Incorporating Energy-Efficiency into Affordable Housing Construction Practice

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INTRODUCTION

Inclusion of energy-efficient features in the construction of affordable housing offers many benefits to low-income homeowners, including reduced operating costs and improved comfort. Current challenges to building energy-efficient affordable housing include overcoming first-cost biases, incorporation of energy-efficient features into construction designs and plans, and altering current construction practices in the field.

Housing program managers, construction foreman, and laborers often ask what are the important elements in constructing an energy-efficient home and what are the first steps that they can undertake now to achieve energy efficiency in their housing. Some also have the perception that achieving energy efficiency requires higher first costs, knowledgeable, skilled installers, and use of new, unfamiliar materials or methods of construction.

We believe that simple, clear, energy-efficiency construction guidelines will help affordable housing providers surmount these hurdles and make an initial, significant step toward achieving energy efficiency in their house plans and construction. In this paper, we offer examples of such guidelines developed for Habitat for Humanity's 1997 Jimmy Carter Work Project (JCWP) and present a unique approach to implementing the guidelines that involved the use of an energy expert at each house site.

1997 JIMMY CARTER WORK PROJECT

The JCWP is an internationally recognized annual event in which Jimmy and Rosalyn Carter join Habitat volunteers in a week-long "blitz-build." In a "blitz-build," houses are built in one week. During this year's event in June, over 2,400 volunteers constructed 50 houses at seven rural areas in the Appalachian area of Kentucky and Tennessee.

A year before the actual construction of the houses, Habitat's design committee began the development of a construction manual for the project. This manual identified the construction details of the several house plans to be built during the project and identified a daily schedule that had to be met to ensure that houses would be fully constructed at the end of the week's building period. Material requirements were identified from the construction manual, and materials were obtained so that they would be on hand at each site before the start of construction.

Each house was supervised by a house leader who was responsible for seeing that the house was constructed as planned and within schedule. Volunteers from around the world - some skilled and some unskilled - worked on site during the week to build the houses. Plumbers, electricians, and heating and cooling contractors were generally used to install these specialty services.

ENERGY-EFFICIENCY CHECKLIST

In making a first step to achieving energy-efficient construction in affordable housing, we believe the key is to correctly perform current construction-related tasks that impact energy. Consequently, we developed a 34-item checklist (Figure 1) to support the 1997 JCWP that focused on three construction-related, energy-efficiency details: air sealing, insulation, and water-heating efficiency. These three areas significantly impact energy efficiency, and we felt that they could be improved in the JCWP without adding major up-front costs. Addressing these areas only required additional use of commonly available materials that could be installed using low-skilled laborers.

Thorough air sealing, while labor intensive, does not require skilled workers and can easily be done by volunteers (Figure 2). The materials required (caulk, foam, housewrap tape, polyethylene plastic, scrap rigid board insulation, other scrap sheet goods such as plywood or drywall, etc.) are inexpensive and available from local building suppliers. The goal was to seal all framing joints that could allow air movement into the home and to seal all other holes that are made in the building envelope during construction. The intent of the checklist was to direct volunteers to the most important areas needing this sealing work. The checklist identified four key steps to correctly installing housewrap which was recommended as a backup or contingency to caulking and sealing.

Since insulation is routinely installed in any new house, the checklist emphasized using the appropriate insulation levels to meet state and local energy codes and installing it correctly. Installing appropriate insulation levels during new construction is significantly more cost-effective than retrofitting additional insulation later. Insulation has to be installed correctly to achieve intended results, and volunteers or unskilled workers can do a successful job if given proper instruction. The checklist highlighted thorough coverage of insulation, installing insulation flush against surfaces, and not over compacting it.

Regarding water heater efficiency, the checklist required an insulation jacket on the water heater, heat traps on both hot and cold water pipes, and insulation on all hot water piping in the closet and the first two feet of cold water pipe.

The energy-efficiency items provided on the checklist were specific to the JCWP houses. For example, items were applicable to houses with crawlspaces since slab and basement foundations were not going to be built under this project. Additionally, items were selected that were readily available and could be installed by volunteers within the time constraints of the JCWP. A more universal checklist or a checklist for another project would therefore have a different set of energy measures listed, although many of the items on our checklist should still be applicable.

The checklist we developed focused primarily on energy-efficiency details that occur during the actual construction process. The checklist did not address design issues to a great extent because the house designs were essentially established before the checklist was developed. Many energy-efficiency improvements can be made during design, and a separate or expanded checklist addressing design would greatly assist affordable housing providers. Some design issues that could be addressed by a checklist include use of energy-efficient framing and sizing, orientation, and shading of windows.

HVAC CONTRACTOR GUIDES

We developed separate installation instructions for heating and cooling contractors on how to size and install gas furnace and heat pump systems, and we provided them to the contractors one month prior to the start of construction. We separated these instructions from the energy-efficiency checklist to provide each audience (Habitat construction personnel and contractors) with just the specific information they needed to perform their respective tasks.

Sizing equipment properly is important for energy efficiency and comfort. We explained why this is important in the guidelines so that the contractors could better appreciate the need for our subsequent instructions. We calculated heating and cooling loads for each of the floor plans for the JCWP and instructed contractors to size and select equipment according to our load calculations. We recommended installation of medium efficiency equipment, setting an AFUE rating of 80 as a minimum for gas furnaces and ratings of 7.4 HSPF and 11 SEER as a minimum for heat pumps.

We instructed HVAC contractors to design ducts according to Air Conditioning Contractors of America's Manual D (*Residential Duct Sizing*, ACCA Manual D, 1995 edition). We also provided them with several rules of thumb for laying out duct work in a manner which would provide a well-balanced and energy-efficient air distribution system. We suggested adapting duct sizes for length of run and room size and discussed location of supply registers, sizing of return grilles, and location and construction of return ducts.

We gave detailed instructions for how to install and seal air distribution systems, stressing the importance of fastening joints with mechanical fasteners, making sure that airflow through flexduct is not restricted, ensuring that boots at supply and return registers fit snugly, and making sure duct chases are thoroughly sealed. Duct sealing guidelines emphasized the use of mastic at duct connections, joints, unused holes and seams at the air handling unit, plenums, and condensate line penetrations through the building envelope. The use of duct tape for sealing connections was not permitted as per the 1995 Model Energy Code.

The instructions directed the contractor to locate gas furnaces or heat pumps where they could be easily serviced and air filters where homeowners could easily replace them. The contractor was urged to locate an atmospheric (non-sealed combustion) furnace preferably in a non-conditioned space. If plans required its location inside the house, the contractor was instructed to make sure that the combustion closet (mechanical room) was completely isolated from the return duct and the conditioned space of the house. The outdoor units of heat pumps were to be located away from landscaping and outdoor structures which could restrict airflow or clog heat exchanger surfaces. A list of specific commissioning procedures were provided for gas furnaces and heat pumps.

IMPLEMENTATION IN THE 1997 JCWP

The 1997 JCWP provided a case study for how the guidelines we developed were implemented in an affordable housing context to ensure the construction of energy-efficient houses (Figure 3). Guidelines should not be simply developed and handed out with the expectation that recipients would understand them and know how to use them. Such guidance needs to be reinforced in order for energy efficiency to be achieved.

Consequently, we worked with Habitat for Humanity International (HFHI) to develop a three-step implementation process: we provided training on the checklist, we developed a poster to draw attention to energy efficiency at the construction site, and HFHI arranged for energy specialists to be present at each site to ensure that the guidelines were followed.

Several months prior to the JCWP, we provided energy-efficiency training sessions to construction managers at the local Habitat affiliates involved in the 1997 JCWP. This training centered on the material addressed in the energy-efficiency checklist and HVAC instructions. In order to promote the concepts we were advocating, we explained throughout the training how energy-efficient homes can be more comfortable and can have significantly lower utility costs for very little additional initial expense. We explained the energy-efficiency measures on the checklist and HVAC instructions and demonstrated their use by low-skilled volunteers on other Habitat construction projects. We showed the local affiliates that the materials on the checklist were inexpensive and available from their local building suppliers.

We developed an energy-efficiency poster (Figure 4) to be hung at each of the 50 houses during the week of the blitz build. The intent of the poster was to help focus attention at the construction site on the importance of energy efficiency and to be an educational tool. The poster listed the 34-item energy-efficiency checklist and provided blocks next to each item to be checked off as they were completed. The list of measures was accompanied by detailed diagrams showing how the measures should be installed.

As a final step to ensuring the construction of energy-efficient houses during the 1997 JCWP, an energy specialist was assigned to each house during the week-long construction of the homes. Many Energy Efficient Building Association members served as energy specialists. Other specialists came from national laboratories, research facilities, and even other Habitat affiliates.

The primary role of the energy specialist was to champion energy efficiency at the site by demonstrating an enthusiastic commitment to energy efficiency and making sure energy details were completed during construction. The energy-specialist was also charged with educating house leaders and volunteers on energy-efficient construction techniques and how energy-efficiency measures work.

Energy experts obtained acceptance to the energy-efficiency work from house leaders by explaining the importance of energy efficiency. They had to work with house leaders, crew leaders, and the skilled volunteers to overcome their resistance to changing standard operating procedures so that energy-efficiency measures could be correctly installed. They did this by being constantly open to questions, willing to provide hands-on training, and patient and persistent in seeing that energy-efficiency work was correct and complete.

Energy experts developed job assignments for the energy-efficiency work on a house by house basis depending on house leaders' preferences, availability of volunteers to serve as energy assistants, and other individual situations. Experts typically organized volunteers to do energy tasks and used the diagrams on the energy poster to explain to volunteers how to install energy measures. The energy coordinators then worked "hands-on" with volunteers to install efficiency measures and checked off tasks on the energy poster as they were completed. Throughout the week, energy experts answered questions from house leaders, contractors, and volunteers on the reasons for and benefits of energy efficiency.

We found that unskilled workers often became the best energy assistants despite the need to demonstrate and instruct clearly. They were the most willing to learn something new. When they clearly understood the benefits of energy efficiency and the need for completeness of coverage, they became the most methodical, persistent, and enthusiastic workers.

Energy specialists proved to be essential to the success of the energy-efficiency initiative. The focus of many house leaders and workers was on completing construction of the house as scheduled within the week allotted. Efficiency measures would have been neglected or installed incorrectly if the energy specialist had not been present to make sure measures were installed as intended at the proper time during construction. This was especially true during the first hours of construction when almost everybody's attention was directed at raising the walls of the house. Continuous beads of caulk had to be applied to the flooring (to air seal the bottom plate) before the preassembled exterior walls were put up, a detail that could have been overlooked during the exuberance of the hour (Figure 5).

Good energy specialists had to be good teachers. On one house, volunteers were installing floor insulation with the kraft paper facing the wrong direction until an energy specialist discovered it and gave them guidance on correct installation. Energy specialists were also needed to show workers the diligence needed to perform some measures. For example, the energy specialist showed volunteers how sealing every penetration, gap, or hole in the thermal envelope was important to reducing house air leakage.

The energy specialist's role as an inspector was critical. In some instances energy specialists would demonstrate and instruct volunteers on correct installation techniques, leave the volunteers to do the work, and come back later to find that it had been done incorrectly. In most cases where this was a problem, the volunteers did not understand the need for complete coverage and thoroughness. Energy specialists learned that they had to check behind volunteers before the work was covered up to make sure that the work was correct.

At one construction site involving 10 houses, energy specialists tested and found a large duct leak in the first system installed (Figure 6). A sheet metal box was being installed in the crawlspace underneath the return plenum so that a return duct could be run from it to the heat pump. This box had to be cut to fit around a center support beam of the house. The contractor was following the installation guidelines and was sealing the duct work and plenum with mastic. However, the contractor had inadvertently missed a large leakage site where the box fit around the center support because of cramped conditions. The energy specialists alerted the contractor to this problem before the job was finished so that it could be fixed and not duplicated on the remaining houses. Later duct work testing revealed that the contractor had successfully sealed this leak in the next house.

The energy specialists' commitment to energy efficiency helped them to be creative and persistent when materials which were expected to be available on site were not always provided. For example, we recommended inserting backer rod (sill seal) in gaps at windows and doors to seal the openings. With no backer rod available on site, energy specialists improvised with other materials (e.g., stuffing insulation and other building materials in gaps and caulking over insulation).

Blower door and duct blower tests revealed that tight houses and duct work can be obtained from use of the checklist, HVAC instructions, and on-site energy specialist even when using volunteers and working in the time constraints of a week-long blitz build. Blower doors tests on 12 sampled houses measured a range of 0.17 to 0.49 air changes per hour (natural) for the envelope only (with duct systems isolated). Our goal was to achieve a rate of about 0.40 air changes per hour. We often assume a typical Habitat house has a leakage rate of 0.60 air changes per hour based on previous measurements. Duct air leakage tests on four houses measured a leakage rate of approximately 76 - 94 cubic feet per minute at 25 Pascals which is much tighter than that often found in typical practice.

Energy specialists made several suggestions for improvement at the conclusion of the week that can be used to improve energy-efficiency efforts in future work for Habitat for Humanity and other affordable housing providers. One suggestion was to make the energy specialist an official crew leader to give legitimacy to the energy-efficiency work. Several energy specialists suggested meeting with each other to compare notes and make suggestions to each other during construction. They also thought that having more written information and copies of the poster would help with education of volunteers to conquer misconceptions and encourage a commitment to energy efficiency.

CONCLUSIONS

A first step in energy-efficient construction can be achieved by improving a few current construction practices and, sticking with simple tasks and inexpensive materials. An on-site poster lists and describes energy measures is an effective training tool which provides an energy focus to construction activity. It helps people understand how energy measures work and how to install them.

A persistent "energy champion" on each site is a key to ensuring that energy efficiency is achieved in practice. HFHI is in the process of forming a Green Team. A Green Team member at each local Affiliate will advocate energy efficiency within the Affiliate and should be able to work on site during construction to make sure energy practices are followed. Within the broader affordable housing community and even Habitat itself, always having an energy specialist on site during construction may not be realistic. The challenge is to empower the responsibilities of the energy specialist to the construction leader and crew members so that energy concepts become their standard construction practice.

Through the use of an energy checklist, HVAC instructions, and energy specialists, 50 energy-efficient Habitat houses were constructed and hundreds of volunteers learned that conserving energy saves money and improves the quality of homes. Aileen Pistone, training coordinator for HFHI's Department of Environment, said that "hundreds of people now understand what is meant by energy efficiency and that it is not beyond their skill level to increase the affordability of a Habitat house."

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Figure 1. A checklist of energy-efficient construction practices that we wanted to implement in the 1997 Jimmy Carter Work Project was developed.

Energy-Efficient Construction Checklist

FOUNDATION

- ☐ 1. Grade slopes 5% or more *away* from foundation
- ☐ 2.
- ☐ Install 6 mil plastic ground cover
- ☐ 3. *Close* crawlspace vents

AIR SEALING (Use caulk, foam, and other materials as identified below)

Before drywall is installed:

- ☐ 4. Seal bottom plate *during* construction
- ☐ 5. Seal inside edge of bottom plate *after* frame walls erected
- ☐ 6. Airseal *behind* and *around* bathtub *before* bathtub installation and *after* insulation installed (see Item 25 below) using plastic, drywall, or other sheet goods
- ☐ 7. Seal windows and exterior doors (backer rod *preferred*)
- ☐ 8. Seal wiring, plumbing, and HVAC penetrations at top and bottom plates, ceilings, and floors

After drywall is installed:

- ☐ 9. Seal bathtub drain penetration *after* bathtub installation and *before* floor insulation installed
- ☐ 10. Seal electrical boxes (receptacles, switches, lights, and circuit breaker box) to drywall
- ☐ 11. Seal bathroom ventilation fan to drywall
- ☐ 12. Seal attic bypasses and chases (open partition walls, dropped ceilings, duct and flue chases) *before* attic insulation installed
- ☐ 13. Seal return duct plemum (if present) (mastic *preferred*) or caulk
- ☐ 14. Seal duct boots to floor or drywall
- ☐ 15. Verify that the HVAC contractor has sealed return and supply duct connections (mastic *preferred*) and openings at the air handler (tape at access panels)
- ☐ 16. Seal exterior penetrations (e.g., porch light fixtures, outside outlets, phone and electric service holes)
- ☐ 17. Seal gaps around whole-house fan frame (tape or foam *preferred*)
- ☐ 18. Fabricate whole house fan cover using rigid board insulation
- ☐ 19. Weatherstrip attic access hatch cover

INSULATION

- ☐ 20. Use rigid board insulation to insulate slab edge and install flashing as a termite shield
- ☐ 21. Use insulation hangers (rods) placed *every* 12 inches to hold floor insulation in place
- ☐ 22. Use energy efficient framing (e.g., energy corners, T-walls, insulated headers) to improve coverage
- ☐ 23. *Carefully* staple kraft paper facing of wall insulation batts to side of studs or front (*preferred*) to avoid compressing batts
- ☐ 24. *Cut* wall insulation batts to fit around wiring, wall outlets, and plumbing
- ☐ 25. Insulate around bathtub *before* bathtub installation
- ☐ 26. Install soffit dams and rafter guides to provide clearance for soffit ventilation
- ☐ 27. Insulate attic access hatch cover

SHEATHING

- ☐ 28. Repair and replace any deficiencies in the rigid board insulation
- ☐ 29. Tape sheathing seams *or* install housewrap (*preferred*)
  - (a) Cover and *seal* housewrap to top and bottom plates and sills
  - (b) Cut *diagonals* for windows and doors and fold back to *inside*
  - (c) *Overlap* and caulk or tape seams
  - (d) Seal *all* cuts and openings

EQUIPMENT CLOSET

- ☐ 30. Isolate equipment closet from conditioned space if gas furnace or water heater used by:
  - (a) Insulating and sealing perimeter walls
  - (b) Installing solid, non-louvered door with weatherstripping and threshold
  - (c) Sealing gas and water line penetrations
  - (d) Providing inlet air for combustion

WATER HEATER

- ☐ 31. Insulate water heater with jacket
- ☐ 32. Install heat traps (check valve or inverted loop) on both hot and cold water pipes
- ☐ 33. Insulate all hot water piping in closet and first two feet of cold water pipe
- ☐ 34. Insulate water pipes in crawlspace for freeze protection

Figure 2. Thorough air sealing, while labor intensive, does not require skilled workers and can easily be done by volunteers.

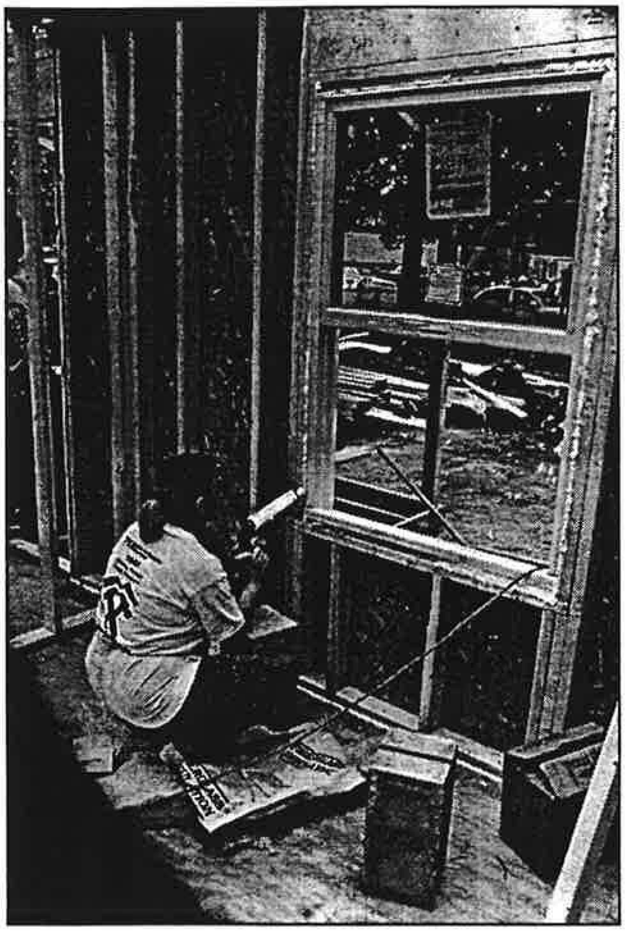

Figure 3. Habitat for Humanity's 1997 Jimmy Carter Work Project provided a good test for the effectiveness of checklists and instructions in making a first step at improving energy efficiency in affordable housing.

Figure 4. Energy-efficiency posters hung on site listed energy-efficiency measures to be performed during construction and provided graphics on correct installation techniques.

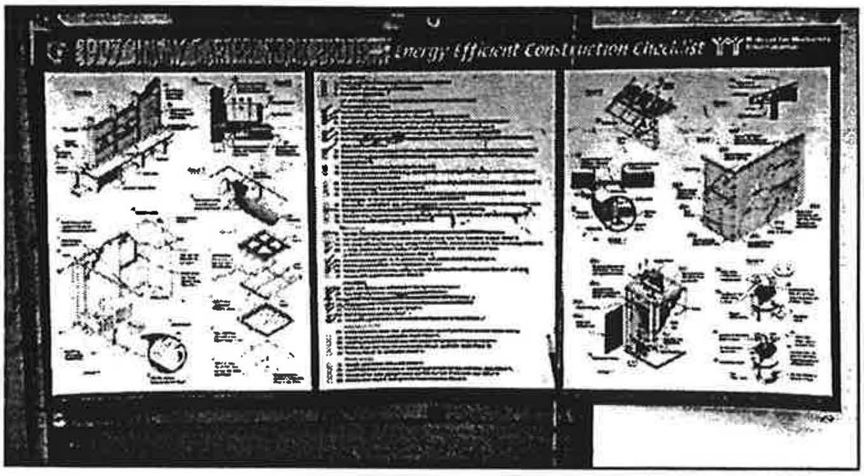

Figure 5. Energy specialists at each construction site made sure energy-efficient construction practices were followed, especially at the beginning of construction when caulking was required before walls were raised.

Figure 6. Energy specialists demonstrated methods of measuring energy efficiency to volunteers during the week of construction. Here, a duct test revealed a large duct leak that was sealed in this and subsequent houses.