced use of energy and of natural resources.

The research materials used for the training sessions were made available to homeowners throughout the training, and were tested for their effectiveness. At the end of the last training session, the Education and Outreach committee will produce a homeowner training manual.

TABLETOP DISPLAY EXPLAINING BUILDING MATERIALS USED IN THE HOUSE

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COMMUNITY OUTREACH AND EDUCATION

A large part of building an affordable, environmentally sustainable demonstration house is communicating to others what you have learned. Building this house would have had very limited impact if we did not share our experiences with the community, both locally and nationwide.

GreenHOME volunteers have given presentations to a wide range of environmental and building professionals, as well as to community groups. We have also participated in several Earth Day celebrations, community street festivals, and DC Habitat for Humanity events to provide information about GreenHOME and our experiences. We are listing several of these outreach events below, with the hope that they might help your group further develop ideas on how to address community education and outreach goals.

Members of GreenHOME's Education and Outreach Committee worked to raise awareness of the benefits of green living in the community where our first demonstration house was built. During the research and design phase of the demonstration home, we met with volunteer and civic organizations in the neighborhood, such as a neighborhood public safety group. GreenHOME also received support from several local elected officials, who spoke at events for the house, including the Groundbreaking and Dedication ceremonies. The local affiliates of the Kiwanis Club and the Salvation Army helped feed volunteers during the initial Blitz Build.

We took care during our construction process to educate our volunteers about the specifics of the house we were building. We gave a presentation on each day that volunteers worked, usually during the lunch break, to detail the green aspects of the materials used in the house.

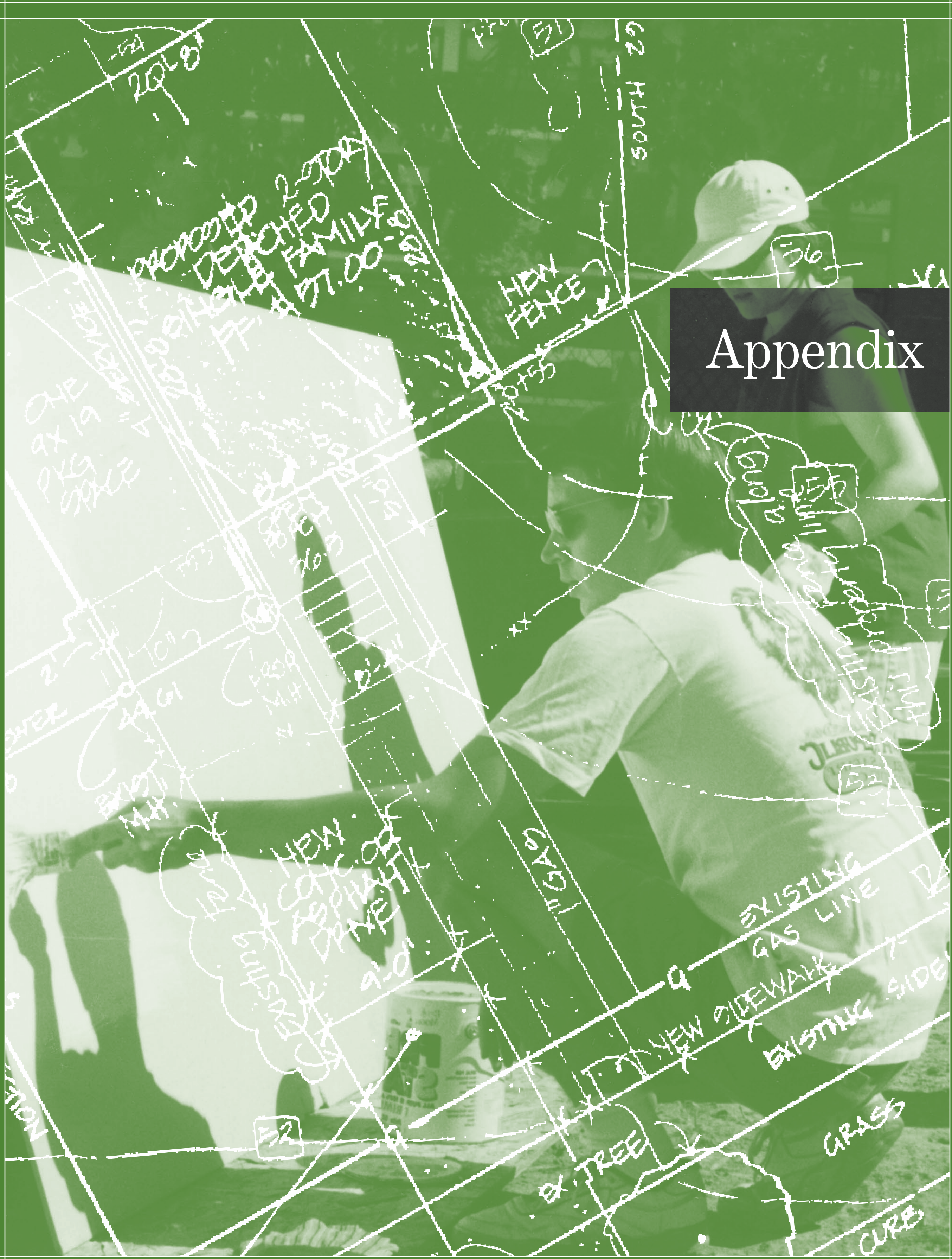
One of the best methods to reach audiences across the nation is through documenting our project in writing. This book is one obvious example of how we have tried to detail the design and construction process of our first project. We also have written an article for the *New Village*, the newsletter for Architects, Designers, and Planners for Social Responsibility, and our project has been featured in Habitat for Humanity International's *GreenTeam* newsletter, as well as a television show on the Home and Garden Network.

We have used our partnership to teach the principles of living and building green to the local affiliate of Habitat for Humanity. We are currently working with this affiliate's Family Partnership Committee to present workshops to homeowner candidates on "How to Save Energy and Save Money" and "Backyard Gardening." Some of our more experienced volunteers also trained several of their AmeriCorps volunteers on energy efficient building techniques, including air sealing, caulking, and insulation.

GreenHOME volunteers have given numerous presentations, sharing our experiences with local, national and international communities, including: the EPA Smart Growth Network at the National Building Museum in Washington, DC in 1998; Habitat for Humanity International in Atlanta in 1999; and the Sustainable Urban Initiatives Workshop at the Urban Issues 1998 Conference in Winnipeg, Canada. We also participated in a panel discussion on Energy Efficiency in Affordable Housing at the 1998 Energy Efficiency Building Association (EEBA) conference in Washington, DC. During construction, we conducted a presentation and hands-on workshop at our construction site to participants in the Student Conservation Association's Conservation Career Development Program (SCA-CCDP).

CAULK IS CHEAP BUT ENERGY ISN'T

Appendix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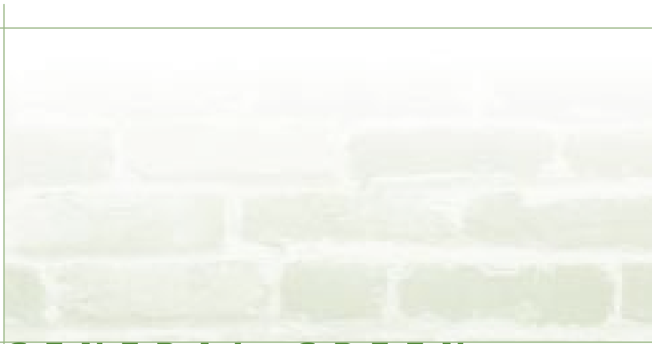

GENERAL GREEN BUILDING RESOURCES

This is a list of selected resources on green building that we found helpful in designing GreenHOME's first demonstration house and while writing this book.

Center of Excellence for Sustainable Development, Green Buildings, Affordable Housing Offers a comprehensive paper on affordable housing techniques and approaches, and identifies many additional resources. *www.sustainable.doe.gov/buildings/affhousing.shtml.*

Center for Resourceful Building Technology (CRBT) Publishes several books on resource efficient building, such as a Guide to Resource Efficient Building Elements. *www.crbt.org*

Energy and Environmental Building Association (EEBA) Publishes comprehensive environmentally-sustainable builder guides, and runs an annual conference. *www.eeba.org*. 612- 851-9940.

Efficient Windows Collaborative Offers several geographic-based fact sheets on energy-efficient windows. *www.efficientwindows.org*.

ENERGY STAR® Lists and compares energy efficient household appliances and other ENERGY STAR® products. *www.energystar.gov.*

Environmental Building News This journal offers information on environmentally sustainable design and construction, including a mix of project case studies and reviews of new technologies and materials, and links to several other green building sites. *www.ebuild.com.*

Environmental Resource Guide American Institute of Architects, Washington, DC, 1996. Large guide with information about the environmental performance of building materials and products. *www.aiabooks.com.*

Flexible Products Manufactures polyurethane foams, sealants and adhesives, including products for insulating and air sealing cracks and holes in residential construction. *www.flexibleproducts.com.* 815-774-6500.

Good Wood Resource for information on forestry, environmentally sustainable wood, certified wood, wood alternatives, and conservation by design. *www.goodwoods.org.*

Green Building Resource Guide By John Hermannsson, Taunton Press, 1997. Briefly describes many of the environmentally friendly products available for residential construction.

GreenClips E-mail summary of new on sustainable building design. *www.solstice.crest.org/sustainable/greenclips.*

Greendesign Net Contains pointers to various other green resources. *www.greendesign.net.*

HomeEnergy Magazine Magazine on residential energy conservation. *www.homeenergy.org.*

Home Energy Saver Developed by the U.S. Department of Energy's Lawrence Berkeley National Laboratory, this site's Energy Advisor computes a home's total energy use, and has links to energy-efficient building sites. *www.homeenergysaver.lbl.gov.*

Infiltec Sells blower door and radon migration equipment, has many articles on blower door and radon testing. *www.infiltec.com.*

National Association of Home Builders (NAHB) Research Center Has several publications, fact sheets, and technical articles on different construction materials and techniques, a catalog of building products and services, and more. *www.nahbrc.org.*

Oak Ridge National Laboratory Buildings Technology Center Fact sheets and articles on the lab's research in such topics on building envelope systems (including roofs, walls, and foundations) and building design and performance. *www.ornl.gov/ornl/btc.*

U.S. Department of Energy, Office of Building Technology, State and Community Programs—Codes and Standards Contains information on energy-efficient appliances and heating/cooling equipment. *www.eren.doe.gov/buildings/consumer_information.* Hotline 1-800-270-2633.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy Has articles on many aspects of energy savings in residential buildings. *www.eren.doe.gov/ee/buildings.html.*

Oikos Reference for green building products and literature. Has a database of 1,800 green building product companies. *www.oikos.com.*

Residential Energy Efficiency Database Offers free of charge over the internet several guides to understanding residential energy efficiency and residential construction techniques, including a glossary on home construction terms. *www.its-canada.com/reed.*

Rocky Mountain Institute Publish books and briefs on green building design. *www.rmi.org*. 970-927-3851.

Southface Energy Institute Education and research in energy, building science and environmental technologies, web site has several of their fact sheets and other information. *www.southface.org.*

Sustainable Sources Provides links and articles on sustainable building. *www.greenbuilder.com.*

GLOSSARY

Annual fuel utilization efficiency (AFUE)
The percentage of the energy that is used for heating that is converted into heat, used in determining the efficiency of furnaces. Minimum allowed AFUE is 78 percent, mid-efficiency units have AFUEs of 80 to 82 percent, high-efficiency units range from 90 to 98 percent.

Air changes per hour (ACH)
The air leakage rate of a building, specifically the number of times each hour that the air in the building is replaced with outdoor air. Large numbers indicate larger air leakage.

Backdrafting
Occurs when exhaust from combustion appliances does not properly exit the building, possibly due to blocked flues or pressure differences, and can cause high carbon monoxide levels in the house.

Ballasts
Electrical “starters” required by certain lamp types, especially fluorescents.

British thermal unit (BTU)
Measure of heat, equal to the amount needed to raise the temperature of one pound of water by 1 °F.

Building envelope
Floor, walls, ceiling that separate the conditioned internal space from the outside air.

Conditioned air
Air internal to the house that has been cooled, heated and/or dehumidified relative to the outside air.

Embodied energy
The total energy that grows into growing, extracting, manufacturing, and transporting a product.

Finger-jointed lumber
Lumber formed by joining small pieces of wood glued end to end, so named because the joint looks like interlocked fingers.

Fly ash
The fine ash waste collected from the flue gases of coal combustion, smelting, or waste incineration.

Heating degree days (HDD)
A measure of the severity of the local winter climate. Degree days equal 65F minus the average daily temperature, summed up for a year. (Larger values correspond to colder winters)

Heat recovery ventilation unit (HRV)
Ventilation system that contains a built in heat exchanger to transfer heat to (or from in the summer) incoming fresh air from (to in the summer) the stale exhaust air.

HVAC
Heating, ventilation, and air conditioning.

Infiltration
The amount of air leakage into and out of a building envelope, usually measured in ACH (see above).

Life-cycle cost
The costs accruing throughout the service life of a product, including the initial purchase price, energy usage, maintenance, and disposal costs.

Lumens
Measure of the brightness of light from a light bulb. Higher numbers indicate brighter bulbs.

Offgas/outgas
A process of evaporation or chemical decomposition through which vapors are released from materials.

Oriented strand board (OSB)
Manufactured wood sheet product made from large flakes of wood pressed together with glue, usually made from small, fast-growing trees such as aspen which are unsuitable for other structural uses. OSB is used for structural sheathing and subfloors.

Passive solar design
Designing a building’s architectural elements to collect, store, and distribute solar resources for heating, cooling, and daylighting.

Permeability
Ability of water to diffuse and pass through a material. A material with low permeability has a high resistance to water diffusion.

Photocells
Light-sensing cells used to activate controllers at dawn or dusk.

Mastic
Thick paste used to provide a durable seal for all types of ductwork.

R-Value
The resistance of a material to heat flow. The higher the number, the greater the resistance (i.e., the better the insulation) to heat flow. Units are square feet x hours x F/BTU.

Seasonal Efficiency Ratio (SEER)
Used when comparing air conditioners, depends on the cooling produced per unit of used electricity. Minimum allowed is 10; mid-efficiency units have 11 SEER ratios, high-efficiency models have a SEER of 12 or greater.

Structural insulating panels (SIPs)
Framing system which consists of a sheet of OSB on either side of an insulating core.

Sustainable
The condition of being able to meet the needs of present generations without compromising those needs for future generations.

Therm
Measurement of natural gas equal to 100,000 BTU, or 100 ft3.

Ton of cooling
Rating for the cooling capacity of an air conditioner, 1 ton of cooling equals 12,000 BTU/hr (because it takes 12,000 BTU to melt one ton of ice).

Volatile organic compound (VOC)
Solvents and other additives that are outgassed from materials at room temperatures. VOCs contribute to indoor air pollution, which can cause headaches, nausea and respiratory problems. In addition, VOCs contribute to the formation of ground-level ozone.

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LIST OF TABLES & FIGURES

Tables

Figures

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Printed with 100% post-consumer recycled paper, with assistance from New Leaf Paper company (www.newleafpaper.com).

By using this paper, we have saved: 12 trees; 1155 gallons of water; 1507 Kilowatt hours of electricity (enough to power the average American home for 1.9 months); 1050 pounds of solid waste; and 1909 pounds of greenhouse gases (equivalent to traveling 1546 miles in the average car).

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