Understanding the Implementation of Basic Building Science Techniques in Central Indiana Habitat for Humanity Homes as a Practical Example for Affordable Housing Providers

Adam Thies

Undergraduate Thesis

Submitted for the Completion of the Degree:
Bachelor of Urban Planning and Development

From:
Ball State University
College of Architecture and Planning
Department of Urban Planning

Dr. William W. Hill – Thesis Committee Chair
Dr. Eric Damian Kelly – Thesis Committee and Class Advisor

Submitted:
April 27, 2000
table of contents
Chapter One

Adam Thies
Ball State University
College of Architecture and Planning
Department of Urban Planning
May 2000

Introduction
Introduction to the problem

Affordable homebuilders such as Habitat for Humanity are making large changes to the housing stock and development fabric of our cities and countryside. This influence makes these organizations major “players” in the world of land-use and housing development. However, are Habitat homes as healthy and safe as they should be? Are they durable enough to last into the future? Also, are they truly affordable? I believe that most affordable housing can be improved through a general understanding of the processes that occur within homes. Understanding these processes, known as the study of building science, is the key to creating an improved model for affordable housing.

Has the home been improved in keeping with our level of understanding about housing technology and science? While there is no shortage of building science research and a wide variety of solutions to energy conservation and building engineering issues, there is growing evidence that we are constructing homes that are not working (EnergyBuilder.Com, 1999, p.1). Kelly (1996, p.359) states that builders in the US today offer homebuyers of the 21st century a product developed and refined in the 19th century and that indeed the basic house has changed little since the turn of the century.

Has the residential building industry been reluctant or unable to change its techniques and practices? I believe that there is a misunderstanding of building science. Most people view building science techniques as methods of only improving energy efficiency and lowering utility bills. While, this is true in some respect, I think that energy efficiency should not be the largest concern of affordable housing providers.

Through research of Central Indiana Habitat affiliates, I will demonstrate that there are many more concerns that need to be addressed in our homes. Health and safety issues, concerns about long-term durability, and comfort problems all are issues in addition to energy efficiency and affordability. But the issue is not just information on building science techniques, but also strategies for breaking down the barriers that exist towards its implementation.
How then do we study the diffusion of this information into the building practitioner’s world? Due to the limitations of the scope of this thesis, I have chosen only to look at how we diffuse building science information into the affordable housing market of one-story residential homes in Central Indiana. This choice is made for three reasons. First, the affordable housing market builds many one-story residential homes. Second, affordable homes are similar in form (small, few customizations). Those that build small residential homes for affordable housing build them in a similar fashion, typically that of a ranch “box.” Third, my affiliation with Habitat for Humanity provides an excellent opportunity to research the affordable housing market. As Habitat for Humanity, the country’s largest affordable housing provider, moves toward 100,000 homes built by the end of 2001, the need to understand building science in the affordable housing market and its effects on communities has never been so imperative. By analyzing and addressing the building techniques of Habitat homes, I believe a precedent can be set for other affordable housing providers to follow.

Using Habitat for Humanity as a case study for implementing building science techniques has ramifications for all aspects of the affordable housing community, and especially those building single family homes. First, by understanding Habitat’s “barriers” to diffusion of building science information, connections can then be drawn to other affordable housing providers. Second, by studying these “barriers” or at the least “perceived barriers” to using building science, Habitat for Humanity homebuilders can find ways to increase overall resource conservation understanding and practice, resulting in savings and benefits for individual homeowners and communities alike.

**The purpose of this thesis**

This thesis will:

- Examine the connections between affordable housing and the implementation of building science practices.
- Examine and provide background on what has been researched and tested in terms of affordable housing building science techniques and their applications.
- Investigate what barriers to building science education exist and how those barriers might be removed.
• Research the energy efficiency of Central Indiana Habitat homes as a benchmark for understanding the need for building science implementation.

• Examine Central Indiana Habitat for Humanity affiliates as organizational homebuilders to observe the potential for education in basic building science techniques.

• Evaluate the effectiveness of implementing building science in affordable housing construction.

**Personal interest in topic**

I have a strong personal interest in Habitats for Humanity and other non-profit affordable homebuilders for a variety of reasons. First and foremost, I have been heavily involved with Habitat for Humanity homebuilding projects, logging 1200 hours of volunteer time as well as coordinating many work trips and other Habitat for Humanity events during my five years at Ball State University. In 1999, I coordinated the fundraising, construction, and volunteer work for a one-story ranch home in the Muncie area. This project involved building a 1,150 square foot home over the course of nine months (Illustration 1.1). This involvement and activity gives me an understanding of the process of building a home and the work and effort that is required. This experience also gives me an understanding of potential building construction problems and pitfalls in homes built by Habitat.

A good portion of my coursework in Urban Planning has also dealt with affordable housing, historic preservation, and resource efficiency. In the fall 1999 semester I completed a course in building science technology, including lab and diagnostic testing. Many of the building diagnostic tests have utilized Habitat homes as test sites. Therefore, a topic of this nature is within my area of study.

In addition to coursework in these related areas, throughout the fall 1999 and spring 2000 semesters, I have been working on an Undergraduate Fellowship that was granted by the Honors College at Ball State University. This fellowship is under the guidance of Dr. William W. Hill, Professor of Urban Planning at Ball State and a major researcher in the field of building science. The fellowship’s goals run parallel to the purpose and goals of this thesis and all work conducted for the fellowship had a direct impact on this thesis.
Finally, Habitat and other organizations care about people. I do as well. However, affordable housing provider’s efforts are not always grounded in solid building technology information. Often their practices are based on personal beliefs and “hand-me-down” information that may be incorrect. This misinformation leads to poorly built homes, which in turn costs people and our communities in the long run.

It is my hope that this thesis project will help local Habitat affiliates understand the barriers to the implementation of building science and then propose solutions to these barriers. Assisting in these areas of concern would result in a rewarding experience not only from a personal standpoint but also from a professional standpoint. As a community builder, with a goal of improving the quality of life for a community’s residents, it is one of my top priorities.

My role as a researcher and resource in this topic extends from both my knowledge and interest as a planner of spatial environments and as a designer of efficient systems in our environment. I bring a level of general understanding about building science, building technique, and energy efficiency that will meld together to form the basis for my learning. I also bring a curiosity on how to improve things that we already have without creating new. Some of this comes from my interest in historic preservation and some from my interest in building construction. Essentially, I am fond of the BASF commercial that says, “We don’t make the things you buy, we make the things you buy better.”
Background

This section outlines and explains the chain of understanding that is needed to explore the world of affordable housing and building science technology. First, the wide variety of terminology that will be used throughout this paper, including a definition of affordable housing, is discussed and explained. Second, three areas of construction are discussed that have changed our understanding of building science, focusing specifically on how these areas relate to the affordable residential housing market. Third, the goals of building science are examined with specific examples of how each goal is achieved. Finally, the relationship between affordable housing and building science and its importance to Habitat for Humanity as an affordable housing homebuilder is addressed.

Understanding of terminology

Before continuing this discussion, it is necessary to explain various terms used.

- **Building science** is the study of how structures work from a systems approach.
  
  Basically, building science analyzes scientific principles of moisture and airflow and develops constructable solutions to problems that deal with these principles.

- **Durability** relates to how long building materials, assemblies and systems are able to remain functional over time while exposed to normal environmental conditions.

- **Comfort** is a difficult term to represent by definition, but is basically a qualitative measurement of how well a building provides services such as heating and cooling at desired levels.

- **Resource efficiency** is the practice of minimizing the building components (lumber, materials), the resources needed to install and maintain those components (labor), and the resources needed to operate the system in which those components and or whole package operates.

- **Energy consumption** occurs anytime that energy resources are used to generate the needed power to make a process happen -- the furnace kicking on.

- The term **energy efficiency** relates to the ability of a process or policy to use less energy while still providing similar or identical benefit to the user.

- **Energy conservation** is the practice of implementing energy efficiency techniques.

While many view the term “affordable” differently, the definition given below will dictate the use of the term in this thesis in relation to being “low-income.” Matthews (1994) states, “according to the U.S. Department of Housing and Urban Development,
housing, defined as rent and utilities, is affordable for a low-income household if it consumes no more than 30 percent of a household's income.” For the purposes of this paper, $42,200 will be used as a median area family income to determine low-income in Central Indiana. Using this information to calculate a 30% housing cost as described in the definition above, the homes discussed in this thesis cost between $35,000 and $52,000 in the Central Indiana marketplace (Department of Housing and Urban Development, 1999).

What is building science?

Understanding how a home works has traditionally been a process of apprenticeship. Many contractors and homebuilders have no formal education on the science of building new houses and rehabilitating older homes. More often than not, contractors simply follow what has “worked in the past” and what has been taught to them through apprenticeship programs. Jahn (1995, p.8), argues that all too often ideas are not shared about what really works. He states,

One of the problems affecting cost and quality control in housing construction today is that two similar projects going up at the same time, built side-by-side by different companies, can each be making the same costly mistakes without either one benefiting from the other’s experience…. All find themselves on the uphill slope of the learning curve, repeating many, if not most, of the same hard-earned lessons. This is an enormous waste of time, energy, and money. (Jahn, 1995, p.8)

The concept of looking at residential building and construction using scientific principles is essential to truly understanding the house as a system (Illustration 2.1) and developing an understanding of residential home construction science (Hill, 1999). According to the Building Science Corporation (1999), the field of “building science” is also known as “building physics” or “building dynamics.” Building science itself is the “study of the interaction between the various materials, products, and systems used

![Illustration of building science](Image-url)
in building construction, the occupants of these buildings, and the environment in which they are located" (Building Science Corporation, 1999). The Building Science Corporation (1999) goes on to say,

During the past twenty years, there have been revolutionary developments in materials, products and systems in the housing industry, and the technology of construction has become exceedingly complex. As a result, an abundance of specialists have focused only on their own disciplines. However, all of these disciplines including structural engineering, mechanical engineering, architecture, fire protection, acoustics, and interior design are interrelated and have an effect on the long term durability and performance of a building. These relationships must be understood to avoid costly mistakes and long-term costs to society and the environment.

The interrelationships between mechanical systems and building envelopes and their impact on indoor air quality and durability are significant. The design and construction of the building envelope (the walls, roof and foundation) significantly affect the design of the heating, ventilating and air conditioning (HVAC) systems. At the same time, the operation of the HVAC system affects rain penetration, condensation within building cavities, and the durability of the building envelope. Similarly, the interior design and building envelope design and construction affect the indoor air quality within a building.

Many people believe that our homes are improving with better craftsmanship and better materials. However, the problem is not in either of these two areas. According to Joseph Lstiburek, lead building scientist at the Building Science Corporation (1999, p.2), “The problem is understanding. The pieces must be put together correctly. In order to do so, we must understand how homes work. Homes today work differently than they did in the past. The old solutions and old understandings don’t apply.” This addresses a major point in the building profession: namely, that the buildings that we make today, with today’s materials, are not the same ones that a seasoned homebuilder might have learned about as an apprentice.
What has happened to make our homes change?

According to Lstiburek (1999, p.2), there have been three important changes in the last 50 years:

* The introduction of thermal insulation
* The development of tighter building envelopes
* The advent of forced air heating and cooling systems

The introduction of thermal insulation has certainly had a tremendous impact on making our homes more comfortable. However, by keeping the heat in or the heat out, the insulation has kept the heat out of the wall cavities and ceilings themselves. The opportunity for moisture to leave these cavities has been greatly reduced because of this factor. Lstiburek (1999, p.3) describes this loss of heat as an increase in the “wetting potential” of the building system and/or a reduction in the “drying potential.”

For many years builders and architects of buildings have been saying, “You have to let a building breathe!” In fact, a house does need to have several “changes” of air to let the by-products of moisture, formaldehyde from particleboard in furniture and cabinets, volatile organic compounds, radon, and carbon dioxide leave the house (Illustration 2.2) (Lstiburek, 1999, p.23). However, we are now building tighter homes so even those small air leaks in our homes, which used to clear our homes of these by-products, are not as numerous. What makes this important is the trend in lower air leaks in our homes has come at a point in our history when there are more harmful contaminants in our homes than even before (Lstiburek, 1999, p.4). This creates a very dangerous situation and also lends itself to increased importance in affordable homes. Why? Because a simple single-story home is by nature a tight structure. Fewer gable ends, extra dormers, and other house “bump outs” make the typical affordable home tight. However, this does not let the toxins of today leave our homes and presents a pressing problem for today’s homeowners.

Increasing tightness of homes is also a problem in combination with the increased use of forced air systems (heating and air conditioning). Moving air in a tight house can create air pressure differences, leading to a variety of health and safety concerns including the back drafting of hot water heaters and furnaces. Other potential problems from depressurization include the infiltration of radon, moisture, pesticides and soil gases.
The goals of building science

Building science is about more than energy efficiency. In fact, chapter 5 addresses the notion that building science is only about energy efficiency improvements. According to Hill (1999) there are four major goals to improve housing through building science principles. These four goals include:

- Providing a healthy and safe environment for home residents
- Improving the long-term durability through the control and management of moisture sources and moisture driving forces
- Improving the long-term comfort of the home
- Creating energy efficient homes that utilize our environmental and energy resources in an efficient and responsible manner and create affordability

The following section describes the effects that building science has on each of these goals.

Building Science:

Maintaining and improving occupants health and safety

A builder must prioritize building choices regarding the wide variety of needs that are present. Priorities include:

- People priorities
- Building priorities
- Environmental priorities

Of these priorities, Lstiburek (1999, p.11) places occupant health and first. He says, “Houses should be safe and healthy first. A safe, healthy home is one in which concerns about structural adequacy, fire and smoke spread, security, and indoor air quality have been addressed.” Every part of a house has a role in the occupant’s health and safety. For example, backdrafting hot water heaters are a common cause of CO emissions into residential homes. Since homes are much tighter, the home is capable of depressurizing much faster than before. This depressurization can cause the hot water heater to “backdraft,” spilling its combustion gases, including deadly carbon monoxide, into the living area (Hill, 1999). This is one example of why we must understand homes scientifically -- to prevent these health and safety problems.
Building Science: Improving the durability of the home

The use of building science principles will also increase the durability of the home by controlling moisture and its location in the building structure. This understanding of moisture is the key to understanding how to build better homes, according to Hill (1999). In Habitat for Humanity homes, the case is even stronger. Since Habitat works with scarce monetary resources, it is essential that homes last for long periods of time. Therefore, creating a durable model is essential to the success of Habitat's goal of eliminating sub-standard housing (Habitat for Humanity International, 1999).

Building Science: Increasing comfort in the home

Because homes have changed so much in the last 50 years, our understanding of how to provide a comfortable setting has as well. Many of the products used to make homes more comfortable are being installed incorrectly. According to Proctor (1999, p.1) one example of poor installation occurs with air conditioners. “It is generally accepted that the ‘right way’ to specify an air conditioning system is to calculate the loads and select a piece of equipment that will provide comfort to the customer in a wide variety of conditions. Unfortunately this is rarely practiced.”

Equipment specifications, design, and installation directly influence comfort. Once again, the relationship between this aspect of the goals of building science and the study of affordable housing is strong. The typical Habitat affiliate has minimal understanding of the HVAC equipment being installed in the homes they build. This can result in comfort losses for the homeowner and also cost increases for the Habitat affiliate building the home.

Building Science: Making homes affordable

Of all the goals of building science, affordability (often thought of as solely energy efficiency) has probably received the most press. The section, Energy Intensities of Central Indiana Habitat Homes (Chapter 5) provides tangible data that analyzes the energy use of Habitat homes in Central Indiana. Although the other goals of building science, mentioned above, should be also be addressed by Habitat affiliates regardless of energy efficiency, energy costs and affordability are very important to the Habitat process and are addressed below.
The cost of energy is especially important in affordable housing because, while low-income households consume 22 percent less energy than the “non-poor,” they use 20 percent more energy per square foot of living space (Vine and Reyes, 1987, p. 23). Moreover, while low-income residents may not pay larger total bills for energy, they pay a larger proportion of their income for utilities. According to the Southface Institute (1999), some low-income families spend over 15 percent of their income on energy to operate their homes (Illustration 2.3). This often creates a situation of missed bill payments, high utility disconnection rates, and patterns of slow or no bill payment (Jeter, 1995, p.8).

According to the Southface Institute (1999), “Energy efficiency helps families and their communities. If the 900 affordable homes scheduled to be built or renovated in an Atlanta, GA community are made energy efficient, the families will save over 7 million dollars on energy costs over the 30 year mortgage period.” These conserved monetary resources can then be cycled through the community as an economic growth tool.

Mathews (1994, Interview) states,

In metropolitan areas, at least 75 percent of low-income renters pay more than 30 percent of their income for housing. In many areas, low-income homeowners and renters spend over half of their income on housing. In winter, it is not uncommon for energy costs to be the single largest housing cost for many low-income households…. Affordability, the critical element in avoiding abandonment or homelessness, sometimes hinges simply on the cost of energy.

It is evident that decreasing the costs of energy in affordable housing has the potential to increase the ability to house low-income citizens and help them maintain their ownership. But we may ask, “Why is homeownership important?” Housing and Urban Development (1999) tells potential homeowners,

You’ll love the feeling of having something that’s all yours - a home where your own personal style will tell the world who
you are. A thriving vegetable garden in the backyard, a tiled entryway, a yellow kitchen.... When you own, you can do it all your way! But there's more to owning a home than personal satisfaction. You can deduct the cost of your mortgage loan interest from your federal income taxes, and usually from your state taxes, too. And interest will comprise nearly all of your monthly payment, for over half the number of years you'll be paying your mortgage. This adds up to hefty savings at the end of each year. And you're also allowed to deduct the property taxes you pay as a homeowner. If you rent, you write your monthly check and it's gone forever. Another financial plus in owning a home is the possibility its value will go up through the years.

If affordability is a goal of homeownership programs, then resource efficiency must play a major role in achieving that goal. According to a series entitled "Buildings for the 21st Century" developed for the US Department of Energy by the Southface Institute (1999) and other partners, energy efficiency is a major key to affordable homeownership. The series also contends that, "If homeowners pay less for energy, then they can afford larger mortgages.... When added to a mortgage, energy improvements usually cost less than the savings they offer on utility bills." However, the correct building methods and understanding of building science must be employed to achieve these savings on affordable homes. The Habitat for Humanity organization provides a base to study this understanding or lack thereof within a large-scale provider of affordable housing.

The world's largest affordable housing provider:

Habitat for Humanity International

Since its founding in 1976 by Millard and Linda Fuller, Habitat for Humanity International has built and rehabilitated some 80,000 houses with families in need, becoming a true world leader in addressing the issues of poverty and affordable housing. Habitat for Humanity International is a nonprofit, ecumenical Christian housing ministry that seeks to eliminate poverty housing and homelessness from the world, and to make

Understanding the Implementation of Basic Building Science Techniques in Central Indiana Habitat for Humanity Homes
As a Practical Example for Affordable Housing Providers

12
decent shelter a matter of conscience and action. Habitat invites people from all walks of life to work together in partnership to help build houses for families in need. Habitat has provided some 400,000 people in more than 2,000 communities with safe, decent, affordable shelter (Habitat for Humanity International, 1999).

The Habitat for Humanity model works through volunteer labor and tax-deductible donations of money and materials. Habitat then builds and rehabilitates simple, decent houses with the help of the homeowner (partner) families. Habitat houses are sold to partner families at no profit, financed with affordable, no-interest loans. The revenues from the homeowners' monthly mortgage payments enter a revolving Fund for Humanity to build more houses. Habitat carries out its mission at the community level through independent, locally run groups called “affiliates.” Affiliates around the world raise the funds used to construct houses. Some affiliates in developing countries also receive funding grants from Habitat for Humanity International (Habitat for Humanity International, 1999).

Habitat affiliates are local, grass-roots organizations. Concerned citizens come together to address the problem of poverty housing in their community when forming these affiliates. These citizens form committees, research the community's needs and resources, and evaluate the potential success of Habitat's self-help model in their community. The group then applies to HFHI for formal affiliation. Once approved, an affiliate is directly responsible for all aspects of Habitat home building in its area: fundraising, site selection, family selection and nurturing, construction and mortgage servicing. The affiliates' relationship with HFHI is one of partnership. The affiliates build houses, while HFHI provides a wide range of support services and resources.

The cost of houses varies from as little as $700 in some developing countries to an average of $42,500 in the United States. Habitat houses are affordable for low-income families because there is no profit included in the sale price, labor costs are very low and no interest is charged on the mortgage. Mortgage length varies from 7 to 30 years for most homes.

Most affiliates have:
- A board of directors that makes decisions on the financial and organizational matters of the organization
- An executive director or [ED] who carries out those decisions of the board
- A construction coordinator who oversees the construction of the homes
- And many, many volunteers who assist in fundraising, building and administration.
Most of these people do not have a professional background in construction; thus, few have any training in how a building works.

**The connection between building science and Habitat for Humanity**

Building science should play an important role in Habitat’s home building efforts. Habitat as an organization has taken steps to get information out to its affiliates about the topics that have been addressed above. The creation of the Habitat for Humanity Environmental Initiative in 1994 is one area that has received a lot of attention within the organization at the national level. This initiative has focused some of Habitat’s resources on researching and providing affiliates with new knowledge in building science. The Habitat Environmental Initiative has created several handouts that illustrate many of the building science issues that Habitat homes face. These are included in appendix A.

However, there are many barriers to using this information in Habitat affiliates. A hypothesis of this thesis is that the Habitat organization has great potential for breaking down these barriers and demonstrating the usefulness of building science.
Chapter Three

Adam Thies
Ball State University
College of Architecture and Planning
Department of Urban Planning
May 2000

Literature Review
Literature Review

In this review the house as a system is addressed. The scope of study has been limited to four areas that relate directly to the four goals of building science: health and safety, durability, comfort, and affordability. These four topic areas will also serve as benchmarks in this study of Central Indiana Habitat affiliates and building science education and implementation.

After addressing the topic areas, the diffusion of information and technology is examined, paying particular attention to the diffusion of information relating to building science and the barriers that exist to building science implementation.

Focusing on four areas

This thesis addresses four areas of concern in Central Indiana Habitat homes. These include:

- Space heating and hot water systems
- Moisture control (focusing on the foundation and crawl space areas)
- Energy efficiency through air sealing
- Optimal-value engineering

Space heating and hot water systems

Heating loads, duct sizing, and other factors of the heating system make this aspect of Habitat building a candidate for sub-contracting most of the time. The heating system can have a large impact on the goals of building science for three reasons. First, most of these homes are being built with single return systems (one return vent for the whole house), which can cause large pressure differences in the small homes being built by Habitat affiliates. Second, most heating systems have the potential, when coupled with pressure changes, to emit combustion products into the indoor air of a home, creating health and safety concerns. Third, heating system ductwork can leak, resulting in problems in health and safety, durability, comfort, and affordability, if not sealed.

According to Uniacke (1999, p.3), “If a builder doesn’t test (the sub contractor’s work) he or she may not be getting what they have paid for from the sub.” Southface (1999) states, “Studies show that air leakage from poorly sealed duct work can waste over 30 percent of a home’s heating and cooling energy.” It may be that most Habitat...
Construction managers do not feel they have the necessary knowledge to inspect the work of the HVAC subcontractor. The use of single return systems, duct sealing, heating unit sizing, and diagnostic testing will be addressed to achieve a quality heating and hot water system.

**Moisture control**

Because of climate and ground conditions in Central Indiana, most Habitat for Humanity homes in the Central Indiana region are built on crawlspace. A foundation wall that is built on the footings of the building forms this crawlspace as seen in Illustration 3.1. Long boards or “floor joists” make the structure for the floor of the home. Building foundations, including crawlspace, can be built with a variety of materials, but according to Lstiburek (1999, p.29), they all have to:

- Hold the building up
- Keep the groundwater out
- Keep soil gas out
- Keep moisture vapor out
- Let moisture vapor get out if it gets inside
- Keep the heat in during the winter

All of these conditions must be met for a foundation to function properly. In building a foundation for a home, the builder must be aware of a variety of concerns about foundations and their materials due to their important role in house durability (Hill, 1999).

One concern with foundations is that concrete cracks, shrinks, creeps, and moves. This can occur no matter what the reinforcement strategy is in the construction technique (Lstiburek, 1999, p.29). Lstiburek (1999, p.29) says that one must allow these forces of nature to occur and simply try and control their occurrence rather than fighting their effects. Simple understanding of how the concrete works can lead to a reduced threat of foundation failure. Hill (1999) states that protection of the foundation from moisture and moisture penetration is one of the most important aspects of house construction.

Understanding moisture -- its sources, driving forces and holes to entry -- is very important in creating quality foundations for long-term durability (Hill, 1999). Installation of perimeter drains, the application of a “paint-on” capillary break, and
proper design of site drainage are all steps that can improve the quality of foundations in houses.

Moisture control is also a concern when venting the crawl space. The venting of crawl spaces is one of the most misunderstood needs in building homes today. Many people believe that crawl spaces must have air moving through to take out harmful gas and to dry out the subfloor of the house. However, according to Hill (1999), the crawl space vents act as holes to the whole house as an airtight unit. These “vents” actually let air stream out and fail to keep the crawl space in the conditioned part of the home.

The building science solution is to eliminate the crawl space vents and develop a whole-house ventilation system to remove harmful gases. Illustration 3.2 shows research from the Southface Institute (1999) about the need for crawl space venting. Also, additional information about the inefficiency of vents can be found in the article, “Measured Energy Penalties From Space Ventilation” by Bill Hill (1998).

**Air sealing**

Sealing holes in the building envelope is essential to creating a good air barrier in a home. The “air-tightness” of a home directly affects the energy efficiency of the home. According to the Southface Institute (1999), “Reducing infiltration can significantly cut heating and cooling cost because infiltration can account for up to 50 percent of heating and a significant part of cooling loads.” Because every home leaks air at some level, all homes must have controlled ventilation. Techniques for air sealing and testing and other references for finding information on ventilation are listed below in Chapter 7.

---

*Understanding the Implementation of Basic Building Science Techniques in Central Indiana Habitat for Humanity Homes: As a Practical Example for Affordable Housing Providers*
**Optimal-value engineering (OVE)**

According to Southface (1999), building experts have performed considerable research on ways to reduce the amount of framing in our homes. OVE reduces unnecessary framing yet maintains structural integrity. The basic premise is that most homes use too much lumber in creating the frame of the house.

Southface (1999), also states that many builders have been resistant to adopt OVE practices due to concerns about compromising the structure of the home. However, with quality installation, the home’s framing system should be just as strong (Southface, 1999).

**The implementation of building science**

As explained above, there exists a body of knowledge on the topics of building science. But, how well has that knowledge been implemented? In this section, what other professionals have said about implementing resource-efficient building techniques and what motivations exist for their implementation is examined.

In response to the question of whether building science techniques are being implemented Uniacke (1999, p.2) states,

> A visit to homes under construction will reveal that builders are rarely utilizing the most basic energy-efficient building and design principles. Construction supervision on a custom or tract subdivision is an appearance and schedule driven process, and details such as the quality of the trim work, gypsum board finish, paint, cabinets, and final cleanup most often indicate a quality job to both the construction supervisor and consumer. But the housing industry needs to redefine a quality job to include a high quality insulation system, airtight ducts, energy-efficient framing and other areas of building science—benefits that the home buyer doesn’t “see” until the utility bills come in.

To understand why building science is not being implemented, we need to look at the construction industry structure for diffusing this “innovation” into the mainstream of
construction techniques. Burby and Marsden (1980) have dedicated significant research to the problem of diffusion of innovation in the residential housing market. This study, which looks extensively at the situation of energy and housing in North Carolina in the early 1980s, is an excellent source to gain an understanding about factors that influence residential home construction. Lutzenhiser (1994, p.867), in fact, looks toward “clues in social science research on organizations and technology change” for answers to the implementation question.

What does social science research say about the diffusion of innovation? According to Granovetter (1985, p.481), the study of behavior and reactions to new technologies is one of the classic questions of social theory. He discusses the fact that not all decisions are based on a purely rational economic model as traditionally assumed. Lutzenhiser (1994, p.867) supports this point by saying that most markets are believed to act in a pure economic rationale but in reality do not operate in that way. He goes on to argue,

Market failure has little to do with the workings of neoclassical markets, because the rational approach fails to appreciate two critical points. First, innovation, organization and technological substitution are socially regulated matters, and as such, they are shaped by a host of non-economic factors. Second, while current technologies may be less than optimally efficient in energy and environmental terms, they enable a highly integrated network of industry actors to produce housing and profits in uncertain environments.

If economic rationale does not prevail according to social scientists that have researched this topic area, what are the other barriers to building science diffusion? First of all, the social processes that determine the decisions of firms are not well understood (Lutzenhiser, 1994, p.868). Lutzenhiser (1994, p.869) states that “organizations that appear rational make serious mistakes, bad investments and poor management decisions. The behavior of firms seems to be shaped by a combination of cultural, institutional, macro-social/economic and technical factors.” Scheraga (1994, p.803) states, “We also need a better understanding of the process of technological innovation. The exercise of estimating unexplained residuals as a proxy for technological change can only have limited usefulness for forecasting the effectiveness of government programs that are intended to induce the development of more energy efficient technologies.”
Weber (1997, p.833), states that there are four types of obstacles to the efficient use of resources:

- Institutional barriers caused by political institutions (state governments and local authorities enacting building codes and other construction regulation)
- Market barriers with obstacles conditioned by the economic market
- Organizational barriers within organizations, especially in firms
- Behavioral barriers which work inside of individuals.

While Weber contends that it is empirically impossible to find the true reason for not taking an energy-conserving action, his four categories of barriers and possible rationales within each will be discussed.

**Institutional barriers**

An institutional barrier is, by Weber's (1997) definition, one that is imposed by a state government or local government in an effort to create a uniform building situation. This uniformity is achieved in the United States through a system of complex building codes. Although most of the codes are very complex due to their basis as legal documents, most have the objective of creating a healthier, safer, and more efficient built environment.

These institutional barriers such as the building code and its administration are some of the most difficult hurdles that building science faces in its implementation. According to the Pennsylvania Housing Research Center (1999), "One of these sources [of resistance to change to proper building science guided codes] is the resistance of the building code system and the local building code officials who administer these codes. Hill (1999) has stated that instead of facilitating change, the building code framework (details, administration) has impeded change. One of the underlying causes for this "resistance to change" is that the building code officials are not always up-to-date with regard to the technological changes that are being advanced.

Many of the codes that exist for electrical and plumbing are kept up to date and very modern. These codes operate very effectively overall. However, codes that relate to moisture control have not been updated as much as needed (Hill, 1999). The major factor is that moisture control is not the same in all parts of the country. Georgia has more humidity and moisture than Montana. Yet, they both are a part of the United States. As
we move to unify national codes we are missing the basic fact that moisture control strategies cannot be the same for all areas.

The building codes that govern American homebuilding, however, are currently being reviewed in a very extensive process. There are four major codes under review. These codes are:

- International Building Code (IBC)
- Uniform Building Code (UBC)
- Standard Building Code (SBC)
- Building Officials and Code Administrators (BOCA) National Building Code (BNBC)

The Department of Housing and Urban Development is currently reviewing these codes for technical information. Results of the reviews can be found on the Internet at http://www.hud.gov/fhe/modelcodes/.

This has an important ramification to Habitat for Humanity. Many Habitat affiliates strictly follow building codes without understanding the building science involved. The codes really do have a direct impact on how affiliates make decisions on how to build. As the next few years unfold, it will be very important to see how the organizations that determine codes create a guideline that is effective in respecting building science issues.

**Market barriers**

There are a variety of factors that affect the market for energy efficient techniques in the building world that are not well understood. According to Scheraga (1994, p.798), “We still do not have an adequate understanding of the behavior underlying the very energy markets we are trying to influence. Key questions persist about the potential existence of market imperfections, the divergence of private and social discount rates, the factors that influence energy consumption decisions and process of technological innovation that leads to the development of more energy-efficient technologies.”

What aspects of the market continue to make it a barrier to the diffusion of building science principals? Weber (1997, p.834) answers by saying, “Market conditions strongly depend on institutional constraints and prerequisites. An ideal market is defined as a system of transactions with well-informed unbound individuals and prices reflecting the unbiased balance of demand and supply. The subjects obstructed are mainly individuals
and firms which maximize their utility.” Therefore, the market, because it is not a perfect market of supply and demand becomes the obstacle to using a pure market approach to the “sale” of the energy-efficient and building science-endorsed techniques.

Lutzenhiser (1994, p.875) reiterates this understanding by stating, “Efforts to sell efficiency solely on the basis of cost savings offer extremely weak inducements to buyers and builders. These have been largely unsuccessful in an era of stable energy prices, regardless of the objective economic advantages of investment.” He then goes on to state that the main goal of energy efficiency should be not be the saving of economic resources (although that occurs), but rather the marketing of a product as safe and of high quality.

**Organizational barriers**

One barrier to the exchange of building technology exists in the densely woven networks of firms, regulators, builders, and financiers that affect the housing market. This barrier, called the organizational barrier, exists when the organization has or has had a mentality of “we have always done it that way.” This mentality is often prevalent in many affordable housing providers and their organizations, Habitat for Humanity included. Too often the people who make up these organizations mean well but impart, through social interaction and pressure, a barrier to change things for the better.

Weber (1997, p.834) discusses the organizational barrier in the following way.

> Models of organizational barriers define firms as social systems influenced by goals, routines, organizational structures, etc. Organizations are dominated by decision-makers. Barriers to energy efficiency in organizations may result in asymmetry of information, a trade-off with non energy-specific goals or missing responsibility with regard to energy consumption. Obstacles may occur in budgeting, in acquisition of new equipment, or in service and maintenance of that equipment.

Lutzenhiser (1994, p.869) discusses the fact that organizations must develop networks to successfully stabilize and control their decision-making environments. Consortiums, business links, and other connections to firms needing better information and support in their actions are all possible ways to clear the organizational barrier. He also states that
“progress is neither inevitable nor steady in pace. The historical record shows that it proceeds in fits and starts, is frozen in some cultures in some time periods and expands explosively in others.”

Behavioral barriers

Many times the barriers to change are the direct result of individual values or beliefs. These barriers may be fostered by a sense of “old school” dedication to building practices as well as by the respect for the teaching methods given to each respective individual. Weber (1997, p.834) describes behavioral barriers in the following way: “Behavioral barriers focus on individuals with their values and attitudes toward energy conservation. Obstacles may occur as lack of attention to energy consumption, lack of perceived control or a missing link between attitude and action. Social norms and lifestyle patterns may also hinder individuals to use energy more efficiently.”

Review of Building Science Implementation Problems

Clearly, the issue of building science and its implementation is more than a simple economic rationale of “savings equals a desire to implement.” There are many issues that are of concern in looking at the diffusion of that building knowledge. In review, these barriers include:

- Institutional barriers in the form of building codes and government implementation of the codes
- Economic barriers in a market that is not perfectly affected by supply and demand
- Organizational barriers that are a result of risk adverse organizations with a need for networked information paths
- Behavioral barriers that exist in personal values and knowledge and result in either a positive attitude toward building science implementation or negative attitude toward any changes to the “norm”

The following chapters of this thesis explore these barriers and techniques to overcoming them. A background and review on some of the knowledge that we have in the area of building science implementation has been laid out. In the next chapter, Chapter 5, weather-normalized data on energy consumption in Habitat homes is used to evaluate energy use. Then, in chapters 6-9, a variety of topic areas are examined that could be used in the future to implement building science techniques under the premise that there
are higher priorities than just energy efficiency. Finally, in chapter 10, recommendations to breaking the barriers to building science implementation in the Habitat model are provided.
Chapter Four
Research Methodology
Research Methodology
The Habitat model reviewed

Several factors influence the decisions about the construction of Habitat homes in Central Indiana affiliates. Gaining the support and understanding of the Habitat local affiliate the only way to improve the homes through building science. Educating the executive director (ED), construction manager, and other typically older volunteers who have influence in building decisions is the key. The attached diagram shows all of the actors in the process of homebuilding in the Habitat world (Illustration 4.1). The local affiliate is central to the process. Because of this fact, the local affiliate as the main decision-maker in the building process has been focused upon in this study.

Habitat as a case study has been chosen for a variety of reasons:

- As one of the nation’s largest affordable housing providers, Habitat provides an excellent example of an established organization with a long history of providing affordable housing.
- Many of Habitat for Humanity’s floor plans and home designs are similar. That is, many of their housing products have similar floor plans, require similar materials, and are assembled by a workforce that has a similar knowledge base no matter where in the country one travels.
- Habitat for Humanity International has already recognized its impact in the built environment through the efforts of its environmental initiative, started in 1994. This initiative opens the door for a research study focusing on implementation of building science and resource efficiency.
- Habitat has a workforce that is made up of a majority of volunteers. One hypothesis of this thesis is that Habitat is an excellent conduit for building science knowledge because of the ability to train and education the thousands of volunteers who participate in Habitat builds across the country.
- As described in the introduction section, I have an intimate knowledge of Habitat for Humanity practices, policies and construction methods. This knowledge gives me unique insight into potential areas for increased diffusion of building science techniques. Personal contacts and affiliations with local level and national level
A New Habitat Home
Habitat for Humanity representatives will allow for a more thorough understanding of issues facing the implementation of building science techniques.

- The nature of Habitat as a provider of homeownership opportunities lends itself to analysis of life cycle costing of certain building science techniques. This aspect of the “Habitat for Humanity market” allows for the direct analysis of the “whole picture” or long-term durability, safety, and overall quality of the house itself.

**Methodology goals and objectives**

To create a research methodology that follows a clear line of reasoning, it is necessary to establish understood goals of the research, describing the process for the research, the methods used, the questions used to seek answers, and an evaluation of the results discovered. These goals are meant to be a guideline to both reader and researcher, providing a framework of understanding for the topic area as well as a “checklist” for topic coverage and analysis. The goals are simple but relate directly to the issues that have been addressed in both the introduction and background sections of this paper. The goals for this research were:

- Research and obtain data on Central Indiana Habitat homes energy consumption to show that energy efficiency is not the major concern of building science in most Habitat homes
- Develop a detailed understanding of how Habitat for Humanity local affiliates make key decisions about construction and building issues
- Document the process of building science diffusion from Habitat International to the local affiliate level
- Document specific impediments that block the penetration of building science knowledge into the Habitat building environment.

**Research limitations and expectations**

The work of this thesis has been completed during the fall and spring semesters of the 1999-2000 school year. A limited research budget was obtained for trips and travel.

Noting these limitations on both time and monetary and physical resources, I have chosen a research study area of Central Indiana and the affiliates that reside in that area. This decision has been made for a variety of reasons:
• Proximity of affiliates to the Ball State University area, providing a low-cost opportunity for face-to-face interview and field research activities.

• Personal understanding of Habitat building techniques used in Central Indiana.

• Ability to develop key energy and resource data from existing homes through contacts at local utilities and energy service providers.

• Association with Dr. William W. Hill, who has a history of affordable housing energy analysis in the Central Indiana area.

There are several expectations for this thesis work. In Chapter 5, energy consumption data is given to understand how Habitat homes are functioning from an efficiency standpoint. This will be done using a standard program for calculating the intensity of energy use in a home with weather factors included in the calculations. This intensity shows how well the home is using its energy. With this information the initial hypothesis that most Habitat homes, because of their “box” style, are relatively energy efficient will be proved or disproved. This then pushes exploration of the other goals of building science: health and safety, durability, comfort, and affordability. They are explored because of the belief that most affiliates stop their building science efforts at energy efficiency, if they address that at all.

Research schedule

I have researched many areas of Habitat housing market. The following is a summary of my research activities:

• Direct mailings to all Habitat affiliates in the Central Indiana region.

  [November 1999] The goal of these mailings was to obtain preliminary information about Habitat affiliates and homes that they have built to date. Requests were made for total number of homes constructed and individual street addresses. These addresses were then used to obtain energy consumption data for each home.

• Site visits. [December 1999 and February 2000] The purpose of these visits was to gain qualitative data on the framework that exists within local affiliates, especially the jobs of the construction coordinator and executive director. The trips also included on-site observations of building science “concerns” that are addressed in later chapters. This information was then reviewed in an effort to gain a better understanding of implementation problems and barriers.
• **PRISM Analysis. [February 2000]** The data obtained from the direct mailing was analyzed using PRISM (The PRInceton Scorekeeping Method), a software program used to provide "weather normalized" annual consumption data for each home. The results of this analysis showed that most Habitat homes are energy efficient relative to other similar homes. Details of this analysis and results can be found in chapter 5.

• **Research and documentation of specific topic areas. [February through April 2000]** After researching that energy efficiency in Habitat homes, the other building science objectives mentioned above were researched. This technical information can be found in Chapters 6 through 9.

• **Barriers to building science implementation. [March and April 2000]** The challenges to breaking down the barriers to building science that were raised in the literature review were researched. This information is addressed in Chapter 10.
**PRISM analysis**

Determining the energy efficiency of a home has many variables. Weather conditions in the area, the average thermostat setting of the home and the style of the home are all important to determining energy efficiency. A process for addressing and then comparing energy use in Habitat homes in Central Indiana is outlined in this chapter. The purpose of this analysis is to understand how well Habitat homes are performing in terms of energy consumption and use. By addressing home energy efficiency, the most common concern associated with building improvements at the "building science" level is addressed. Whether Habitat homes are inefficient users of energy in comparison to other homes can then be analyzed. These two points will then lead to a discussion of other priorities of building science in Chapters 6-9.

**The process for addressing energy efficiency**

Habitat for Humanity homes in Central Indiana are mostly single story ranch homes ranging from 900 – 1100 square feet in size. This fact makes analyzing and comparing their energy consumption easier than if they had many different styles. It is also helpful that all Habitat affiliates use gas heating systems. This fact facilitated obtaining data on energy consumption over the history of the house and the ability to analyze that data with special software. The process for obtaining data follows:

- Letters of inquiry were sent to all Habitat affiliates in the Central Indiana area. This letter requested addresses of Habitat homes built to date by each affiliate. Six affiliates returned information on house addresses. Each address was then placed into a spreadsheet for analysis. The spreadsheet was formatted and checked for typographical errors.

- Using a contact for billing information at Indiana Gas Company, billing information was assigned to each address from the Indiana Gas Co. meter reading files. These files include dates and corresponding meter readings.

- Upon return of the meter reading data (gas consumption) the spreadsheet was analyzed by a software program called PRISM (PRInceton Scorekeeping Method) to produce a picture of how Habitat homes are using energy.
Understanding PRISM and energy intensity

According to the PRISM User’s Guide (1995, p.1), “PRISM is a statistical procedure that converts run-of-the-mill utility billing data into useful, weather-adjusted estimates of energy savings.” PRISM is regarded as an excellent program for evaluating energy usage. Application of the software program to this research was made on the basis of Dr. Bill Hill’s recommendation and expertise.

The only data requirements for the PRISM system are utility bills (gas meter readings obtained from Indiana Gas Co.) and average daily temperature from a nearby weather station. Once again, the resources of Dr. Bill Hill have assisted this research. He has collected weather data throughout past years in the Central Indiana area. This data was already formatted for the analysis of these Central Indiana home locations and was applied to this analysis.

Using a system of scientific equations and statistical analysis, PRISM produces a weather-adjusted index of consumption called Normalized Annual Consumption (NAC) for each house being analyzed. This means that weather has been taken into account when looking at the usage of gas energy. For example, if a winter was particularly cold, PRISM looks at the weather data and adjusts the NAC accordingly. This produces a reliable picture of house energy consumption on an annual basis for that home.

The NAC has many parts. PRISM creates a data picture that shows heating NAC, cooling NAC and baseloads of usage. This information can then be manipulated to show how much money is spent on heat, baseload, and the standard service charge, which is $108 for Central Indiana. Using a cost of $.60 a therm (standard unit of gas measure) for gas in Central Indiana, I calculated the mean gas heating bills annually for all affiliates. This data can be found in Illustration 5.1.

<table>
<thead>
<tr>
<th>Illustration 5.1</th>
<th>Mean per year breakdown of heating costs for a home in the study (93 Homes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$314.47</td>
<td>$108.00</td>
</tr>
<tr>
<td>$107.86</td>
<td></td>
</tr>
<tr>
<td>$108.00</td>
<td></td>
</tr>
</tbody>
</table>
The analysis, however, is not yet complete. In order for the NAC and information provided from PRISM to be effective it must be manipulated to allow for comparison to other homes. The standard system for comparison is using a house energy intensity (Hill, 1999). The energy intensity of a house shows how well a house has used the energy that it has consumed for heating and cooling activities. It is a statistical number that is for comparison purposes only. Energy intensity allows the comparison of homes in different climates and different regions. The energy intensity of a house is found using the following equation:

Heating NAC (based in therms) / 100000 (to convert to Btu) / House square footage / Heating Degree Days (5700 is used for this analysis; standard for Central Indiana according to Dr. Hill.)

Following this calculation, the energy intensity (Btu/ft²- DD) is then used to compare homes with other homes. It can do this because it has been adjusted for weather differences and the size of the house. (I have used 1050 square feet as an average for the Habitat houses.) The resulting number (total energy intensity) is usually in the range of 5 to 30, with 5 being an efficient user of energy and 30 being an inefficient user of energy. The real importance, however, comes in the comparison to other homes.

**Energy Intensity Results**

Following the procedure outlined above, information about the efficiency of the homes in the research study was derived. The mean total energy intensity of all the homes in the study is 12.1. On a scale of 5 to 30 that is a very good number and shows that the homes are operating at an efficient rate. Table 5.2 (Illustration 5.2) shows how each affiliate in the study compared to the other.

<table>
<thead>
<tr>
<th>Central Indiana Habitat Affiliate Energy Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Affiliate</strong></td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Clinton County</td>
</tr>
<tr>
<td>Grant County</td>
</tr>
<tr>
<td>Greater Muncie</td>
</tr>
<tr>
<td>Hamilton County</td>
</tr>
<tr>
<td>Jay County</td>
</tr>
<tr>
<td>Madison County</td>
</tr>
<tr>
<td>Monroe County</td>
</tr>
<tr>
<td>Richmond</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table 5.2
However, to give energy intensity an additional frame of reference, the homes in this Habitat study were referenced against homes that have been studied by Dr. Bill Hill that are of similar size. The results of this comparison are summarized in Table 5.2 (Illustration 5.3).
## Comparisons With Housing of Similar Size Across Central Indiana

<table>
<thead>
<tr>
<th>Number of homes in sample</th>
<th>Average size (ft²)</th>
<th>Total gas use</th>
<th>Gas used for heating only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Energy Intensity (Btu/ft²-DD)</td>
<td>($/ft²-yr)</td>
</tr>
<tr>
<td>1 Pre-Wx</td>
<td>78</td>
<td>23.3</td>
<td>$0.80</td>
</tr>
<tr>
<td>2 Post-Wx</td>
<td>78</td>
<td>18.3</td>
<td>$0.63</td>
</tr>
<tr>
<td>3 New PHA</td>
<td>63</td>
<td>17.4</td>
<td>$0.60</td>
</tr>
<tr>
<td>4 Old PHA</td>
<td>100</td>
<td>16.8</td>
<td>$0.57</td>
</tr>
<tr>
<td>5 W. Lafayette</td>
<td>25</td>
<td>13.2</td>
<td>$0.45</td>
</tr>
<tr>
<td>6 Thies Study</td>
<td>93</td>
<td>12.1</td>
<td>$0.41</td>
</tr>
<tr>
<td>7 MHODC</td>
<td>18</td>
<td>8.2</td>
<td>$0.28</td>
</tr>
</tbody>
</table>

### Notes

1. Anderson homes in DOE's Low-Income Weatherization Assistance program, 1995-96, prior to weatherization
2. The same homes as in #1, following weatherization
3. Public Housing — detached single family and duplexes, built in 1997-98, Indianapolis
4. Public Housing — detached duplexes built in the 1930's, Muncie
5. Detached single family homes of less than 1500 ft² for which building permits issued in 1990-96, West Lafayette
6. All homes in this study (Thies Study)
7. Homes built by the Muncie Home Ownership Development Center between 92 and 97

### Assumptions:

- Price of natural gas: $0.60 per therm
- Heating degree days: 5700 per year

Ultimately, this research has shown that Habitat homes are comparatively energy efficient. However, there are also other priorities that are important to Habitat home construction. These priorities are outlined in the next four chapters.
Energy intensities of homes of similar size in Central Indiana

Pre-Wx: 23.3
Post-Wx: 18.6
New PHA: 18.3
Old PHA: 17.4
W. Lafayette: 16.8
Thies Study: 13.2
MHODC: 12.1

Total gas use ■ Heating only □
Chapter Six

Heating and Hot Water


Heating and hot water systems

All Habitat homes have some form of a heating and hot water system. The quality of this system plays an important role in the house's long-term success as a habitable structure. Providing heat and hot water have become part of our lifestyle. This section explores the influence that this important system has in understanding many areas of building science.

Not all heating and hot water systems are the same. Different systems have different effects on those areas of building science concern. To understand how they affect the lives of the residents of a home, we need to understand of the components of the system. By understanding the components of the system we gain knowledge of potential problems that might occur. Most Habitat homes in Central Indiana contain a heating system, which includes a furnace and duct system for air transport.

Heating

There are many different types of heating systems available today. Wood fireplaces, solar roofs, electric baseboard heaters, and gas-fired combustion furnaces are all options to heat the home. For the purpose of this research, I will be addressing heating systems comprised of gas-fired combustion furnaces (Illustration 6.1). I have chosen this type of heating system for two reasons. First, it is the most popular in Central Indiana Habitat homes. Second, gas-fired combustion systems have the potential for serious health and safety concerns, which is the top priority area of building science.

There are a wide variety of gas furnaces on the market today. In past, older furnaces have been very poor at using energy efficiently. Many homes built in the 1950s and 60s have furnaces that use only 50% to 60% of the gas energy to heat a house. The rest is simply wasted. Fortunately, United States law now requires all furnaces to have AFUE (Average Fuel Utilization Efficiency) ratings of 78% or higher. Most of the gas furnaces that are being installed in Habitat homes have an 80% AFUE rating.
There are also 90%+ efficiency furnaces available that use energy more efficiently. 90%+ AFUE systems have several negatives, however, with respect to Habitat homes. A list of concerns follows:

- It is difficult to find high efficiency furnaces small enough for a typical (1100 sq. ft.) Habitat home built to Indiana code. That's right! A home as small as most Habitat homes do not need large furnaces. If a large furnace is installed the system could run very inefficiently. The affiliate often accepts the oversized unit because they assume "bigger is better."

- 90% AFUE heating systems are more costly than 80% systems. This fact is difficult to overcome when resources are scarce for Habitat construction projects.

Understanding these negatives for Habitat homes, I have chosen to assume an 80% AFUE heating system for my Habitat research.

**Hot Water**

The other major mechanical component is the hot water heater. This appliance is responsible for the delivery of hot water for everyday activities like taking showers and baths, washing clothes, and washing dishes. Almost all Central Indiana Habitat affiliates are using gas-fired hot water heaters (Illustration 6.2), but electric hot water heaters are also available. Gas hot water heaters are typically large cylindrical tanks that hold anywhere from 60 to 80 gallons. These hot water heaters have quicker recovery (time needed to heat water on demand) than electric hot water heaters, but they are atmospherically coupled (take air needed for combustion from the air surrounding the unit; natural draft system) creating a potential problem with backdrafting combustion products.

For safety reasons, one easy alternative is an electric hot water heater that is not atmospherically coupled like the gas hot water heater. Because the recovery is slower, a larger tank might be required with an electric hot water heater. As an energy conservation measure, off-peak electric storage water heaters are available in some areas. (Contact a local electric utility for more information about cost and availability.) These are typically 120 gallon units and heat water during off-peak energy hours reducing the strain on the energy system and the cost of heating.

---

*Understanding the Implementation of Basic Building Science Techniques in Central Indiana Habitat for Humanity Homes As a Practical Example for Affordable Housing Providers*

35
Heating and hot water system location

In the design of Habitat homes, the furnace and hot water heater are often placed in the same room, which is often referred to as the mechanical room. Another name for this room, and the one that will be used for this thesis research, is the Combustion Appliance Zone (CAZ).

The CAZ is so named because it contains combustion appliances, i.e., appliances that burn fossil fuels (natural gas or LPG in Central Indiana). Combustion appliances produce combustion products. The principal combustion products in an appliance that is operating correctly are carbon dioxide (CO₂) and water vapor, with lesser amounts of SO₂ and NOₓ. In a properly operating appliance these combustion products are vented out of the house through a vent system consisting of a flue or chimney (atmospherically coupled system), or plastic pipes (direct vent, sealed-combustion, 90%+ efficiency system) (Hill, 1999). See Illustration 6.3.

Health and safety problems can occur to this system if a combustion appliance is not functioning correctly. A combustion appliance may be not operating correctly in either of two basic ways: 1) If it isn’t combusting fuel properly, it produces, not carbon dioxide (CO₂), but carbon monoxide (CO), a colorless, odorless and deadly gas. 2) If it isn’t venting correctly, it “spills” these combustion products into the home instead of safely up the chimney to the outside. It’s the combination of the two things that can be deadly -- a combustion appliance making CO and also spilling it into the living space of the home. We used to think that this provided an extra margin of safety — to be deadly, the appliance had to be making CO and spilling it into the home. We now know that the two “failure modes” are not at all independent. That is, a properly operating combustion appliance that makes no CO when venting correctly will suddenly start making CO when the vent system fails to carry the combustion products out of the house.

Illustration 6.3

Understanding the Implementation of Basic Building Science Techniques in Central Indiana Habitat for Humanity Homes
As a Practical Example for Affordable Housing Providers

36
The science of gas forced air (GFA) heating systems

The GFA heating systems in Central Indiana Habitat homes have two basic components, combustion to create heat and air distribution to move the heated air throughout the house. Because of this fact, two major points must now be made.

- Both of these heating system components use air for their operation. However, air used with combustion cannot be the same as air used for distribution. This is important because air for combustion is harmful or “bad air” because it contains combustion products like CO. The air used to distribute heat to the house has to be safe or “good air” having no contact with the air of the combustion process. (Reference Illustration 6.3 for a picture of this process.)

The “bad air” side in an atmospherically coupled or natural draft, appliance has a big “hole” in it, by design. This is the draft diverter or draft hood (Illustration 6.3), through which it gets house air to help get the combustion products up and out of the house. That intentional hole becomes the problem when the air handler -- part of the “good air” side of the furnace -- is able to “suck” on this vent.

Combustion products discussed in this thesis include CO, or carbon monoxide. This odorless, colorless gas poses a great threat to inhabitant safety (Lstiburek, 1999). CO inhalation has many side effects including headache and nausea. Death from extensive CO exposure is also possible.

Combustion

As mentioned above Central Indiana Habitat homes currently use gas-fired combustion furnace systems with an 80% AFUE rating for efficiency. That means that the furnace needs to get air from the house to perform the combustion process, leaving the potential for harmful combustion products to mix with the “good air” mentioned above and causing health and safety concerns for residents. Additionally an 80% AFUE furnace needs to create natural draft (warm air rising through the chimney to make the airflow move up the chimney) to vent combustion products. According to Hill (1999), this natural draft relies on very small air pressure differences. If the chimney is cold and the air handler is sucking air from the CAZ, the draft may not start and combustion products can spill out into the living area.
As mentioned above, 90%+ AFUE systems are available in the market. These systems circumvent the possibility for “bad air” to mix with “good air” because of a controlled combustion system (air is directly vented into the system; there is no chance for air to “mix”), reducing the potential of a health and safety concern due to backdrafting.

**Air Distribution**

The second component to the heating system is air distribution. This system transports the heated air to all parts of the house creating a comfortable living environment. But to understand how this system operates an explanation of the air distribution system’s components and terminology must be made.

The first component to any air distribution system is the blower or fan. The blower is the mechanism for “pushing” the heated air to all parts of the house through the ductwork. A typical fan for a house this size will move 700-1000 cubic feet of air per minute (cfm). That is a pretty powerful fan, certainly much more than the typical box window fan. (Remember that this fan has to push air to all parts of the house.) This fan pushes air into a supply plenum (Illustration 6.4). This supply plenum then serves as the central hub to the supply duct system (Illustration 6.4).

Because of this powerful blower, air is being pushed in the supply plenum at a rate of 1000 cfm. (Assumed to make understanding easier; could be anywhere from 700-1000 cfm.) But where is the blower “getting” this air? According to the laws of physics air can neither be created nor destroyed. Therefore, the blower must “suck” the equivalent of what it “blows.” That means that the fan must be “getting” air from the return system (Illustration 6.5). Because of the need for equal airflow mentioned above, this return system should be a mirror of the supply system. Where the supply is pushing air into the house, the returns are in essence pulling air into the blower. And, much like the supply system, the point of return to the blower is called the return plenum. This plenum is “fed” air from the return duct system (Illustration 6.5).
Now that the science of the blower and accompanying supply and return plenums has been explained, duct systems can be addressed. The duct systems of any heating system are the transport "roads" for air to move through out the house. In most Habitat homes in Central Indiana supply ducts are located in the crawl space of the home. Regardless of duct material, all supply ductwork leads to duct "boots" on the floor of each room in the house (Illustration 6.6). It is from this opening that warm air fills each room. In plan view, the supply ducts look like a "spider" with a center at the furnace unit.

The return duct system is also very important. Multiple return ducts should be placed in the conditioned space of the home. Often return ducts are placed in the attic. If the attic is properly sealed and insulated, this location is very uncomfortable for a duct because it is then located outside of the conditioned air part of the house. Therefore, return ducts should be placed in the crawl space or in dropped soffit within the building envelope. This is an excellent example of why design before the house is in construction is important. Return ducts get placed in the attic because they often are not designed properly for the house!

A multiple return system was described above. Most Habitat homes have single return systems. This occurs for several reasons. The first reason is that there is little understanding about the need to equalize the supply and return plenums’ respective pressures that are caused by the blower mentioned above. Second, the installation of multiple return systems costs additional money in an organization with scarce resources. Finally, multiple return systems have not traditionally been a part of the Habitat model.

**The problem of the single return system**

The air handler in a heating system in Habitat homes forces air to move. When air moves it can create changes in air pressure. If the heating system is balanced, with multiple returns, supply ducts feeding the room with air at the same rate that return ducts remove the air, there is no pressure problem. But, Habitat homes typically have single return duct systems. What happens when someone closes the door to some bedrooms and stops the flow of air from the supply to the return duct (usually located in the hall)? It is this situation that can cause serious problems.
Let's first address the issue of pressurization in multiple bedrooms. The doors are shut in the evening. The blower is sending air through the supply ducts to the bedrooms. Without a return duct in the bedrooms, the air builds a positive pressure. A common argument is that air can move under doors to the return duct system. The reality of this situation is that most doors do not have enough space underneath of them to allow this to happen. This positive pressure now causes the first problem of the single return system, that is, pushing moisture (which is in the house's air) into the wall (Illustration 6.7) through the very small holes that are in the drywall (it's porous). This moisture can cause durability concerns for the house because the moisture degrades the building materials inside of a wall such as wood and insulation. (Think in terms of a full heating season of this happening every night. That is a lot of moisture!)

The next problem is comfort. If the rooms are pressurized, the supplies stop delivering warm air. It therefore, doesn't deliver as much as it should or as much as the bedroom needs. The owner who feels the cool air may turn up the thermostat. This makes the furnace run longer and wastes energy. This waste then translates into higher heating bills. Furnaces don't work harder, they only know on and off; but they do run longer (Hill, 1999) which leads to affordability issues.

But the problem does not stop there. The biggest concern is yet to come. With a positive pressure in the bedrooms, there will be a negative pressure in the hallway by the return, which is trying to “suck” enough air for the equalization of the blower system. This negative pressure pulls air from wherever it can find it. The closest source of air is the air in the combustion appliance zone (CAZ) mentioned above. From what appliance is air trying to move out of the house? The hot water heater. What products is the hot water heater producing when it kicks on? CO and other harmful combustion contaminants. This negative pressure can then cause these contaminants to “backdraft” out of the draft hood from the hot water heater and flow into the rest of the house. Even worse, the CO can flow into the supply duct system and be pumped to every supply, including the bedroom with the door shut. This room, with sleeping residents, now becomes a mini gas chamber. The residents inhale the CO without even knowing it.

Illustration 6.7
This problem with single return systems is very real! Nearly 300 people die every year from carbon monoxide exposure related to residential combustion appliances, and thousands of others become ill or seek medical attention (American Lung Association, 2000). CO problems in the news are often misdiagnosed as mechanical problems and instead can be attributed to this problem (Hill, 1999). Unfortunately, Habitat homes, with single return systems and gas-fired heating systems, are the models for this problem. That fact, in my opinion, makes single return systems, in combination with gas hot water heaters, one of the most dangerous parts of a Habitat home.

The Multiple Return Solution

If the single return system creates all these difficulties, then using a multiple return system is a logical fix. Not exactly. A multiple return system does decrease the potential for pressurization problems, but there are other installation issues that can cause significant pressure differences. Leaky supply and return systems also can cause pressurization of the home. It is not within the scope of this thesis to address these issues. For more information on proper duct sealing strategies, see EEBA's Builder's Guide (Lstibruer, 1999).

Recommendations to affiliates

As mentioned above, most heating systems in Central Indiana Habitat homes are gas-fired combustion appliances. That means that they produce combustion products that pose a potential threat to the health and safety of the home's residents. People (residents) are the major mission of Habitat and therefore protecting those residents is a top priority. Giving a new low-income homeowner a house that causes health and safety problems can only be a negative in Habitat's mission. That fact is the major reason why heating and hot water systems have been placed first in this thesis discussion.

There are other motivations for looking at heating and hot water systems in Habitat homes. First, from a cost standpoint, heating systems and their installation are expensive parts to the construction package of the Habitat home. A standard heating system (furnace and duct system with hot water heater) costs roughly $4,000 to $5,000. Since Habitat resources are scarce, heating systems are important to analyze.
The second factor is a little more complex. No Central Indiana Habitat affiliates install their own heating systems. The misconception is that this is good for Habitat because “professionals” are doing the work and it will be done correctly. This may not be true. Most professional HVAC contractors have not been taught about these pressure diagnostics and the circumstances under which furnaces they install could backdraft the hot water heater. It is not that they don’t understand the heating system. Rather, they are not aware of the other parts of the house system interacting with the heating and hot water systems.

Look at a possible situation to illustrate this point. A Habitat affiliate hires an HVAC contractor for the installation of a heating and hot water system. The affiliate assumes that the contractor understands the science of the system. The reality of the situation is the contractor does understand the heating and hot water systems but does not understand their interactions with the house as a system. Because the affiliate lacks the knowledge of how the system works, they are not able to “call” the contractor on missed or incorrect areas of construction. Also, because the contractor does not understand the rest of the house system, they are not able to catch problems in the heating and hot water system before they occur.

This problem is not unique to Central Indiana. It really relates to an institutional barrier that exists in homebuilding. Because the Habitat affiliate has limited knowledge as well as the contractor, the system does not function properly. Neither of the two parties can then be a catalyst to change. This creates a barrier to improvement of the system and increased potential for a health and safe home. Chapter 10 addresses this issue by claiming that an informed affiliate can break the barrier through knowledge of the systems involved.
Seven Chapter
Moisture Control
The control of moisture is a major factor in the long-term durability of a home. The
moisture that can cause problems in homes comes in many forms – rainstorms, dew, ice
and snow, and water vapor. The key to effectively shielding homes from moisture
problems is to manage the moisture and give the moisture routes to leave the home.

Moisture control is an issue in many parts of the home. Roof systems, siding and wall
cavities, attics, and subfloors are all parts of a home that come in contact with moisture
on a regular basis. The long-term durability of these systems is heavily influenced not by
the fact that they come into contact with moisture, but how they handle the moisture
when it is within each house system. Building science looks at all of these systems and
develops solutions that address the holes, moisture sources, and driving forces in order to
manage the moisture (Hill, 1999). Not all of the potential issues that relate to moisture
control are covered in this thesis. However, for further reference beyond what is covered
in this thesis, the Energy Efficient Building Association’s Builder’s Guide (Shown above)
or Lstibruke’s Moisture Control Handbook (Lstibruke, 1999) is recommended.

This study looks only at moisture control issues in foundations. I have focused on
foundations for four reasons. First, due to limited time I could not detail each potential
moisture control issue. Second, according to Hill (1999), “The perimeter drain (around
the foundation) is perhaps the most important moisture control detail in the house.”
Third, most of the homes that I visited in field study of Central Indiana Habitat homes did
not have perimeter drains installed to control moisture. Finally, if moisture control is not
implemented in the foundation, everything else done will be little more than a “band-
aid.”

Moisture in Foundations
Buildings will always move. Concrete will always crack. For these reasons it is
impossible to make a “waterproof foundation.” Instead of waterproof foundations, we
should create “water-managed foundations.” According to Lstibruke (1999, p.25),
“Water managed foundation systems rely on two fundamental principles: Keep rainwater
away from the foundation wall perimeter and drain groundwater with sub-grade
perimeter footing drains before it gets to the foundation wall.”
Water managed foundation systems are not the same as waterproofing systems. According to Lstiburek (1999, p.25), “Waterproofing relies on creating a watertight barrier without holes. It cannot be done. Even boats need pumps. Water managed foundations prevent the buildup of water against foundation walls thereby eliminating hydrostatic pressure. If there is no pressure, there is no force to push water through a hole. Remember, we know the foundation wall will have holes.” Since we know that concrete will crack and holes will be present, it is important to put into place a system that can manage moisture even when, not if, the foundation has cracked.

There are four mechanisms of moisture movement that affect the foundation assemblies of homes:

- Liquid flow (rainwater and runoff)
- Capillary suction (groundwater)
- Air movement
- Vapor diffusion (primarily from the ground)

Liquid flow consists of the moisture that comes off the roof system and though the gutter system (if installed). It also consists of rainwater that hits the ground and flows to areas of lower elevation on the house lot. This source, which is referred to as “bulk moisture,” (Illustration 7.1) is typically the largest and should be addressed with top priority.

Moisture that exists in the ground (groundwater) is also a concern. The main transportation mechanism here is capillary action through the pores of the soil. This mode of moisture transport can move moisture through anything that has pores. That’s right, concrete foundations fit that description.

Air movement and vapor diffusion are also moisture control concerns. They move moisture both from the exterior to the interior of the building envelope and vice versa. They are not difficult to control, but do require some understanding of climate and heating and cooling concerns. In fact, controlling the vapor diffusion of moisture from the ground below a home is a simple action. The installation of a 6 mil polyethylene vapor diffusion retarder will be
discussed below as an effective option for controlling the diffusion of moisture from ground sources.

Frost is a moisture concern that is a little different. Frost is frozen moisture and can only develop when moisture is near when transported by any of the four mechanisms mentioned earlier. A simple logic follows, keep moisture away from the foundation and prevent frost problems. Frost has the potential to cause the most destruction to a foundation. When water freezes it naturally expands. The force of this expansion is great and can cause tremendous damage.

Designers and homebuilders can not control how much rainwater falls on the site of a house. However, they can prepare for its arrival. In Illustration 7.1, notice how the rainwater ends up next to the foundation of the house. This is a very common situation in homes that have no gutters or downspouts. This bulk moisture travels to the base of the house’s footing and foundation. Gravity is the major transport mechanism in this situation. Without the installation of a perimeter drain to relieve the hydrostatic pressure caused by gravity as a driving force a potential exists for moisture entry into the cracks of the foundation. Additionally, moisture can travel up through the ground by process of capillary action.

**Moisture control practices of Central Indiana Habitat affiliates**

Few Habitat affiliates in the Central Indiana area understand the process of moisture control in the foundation area. In interviews with several construction managers, few pointed out moisture control techniques in the foundations of their homes. All construction managers interviewed stated the no perimeter drainage system was being installed on their homes.

One affiliate in this study had encountered a “sinking foundation” problem (Illustration 7.2) in the last year. Knowledge of the situation arose when the homeowner complained to Habitat about the back corner of her house sinking considerably. The Habitat affiliate came out to the house and fixed the problem, which entailed the hiring of a contractor to jack the home up and replace the foundation corner. This however has not completely solved the problem. The foundation has sunk additionally...
since the repair. What conditions exist that might explain this situation? First, the house has terrain that slopes towards the corner of the home, not away, allowing rainfall to run towards the house. Second, the downspouts do not direct water away from the house. These factors combined create sufficient conditions for some forms of foundation failure because of moisture, but there certainly could be other factors that are affecting the sinking foundation. The point is that looking at building problems (e.g. sinking foundations) from a building science standpoint gives some understanding of forces and sources that might be acting on the problem.

A potential for moisture concerns in a few homes on which no guttering and downspouts had been installed was observed. While this lack of guttering was not widespread, it was explained to me by one affiliate that these “amenities” went above and beyond the call of Habitat to provide a simple and decent home. In addition, several recently built homes had piles of dirt two to four feet from the edge of the house, leftover from the excavation of the foundation. When asked if the piles would be moved or made to slope away from the home, it was explained that they were waiting for the piles to “settle.”

All of the visited affiliates were applying what is commonly known as “waterproofing” paint to the exterior of the foundation wall. As discussed above, waterproofing is intended to stop bulk moisture and “seal” the foundation wall. But, as discussed above, buildings move and holes and cracks open up. This paint is not intended to provide “waterproofing.” Instead, it is designed to seal the small pores of the concrete or block and then stop moisture transport via capillary action. This procedure is referred to as dampproofing.

**Moisture control recommendations for Central Indiana Habitat affiliates**

Several possible actions can help to alleviate moisture concerns in foundation assemblies. All are simple to install or implement and each can prove very beneficial to the life of the home.

**Roof and Surface Drainage**

**Install Gutters and Downspouts.** These assemblies, installed correctly with proper slope and downspouts, are essential parts of a moisture management system. Each home should have continuous guttering installed with downspouts (Illustration 7.3) that either
have extensions allowing water to flow away from the house or connections to drain tile that moves water away from the house. I also recommend that each Habitat affiliate encourage homeowners to clean gutters and downspouts after fall leaf seasons to prevent clogging of the gutter system.

**Make the ground slope away from the house.** According to Lstibruke (1999), “Poor site location and/or site grading practices can lead to surface water flow toward building foundations.” Backfill is sometimes mounded two to four feet away from the foundation after excavation and pouring creating a slope towards the house. A process for replacing backfill follows:

- Push the “backfill” soil back against the foundation wall and create a slope that runs away from the foundation wall.
- This slope should be compacted with a hand compactor and have a slope of at least 5% for 5 feet away from the house.
- Allow the backfill soil to settle through a rain after the initial compacting.
- Return to the area after the backfill has settled, add more soil where necessary and compact the soil again.
- Remove any excess backfill that does not allow a sloped surface from the house.
- Check to insure 5% grade.

Letting the backfill “settle” two to four feet from the foundation wall will not be an acceptable solution. More often than not, the job will be forgotten and it is a very important detail in moisture control of foundations. Sometimes the slope of the ground is even more severe and needs to be corrected immediately (Illustration 7.4).

It would be ideal to install a clay “cap” over backfill. Clay is relatively impermeable and will resist moisture movement better that compacted backfill. But, it is understood that clay might not be feasible to have trucked in or found on site.

A common error is committed by installing landscaping materials, such as shrubs, near a house’s foundation. These materials can hold moisture long enough for the moisture to
transport itself downward to the base of the foundation or directly into the wall at ground level. Habitat should not install large plants near the foundation and should advise homeowners to follow the same process.

**Perimeter Drain and Damproofing**

**Install a perimeter drain.** As can be seen in Illustration 7.5, a perforated drain tile should be located next to the foundation to provide an outlet for moisture to leave the sub-grade area. A checklist for installing a perimeter drain follows:

- Determining where the pipe will flow to is key to the success of the system. On a plan of the house arrows should be drawn to show directional flows of the pipe. (These decisions must be made with an understanding of overall site slope and grade.)

- The pipe must exit to “daylight,” a sump or storm sewer. Exiting to daylight requires the slope of the lot to be sufficient to get the water off the site. If a site is not conducive to the “daylight” option of drainage, then the pipe must be directed to a sump for drainage. (A sump (Illustration 7.6) is a pit in the crawl space floor that allows for water to gather and then be pumped.)

- The area near the foundation should be cleaned of all backfill material down to the bottom of the footing and a width of 8 to 10 inches. This will allow space for pipe, gravel and installation “elbow” room.

- Dampproofing (such as “Dry-Loc”) should be applied to the walls of the foundation and the top of the foundation block. The application on the top of the block will help restrict capillary transport of moisture to the wood of the subfloor. *The process must stop here until the dampproofing*
has dried. Working against the wet foundation wall is messy and the wet dampproofing will clog the filter fabric explained below.

- After the dampproofing has dried, inspect the trench for slope and direction of water flow before installing the pipe and other materials. Remember, maintaining a slope for proper flow is key to the success of the system.

- The perimeter drainage system is made of a 4 inch perforated drain tile with holes facing downward to allow for moisture “percolation” into the pipe. In order to calculate how much pipe is needed, add all the dimensions of the perimeter together along with the amount of pipe needed for extensions to “daylight” drainage or to the sump. Add 10 to fifteen feet to this amount for extra material that might be needed for joints and corners. This length dimension of pipe will also be the dimension that will be needed of the filter fabric described below.

- An additional factor to remember is the amount of pipe per roll. Most hardware stores offer perforated tile in rolls of 100 feet. For example, it is not effective to use “joint connectors” to make pieces of 5 feet, 10 feet, and 15 feet to make a total piece of 30 feet. Make certain that all lengths can be covered continuously. A 250-foot perimeter might require 3 100-foot rolls of pipe rather than 2 100-foot rolls and a 50-foot roll.

- “T” joints and corner elbows will be needed for connecting pipe at key junctures. Count out these junctures ahead of time. Creating a “make-shift” corner is neither fun nor effective, and bending pipe around corners is not acceptable.

- In the trench that has been prepared, lay down a 6-foot wide piece of filter fabric, sometimes called weed block at your local hardware store. The purpose of this material is to keep small particles of soil, called fines, from clogging the pipe. Lay the fabric in the trench with the center in the lowest part of the trench.

- On top of the filter fabric, pour a thin layer of crushed stone or pea gravel and smooth with hands to maintain grade. (Don’t allow this thin layer of stone to change the grade of the trench. If it does, it might change the direction of the pipe’s flow, rendering the system useless.) Then, lay the piping in the trench with perforations facing down. Install all elbows and “T” joints at this time.

- The pipe should then be encased by crushed stone or pea gravel. This is a two- or three-person job. One person should hold the pipe as gravel is poured around it, because the pipe will want to creep up.
- Fold the filter fabric over the top of the gravel. A technique that I have found to be effective is to staple the top of the fabric. This keeps the fabric overlapped during gravel encapsulation and prevents the wind from blowing the fabric apart.
- The final step is the backfilling and grading described above.

Installing a perimeter drain is not expensive when compared to the benefits that it brings to a house. Habitat affiliates typically have plenty of unskilled labor to help clean the footing trench and backfill with gravel so labor costs are minimal. Material costs are also small. Table 7.7 shows the costing of a perimeter drain system on a one-story ranch home in the Muncie, Indiana area. (Prices reflect local markets.)

### Perimeter Drain Information

<table>
<thead>
<tr>
<th>Table 7.7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>House Characteristics</strong></td>
</tr>
<tr>
<td>Exterior Perimeter</td>
</tr>
<tr>
<td>Perimeter Drain Cavity in Cubic Feet</td>
</tr>
<tr>
<td><strong>Material Characteristics</strong></td>
</tr>
<tr>
<td>Pea Gravel to fill 300 cubic feet of space in tons</td>
</tr>
</tbody>
</table>

| Perimeter Drain Assembly | |
|--------------------------|---|---|---|
| **Item Description** | **Units** | **Unit Price** | **Total Cost** |
| 4" Perforated Drain Tile (50 ft.) | 3 | $12.00 | $36.00 |
| Elbows for Corner Connections | 2 | $3.52 | $7.04 |
| "Y" for Corner drain Connections | 2 | $4.63 | $9.26 |
| Pea Gravel (ton) [Not Hauled] | 2 | $6.70 | $13.40 |
| 48" Drain Fabric (300 feet) | 1 | $31.00 | $31.00 |
| Dry Loc Foundation Sealer (gallon) | 4 | $15.99 | $63.96 |

**Cost** $160.66

*Notes:
Prices through Lowes Stores and Irving materials.
Does not include PVC pipe to Sump if needed nor sump cost.*

---

Crawlspace vapor diffusion retarder

As mentioned above, vapor diffusion of moisture from the ground can be a significant source of moisture in a house. Most of this can be eliminated with the installation of a 6 mil polyethylene vapor diffusion retarder on the floor of the crawl space. The process for installing this vapor diffusion retarder follows:

- Calculate the amount of material by finding the area of the crawl space.
- Purchase 6-mil polyethylene material from a local supplier. Account for extra and error cuts by adding 10% to the amount calculated.
- Following the completion of the foundation walls spread 4" of pea gravel over the entire crawl space floor. This pea gravel will act as an effective capillary break to ground moisture.
- The retarder should not be installed on top of the pea gravel until all work is completed in the crawl space area. This will reduce the potential for cutting holes into the polyethylene material.

- After work is complete, install the retarder. It is ideal to tape and seal all joints of the vapor diffusion retarder. However, the key is that the material covers the majority of the crawl space floor.

Note: Some construction managers prefer that the retarder be placed under the pea gravel. The method described here is meant to take advantage of the pea gravel as a capillary break before the moisture reaches the retarder. The key is to understand that the polyethylene can ripped and torn. Care should be given to protecting this barrier.