INFORMATION FRAMEWORK FOR RESIDENTIAL ENERGY RETROFIT

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ABSTRACT

INFORMATION FRAMEWORK FOR RESIDENTIAL ENERGY RETROFIT

Buildings in general, particularly residential buildings are one of the major consumers of energy. The majority of the housing stock consists of existing homes which are energy inefficient. Retrofitting these homes to make them energy efficient will contribute immensely to energy savings, reduce the country's dependence on foreign fuel and prove beneficial to the natural environment.

The literature studied as part of this research revealed that one of the major impediments to home energy retrofit is the lack of information, or lack of the right formats of information that home owners can use to successfully implement retrofits and produce the maximum energy savings. It also found that homeowners traditionally depend on experts in the field of home energy retrofits, such as energy auditors and trade contractors for information. There are however several problems with such information including high costs and biased or inaccurate information.

To overcome this problem, this research aimed at developing a query-based expert system framework. The system, which if developed based on the framework will capture the knowledge of real experts, substantiate it with proper building science literature and codify it into an interactive computer-based decision tool to deliver relevant retrofit information to the end user. The system will analyze the current situation of a home through queries to the user and provide customized and prioritized information to suit their need. Information provided in this format will accelerate implementation of retrofits on a large scale.

Dedicated to my Parents…

ACKNOWLEDGEMENTS

I would like to thank God above all else, who strengthened me to make this possible.

I would like to thank my advisor, Dr. Matt Syal for guiding me through this research and beyond, to make me the individual I am today. I would also thank him for shaping me in a manner that will make me a thorough professional as I step out into the world.

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CHAPTER 1

INTRODUCTION

1.1 Overview

With the world facing the problems of climate change and the possibility of exhausting fossil fuels, there is an increased need today for a sustainable lifestyle. The traditional definition of sustainability is "meeting society's present needs without compromising the ability of future generations to meet their own needs" (USEPA 2010 b). Energy conservation is one of the most important means of achieving a sustainable lifestyle.

Compared with other sectors such as transportation and industry, the building sector stands in the forefront of energy consumption; buildings in the United States consume 72% of electricity, 36% of natural gas and 40% of all energy use. Between 1985 and 2006, retail sales of electricity to buildings increased by 1180 billion kWh while, over the same time, the increase in industry was 165 billion kWh. Hence, there is a necessity to increase the energy efficiency of buildings.

Increasing the energy efficiency (EE) of buildings would also have an immense economic impact. The United States Environmental Protection Agency (USEPA) estimates that increasing the energy efficiency of existing buildings would have economic advantages by reducing operating costs, improving occupant productivity and optimizing life-cycle economic performance (USEPA 2011).

Under the scope of this study, home energy conservation has been classified into two categories: the energy efficiency of "new construction" and the energy efficiency of "existing homes". This research will concentrate on retrofitting existing homes to increase their energy efficiency. There are approximately 130 million existing housing units in the United States today, compared to an annual addition of about half a million to two million new homes (AHS 2009 & BA 2010 a). These numbers indicate the importance of conducting research focused on improving the energy efficiency of existing homes to produce a large scale impact on energy conservation.

A 2009 study by The Joint Center for the Housing Studies (JCHS) of Harvard University found that "rising home energy costs and growing environmental concerns have boosted demand for green remodeling projects." The study also found that homeowners spent $52 billion on energy efficient remodeling projects in 2007, as opposed to $33 billion (adjusted for inflation) in 1997, which shows that homeowners are becoming increasingly concerned with energy conservation and the energy efficiency of their homes. The study also found that homes built before the 1970 oil embargo tended to be highly energy-inefficient because consumers at that time were less concerned with energy prices and availability. In addition to this, the government has many programs in place to accelerate the growth of energy efficiency retrofits of existing buildings. The main goal of programs such as "Building America" and the "Weatherization Assistance Program" from the US Department of Energy (BA 2010 b and WAP 2010) is the energy efficient retrofitting of existing buildings.

1.1.1 Cost Effective Energy Retrofit Team Project

This research has been conducted as part of a larger project funded by the US Department of Energy's Building America Program, and is known as Task 6.3. The larger project team is known as the Cost Effective Energy Retrofit Team, and performs research on four major tasks, Task 6.3 and Tasks 6.1, 6.2 and 7.1.

Task 6.1 is a market characterization project that aims to identify the dominant archetypes of homes in the Great Lakes Region of the USA. The archetypes may be identified by architectural style, vintage or construction style. Once identified, they will be tested, and a prescriptive package of measures will be identified for them.

Task 6.2 attempts to identify key stakeholders in the value chain of home energy retrofits, and to collect information about the needs of those stakeholders. This information will then be used to implement retrofits in a manner that targets the end-user.

Task 7.1 will perform field testing of the dominant measures, to identify a prescriptive package of measures that will improve home energy performance. In addition, it will identify quality control strategies for the installation of the identified measures.

1.2 Need Statement

Many of the traditional building materials and equipment in older homes are known to be energy-inefficient and to cause other harm, such as toxic waste disposal and the emission of greenhouse gases. In order to mitigate the above problems, homeowners have to retrofit their homes, switching to innovative and green technologies (Jaffe & Stavins 1994). The construction industry, however, has generally been identified as being a laggard industry for adopting innovations. Several causes have been attributed to this characteristic, including the lack of access to information about new technology, inadequate training on products, a lack of material on installation techniques, an inadequate flow of information between manufacturers and industry, and a lack of research flowing from labs on to the field (Koebel et al. 2003). One common theme echoes from these reasons: Information does not flow adequately between various areas of construction, making it a laggard industry to adopt innovative and green technology. Similarly, for the home energy retrofit industry, the issues related to the clogged information flow will have to be resolved if it is to successfully implement the large-scale distribution of the latest technologies in energy conservation.

1.2.1 Insufficient Implementation of Home Energy Retrofit

Some reasons for the unsatisfactory implementation of home energy retrofit are illustrated through the following three examples. Example 1 illustrates the lack of research flowing from labs to the field, while examples 2 and 3 show how the lack of access to key information can impede government programs designed to encourage home energy retrofitting.

1.1.1.1 Example 1: National Renewable Energy Laboratory (NREL) Research

Energy modeling of homes is an important step in the energy efficiency retrofit process. Realizing this, the National Renewable Energy Laboratory (NREL) performed research on the subject in the early 1980s. The results of the research were not published until 2008, however, after a period of twenty five years. Figure 1.1 shows the cover page of the 2008 publication.

1.1.1.2 Example 2: The Weatherization Assistance Program

Under the American Recovery and Reinvestment Act of 2009, about $5 billion was awarded to weatherize modest income homes in the country through the Weatherization Assistance Program. This program was intended to both assist modest income homeowners with reducing their utility expenses and create jobs. The program authorized grantees to withdraw up to half of the total

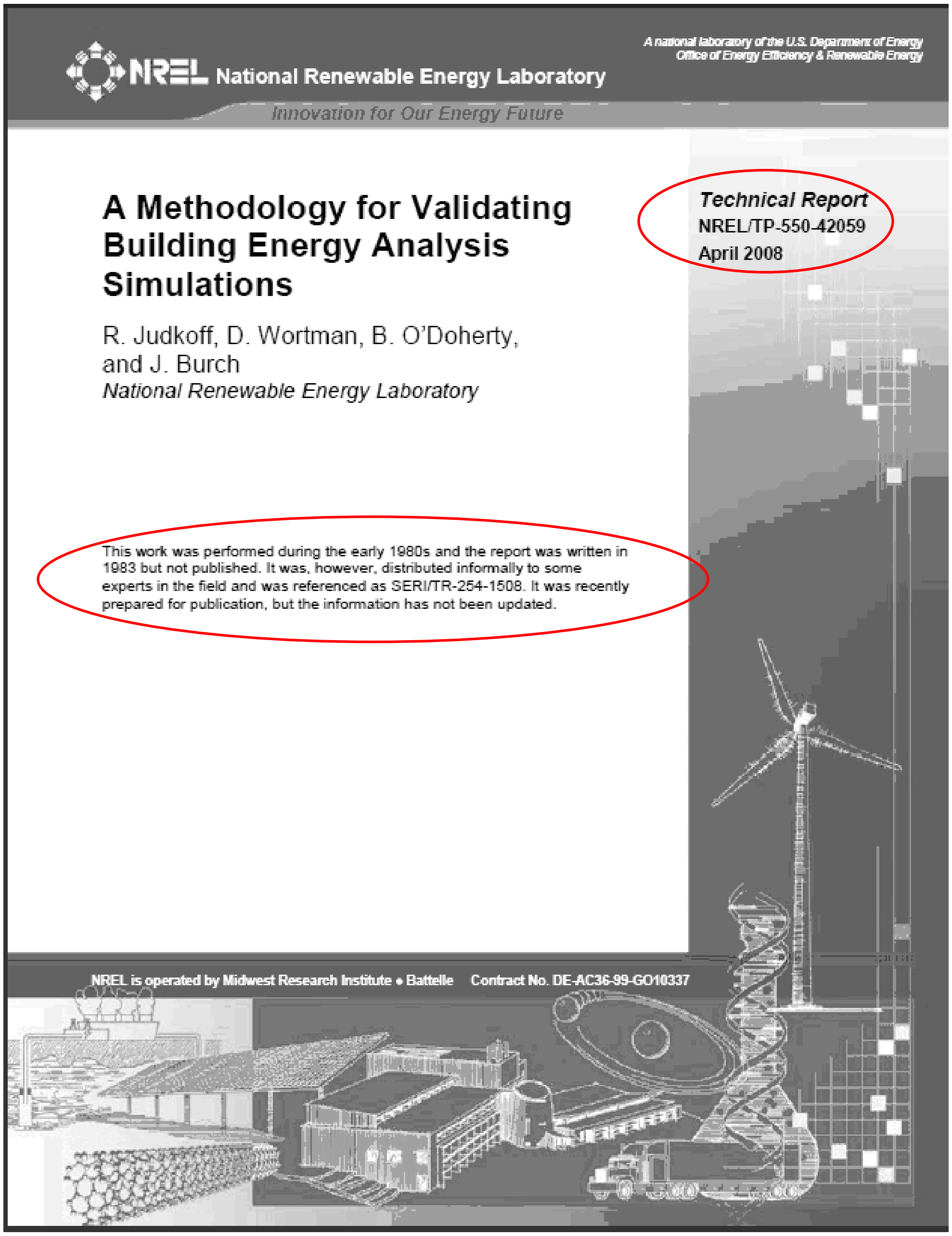


Figure 1.1: Research Paper Published by the National Renewable Energy Laboratory (NREL) in 2008 (Source: Judkoff et al. 2008)

allocated funds by December 2009. By February 2010, however, only 8% of the total funds had been drawn for weatherization work (USDOE - IG 2010). Table 1, below, shows a sample of the completion of units against the planned numbers, by state.

Table 1.1: Snapshot of the WAP performance (source: USDOE – IG 2010)

State	Units Planned	Units Weatherized as of December 2009	Percentage of Units Completed
New York	45,400	280	0.62%
Texas	33,908	0	0.00%
Ohio	32,180	6,814	21.17%
Pennsylvania	29,554	378	1.28%
Michigan	33,410	385	1.15%
Illinois	26,933	331	1.23%
California	43,400	12	0.03%
Florida	19,090	312	1.63%
Wisconsin	20,678	772	3.73%
North Carolina	22,203	197	0.89%

The US Department of Energy, Office of Inspector General's report on the WAP progress identifies several reasons for the poor implementation of WAP (USDOE - IG 2010). Two of the reasons are:

- Grantees lack an understanding of the Davis Bacon Act requirements; they must comply with these when performing a federally funded project.
- There is lack of knowledge regarding the requirements for weatherizing homes in historic districts.

This shows the failure of a government program due to a lack of information.

1.1.1.3 Building America Program

a. "The problem is not a lack of energy efficient technology, but a lack of information required to implement such technologies." A classic illustration of this statement was from an expert's meeting held in October 2010 in Albany, New York. The meeting was held to "optimize condensing boilers with low-temperature distribution"—to identify key research and find gaps in the condensing boiler industry. (Condensing boilers are different from conventional boilers; they utilize the latent heat of water in addition to its sensible heat. This feature makes them 10%-12% more efficient, compared to conventional boilers; an energy efficient option in US homes.). This event was hosted by the US Department of Energy's (DOE's) Building America Program and was co-hosted by the New York State Energy Research and Development Authority (NYSERDA). One important conclusion drawn from this meeting was "condensing boilers are not being successfully implemented in a large scale because of a clear lack of information on optimum installation strategies and insufficient training for installers and designers." At the meeting, goals were set to assess the current literature and try to remedy the current "information vacuum" (Aspen Publishers 2010).

b. In July 2010, a meeting sponsored by the Building America Program was held in Denver, Colorado, to discuss key opportunities and barriers associated with residential energy efficiency. The meeting brought together more than 220 professionals involved in residential research and outreach. Some of the key barriers identified at the meeting include (NREL 2010 b):

- Information is out there but is not getting into the hands of the right people.
- There is limited access to information for consumers and contractors.
- Homeowners lack the information to distinguish between an energy efficient product and those which use false claims of energy efficiency as a marketing device.

All of these examples highlight the importance of appropriate and timely information flow from research labs, manufacturers and public institutions to the home energy retrofit industry, to promote large scale adoption.

1.2.2 Information is a Key to Achieving Large-Scale Implementation of Home Energy Retrofits

One of the important reasons for the market failure of energy efficient technology is imperfect information about such technology (Golove & Eto 1996). In an ideal world, information is perfect and free (Harris & Carmen 1991 from Golove & Eto 1996). Imperfect information can include a lack of information, the cost of acquiring information, the inaccuracy of information and an inability to use information effectively (as illustrated in the previous examples) (Golove & Eto 1996). The "cost of acquiring information" refers to a cost in time, money or both, when information is available (Golove & Eto 1996). This cost of information acquisition is part of the initial investment related to technology adoption. Any reduction in the cost of information that leads to a decrease in adoption costs will accelerate technology diffusion (Jaffe & Stavins 1994).

Inaccuracy of information has been seen in recent times, with the self-interests of manufacturers of EE technologies leading to a lot of misinformation in their product advertisements. This leads to mistrust among consumers who may have suffered previously from such misinformation (Golove & Eto 1996, Path 2002).

1.2.3 Lack of Unified Source of Information

Unified and systematic information about product availability, cost, manufacturers, potential energy savings, performance certification and building codes help consumers make the right choices and can accelerate the diffusion of EE technologies. However, most of this information is scattered and difficult to find (PATH 2002).

To improve information delivery in the home energy retrofit industry, this research intends to first investigate barriers and catalysts related to home energy retrofits, and then to identify and develop an information system to be used as a tool to deliver optimal, appropriate and timely information to consumers.

1.2.4 The Need for Standard Protocol

PATH (2002) identified several barriers to the large-scale implementation of energy efficiency in existing homes. One of the identified barriers was the lack of a standard protocol to dictate the methods used by home energy efficiency professionals, such as trade contractors and energy auditors, to retrofit a home. The process of overcoming this barrier requires conducting interviews with industry professionals and developing a standard protocol for retrofits. This research will implement the idea by developing a standard protocol. This protocol will form the basis of the framework for the query-based expert system.

1.2.5 Need for Experts in Home Energy Retrofits (NREL 2010 and Romero 2011 PATH 2002 and RESNET 2010b))

The involvement of experts in home energy retrofits is inevitable. Homeowners trying to do energy retrofits may reach several roadblocks especially in trying to find the right information. Some reasons for this include:

- They are confused about the varied and conflicting quantitative and qualitative information that is available in published sources (PATH 2002).
- They are unsure about information coming from utility companies (PATH 2002).

- They may have a perceived distrust of contractor's and manufacturer's claims (NREL 2010 and Romero 2011)
- They may have a perceived distrust of energy auditors especially those with a contracting interest.
- May not have the knowledge to customize all the available published information to their particular case.

To overcome the problems above, homeowners can approach experts in the field of home energy retrofit to find solutions. If this information can however be captured from experts and presented to the homeowner through an objective source such as a query-based expert system, homeowners can benefit from such information free of cost. The information provided from this source must also be substantiated with properly organized building science related published information. In addition, by providing the information in an expert system, the user can access it in an easy to use format.

1.3 Goals and Objectives

The overall goal of this research is to promote the implementation of EE retrofits in existing homes by developing an appropriate information system such as a query-based expert system, which would greatly reduce the cost and effort of acquiring information. This would help increase homeowner motivation to make their homes energy efficient.

Objective 1: Barriers and Catalysts

Identify barriers and catalysts for improving EE in existing buildings and homes, and form the basis of the information categories/entity sets of the quantitative database.

Objective 2: Database and Knowledgebase

2a: Investigate the existing Building America Website and the National Renewable Efficiency Database (NREM) database, and propose ways to utilize the latter as the database for EE information.

2b: Develop the framework for a qualitative experienced-based knowledgebase by interviewing trade contractors and energy auditors.

Objective 3: Query-based Expert System Framework

3a: Develop the overall framework for a query-based expert system that combines qualitative knowledge and quantitative data to support decision making/expert advice on retrofit measures.

3b: Demonstrate a working example of the query-based expert system.

1.4 Methodology

The objectives mentioned above need to be explored and/or developed to achieve the targets of this research. Steps 1 to 12, below, defines the course that this research took to achieve the objectives. The steps have been included below their respective objectives.

Objective 1: Barriers and Catalysts

Step 1: Perform a literature-based study of the existing barriers and catalysts in the overall issue of implementing home energy retrofits.

Step 2: Perform a literature-based study of the barriers and catalysts of the construction issues of home energy retrofits.

Step 3: The barriers identified in Steps 2 will be categorized under appropriate topics; these topics will then form the information categories/entities of the quantitative database.

Objective 2: Database and Knowledgebase

2a: Investigate the existing Building America Website and National Residential Efficiency (NREM) database and propose ways to utilize the latter as the database of EE retrofit information.

Step 4: Study the existing Building America information portal to determine whether there are existing databases related to any category of Step 3.

Step 5: The categories of existing information found in Step 4 will then be deleted from the comprehensive category list created in Step 3, to determine the final categories of information to be added to the proposed quantitative database.

2b: Develop the framework for a qualitative experienced-based knowledgebase by interviewing trade contractors and energy auditors.

Step 6: Study the theory of query-based expert systems (QBES) from the literature.

Step 7: Develop a preliminary framework of the QBES, which will define the desired functions of the system.

Step 8: Conduct expert interviews with energy auditors and trade contractors.

Step 9: Analyze the expert interviews to extract relevant information for the QBES framework.

Step 10: Use the extracted information to develop the final framework of the Knowledgebase.

Objective 3: Query-based Expert System Framework

Step 11: Demonstrate the integration of the quantitative database and qualitative knowledgebase with other tasks (6.1, 6.2 and 6.3) of this project to develop the final framework of the query-based expert system.

Step 12: Demonstrate the functioning of the expert system framework by a working example.

1.5 Chapter Summary

The first part of this chapter explored the current scenario of the energy conservation needs of the country and confirmed that home energy conservation will have the biggest impact on overall energy saving goals. It also showed the importance of retrofitting existing homes in the country, to make them energy efficient. Out of the many areas of retrofit-related research, it was found that researching and developing better information delivery methods to accelerate home energy retrofits was the most immediate need.

The second part of this chapter dealt with the methodology that will be used to develop a query-based expert system to assist consumers in obtaining expert advice on retrofit optimization and the associated procedures.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Chapter 1 gave the introduction to overall scope of this research, including goals, objectives and the methodology used to achieve the objectives. This chapter presents the literature review for this research; it was performed in four categories. The first category looked at the history and current state of home energy efficiency. The second category summarizes the existing literature on the barriers to improving home energy efficiency. The third category summarizes the literature dealing with the importance of information flow in the process. Finally, the fourth category focuses on and summarizes the literature on information portals, databases and query-based expert systems in home energy efficiency and other construction industry-related systems. The structure of the literature review is illustrated in figure 2.1.

2.2 History and Current State

The energy crisis of the early 1970s triggered government policies and public awareness aimed at increasing the energy efficiency of homes (Aroonruengsawat et al. 2009). Ever since, efficiency in homes has progressively increased to the point it is at today. This category examines literature on various factors that affected the evolution of EE in homes. It also summarizes the existing condition of EE in homes.

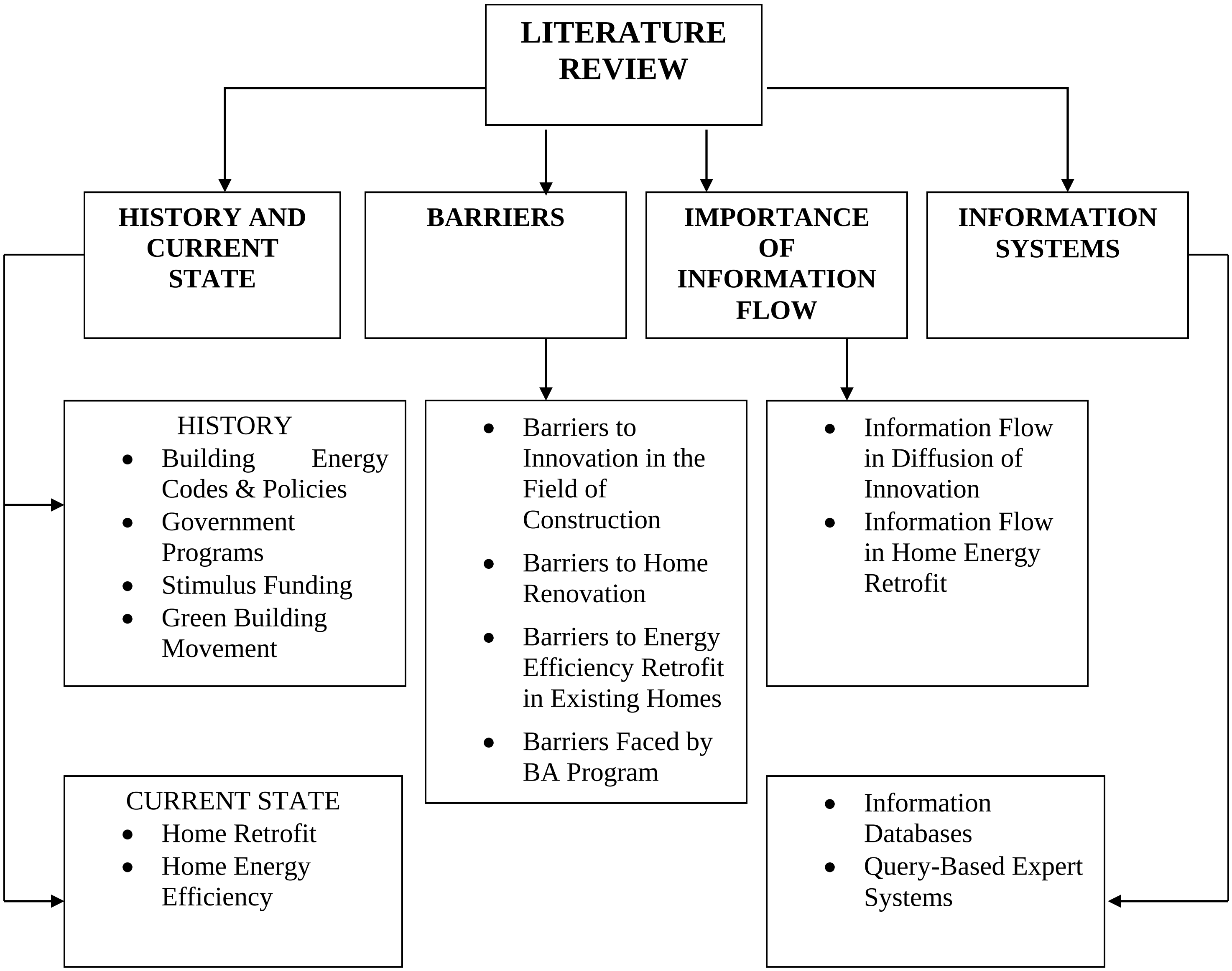


Figure 2.1: Structure of the Literature Review

2.2.1 History

Since the energy consciousness of the early 1970s, several agencies—government and non-government—have sought to implement measures to promote EE in buildings; these measures can be separated into four classes:

1. Building energy codes and policies

2. Government programs

3. Stimulus funding

4. Green building movement

2.2.1.1 Building Energy Codes and Policies

In Michigan, the first adopted building energy codes were implemented in 1977 (ASHRAE/IES 90-1975). In 1985, Michigan adopted the ANSI/ASHRAE/IES Standard 90A-1980 energy code statewide. In 1999, the State adopted the Michigan Uniform Energy Code, Part 10 rules. Finally, in 2008, the state enforced the adoption of the 2003 Michigan Uniform Energy Code (MUEC) for all new construction permits (Aroonruengsawat et. al. 2009).

At the Federal level, the first major milestone in home energy efficiency was the enactment of the 1975 Energy Policy and Conservation Act. The act was amended in 1978, requiring states to promote EE in buildings in order to be eligible for Federal funding. Consequently, through the 1980s, many states adopted codes either based on the ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) code 90-1075 or the Model Energy Code (MEC) developed by the Council of American Building Officials (CABO) (Howard and Prindle 1991 from Aroonruengsawat et. al. 2009). The Energy Policy Act was further amended in 1992, requiring states to revise their residential building energy codes to meet the CABO Model Energy Code requirements. The MEC has undergone several updates over the years, to be succeeded by the International Energy Conservation Code (IECC). As of 2009, all states except Hawaii, Kansas, Mississippi, Missouri, Illinois and South Dakota, had implemented a statewide version of building energy codes. The latest milestone in energy codes was Title II of The American Clean Energy and Security Act of 2009, passed by the US House of Representatives.

This includes the establishment of national energy codes for residential and commercial buildings, with the residential codes based upon the IECC 2006 code (Aroonruengsawat et. al. 2009).

One of the first government policies related to buildings was the 1975 Energy Policy Act (EPACT), amended in 1987. This policy required the inclusion of energy efficiency in building codes. In 1992, the EPACT was further amended, requiring states to review their building energy codes to meet the MEC of the CABO (Aroonruengsawat et. al. 2009).

2.2.1.2 Government Programs

The government has initiated several programs aimed at decreasing consumption of building-related energy. Out of many programs, this report analyzed the history of three programs: the Weatherization Assistance Program, the Energy Star Program and the Building America Program.

Weatherization Assistance Program (WAP) (Berry et al. 1997 and USDOE-IG 2010)

In the early 1970s, homeowners and renters began to feel the burden of costly home energy bills. To reduce consumption, community action agencies in Maine began assisting homeowners and renters to air seal their homes. This was the beginning of the WAP, which was officially instituted by Congress in 1976, under the Title IV of the Energy Conservation and Production Act. Though the program began as a means of implementing low cost emergency methods, such as weather stripping and caulking, it advanced to more permanent measures, such as installing storm doors and windows and insulating attics. Funds were released to the program in 1984, to increase the efficiency of space heating and cooling systems. In 1985, the replacement of defective furnaces and boilers were approved. In the early 1990s, WAP began performing advanced energy audits in homes in 37 states. In the late 1990s, the program began achieving higher efficiency as a result of better management practices, audit tools and training methods. Increases in efficiency were as high as 80% per dwelling.

Recently, the program received funding of about $5 billion from the American Recovery and Reinvestment Act (ARRA) 2009. The program authorized grantees to withdraw up to half of the total allocated funds by December 2009. By February 2010, however, only 8% of the total funds had been drawn for weatherization work.

Energy Star Program (Energy Star 2010)

The Energy Star Program is a joint program of the US Environmental Protection Agency (USEPA) and the US Department of Energy (USDOE), created to protect the environment through energy efficient products and measures.

The program was established in 1992, in an effort to voluntarily label energy efficient appliances, especially computers. Through 1995, the program expanded to include several other appliances, including space heating and cooling equipment. By the end of 2009, Energy Star had sixty product categories under its purview. Energy Star claims that in the year 2009, it saved consumers across the country over $17 billion worth of energy-related expenses.

Building America Program (BA 2010 a)

The Building America program is an industry driven program, sponsored by the US Department of Energy and is comprised of industry-driven partners, working to develop technologies that make buildings energy efficient. Because of the large number of existing buildings in the country today, Building America has begun to stress the importance of, and conduct research targeted at, the existing building EE retrofit. One of the important goals of the Building America Program is to develop retrofit strategies for existing homes that achieve significant energy savings, and ensure the safety and quality of the homes. Specifically, by the year 2020, BA aims to reduce energy use in existing homes by 20%-30%.

2.2.1.3 Stimulus Funding

The government has been a constant source of funding for home energy efficiency improvements, both for research and development (R&D), and implementation. Some of the funding and mortgage programs instituted in the past are mentioned here:

The energy crises of the 1970s prompted the federal government to expand its R&D programs to include energy efficiency technologies. From 1973 through 1977, the federal government spent about $140 million on energy efficiency R&D. The US Department of Energy was established by law in 1977. All of the energy R&D programs (fossil, nuclear, renewable, and energy efficiency) were brought under the administration of the USDOE. Funding for those technologies began in 1978 (RESNET 2010 a).

In addition, energy mortgage programs were adopted in the 1980s by Fannie Mae, Freddie Mac, the Federal Housing Administration (FHA) and the Veteran's Administration (VA). However, these programs were not implemented on a large scale; reasons included a lack of consumer and lender awareness and no uniform method of efficiency evaluation. The Housing and Community Development Act of 1992 required the Department of Housing and Urban Development to test a pilot energy efficient mortgage program in five states (RESNET 2010 a).

2.2.1.4 Green Building Movement

The US Environmental Protection Agency (EPA) defines green building as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction.” The green building movement has been a significant contributor to the energy efficiency of buildings in recent times (Syal et al. 2009).

The first significant movement toward green buildings can be attributed to the environmentalism movement of the early 1970s. This movement was mainly ignited by a 1962 book authored by Rachel Carson, “Silent Spring,” which spoke against the conventional environmental practices of the government. The second major milestone related to the green building movement was the 1970s oil crisis. Though the crisis lasted just one week, it had long-term consequences, inciting fears of rising fuel costs and the exhaustion of fossil fuels. This triggered several government policies and laws aimed at energy conservation. In 1982, the U.N. General Assembly created the Brundtland Commission. The main objective of the commission was to reduce the degradation of human environments and natural resources. It was responsible for defining sustainable development in 1987. The U.S. Green Building Council (USGBC), the primary body for certifying green buildings in the US was formed in 1993. The USGBC launched the Leadership in Energy and Environmental Design for New Construction (LEED-NC) version 1.0 in 1998. The LEED rating system is a third party verification system that rates green buildings (Syal et al. 2009).

The USGBC has constantly updated the LEED-NC requirements since the 1.0 pilot version. The upgrades include LEED-NC versions 2.0 in 2000, 2.1 in 2002, 2.2 in 2005, and 3.0 in 2009. USGBC, accepting the importance of EE in buildings, increased weight of Energy and Atmosphere related credits in LEED-NC 3.0, compared to previous versions. Energy and Atmosphere is a category of LEED-NC that encourages energy efficiency in buildings. In addition to LEED-NC, which is mainly oriented to commercial buildings, LEED has brought out different rating systems for other types of buildings, including LEED for Homes in 2008, recognizing that homes are a major consumer of energy in the building sector (USGBC 2010a & USGBC 2010b).

2.2.2 Current State

The previous section gave an overview of the history of energy efficiency in homes. The following section gives an overview of the current state of energy efficiency retrofits in homes. Section 2.2.2.1 provides a description of the current state of general home remodeling, while section 2.2.2.2 gives an overview of the current state of home energy retrofits.

2.2.2.1 Home Retrofit (Remodeling)

In 2007, annual consumer spending on home remodeling reached $326 billion. During the recent housing downturn, the home improvement share in residential investment climbed from 37% in

2005 to 48% in 2007. The bulk of this spending has been on major home improvement measures, rather than regular maintenance work. Major improvements include increasing the structural integrity, functional performance, and long-term cost-saving measures. Consumer spending on electrical systems, plumbing, HVAC and major appliances saw a tremendous rise between 2005 and 2007. With 130 million existing homes in need of improvements and 1 to 2 million new homes added annually, the remodeling industry seems to have an assured future (JCHS 2009).

There are currently about 172,000 home remodeling firms in the U.S., and another 200,000 self-employed remodelers (JCHS 2009). The majority of remodeling contractors are small businesses; in 2002, only 12 percent of contractors reported revenues greater than $1 million and only 1 percent reported revenues greater than $5 million. In addition to remodeling work done by professionals, there has also been a marked increase in the "Do-It-Yourself" type of remodeling work (JCHS 2009).

2.2.2.2 Home energy efficiency

Homeowners are becoming increasingly aware of the need for environmental friendliness and energy conservation—that is, improvements that will have long-term economic implications. According the US Department of Labor, though the recent economic recession has affected the construction industry, the rising energy costs have made "green renovation of buildings" an attractive option (JCHS 2009).

Space heating and air conditioning consume nearly 50 percent of residential energy, water heating about 20 percent, and appliances and lighting account for nearly 32 percent. Consumer spending on home energy efficiency climbed from 32 billion in 1999 to nearly 52 billion (inflation adjusted) in 2009 (USDOE 2010 from JCHS 2009).

This increased spending in home energy efficiency remodeling has made existing buildings more energy efficient. In 1980, the average amount of energy consumed by a home built in the 1960s was about 65 British Thermal Units (BTU) per square foot. The same buildings, when measured in 2005, showed an increase in energy efficiency of 25%. Homes built before the 1950s, showed an even greater improvement in their energy efficiency (JCHS 2009).

Pimentel et al. (2007) suggested several methods for improving the energy efficiency of homes:

- Improving and upgrading windows
- Adding insulation
- Caulking leaks and plugging air vents
- Upgrading HVAC equipment
- Reducing thermostat temperatures

Improvements like these could save the average American homeowner up to $1000 annually, and reduce heating energy consumption by 50 percent.

Over the years, the USDOE has increased the efficiency threshold for various appliances. In 2006, USDOE increased the required efficiency of air conditioners to a Seasonal Energy Efficiency Ratio (SEER) of 13 or higher, from a previous standard of 10 (A SEER rating of 13 is 30 percent more efficient than 10); similarly the minimum allowed Annual Fuel Utilization

Efficiency (AFUE) rating for a non-condensing fossil-fueled, warm-air furnace was raised to 78% (USDOE, EERE 2010).

In addition to increasing the efficiency of homes, the industry is becoming increasingly aware of health aspects associated with these retrofits, particularly with respect to air sealing and carbon monoxide production. Several research studies have been conducted to look at the health impact of buildings. Pillai (2006) lists the attributes that contribute to the indoor environmental quality of building, which in turn affect occupant health. The attributes identified were “temperature, humidity, ventilation, lighting, acoustics and ergonomic design/safety.” Straube et al. (2005) states that increased air tightness of homes below 1 Air Change Per Hour (ACH) can drastically increase the humidity and carbon monoxide levels in homes, which are detrimental to occupant health. Singh (2009) proved that occupants in buildings with better indoor environmental quality were (and still are) healthier.

2.3 Barriers to Home Energy Efficiency

Several articles in the literature focus on barriers associated with home EE. To provide a comprehensive illustration of the identified barriers in home EE, this section is deconstructed into four sub-categories:

1. Barriers to innovation in the field of construction.
2. Barriers to home retrofit.
3. Barriers to energy efficiency renovation in existing homes.
4. Barriers faced by the Building America Program.

2.3.1 Barriers to Innovation in the Field of Construction

Many of the traditionally used building materials and equipment in older homes are known to be energy inefficient, and to cause other harm like toxic waste disposal and emission of greenhouse gases. In order to mitigate these problems, homeowners have to retrofit their homes and switch to innovative and green technologies (Jaffe & Stavins 1994). The construction industry, however, is considered a laggard industry in adopting innovation (CERF 1996a from Koebel et al. 2003).

Two important literatures were identified, which focused on the barriers to the process of the acceptance and diffusion of innovation, specifically related to the residential building industry; Koebel et al. 2003 and NAHB 1991. A summary of the barriers identified are:

- The construction industry is highly cyclic; the volume of construction activity is highly dependent on the economy. Thus, companies might be hesitant to accept innovation because of the unpredictability of profits.
- The construction industry is dominated by small firms. Small firms are generally known to be slower than larger firms in adapting to new technology.
- Participants in the process lack integration.
- Building codes are highly diverse, varying from locality to locality. An innovation may be accepted by one code but rejected by another.
- There is a dire lack of performance standards or certification to distinguish a good product from a bad one. This leads to unreliability and a lack of trust in innovation.
- There is a lack of information or a lack of access to information about new products in construction.

- Any innovation would require changes in business practices and installation techniques by trade contractors. However, there are inadequate education and training avenues for implementing such changes.
- An innovation is required to be accepted not only by project participants but by the insurance and finance industries involved in the project.
- Funds for research are limited.
- Homebuyers resist the acceptance of innovation.
- Once research on new technologies and ideas has been performed in government and university labs, there the means to move them to the field, where they could be ultimately deployed, is lacking.
- The government provides little support for technology development.
- Buildings have a very long service life; during this period there could be a large number of changes in its ownership, acting as an impediment to change.
- There is an insufficient flow of information between project participants within the industry, and between the industry and product manufacturers.
- Most construction projects are fixed-price projects. In such cases, designers and constructors find themselves holding highly opposed positions, preventing either side from innovating or accepting innovations.
- There is inadequate capital for deployment; in some cases the initial cost of deployment for an innovation could be high.

2.3.2 *Barriers to Home Renovation*

Since this research concentrates on energy efficient retrofits of existing buildings, it was imperative to identify literature dealing with barriers to the general rehabilitation of homes. Listokin et al. (2001) recognized several barriers to home remodeling, some of which are summarized below.

- The process of renovation is a lot more unpredictable when compared to new construction, because the process has to cater to a lot of the unique features of the existing building, hence requiring more intensive management than new construction.
- Excessive building codes relevant to renovation, especially historic preservation, add to the unpredictability of estimating costs for rehab. Thus, the contractor pool is usually limited, decreasing competition and increasing costs.

These increased costs sometimes make renovation unaffordable for many homeowners. Additional costs may be encountered in hiring professionals to estimate costs, mitigating environmental hazards and adhering to codes.

- Inadequate skill of professional consultants.
- Reliance on smaller trade contractors for most of the renovation work. This problem is aggravated because the management skill level required for renovation is higher than for new construction, but the larger, skilled contractors are mainly involved in new construction.
- Regulatory requirements demand new rehabilitation work to be up to the same standards as new construction. Sometimes, meeting this requirement is a near impossibility.

- Varying building codes from locality to locality.
- In rehabilitations that involve federal subsidy, the Davis Bacon requirements will have to be met, adding to the regulatory requirements.
- Renovation work involves many environmental hazards such as lead paint, asbestos abatement, radon, etc.

2.3.3 Barriers to Energy Efficient Retrofits in Existing Homes

The laxity in the deployment of energy efficient retrofits in existing homes, as highlighted in the preceding sections of this report, evidently point to certain barriers that caused the inefficiency. PATH (2002) identified several barriers to the effective deployment of energy efficient retrofits in homes. This was done in two categories:

- Barriers faced by homeowners.
- Barriers faced by trade contractors and consultants.

2.3.3.1 Barriers faced by homeowners

- Manufacturers of EE technologies have a self-interest in promotion and advertising that leads to a lot of misinformation on their part. This leads to mistrust among consumers, who may have previously suffered from such misinformation. Many consumers view remodelers as scam artists.
- Consumers are misinformed about the benefits of energy efficient remodeling; hence, many do not view it as a wise option.

- Different consumers have different motivations for opting for EE of their existing homes. The promoters of energy efficiency have to understand the varied motivations and advertise accordingly. Energy efficiency information given by Federal agencies lack consistency. Consumers do not seem to be driven by social consciousness to conserve energy.

2.3.3.2 Barriers faced by trade contractors and consultants

According to the report, most of the energy efficiency remodelers are small business entrepreneurs. Some of the barriers faced by them include:

- The advent of new technologies for energy efficiency in buildings requires remodelers to change their business practices and educate themselves, to be able to adapt to them. However, remodelers have very limited time available to make such changes to their practice.
- A major concern for remodelers is the uncertainty they face in revenues and profits, when presented with innovative technology.
- The information available on energy efficient products and systems—including availability, cost, manufacturers, and potential energy savings—are scattered and difficult to find.
- There is a lack of performance standards for the retrofit process, to distinguish a high quality job from a poor one.
- Remodelers are skeptical about the consumer demand for energy efficient solutions.

Golove & Eto (1996) identified market barriers to achieving home energy efficiency. They are summarized here:

- Incentives for energy conservation are misplaced in some cases; that is, the entity that would benefit from home energy efficiency is not the financial decision-maker for investing in it. This is commonly seen in rental homes. Here, landlords may not be inspired to invest in EE technology, as the benefits from lower utility costs will only affect the tenant.
- There is limited access to financing EE technologies.
- In some cases, powerful manufacturers of EE technology prevent more energy efficient competitors from selling their product.
- There is a lack of information, or a lack of access to information, required for the process of home energy efficient investment. Since the EE related investment decisions require large amounts of complex information, this lack of information is a major barrier. Available information may be flawed because:
    - ✓ There is a lack of information.
    - ✓ Information is costly to acquire.
    - ✓ Available information may be inaccurate.
    - ✓ Information may not be usable.
- Consumers mistrust information supplied by manufacturers of EE technologies. This is a result of consumers feeling cheated by the false advertising of EE products by manufacturers in the past.

RESNET (2010 b) identified several barriers to home energy efficiency:

- There is no credible source of information required for energy efficiency investments. The labeling on equipment may not be easily understood by an average consumer.
- There are a lack of the incentives and financial opportunities necessary for home energy efficiency.
- Homeowners, especially builders, tend to reduce the first cost of home building and, hence, opt for low efficiency features for the home.
- There is a lack of common language to understand terminology typically used in energy efficiency technologies. These terminologies are not easily understood by consumers and lenders.

2.3.4 Barriers Faced by the Building America Program

The Building America (BA) program has identified a few barriers to the implementation and adoption of home energy retrofits.

Building America's Residential Energy Efficiency Meeting was held in Denver, Colorado in July, 2010. The meeting was held to identify key gaps and barriers in US home energy retrofit, and was attended by 220 professionals in the residential research and outreach industries. The session identified barriers including the following categories (NREL 2010 b):

- Financing
- Total quality assurance
- Safety
- Neighborhood scale retrofit

- Homeowner motivation
- Key market player motivation
- Government incentives and partnership programs
- Building component standards

Once the barriers were identified, the session proceeded to identify future steps that can be taken to overcome the barriers. The barriers identified by Building America are discussed in greater detail in Chapter 3 of this report. They are also listed in Appendix 1.

Building America had previously held a similar session in October 2010, in Albany, New York, to “optimize condensing boilers with low-temperature distribution.” That is, to identify key research and find gaps in the condensing boiler industry. (Condensing boilers are different from conventional boilers, in that they utilize the latent heat of water in addition to its sensible heat. This feature makes them 10%-12% more efficient compared to conventional boilers; an energy efficient option in US homes). This event was hosted by the US Department of Energy’s (USDOE’s) Building America Program, and co-hosted by New York State Energy Research and Development Authority (NYSERDA). One important conclusion drawn from this meeting was “condensing boilers are not being successfully implemented in a large scale because of a clear lack of information on optimum installation strategies and training for installers and designers”. A goal was set at the meeting, to assess current literature and try to remedy the current “information vacuum” (Aspen Publishers 2010).

2.4 Importance of Information Flow

The importance of information flow has been established in preceding sections of this report. Information flow is pivotal to both the diffusion of innovation and overcoming barriers to home energy efficient retrofits. This section has been deconstructed into two categories. The first category surveys the existing literature dealing with the role of information flow in the diffusion of innovation. The second category will survey the existing literature on the role of information flow in the home energy retrofit industry.

2.4.1 Information Flow in Diffusion of Innovation

Arguably, the most significant research on the diffusion of innovation in recent times was performed by Everett Rogers, whose studies on the subject have been used widely since his first book “Diffusion of Innovation,” in 1962. Rogers (1971) discussed effective communication strategies that would accelerate the diffusion of innovation in a market.

Rogers (1971) identified two important channels of communication, from the manufacturer to the user, for the spread of an innovation.

- Mass Media
- Interpersonal Channels

Mass Media

These channels have contact with large audiences and are able to reach them rapidly. They are the primary creators and spreaders of knowledge. Examples include television, radio and internet.

Interpersonal Channels

These communication channels involve real or virtual face-to-face contact between two or more individuals. Rogers states that, although mass media bring awareness of a new product, it is the interpersonal communication channels that actually persuade the user to try it. Rogers also states that the most effective form of communication to rapidly diffuse any innovation would be to combine mass media with interpersonal communication.

2.4.2 Information Flow in Home Energy Retrofits

Literature has identified the link between effective information flow and home energy retrofits. Golove & Eto (1996) identified imperfect information about retrofit technology to be an important reason for market failure. Imperfect information may include a lack of information, information acquisition costs, inaccuracy of information and an inability to effectively use information. Jaffe & Stavins (1994) asserted that the cost of acquiring information about an innovative energy efficient technology is a part of its installation cost. Any reduction to this cost would accelerate the energy efficiency of homes. Golovo & Eto (1996) and PATH (2002) have both stated that manufacturers of EE technology often promote inaccurate information about their products, which leads to consumer mistrust. PATH (2002) stated that the current information about EE technologies and measures are scattered and difficult to find. RESNET (2010 b) stated that there is no credible source of information, which is necessary to perform an energy efficient retrofit. Most of the information may be on labels of EE equipment, which may not be understood by consumers purchasing the product. In addition, there is a lack of understanding of the complex terminology used by manufacturers of EE technologies.

Information involving difficult terminology must be communicated in a manner that is easily understood by consumers and lenders.

The Building America Program has identified the importance of information flow in home energy efficiency retrofits. A meeting hosted by Building America in August 2010, in Denver, Colorado, reached a consensus on the necessity of information flow. Some of the facts identified were (BA 2010 c):

- Information is necessary to quantify energy efficiency in appraisal forms.
- There is a lack of understanding of energy efficient terminology in the industry.
- There is a lack of documentation to remove lead paint from exteriors.
- Information is out there, but it is not getting into the hands of the right people.
- There is a lack of information to protect trade contractors from liability.

2.5Information Systems

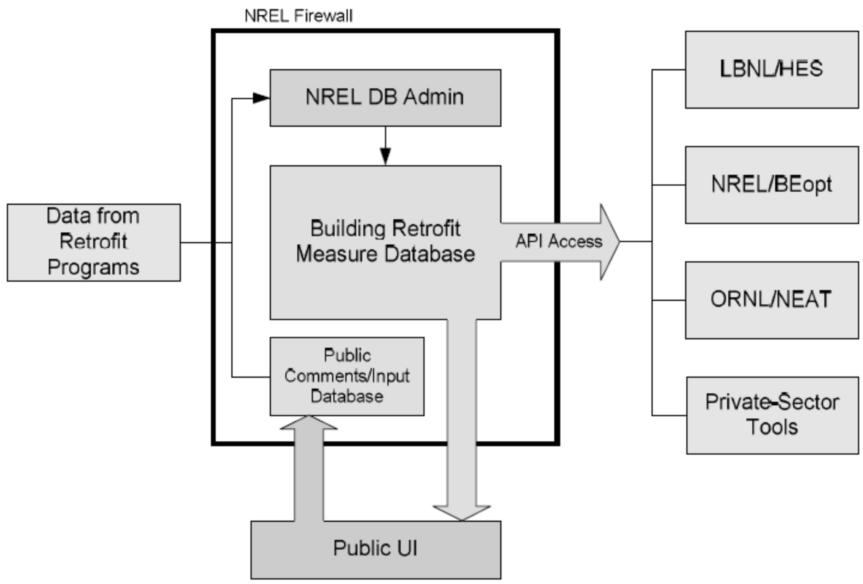
The literature reviewed in this section aims to summarize the existing literature on information portals, databases and query-based expert systems (QBES) used in the home energy efficiency industry and other construction-related industries.

2.5.1 Information Portals and Databases

Several construction- and home energy efficiency-related information portals and databases currently exist. A few examples have been reviewed.

2.5.1.1 National Residential Efficiency Measures (NREM) Database (NREL 2010)

The NREM database is a public, centralized resource of home retrofit measures and costs. It is mainly designed to assist users with deciding upon the most cost-effective retrofit measure(s) for improving the energy efficiency of homes. The database allows constant feedback from users, so it can constantly improve its effectiveness. This database was developed by integrating several DOE databases of building retrofit measures into a unified national database. The database is mainly intended for software developers of home energy simulation type software such as BEopt. However, the data is also useful for other participants in the retrofit process, such as designers, trade contractors, and homeowners. The database was publicly released in February 2010, and the current version, 2.0, was released in October 2010. The overall structure of the database is shown in Figure 2.2. It shows that input to the NREM database is from two sources: data from retrofit programs and data from public feedback. Both of the inputs are monitored by the database administrator. Once the data is input, various parties can use it for their benefits. Figure 2.3 shows a screenshot of the NREM database.



Abbr: API – Application Program Interface; DB – Database; LBNL/HES – Lawrence Berkley National Lab/Home Energy Saver; NREL/BE-opt – National Renewable Energy Laboratory/ Building Energy Optimization; ORNL/NEAT – Oak Ridge National Laboratory/National Energy Audit Tool; UI – User Interface

Figure 2.2: Overall Structure and Working of the NREM Database (Source: NREL 2010)

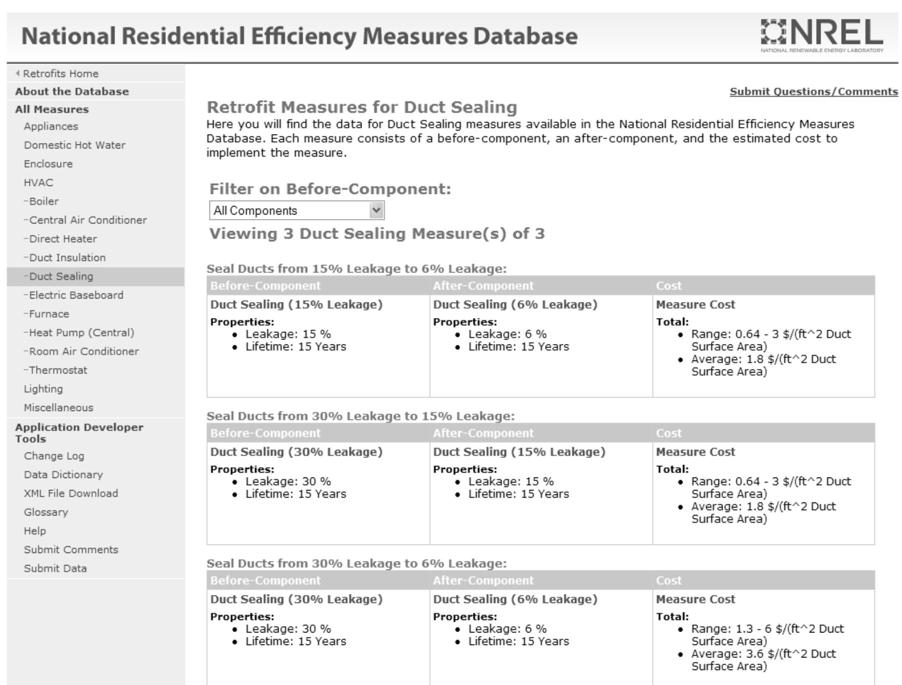


Figure 2.3: Screenshot of National Renewable Energy Laboratory Database of Retrofit Measure (Source: NREL 2010)

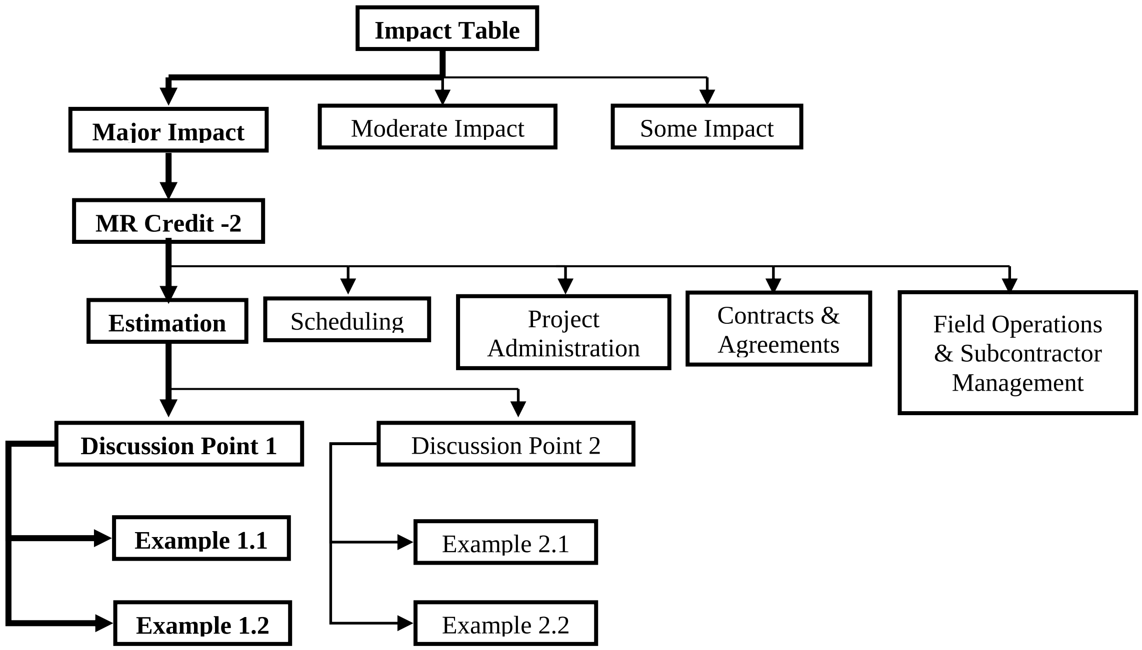


Figure 2.4: User Interface of the LEED Query Database (Source: Syal et al. 2007)

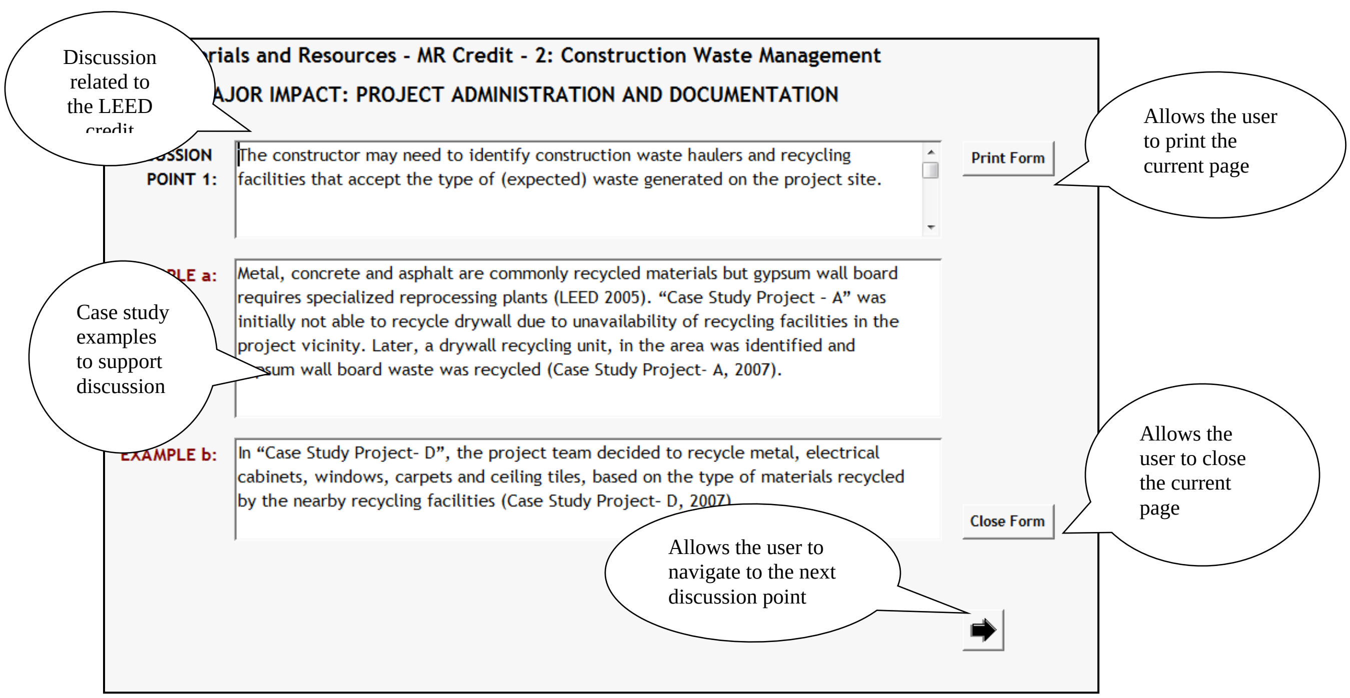


Figure 2.5: Sample Analysis of Output (Source: Syal et al. 2007)

2.5.1.3 Building America Portal

The Building America program has developed a useful portal for providing information to the public—consumers, researchers and designers of home energy efficiency technologies and measures. The layout of the BA portal mainly includes:

- Information about the BA program including research teams, current research, and future goals and deployment strategies.
- Technical and scholarly publications related to home energy efficiency.
- Links to building science educational institutions and curricula.
- Information related to EE technologies, measures, and best practices.
- Sources of EE incentives.
- Links to other EE databases such as the National Residential Efficience Measures database.
- Search portal useful for quick retrieval of specific data.

2.5.1.4 Energy Star Portal

The Energy Star Program is a joint program of the US Environmental Protection Agency (USEPA) and the US Department of Energy (USDOE), created to protect the environment through energy efficient products and measures (Energy Star 2010). The Energy Star program has an information portal that contains the following information:

Figure 2.6: Screenshot of the Building America Portal (Source: BA 2010 b)

- Products and measure to increase home energy efficiency.
- Tool that assesses the energy performance of a home. Data required to run the tool are "location of the home" and "past energy consumption."
- Tool that suggests retrofit strategies for increased energy performance, based on the location of the home and its typical features.
- Links to other EE databases.
- Search portal useful for quick retrieval of specific data.
- Scholarly and technical publications related to home EE.

Figure 2.7 shows the screenshot of the Energy Star information portal and Figure 2.8 shows the retrofit suggestion tool. The link to this tool is shown in encircled Figure 2.7.

Figure 2.7: Screenshot of the Energy Star Information Portal (Source: Energy Star 2010)

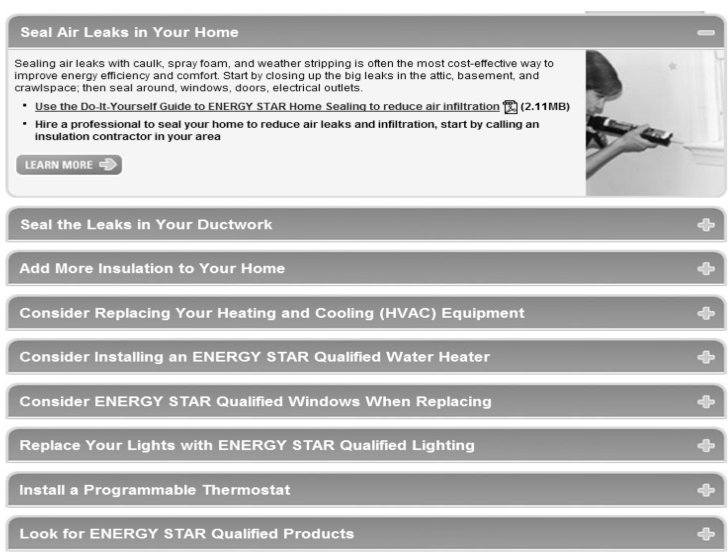


Figure 2.8: Home Retrofit Strategy Advisor (Source: Energy Star 2010)

2.5.2 Query-Based Expert Systems

Warzawski (1985) defines an expert system as "a problem solving program which solves substantial problems generally conceded as being difficult and requiring expertise." He identifies four main parts of the expert system:

- A database that contains data related to a specific problem.
- An inference engine that can retrieve relevant data to produce the solution to a problem.
- An information acquisition facility that constantly updates the database.
- An explanation facility that provides the reasoning behind each piece of expert advice.

The following section summarizes the literature based on existing query-based expert systems and other decision making tools that are used for home energy retrofits and other areas of construction.

2.5.2.1 Home energy tools

In its 2011 report, the Climate Policy Initiative (CPI) confirmed that online information tools useful for decision-making in residential energy retrofits are the most popular sources of information, providing the information at very low cost per household (Novikova et al. 2011). The report specified qualities that the tools must have:

- The level of complexity, use time, and accuracy of the system must be balanced to suit the needs of the customer.
- Information on the benefits of energy efficiency must be included.

- The tools must have sound quality control and constant improvement to be trusted by users in the long run.

Mills (2004) suggested the following:

- No single tool is perfectly designed.
- Some of the problems with tools are: too much use time, too much input required from users, output not suited to customer needs.
- The tools can be effective if simple but cost-effective retrofit measures are suggested.

Upon analysis of existing tools for home energy retrofit decision-making, the researcher feels that most of them provide retrofit measures for improving home energy performance, but none were found to provide the user with information on all aspects of the retrofit, including installation. One of the key limitations of the retrofit process is the lack of proper installation information. Thus, this research aims to develop a system that not only provides decisions on retrofit measures, but will also provide installation advice to the user.

2.5.2.2 Other Construction Area Tools

Syal et al. (1992) identified the use of knowledge-based systems in the construction project planning process. He stated that knowledge-based systems are a useful tool for providing information related to the decision-based steps in construction planning. The steps that do not require decisions made by a project team can utilize conventional computer applications.

Al-Jibouri & Mawdesley (2002) developed a knowledge-based system for linking information to support decision-making in construction. Since this system was being developed as a construction management tool, it was necessary to generate tasks in a construction project, with logical input, and with output links to other tasks. The aim of the system was to assist project managers to know what logical action to take at any point in the construction process.

The steps involved in the development process included knowledge acquisition from experts, knowledge elicitation to interpret the gained knowledge, and validation of the model. The process included representing the decision process in the form of decision trees. to mimic knowledge experts. Finally, the model was developed using the expert system shell XpertRule.

Shaked & Warzawski (1995) developed HISCHED, a knowledge-based system for the construction planning of high rise buildings. HISCHED performed the construction planning functions of task enumeration, determining dependencies between tasks, allocation of resources for tasks and time determination.

Several expert systems currently exist in the field of construction. One of the leading manufacturers of expert systems, “Exsys,” has developed several such expert systems, including (EXSYS 2011):

- Concrete Structure Diagnostics
- Highway Construction Equipment Selector
- Construction Method and Labor Cost Diagnostics

- Work Zone Safety Advice and Training Assistance
- Asbestos Hazard Advice

2.6 Chapter Summary

This chapter identified relevant literature related to the home energy efficiency retrofit. The review looked at the history and current state of home energy efficiency in the country, barriers faced by the construction industry—specifically the home energy efficiency industry—and literature related to information flow in home energy efficiency. Finally, information tools and systems that are used in the construction and energy efficiency industries were reviewed.

CHAPTER 3

FRAMEWORK OF QUANTITATIVE DATABASE

3.1 Overview

The ultimate objective of this research is to develop the framework for a query-based expert system. The information required for the expert system is stored in two categories, quantitative information (data) and qualitative information (knowledge). The parts of the system that store these two categories of information are referred to as the database and the knowledgebase. A detailed description of all of the parts and functioning of a complete expert system is provided in the following section. This chapter develops the framework for the quantitative database of the expert system and Chapter 4 develops the framework of a qualitative knowledgebase. Chapter 4 also describes the integration of the database with the knowledgebase to develop the final framework of the expert system.

This chapter is divided into three sections: Section 3.3 explores the barriers and future steps related to home energy retrofits. Future steps refer to those steps that need to be taken to overcome barriers. Section 3.2 provides a brief discussion of the architecture of an expert system analyzes the existing Building America information portal and related databases, and section 3.5 develops the framework for the database. Sections 3.3 and 3.4 will help establish the categories of information the database will require. Section 3.5 will then use those requirements to develop the final framework.

3.2 Query-Based Expert System (QBES) Architecture

An expert system is defined as "a computer system that employs human knowledge captured in a computer to solve problems that ordinarily require human expertise/knowledge." These systems reason and produce decisions in a manner similar to humans (Syal 2011). The expert system uses Boolean logic (if-then rules) to formulate a decision. The major parts of a QBES are shown in Figure 3.1.

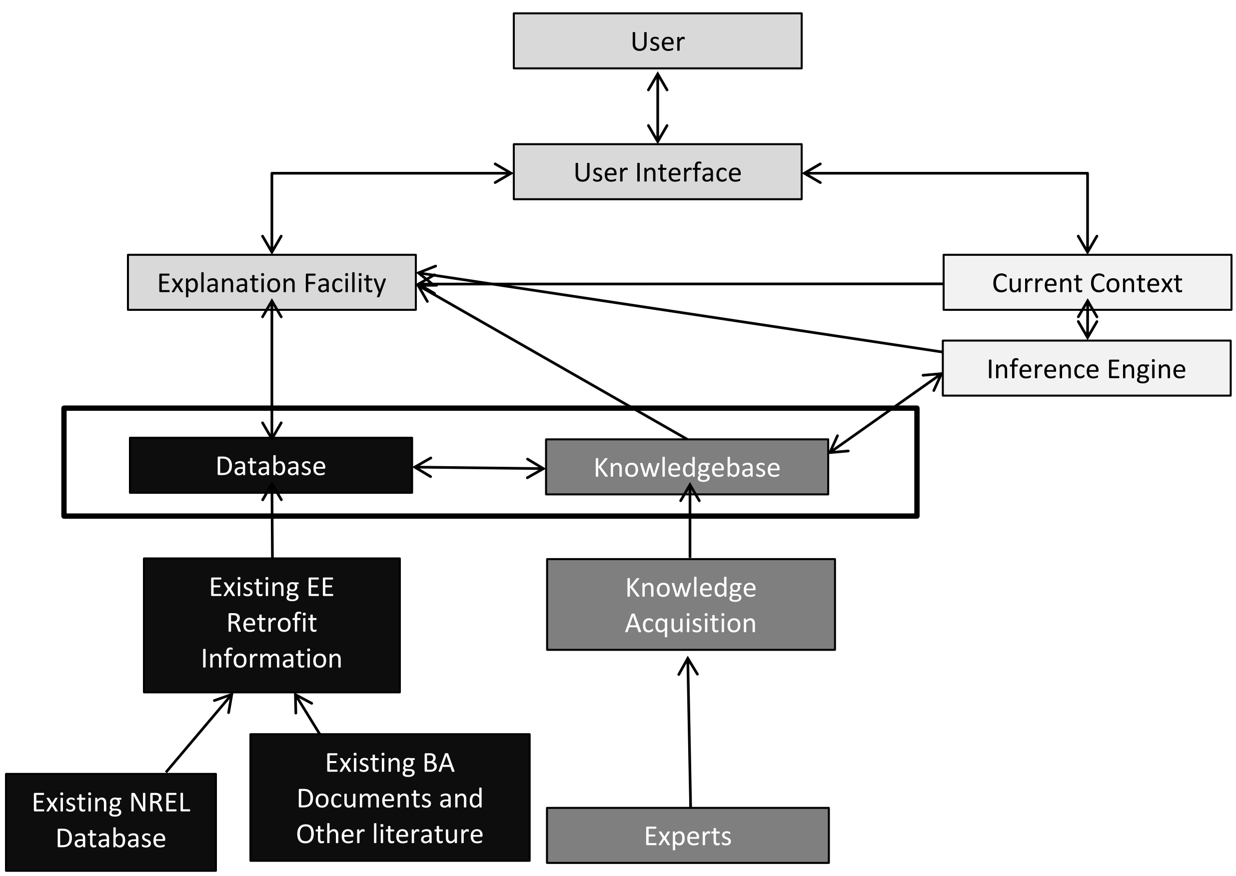


Figure 3.1: Overall Structure of a Query-Based Expert System (Source: Syal 2011)

3.2.1 Functioning of QBES (Turban 2005, Syal 2011)

A Query-Based Expert System has four stages of functioning:

Stage I: Qualitative Information Acquisition and Storage (Knowledge)

Stage II: Quantitative Information Acquisition and Storage (Data)

Stage III: Information Processing by Integration of Knowledgebase and Database

Stage IV: User Interface

3.2.1.1 Qualitative Information Acquisition and Storage (Knowledge)

The term "knowledge" is used to indicate human reasoning in making a decision. Human reasoning consists of a series of steps taken to come to a decision or solve a problem. If these steps can be collected, codified and stored in a computer, the action is referred to as *knowledge engineering*. Knowledge from *experts* is usually collected through expert interviews. Such a collection of knowledge is called a *knowledgebase*. Knowledge is stored in the form of Boolean logic, which can then be interpreted by the *inference engine* of the expert system for a variety of situations, and produce decisions or solutions. The computer identifies the nature of a situation/problem through answers to queries directed at the system user.

The framework of the knowledgebase developed for this research is dedicated to information related to home energy retrofits. When the actual system is developed upon this framework, it will assist homeowners with diagnosing the energy-related problems/inefficiencies in their homes and produce solutions to increase their homes' energy performance. The system will provide two types of solutions in home energy retrofit. First, it will help the homeowner identify optimal measures to increase home energy efficiency. Second, it will provide expert advice on installation methods for the identified measures.

It is beyond the scope of this research to populate the knowledgebase with actual knowledge related to the home energy retrofit. This research only aims to establish a framework for such a knowledgebase. The framework developed here will be used in future stages of this project to develop the actual knowledgebase. The interviews conducted for this research were designed to help establish the framework. Details of the interviews are provided in later parts of this chapter.

3.2.1.2 Quantitative Information Acquisition and Storage (Data)

Quantitative information or data is also known as “factual information.” Such information does not involve any reasoning process, nor does it provide outputs customized for a specific situation. Most of the published information in documents, articles, databases, etc. would fall under the category of quantitative information. The development of a framework for a quantitative database, including identifying categories of information, was demonstrated in Chapter 3 of this report. The sources of quantitative data are the NREM database, the DSIRE database, published information contained in the Building America literature, other building-science-related publications, and input from the other tasks of this project. Details of the other tasks can be found in Chapter 1.

3.2.1.3 Information Processing by Integration of Knowledgebase and Database

As shown in Figure 3.1, the expert system functions by integrating the qualitative knowledgebase and the quantitative database, to deliver expert advice. The reasoning process performed by the *inference engine*—using knowledge stored in the knowledgebase—must be supplemented with adequate quantitative data from the database.

The integration of the database and the knowledgebase is best demonstrated by an example. Consider the following Boolean expression:

"IF the *heating system* of the home is *inefficient*, THEN it must be replaced with a *state of the art efficient system,* AND the new system must be installed according to the *manufacturer's requirements."*

This expression contains two parts:

Part 1 is the diagnosis of the existing energy performance of a component (heating system).

Part 2 is the installation-related advice.

The italicized terms are the variables of the expression. These variables are connected by Boolean logic.

The question in this case is on the efficiency of the existing heating system. The information about the existing efficiency can be obtained if the user of the system provides it as an answer to the following query:

Q. "What is the efficiency of the heating system of your home?"

Answer: Existing Efficiency

The knowledgebase will thus contain knowledge in the form of Boolean expressions, as above.

Now consider the other variables in the expression: “state-of-the-art efficiency of heating systems” and “manufacturer’s installation requirements.” These are quantitative data which are necessary to make the final decision.

Thus, we see that unless there is integration between the quantitative database and the qualitative knowledgebase, an appropriate decision/solution cannot be produced.

In many cases, users’ knowledge about their existing situation may be limited, causing them to be unable to provide that information to the system. In such cases, the system will try to develop a decision/solution with the amount of information available. This function is known as *current context.*

3.2.1.4 User Interface

The user interface provides the user with a convenient medium for interaction with the system. In addition to providing decisions/solutions/advice, the system also explains the logic it used to produce the output. This is provided in the *explanation facility*.

3.3 Barriers and Future Steps

This section explores the barriers and future steps to energy efficiency in existing homes by looking at a variety of literature dealing with these topics. The literature selected for this chapter encompasses those items dealing with barriers related to general home remodeling, home energy efficiency, and the Building America Program (BA).

A database is a collection of interrelated data, together with a set of programs to access that data. The primary goal of a database is to provide the means to store and retrieve information in a convenient and efficient manner (Sudarshan et al. 2002). The information stored in a database is relevant to a particular need, which, in this case, would be an energy efficient retrofit of existing homes. The first step in developing a database is to define the categories of information (entity sets) that have to be provided to retrofitters so they can effectively carry out the retrofit process. The categories will be identified using the following methodology:

a) Study the barriers and future steps related to home energy retrofits.

b) Classify the barriers into appropriate categories.

c) Use the categories in step b as categories of information required for the database.

3.3.1 Classification of Barriers and Future Steps

The literature related to barriers and future steps for home energy retrofits was studied in detail. These barriers and future steps were then classified under two broad categories:

a. Overall issues (innovation in construction, home retrofit, home energy retrofit/Building America Program).
b. Construction-related issues (performance, cost issues and installation issues).

3.3.1.1 Classification Based on Overall Issues

Barriers were classified into three categories based on overall issues. Appendix 1 shows this classification in the form of check marks in the y axes. This classification is only for academic purposes and for use in future research that will be built upon this research. It will not influence the categories of information for the database framework. The three categories are:

- Innovation in Construction
- General Home Retrofit
- Energy Efficiency/Building America

Innovation in Construction

In order to increase the energy efficiency of their homes, homeowners have to retrofit their homes, switching to innovative and green technologies (Jaffe & Stavins 1994). When it comes to adopting innovation, however, the construction industry is described as a laggard industry (CERF 1996a from Koebel et al. 2003). This means there are barriers to innovation in construction, which will be investigated here.

General Home Retrofit:

Homeowners primarily remodel/retrofit their homes for improvements to maintain the structural integrity and efficient functioning of their homes, and/or to generate cost savings (JCHS 2009). The researcher believes that many of the barriers that one would face in general remodeling/retrofitting work would closely relate to barriers in home energy retrofits.

Energy Efficient Retrofit/ Building America Program:

For this research, understanding barriers and the future steps related to home energy efficiency retrofits are most important and relevant.

3.3.1.2 Classification Based on Construction-Related Issues

The barriers and future steps identified in the literature were classified based on the construction issues they address. These barrier categories will become the categories required for the database framework.

Syal (2011) breaks down the life cycle of a typical construction project into four stages, as shown in Figure 3.2. These stages are typical of a new construction project, but were deemed relevant by the researcher for retrofit projects as well. Due to time constraints and the scope of this research, classification of the barriers and future steps in this chapter are only based on the construction stage.

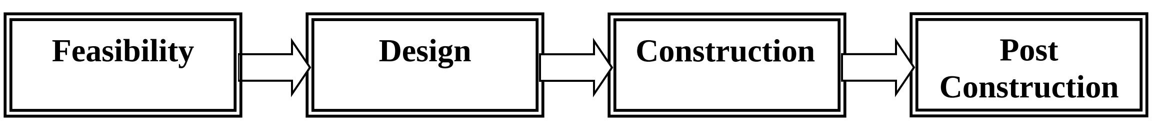


Figure 3.2: Life Cycle of a Typical Construction Project (Source: Syal 2011)

In addition to construction-stage-related barriers, barriers in this section were also analyzed under: “Information-Related Issues,” and “Market and Consumer Motivation Issues”. These categories, although not directly related to the process, are important barriers that need to be overcome for the large-scale implementation of strategies for improving the energy efficiency of existing homes. Although these two categories will not be included as information categories in the final framework of the database, they have been included for reference, for future research studies that will be based upon this research.

After studying the barriers and future steps, categories that would be used to develop the categories of information in the database framework were suggested. The categories are shown in Figure 3.3. A brief description of each category, with examples of existing barriers, follows. The entire list of barriers identified under the respective categories is listed in Appendix 1 of this report.

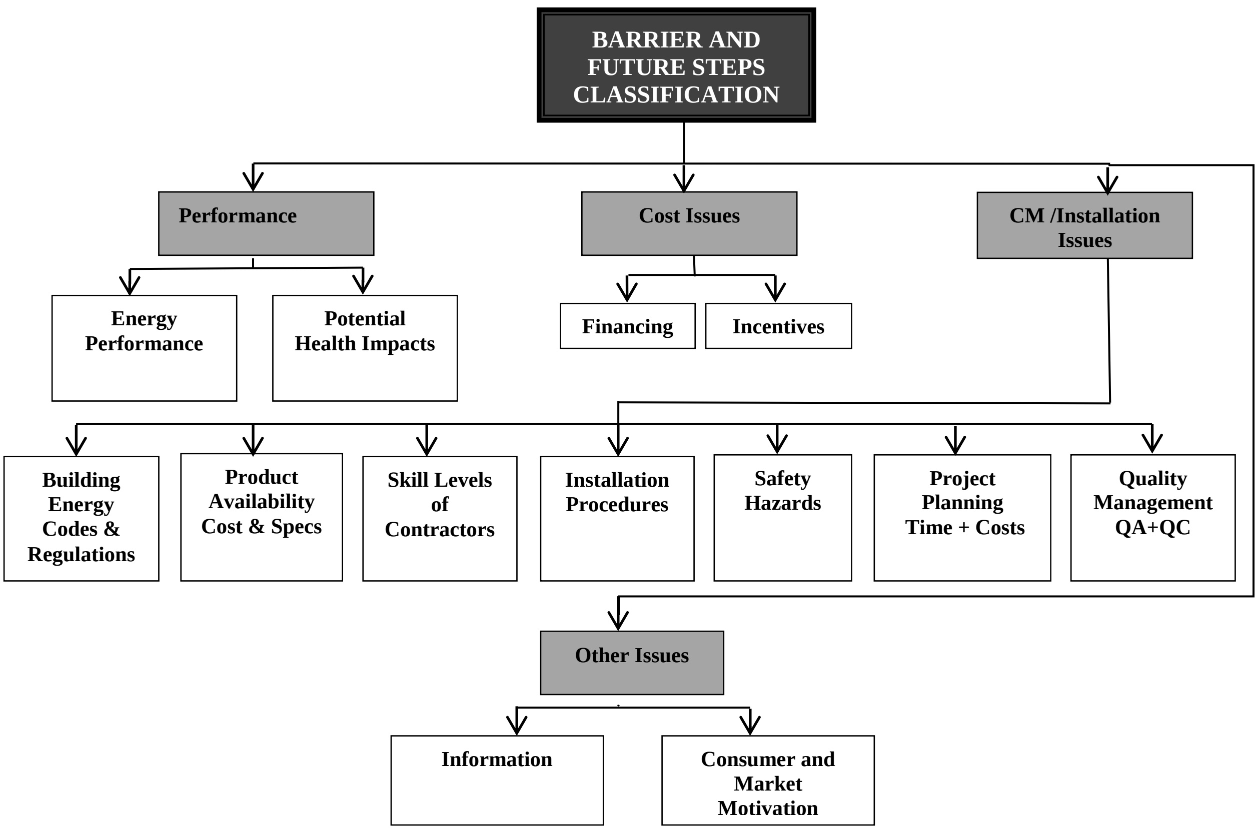


Figure 3.3: Classification of Barriers and Future Steps/Categories of Information for Database Framework

Performance

The Building Performance Institute (BPI) defines building performance as addressing the issues of comfort, health and safety, durability, and energy efficiency (BPI 2010). These aspects of performance can also be related to energy efficient technologies and measures for the home. Of these four issues, durability does not directly relate to the scope of this research and has not been identified as a category. Health and energy efficiency are discussed under Performance, and safety hazards under CM/Installation Issues.

Potential Energy Savings

The energy efficiency of technologies and measures can be quantified based on the energy they save, compared to a conventional technology or measure. Several barriers and future steps have been identified, relative to potential energy savings. For example, NREL (2010 b) states that it is "difficult to know expected efficiency of current space conditioning equipment and needs a library/database of performance expectations for different makes and models." It also states that "manufacturers do not have incentive to provide this information." This implies that without understanding the quantifiable potential energy savings from space conditioning equipment, consumers may not be motivated to implement a change in space conditioning. Manufacturers must be provided with incentives to display the possible energy savings. All other identified barriers related to the performance of EE technology and measures are listed in Appendix 1.

Potential Health Impacts

Health risks are inherent in energy efficient home retrofits (NREL 2010 b). This section deals with the barriers and future steps related to health and safety issues, post-retrofit. The barriers and future steps related to safety hazards during the process are covered under "Safety hazards". The Environmental Protection Agency (EPA), recognizing the potential health risks associated with EE retrofits, prescribed certain "Healthy Indoor Environment Protocols for Home Energy Upgrades" useful for retrofit contractors, trainers, and program administrators involved in the retrofit process (USEPA 2010 a).

There are several barriers relevant to safe-guarding health in homes following an EE retrofit. For example, NREL (2010 b) found that "health risks have not been completely mapped and, consequently, the solutions have not been identified." It is clear from this barrier that there is no comprehensive data on the health and safety issues related to the EE retrofit of homes and, hence, limited solutions to the problem. This could lead to a situation where the home is retrofitted to be EE but causes health-related issues for occupants in the long run. All other identified barriers and future steps related to health and safety issues are shown in Appendix 1.

Cost Issues

As mentioned previously, the feasibility of retrofits depend greatly on their affordability. Energy efficient technologies and measures can be an expensive investment and may only be affordable if consumers have adequate access to, and information about, incentives and financial instruments (PATH 2002).

Financing

There are several barriers to financing EE retrofits of homes. The barriers have been listed in Appendix 1. Most of the barriers show that lenders lack the assessment tools or an understanding of the financial benefits of a home energy retrofit. This leads them to underestimate the cost-savings homeowners would accrue by retrofitting their homes, and, hence, they are reluctant to provide loans for retrofits. Additionally, since many of the technologies are new, lenders hesitate to finance them due to a lack of knowledge about their performance (PATH 2002, NREL 2010 b).

Incentives

Incentives may include the government, utility companies or other agencies that offer financial motivation in the form of tax rebates, subsidies etc. Incentives reduce the cost of investment, which motivates consumers to invest in home EE retrofits. There are several barriers to the effective implementation of incentives for the home EE retrofit process, as shown in Appendix 1. For example, the Property-Assessed Clean Energy (PACE) model is a financing structure that enables local governments to raise money through bond issuance or other sources of capital, to fund energy efficiency and renewable energy projects. This program has been put on hold, however, highlighting the fleeting nature of government incentives for home EE (NREL 2010 b).

CM/Installation Issues

The following issues relate to the construction/installation aspects of home energy retrofits. These categories will provide appropriate information required for the proper installation of retrofit measures.

Building Energy Codes & Regulations

States that have implemented residential building energy codes showed a reduction in energy consumption of between 2.09-4.98% in the year 2006 (Aroonruengsawat 2009). However, there are many barriers related to implementing building energy codes and regulations, as shown in Appendix 1. For example, Aroonruengsawat (2009) states that builders are not completely compliant with energy codes, which may be due to a lack of informed builders, the complexity of the building code, and/or insufficient training of code officials. This implies that building energy codes and regulations need to be implemented, and participants in the process must be trained to use them effectively.

Product Availability, Cost and Specifications

Information about the availability, costs and specifications of products are significant factors affecting home EE retrofits. Several recent innovations have produced energy efficient technologies and measures. According to Jaffe & Stavins (1994), the cost of implementing retrofit measures and technologies are a combination of:

- Acquiring information
- Product purchase costs
- Installation costs

One goal of this research is to reduce the overall cost of measures and technologies by reducing the information acquisition cost.

Several barriers related to this section have been identified, as shown in Appendix 1. For example, NREL (2010 b) states that "the labeling on equipment may not be easily understood by an average consumer." This barrier highlights the importance of providing specifications and labeling in a way consumers can understand.

Skill level of Contractors

The skill level of contractors is another important aspect of the home EE retrofit process. Several barriers related to this section are shown in Appendix 1. Most of the barriers and future steps identified in the literature show that trade contractors involved in the home retrofit process are often smaller contractors who lack the knowledge and skills necessary for the installation of energy efficient technologies and measures, and who, therefore, have to be trained to provide better performance and services to consumers (NREL 2010 b, PATH 2002, Listokin et al. 2001).

Installation Procedures

Any retrofit technology or measure, irrespective of its efficiency, can only perform optimally if installed in the appropriate manner. The barriers and future steps related to this section are shown in Appendix 1. For example, the "residential heat pump water heater (HPWH)," developed in collaboration with the Oak Ridge National Laboratory and the Energy Star Program, is a water heater that uses the heat from surrounding air to heat the water. It produces almost twice the amount of heat for the same electricity cost as a conventional water heater. However, in spite of its high efficiency, the water heater had not been a success. Of the 9.8 million residential water heaters sold in 2006, only about 2000 units of the HPWP were sold. Among several reasons attributed to its failure, there was a concern that the technology was not well-suited to universal installation methods (Energy Star 2008 from Dubay et al. 2009). Most trade contractors are used to certain conventional installation procedures. If a technology demands unfamiliar installation techniques, however, the installer must have access to a database of this information.

Safety Hazards

The barriers and future steps related to the health and safety of home occupants, post-retrofit, were previously discussed in the section “Health Issues.” Several barriers and future steps relevant to this section are shown in Appendix 1. Retrofitters of older homes constantly face safety issues such as exposure to lead paint, asbestos, and radon (Listokin et al. 2001). These barriers will have to be overcome in order to eliminate such risks and make it an attractive business option for trade contractors.

Project Planning Related to Time and Costs

Syal (2011) defines the project planning process as obtaining answers to the following project related questions:

- What is to be done?
- Who will do it?
- How will it be done?
- When will it be done?
- How much will it cost?

Barriers to project planning are identified in Appendix 1. As a construction project, home energy retrofits have to be planned well for proper execution. Thus, a study of these barriers is important.

Quality management (Quality Assurance and Quality Control)

Syal (2011) defines quality as the “application of standards and procedures to ensure that a product or a facility will meet or exceed desired performance criteria, including documentation necessary to verify that all steps in the procedure have been satisfactorily completed.” Quality Control is defined as “ensuring that the work on the project conforms to the quality standards.” These steps are imperative for ensuring the success of a retrofit project.

Several barriers and future steps related to quality management are shown in Appendix 1. Poor quality can cause a lack of durability, health problems, and a performance that is not up to the expected standards.

Other Issues

This final section covers those barriers and future steps not directly related to the home energy retrofit process. It is important to consider these issues if strategies for energy efficiency of existing homes are to be implemented on a large scale. These categories will not, however, be part of the database framework.

Information

Previous chapters of this report have emphasized the necessity of delivering optimal, appropriate and timely information to consumers. Several barriers and future steps related to information flow are shown in Appendix 1. Barriers related to information flow in home energy efficiency retrofits mainly relate to the fact that while information related to home energy efficiency retrofits are available, they are not available in a manner that is easily accessible by the participants in the retrofit process. Unified and systematic information about product availability, costs, manufacturers, potential energy savings, performance certification, building codes, etc., will help consumers make the right choices and can accelerate the dissemination of EE technologies (PATH 2002).

In the same manner, information that is developed in laboratories and universities is not being effectively moved into the construction field, delaying the acceptance of energy efficient and innovative technologies and measures (Koebel et al. 2003). To overcome these information-related barriers, this research aims to develop information delivery mechanisms that will grant easy access to participants in the retrofit process. Such mechanisms would accelerate the implementation of home energy efficiency retrofits on a large scale.

Consumer and Market Motivation

Consumer and market motivation play a very important role in the implementation of home energy retrofits. Most of the barriers related to this issue stress the importance of designing retrofit technologies and programs based on the needs of consumers, to encourage and motivate consumers on a large scale. It has been found that consumer motivations are wide-ranging, including trying to save costs on utilities, trying to save the environment, trying to impress neighbors and more (NREL 2010 b, PATH 2002). Once these requirements are met, home energy retrofits can be implemented. One of the future steps identified for increasing homeowner motivation is to investigate the renovation decision-making process in specific populations and contexts (NREL 2010 b). The decision support system/expert system developed in Chapter 4 of this report aims to assist with this requirement.

3.4 Analysis of Building America Information Portal (BA 2010 b)

The categories of information necessary for the effective energy retrofit of homes were established in section 3.3. This section of the chapter analyzes the information related to home energy retrofits that is contained within the Building America Portal. The aim of this analysis is twofold. First, using the frameworks established here, future research will be able to identify useful information from the BA portal and use it in relevant situations. Second, it will establish whether any of the identified information categories in Figure 3.3 are currently available in database formats in the Building America information portal. If they are, these categories will be noted in the framework of the proposed database, to prevent repetition. The analysis was done in two stages, to achieve both purposes. Stage 1 developed a list of all information contained in the BA portal in document/non-database formats and external links; Stage 2 generated a list of data available in database formats.

3.4.1 Major Publications

The following information related to home energy retrofits is available in the Building America information portal in the form of articles, research publications and documents. A few important publications have been summarized below. Publications can be accessed from the Publications Library of the Building America portal.

1. *Air Sealing: A Guide for Contractors to Share with Homeowners – Volume 10*

This document contains useful information related to air-sealing techniques as a retrofit measure in existing homes, to increase their energy efficiency. The following areas of information are covered in this publication:

- Test in/test out procedures
- Contractor Skills
- Equipment and tools necessary
- Health and safety issues
- EE ventilation
- Code requirements
- Checklist
- Start to finish procedures, including installation procedures

2. *Builders Challenge Guide to 40% Whole-House Energy Savings in the Cold and Very Cold Climate – Volume 12*

This publication is mainly intended for builders to promote their energy efficient buildings. The following are the highlights of the publication:

- Business management tools, sales training tips, and marketing strategies.
- A whole-house approach to building science and special considerations for building in cold and very cold climates.
- Construction recommendations for architects and engineers, based on Building America research.

- Guidance on best practices for meeting and exceeding code, with regard to moisture management, insulation, and the air sealing of home foundations, walls and roofs.
- Guidance on windows, heating, air conditioning, ventilation, plumbing, and electrical systems.
- Occupant safety and health related to equipment installation.
- Guidance on inspecting and commissioning.
- Construction contracts, scheduling, and training.
- A useful checklist of all of these recommendations.
- How-to field guides on specific energy-efficiency measures for installers.
- Case studies and examples.

3. *Healthy and Affordable Housing: Practical Recommendations for Building, Renovating and Maintaining Housing: Read This Before You Design, Build or Renovate*

This publication contains information for retrofitters, regarding health aspects related to home energy retrofits. The highlights of the publication include:

- Recognizing asthma triggers in homes: particles from molds, dust mites, mice, rats, roaches, and pets.

- Indoor air contaminants such as carbon monoxide, and volatile organic compounds like nitrogen dioxide, sulfur dioxide, radon and other particles.

- Outdoor air contaminants such as ozone, sulfur dioxide, carbon monoxide, pollens and other particles.

- Design, construction, renovation, maintenance and operation of homes to control asthma triggers, and other indoor and outdoor contaminants.

4. *Energy Performance Techniques and Technologies: Preserving Historic Homes – Volume 13*

This publication helps with planning energy efficient retrofits for historic houses by combining energy-efficient best practices with the process of historic renovation. The document contains the following:

- Background for retrofitting and preserving older homes and homes designated as "historic."
- Planning a whole-house energy retrofit.
- Strategies for maximizing the potential energy efficiency of an original house design and preserving its character.
- Aspects of retrofitting a historic house while preserving its character.
- Health and safety concerns related to past building materials and practices.

In addition to the above "popular" documents, the portal has several other publications relevant to home energy retrofits, including:

1. *Attic Access: Provide Adequate Insulation Coverage and Air Sealing for the Access between Living Space and the Unconditioned Attic*

This document contains useful information related to adding insulation to attics. The main aspects covered in this report are:

- Types of insulation
- Installation Procedures
- Safety Hazards

2. *Basement Insulation. Office of Building Technology, State and Community Programs (BTS) Technology Fact Sheet*

This document contains useful information necessary for creating comfortable basements; that is, basements free of moisture problems that are also easy to condition.

3. *Slab Insulation*

This document contains information regarding adding insulation to basements. The document contains information on:

- Types of insulation
- Installation Procedures
- Safety Hazards

4. *Best practice documents for various climates*

Several best practice documents exist for hot & humid, hot dry, mixed dry, cold & very cold, and mixed humidity climates. It also includes case studies. Though this publication is mainly intended for new construction, several best practice methods could be employed for existing home retrofits.

These publications contain information for:

- Homeowners

- Designers
- Marketers
- Managers
- Site Planners
- Site Supervisors
- Trade Contractors

5. *Region Specific Guidelines*

Several publications provide home energy retrofit information relevant to specific regions, including:

- Colorado
- Wisconsin
- Texas
- Arizona
- Northwest USA

3.4.2 Related External Links

In addition to the technical publications and documents, the Building America Portal has links to several external websites that provide useful information related to home energy retrofits. These websites act as mini-portals themselves, with useful information related to building EE. The external links are:

- Energy Star website, containing information about Energy Star rated products.

- Insulation fact sheet, which contains the cost of insulation, types and appropriate areas, and methods of installation (Last modified 2008).

- Insulation – a zip code based "expert system," which recommends the appropriate amounts of insulation for specific areas.

- Lawrence Berkeley National Laboratory (LBNL) link to duct-related issues; contains information about duct design, leakage, insulation, duct testing, etc.

- Link to NAHB's Toolbase.org, which offers excellent information about building energy efficiency.

- Link to a Building Codes program containing information related to building energy codes.

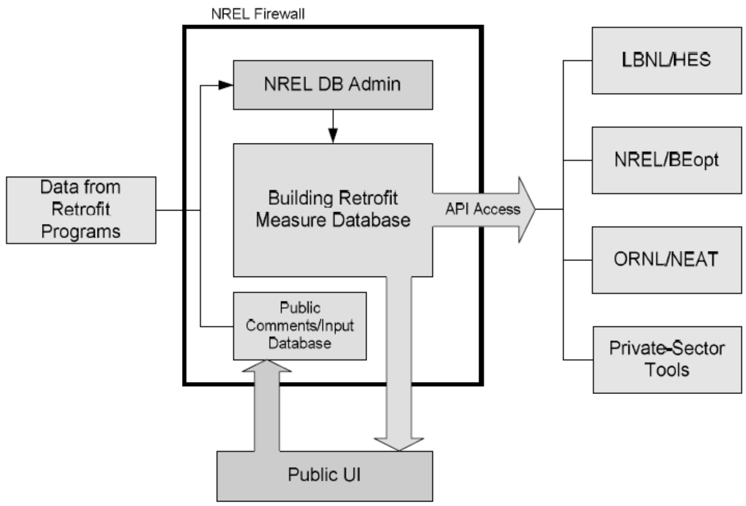
- Links to various research organizations' webpages, including the National Renewable Energy Laboratory (NREL), the Pacific Northwest National Laboratory, the Residential Energy Services Network (RESNET), and others.
- Links to Government webpages such as USDOE, the Partnership for Advancing Technology in Housing (PATH), Weatherization Assistance Program (WAP) and USDOEs Building Technologies Program.

3.4.3 Databases

Each of the publications listed above are part of the Building America information portal; they only exist in non-database formats. Two databases with useful retrofit-related information have been found. These relay that information in a manner that allows for convenient and efficient data retrieval. They are the National Residential Efficiency Measures (NREM) Database and the Database of State Incentives for Renewables and Efficiency (DSIRE).

3.4.3.1 National Residential Efficiency Measures (NREM) Database (NREL 2010)

The NREM database is a public, centralized resource of home retrofit measures and costs. It is mainly designed to assist users in deciding upon the most cost-effective retrofit measures for improving the energy efficiency of homes. The database allows constant feedback from users, so it can constantly improve its effectiveness. This database was developed by integrating several Department of Energy (DOE) databases on building retrofit measures into a unified national database. The database is mainly intended for software developers of home energy simulation type software, such as BEopt. However, the data is also useful for other participants in the retrofit process, such as designers, trade contractors, and homeowners. The database was publicly released in February 2010, with the current version, 2.0, released in October 2010. The overall structure of the database is shown in Figure 3.4. It shows that input to the NREM database is from two sources—data from retrofit programs and data from public feedback. Both of the inputs are monitored by the database administrator. The feedback is used to update the database regularly.



Abbr: API–Application Program Interface; DB–Database; LBNL/HES–Lawrence Berkley National Lab/Home Energy Saver; NREL/BE-opt–National Renewable Energy Laboratory/ Building Energy Optimization; ORNL/NEAT–Oak Ridge National Laboratory/National Energy Audit Tool; UI–User Interface

Figure 3.4: Overall Structure and Working of the NREM Database (Source: NREL 2010)

Data Hierarchy

The data of the NREM database is arranged in a hierarchical format. An example of the arrangement is shown in Figure 3.5.

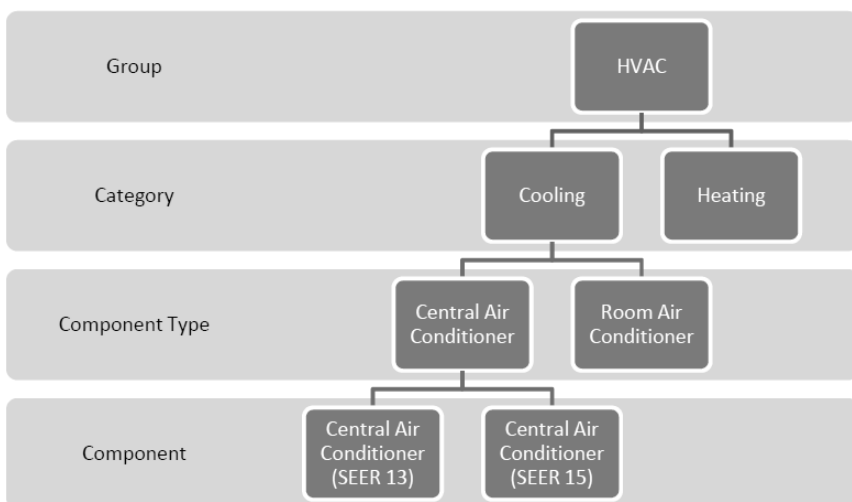


Figure 3.5: Example of the NREM Data Hierarchy (Source: NREL 2010)

Database Output

The output of the database consists of measures, actions, component properties, and costs. Below is a brief description of the outputs:

1. *Measures* – The before component and the after component. (This format allows users to identify the costs of replacing one component with another.)
2. *Actions* – Specific labor operations for implementing the after component.
3. *Component properties* such as performance, lifetime, and codes and standards.
4. *Costs* – Specific costs of the before component, the after-components and actions associated with making a change.

Measures

As noted earlier, the database lists several energy retrofit measures, including a before and an after component. The following rules have been applied to listed measures:

- The after component must be more efficient than the before component.
- Where possible, the after component must meet federal standards/energy codes.
- The after component provides the same level of service as the before component.
- The improvement must be practical.

Actions

The actions refer to specific labor requirements for implementing the after component. They consist of 4 types:

- *Replace* – This action includes the removal of an existing component and the installation of a higher efficiency component in its place. E.g. replacing a central A.C-SEER rating 9 with a central A.C-SEER rating 14.

- *Install* – This action has no before component. It only includes the cost of installing a component without having to remove a pre-existing component.
- *Remove* – This action does not have an after component. It only includes the cost of removing a component.
- *Insulate* – This action includes the cost of adding insulation to existing components.
- *Seal* – This action includes whole house air-leakage reduction and duct-sealing.

Costs

The costs are comprised of the costs of labor and materials. The method for calculating the cost of a measure is:

Total cost = Action cost + Component cost

Cost of a measure = M. Cost of before component + Action Cost + M. Cost of after component. M is a multiplier, shown in Table 3.1.

Table 3.1: Cost Multipliers for Action Types in NREM database (Source: NREL 2010)

Action Type	M (before)	M (after)
Replace	0	1
Install	0	1
Remove	0	0
Insulate	1	1
Seal	0	0

The costs are provided in the format of mean cost and range of cost. The range is between the measure's 10^{th} percentile and 90^{th} percentile cost. Factors such as climate, construction, home features, local economy, contractor pricing, and geographical location influence the cost range.

Classification of Measures

Measures are classified in six categories. They are:

- Appliances
- Domestic Hot Water
- Enclosure
- HVAC
- Lighting
- Miscellaneous

Sources of Cost Data

The NREM database obtains its data from a variety of sources. The following sources are used:

- Services
- Home improvement retail store websites
- Industry Partners
- Publications – government, industry or academic
- Formulaic costing approach for components with limited cost data

3.4.3.2 Database of State Incentives for Renewables and Efficiency (DSIRE 2010)

Established in 1995, the Database of State Incentives for Renewables & Efficiency (DSIRE) is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council (IREC). It is funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), primarily through the Office of Planning, Budget and Analysis (PBA). The site is administered by the National Renewable Energy Laboratory (NREL).

The database contains information related to renewables, and to energy efficient technologies and measures. The database provides three areas of information for both Federal and State resources.

- Financial Incentives
- Rules, Regulations and Policies
- Related Programs and Initiatives

3.4.4 Analysis of Building America Portal

This section analyzes the information found in the Building America Portal, and proposes its usage in the framework of the quantitative database for the QBES.

The Building America Portal contains large amounts of appropriate and necessary information related to home energy efficiency retrofits. However, only three categories of information currently exist in a database format for home energy retrofit measures:

- Cost
- Financial Incentives
- Rules, Regulations and Policies

The other categories identified in the analysis of barriers and future steps discussed in the early part of this chapter were not available in comprehensive database formats. They are, however, deemed to be necessary information categories in a database of home energy retrofits, as outlined for this research. Those categories include:

- Health Issues
- Financing
- Building Energy Codes
- Availability and Specifications of Products
- Skill Level of Contractors
- Installation Procedures
- Safety Hazards
- Project Planning, Including Time and Cost Management
- Quality Management, Including Quality Assurance and Quality Control

The framework of this quantitative database will contain all 12 of these information categories.

3.5 Development of Quantitative Database

This section aims to develop a quantitative database of energy efficient retrofit measures for the home. The two previous sections of this chapter helped to identify the categories of information for the database framework. Section 3.3 provided the basis for determining the required categories of information useful to the process of EE retrofits. Section 3.4 determined which categories of information are already in the Building America web portal in user-friendly database formats. The categories from section 3.4 were removed from the larger list of categories identified in Figure 3.3. The categories to be added to the database are presented in Figure 3.6.

3.5.1 Structure and Conceptual Framework of the Database

The database of EE retrofit measures is a relational database; the relationships between various entities are described in the following section. Figure 3.6 shows the shortlisted categories of information to be used in the framework of the quantitative database.

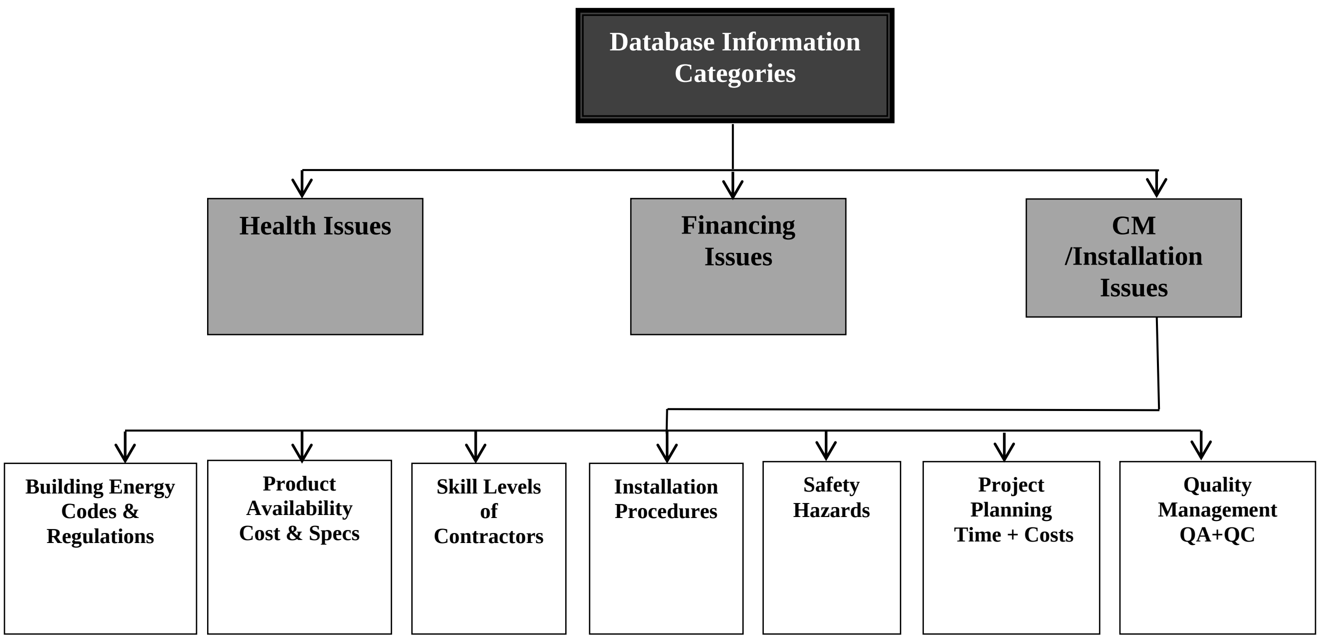


Figure 3.6: Categories of Database Information

The following section defines the conceptual framework of the database. It consists of developing the database entity sets and the database relationship sets.

3.5.1.1 Database Entity Sets

Database entities are “things” or “objects” distinguishable from other objects in a database (Sudarshan et al. 2002). In the proposed database, the following entity sets are required:

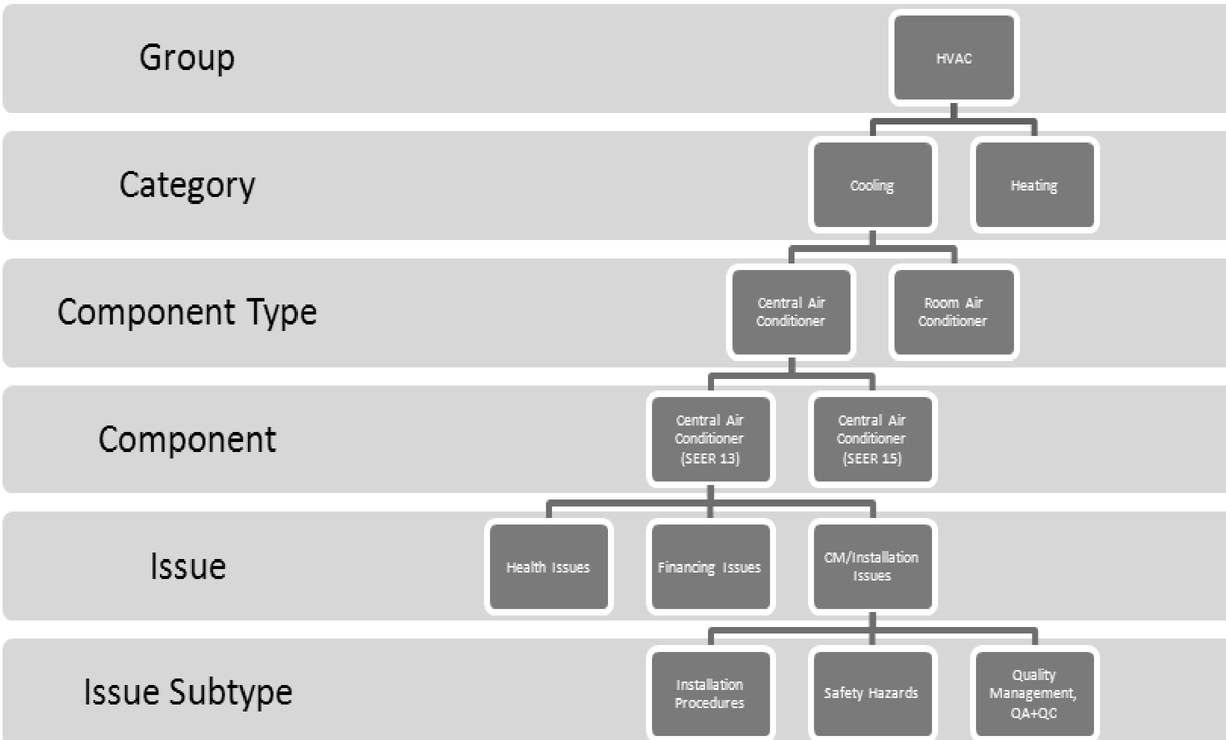


Figure: 3.7: Example Data Hierarchy–Proposed Home Energy Efficiency Retrofit Database

These entities follow a hierarchical structure, like the NREM database, but with the addition of two more entity sets—Issues and Issue Subtypes. These two entity sets were developed as a result of studying the barriers and future steps identified in the Building America Program. These Issues and Issue Subtypes are shown in Figure 3.7. The groups of the database are:

- Appliances
- Domestic Hot Water
- Enclosure

- HVAC
- Lighting
- Miscellaneous

Each entity possesses a set of unique attributes. E.g. the entity set "Issues" will possess the attributes Issue-ID, Issue Name, and Discussion Points. The Discussion Points attributes of the entity sets Issue and Issue subtype will contain the information necessary for the retrofit process. As mentioned previously, the framework of the database is not stagnant but is constantly evolving. As data is periodically added to the database, the discussion points will increase (hence it is denoted in an open-ended manner), ending with Discussion Point n. The terminology "Discussion Point" does not have to be limited to textual discussions but may also contain other mediums of information such as audios, videos, pictorial/graphical data etc.

3.5.1.2 Database Relationship Sets

Once these entities were developed, the Entity-Relationship (ER) diagram was drawn to reflect the relationships between entities in the database. The entities are related to each other in one-to-many relationships, with the symbol "n" used to denote many. Each Entity is represented by a unique identification number, which is useful for retrieving data. The ER diagram is shown in Figure 3.8. The ER diagram consists of tables that represent entity sets. The name of the entity set is shown at the top, and the attributes of each entity set are shown in the bottom part of the table. A practical example of the ER diagram is shown in Figure 3.9.

3.6 Chapter Summary

This chapter developed the framework of a quantitative database that can be used by participants in the retrofit process— designers, trade contractors, builders, and homeowners—to acquire useful and appropriate information related to energy efficient retrofits for the home in a convenient and easy-to-use format. The chapter was divided into four sections: the first section explored the barriers and future steps related to home energy retrofits; the second section discussed the architecture of the query-based expert system third section analyzed the existing Building America information portal and related databases; and the final section developed the conceptual framework for the database of existing home energy efficiency measures.

The first section developed the categories of information necessary to develop an effective database. The second section identified the information that already exists in the BA portal, so as to determine which categories from the first section do not need to be duplicated. The final section developed the framework of a database by using the categories obtained from sections 1 and 2. The framework was based on the existing NREM database, but it contains supplemental information categories to make it comprehensive.

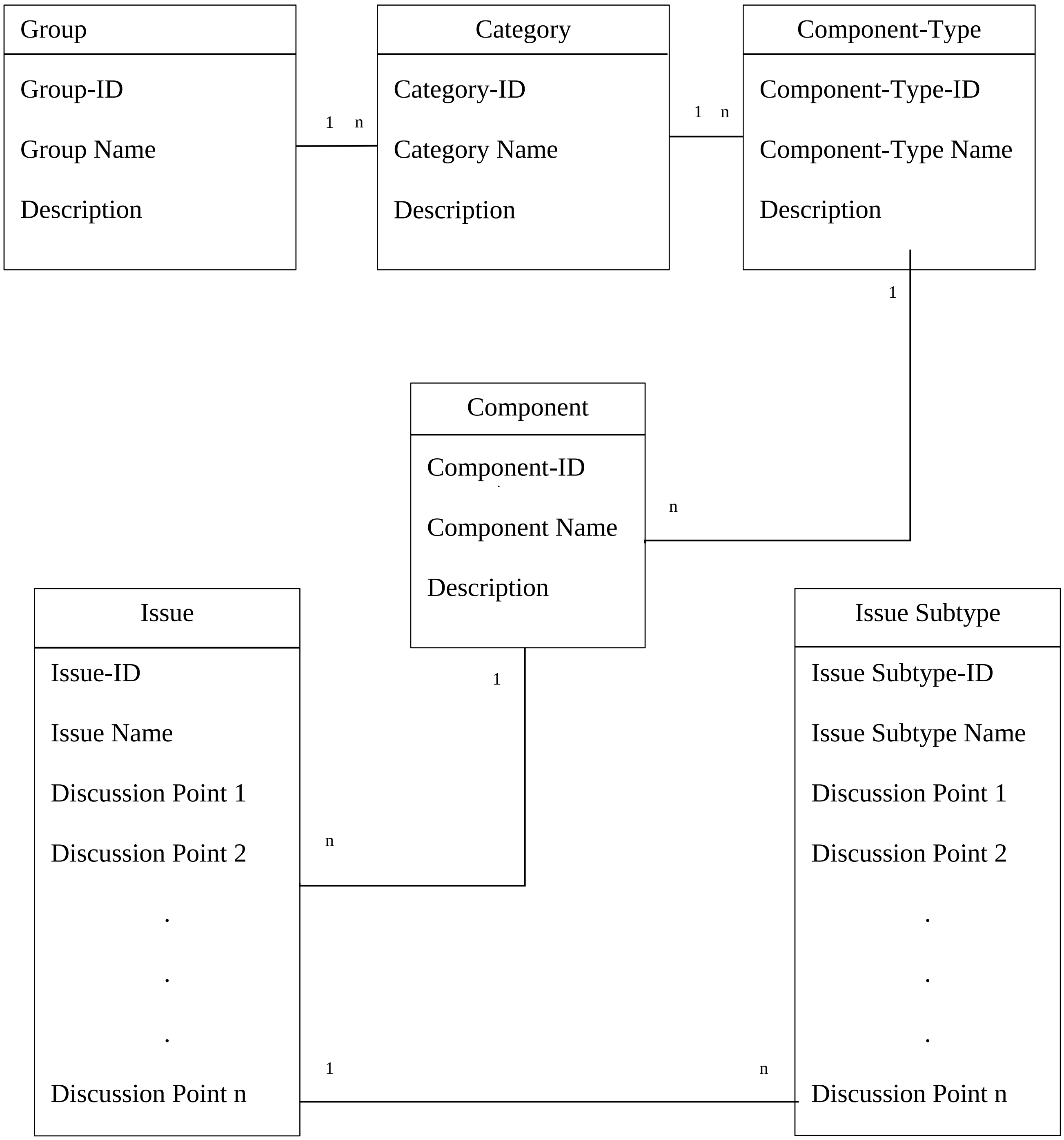


Figure: 3.8: Entity Set-Relationship Diagram – Home Energy Efficiency Retrofit Database

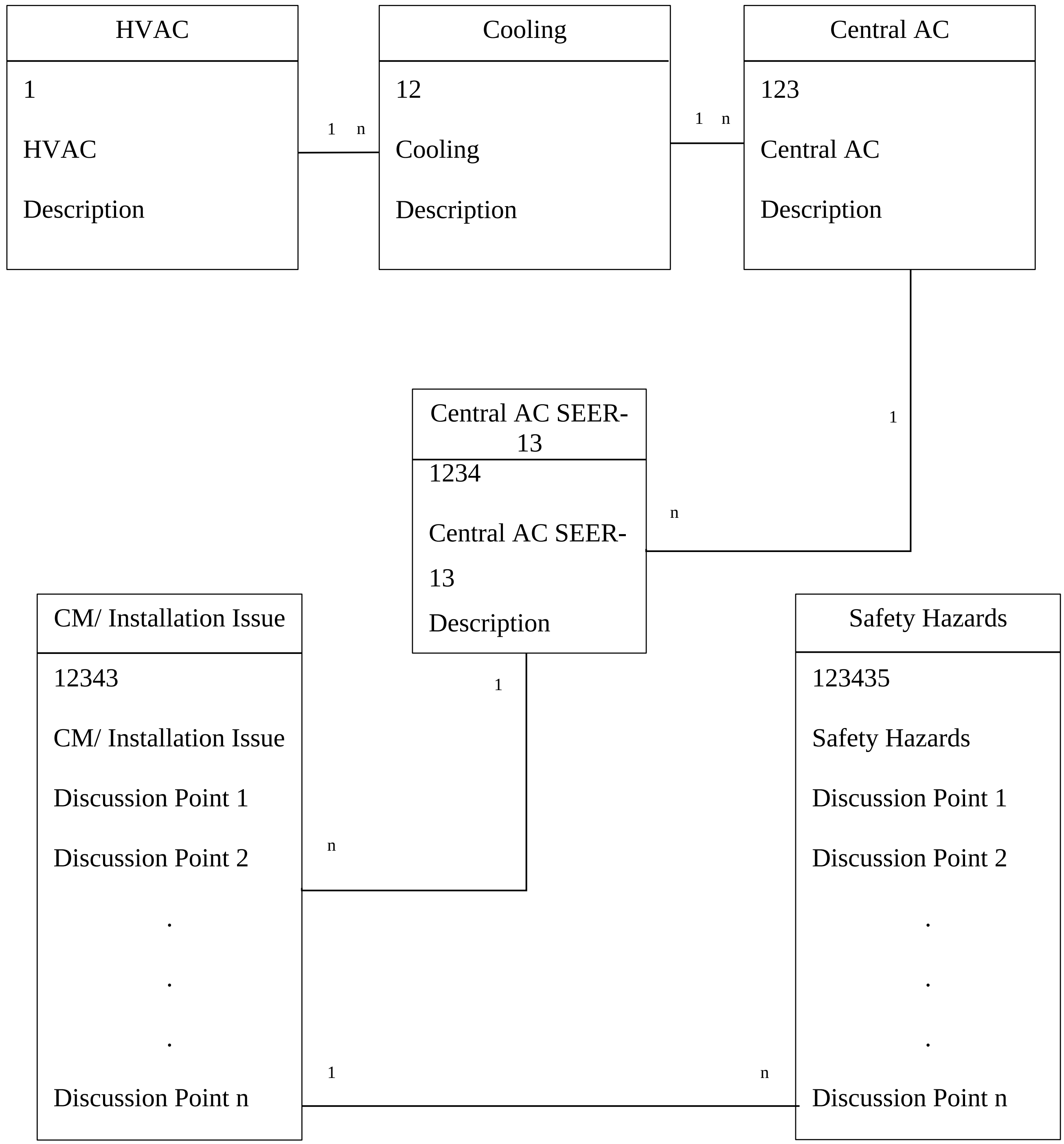


Figure: 3.9: Entity Set-Relationship Diagram Example – Home Energy Efficiency Retrofit Database

CHAPTER 4

QUERY-BASED EXPERT SYSTEM FRAMEWORK

4.1 Overview

Chapter 3 of this report gave an introduction to the architecture of a Query-Based Expert System (QBES) and developed the framework of a quantitative database of home energy retrofit measures, which is a major part of the QBES. The existing Building America information portal was studied in detail and the development of a comprehensive quantitative database was suggested as a means to improve its existing layout.

Objective 3 of this research was to develop the framework for a query-based expert system (QBES), which will guide the homeowner through the entire process of a home energy retrofit. The process includes selecting retrofit measures and providing installation advice for the selected measures. This chapter will develop the framework for the expert system by first developing the framework of a knowledgebase using knowledge acquired from experts, and then integrating it with the previously developed quantitative database.

4.1.1 Glossary

In Chapters 4 and 5, the terms "qualitative information" and "quantitative information" are commonly used. They will also be used interchangeably with other words, as listed below:

i. **Qualitative Information** / Knowledge / Informal Information / Experience / Heuristics
ii. **Quantitative Information** / Data / Formal Information / Published Information

4.1.2 Need for Standard Protocol in Home Energy Retrofits

PATH (2002) identifies several barriers to the large-scale implementation of energy efficiency in existing homes. One of the identified barriers was that there is no existing standard protocol to dictate the methods used by home energy efficiency professionals, such as trade contractors and energy auditors. The process for overcoming this barrier is to conduct interviews with industry professionals and develop a standard protocol for retrofits. This chapter attempts to develop such a standard protocol, forming the basis of the framework for the query-based expert system.

4.1.3 Steps to Develop Framework

The framework for the QBES was developed in four steps, as shown in Figure 4.1. The steps are listed below:

Step I developed a preliminary framework of the expert system from the researcher's previous knowledge of the retrofit process, and from existing literature. There were three reasons for the development of a preliminary framework. First, it helped to identify the experts and explain the standard procedures they follow when performing a total home energy retrofit. Second, it provided a basis for pinpointing the questions used in expert interviews. Finally, it provided the researcher with sufficient background knowledge of the retrofit process to present himself as a knowledgeable interviewer, thus eliciting better responses.

Step II conducted interviews with experts, such as home energy auditors and retrofit trade contractors. This step explained real-life expert reasoning for various tasks performed in a retrofit.

Step III applied the acquired knowledge from Step II in the development of a refined and final framework for the QBES.

Step IV demonstrates the application of the expert system, through a working example, by assuming a hypothetical retrofit scenario.

Steps I, II and III are explained in this chapter, while Step IV will be developed in Chapter 5.

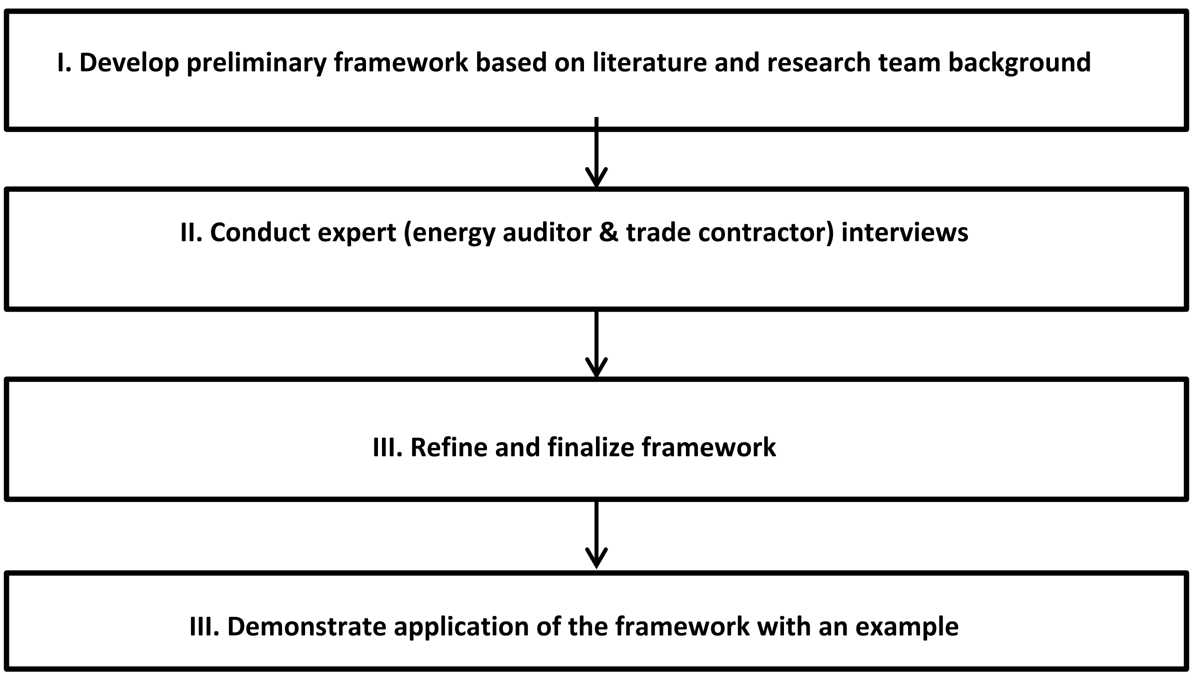


Figure 4.1: Steps to Develop QBES Framework

4.2 Preliminary Framework of Query-Based Expert System

As shown in Figure 4.1, the first step in developing the framework for an expert system is to develop a preliminary framework. There were three reasons to develop a preliminary framework. First, it helped identify the experts and explain the standard procedures they follow when performing a total home energy retrofit. Second, it provided a basis for pinpointing questions used in expert interviews. Finally, it provided the researcher with sufficient background knowledge of the retrofit process to present himself as a knowledgeable interviewer, thus eliciting better responses from the experts.

The common methodology followed by experts in a complete retrofit begins with identifying the upgrade possibilities in a home through an energy audit process. Once the possibilities are identified, the next stage involves narrowing them down to fit the homeowner's budget. The final stage involves providing expert advice on installation, so that measures are properly installed to produce the desired results. These three stages are shown in Figure 4.2:

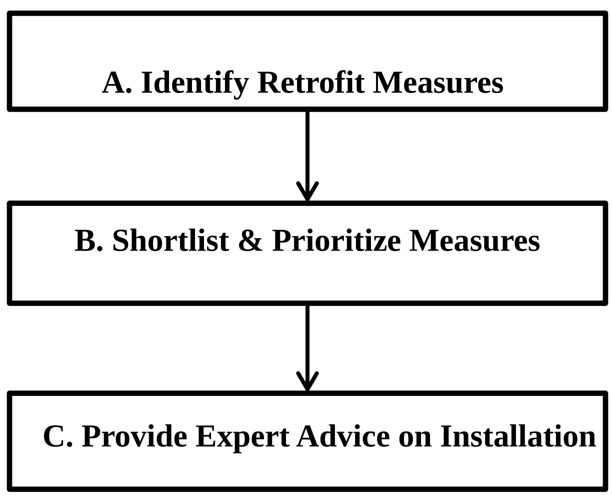


Figure 4.2: Stages of Preliminary Framework Development

4.2.1 Identify Retrofit Measures

In QBES, identification of retrofit measures will be done through a query process, wherein the homeowner will be queried about the existing conditions of those components of a home that affect its energy performance. This process imitates the function of an energy auditor, who gauges a home's existing energy performance. The conditions being assessed will include the age and efficiencies of major appliances, domestic hot water, enclosure, heating ventilation and air conditioning (HVAC) equipment, lighting and miscellaneous components. If a component is identified as older than its useful life, it may be marked for replacement with a new component. Similarly, if the efficiency of a system is low, it will be considered for an upgrade to any of the existing standards, such as Energy Star, IECC 2009, or the Building America Benchmark. Table 4.1 shows how a typical query will be used to analyze the existing condition of a home. Column A consists of the name of a component, with a query to the homeowner about the existing efficiency, Column B will be populated with the existing efficiency of the component. Column C will contain the efficiency of a proposed upgrade, according to the benchmark chosen. Column D will contain the retrofit operation; that is, the upgrade from the existing efficiency to the upgrade efficiency. Column E will contain the age of the system which, if older than a certain age, will be considered for an upgrade. The National Residential Efficiency Measures (NREM) database developed by the National Renewable Energy Laboratory can be used as a basis for a list of components to consider (NREL 2010). This database contains cost data for energy efficiency measures, and provides a useful resource for identifying retrofit measures. The measures derived from the NREM database are shown in Table 4.2.

Table 4.1: Example of Query and Rules to Analyze Existing Conditions

A	B	C	D	E
MEASURE	EXISTING EFFICIENCY	CURRENT EFFICIENCY STANDARDS	RETROFIT OPTION	AGE OF SYSTEM
Replace existing clothes dryer to higher efficiency				
Query: Is your clothes dryer older than x years				
Options: a. Yes b. No c. NA				
Rule 1: If "a" then perform operation Replace CD with 0.95 Efficiency Factor (EF) CD				
Rule 2: If "b" then enter existing energy factor (EF)				
Rule 3: If EF <= 0.85 then perform retrofit as above				

Table 4.2: List of Measures Identified by NREM Cost Database (NREL 2010)

MEASURES
Appliances
1. Replacing clothes dryer
2. Replacing clothes washer
3. Replacing dishwasher
4. Replacing refrigerator
Domestic Hot Water
1. Replace electric/gas water heater with heat pump water heater
2. Adding Insulation to hot water pipes
3. Insulating water heating tank
4. Replacing existing tank water heater with higher efficiency tank water heater
5. Replacing existing tank water heater with a tank-less water heater
Enclosure
1. Reducing air leakage by air-sealing
2. Increasing R-value of attic and ceiling insulation
3. Increasing R-value of basement/crawlspace walls
4. Adding vapor barrier to basement walls
5. Converting crawlspace/basement vented to unvented and conditioned
6. Replacing existing doors with doors of lower U-value
7. Insulating floor above crawlspace/basement
8. Increasing solar reflectance of roofs
9. Increasing R-value of roof
10. Adding energy efficient siding (low –e)

11.	Replacing existing skylights with low U-value skylights
12.	Insulating slab edge
13.	Increasing the R-value of above grade walls
14.	Replacing existing windows with low U-value windows
HVAC	
1.	Replacing existing boiler with a higher efficiency boiler
2.	Replacing existing central air-conditioner with higher efficiency air-conditioner
3.	Replacing existing direct heater with higher efficiency direct heater
4.	Increasing R-value of existing HVAC ducts
5.	Reducing leakage from ducts by sealing
6.	Replacing existing furnace with high efficiency furnace
7.	Replacing room air-conditioner with high efficiency room air conditioner
8.	Replacing existing thermostat with programmable thermostat
9.	Increasing the efficiency of existing lighting
10.	Adding motion sensors to lighting
Miscellaneous (M)	
1.	Replacing existing ceiling fans with high efficiency ceiling fans
2.	Replacing existing water cooler with high efficiency water cooler
3.	Replacing existing well pump with high efficiency well pump

4.2.2 Shortlist and Prioritize Measures

Once the measures have been identified, they must be shortlisted to fit the homeowner's budget. In addition to shortlisting, measures must be prioritized based on cost effectiveness, so the homeowner will obtain the maximum return on investment from the retrofit. The data necessary for calculating the cost effectiveness of measures is tabulated in Table 4.3.

The iteration for prioritizing and shortlisting measures (assuming homeowner budget is known) is as follows:

Step I. Pick the measure with the highest effective return.

Step II. Subtract the effective cost of this measure from the homeowner budget.

Table 4.3: Tabulation of Data for Calculation of Cost-Effectiveness of Measures

MEASURE	COST (C)	INCENTIVE AMOUNT APPLICABLE (I)	EFFECTIVE COST	ANNUAL LOAN PAYMENT (L)	ANNUAL ENERGY SAVINGS (ES)	EFF* RET (ES-L)	PAYBACK (YEARS)
Replace existing clothes dryer to higher efficiency							

DATA	SOURCE (DSIRE 2010 & NREL 2010)
Cost (C)	NREM database
Incentive Amount Applicable (I)	DSIRE database
Effective Cost	C – I
Effective Return	Incentive Amount Applicable
Annual Loan Payment (L)	Average of Leading Financial Institutions/ DSIRE Database
Annual Energy Savings (ES)	Formulae
Effective Return	ES – L
Payback	Formulae

Step III. Pick the next highest effective return measure.

Step IV. Repeat the iteration until no more measures can be included for the remaining homeowner budget.

4.2.3 Provide Expert Advice on Installation

Once the measures have been identified, shortlisted and prioritized, expert advice on the installation of these measures must be provided. Any retrofit technology or measure, irrespective of its efficiency, can only perform optimally if it is installed in an appropriate manner. Several barriers to this have been identified, as shown in chapter 3 of this report. For example, the "residential heat pump water heater (HPWH)," developed in collaboration with the Oak Ridge

National Laboratory and the Energy Star Program, is a water heater that uses heat from the surrounding air to heat the water. It produces almost twice the amount of heat for the same electricity cost as a conventional water heater. However, in spite of its high efficiency, the water heater had not been a success. Of the 9.8 million residential water heaters sold in 2006, only about 2000 units were HPWP. Among several reasons attributed to its failure, one was that the technology was not well-suited to universal installation methods (Energy Star 2008 from Dubay et al. 2009).

Most trade contractors are used to certain conventional installation procedures. If a technology demands unfamiliar installation techniques, the installer must have access to a knowledgebase that provides such information.

This research aims to find categories of information necessary for installation. In chapter 3 of this research, several categories of CM/installation information were identified for the framework of the quantitative database. In a similar manner, categories of CM/installation information will have to be found for the qualitative knowledgebase. When populated, these categories will assist the expert system to perform the reasoning process necessary to provide specific installation information for the measures identified for a home.

4.3 Knowledge Acquisition through Expert Interviews

The preliminary framework was refined through expert interviews. At the beginning of the refining process, it was decided that the functions performed by the preliminary framework would remain unchanged. Hence, the expert system must perform the three functions of:

- Identifying retrofit measures.
- Shortlisting and prioritizing measures to fit the user budget.
- Providing installation information for the shortlisted measures.

The purpose of the interview was to find better methods for executing those functions, compared with those outlined in the preliminary framework; methods that experts use in real home energy retrofits. The functions and methods of execution are the standard protocol for home energy retrofits. This protocol was then used as a basis for the Query-Based Expert System framework.

4.3.1 Knowledge Acquisition Process Theory

Prior to conducting expert interviews, a literature study was conducted to learn how to perform the task efficiently. A major source for the study was Bogner et al. (2009). The following is a brief summary of ideas obtained from the literature, including usefulness and methods of data collection.

4.3.1.1 Usefulness of Expert Interviews

- *"Expert interviews [are] a method used to develop a knowledgebase used in expert systems and useful in the development of decision making tools."*

The literature clarifies that knowledge acquisition for the knowledgebase has to be done by conducting interviews with experts.

- *"Talking to experts in the exploratory phase of research is more efficient than observation or systematic quantitative surveys."*

Since this research deals with the development of a framework for an expert system, it can, in part, be classified as exploratory research; that is, exploring the possibility of developing such a system, and exploring the areas of knowledge and data that are necessary for such a system. Thus, expert interviews are the best method of data collection in a partial exploratory research such as this.

- *"It grants access to his/her extended circle of similar experts."*

Interviewing experts gave the researcher access to the experts' extended circle of similar experts, who were subsequently interviewed.

- *"Results are quick"*

Results obtained through expert interviews were found to be a lot faster than other forms of data collection, such as literature-based data collection. Thus, it enabled the researcher to obtain the information to develop this framework more quickly.

4.3.1.2 Method of Data Collection

- *"Open interview is preferred over questionnaires"*

Although the interviews were structured in a certain format (as shown in Appendix 2), the interviews were mostly open ended in nature. The experts were allowed to give their own opinions and suggestions, which may or may not have fallen within the purview of the questions. Such information proved to be very useful for the development of the framework.

- *"Narrations about episodes in the expert's field of work can provide useful knowledge inputs and tacit data."*

During the process of interviewing, the experts provided many narrations of episodes in their field of work, which was helpful for understanding concepts better.

- *“Questions should be based on the how of decision making – the logic underlying the decision.”*

The logic used in interviews was to understand the process the experts used to make decisions, rather than knowing what decisions they made. These processes were used in the final development of the framework.

- *“It is important that the interviewer has sufficient knowledge on the subject of interview so that the expert does not feel that the interviewer is incompetent and uninvolved.”*

This was one of the reasons for developing the preliminary framework. During the development phase of the preliminary framework, the researcher came to understand several important aspects of the retrofit process. This helped the researcher to be an informed interviewer, resulting in better responses from the experts.

4.3.2 Overview of Experts and Interviews

The QBES mimics the logic and reasoning of real experts, to produce decisions and/or solutions. Hence, to develop the framework, experts were interviewed to get an understanding of their methods of operation in retrofits. The following are overviews of the interviewees and the interviews. For actual interview transcripts, refer to Appendix 2 at the end of this report.

4.3.2.1 Experts

Home energy auditors and retrofit trade contractors were chosen as experts for this research. A total of six experts were interviewed. The experts were Residential Energy Services Network (RESNET) and/or Building Performance Institute (BPI) certified. The breakdown of experts by qualification is:

- 3 (energy auditor + retrofit contractor)
- 2 (energy auditor + HVAC contractor)
- 1 (energy auditor)

Between 28 and 30 hours were spent on interviews. The experts were located in the cities of Midland, Kalamazoo, Grand Rapids and Lansing, all of which are in the state of Michigan.

4.3.2.2 Interviews

Each interview consisted of two sections:

- General Section
- Retrofit-Specific Section

General Section

The purpose of the general section was twofold. It was used to gather information about the expert, including area of expertise, period of time involved in the area, and size and method of business operations. It was also used to eliminate opinion biases by asking questions related to personal likes and dislikes in the retrofit process/industry. If a certain opinion given by an expert in the retrofit-specific section was found to corroborate the bias expressed in the general section, then that opinion would be considered biased and would be eliminated. For example, if the expert's area of expertise is in HVAC, and he/she tries to promote an opinion that the best energy efficiency strategy in a home is to upgrade existing HVAC equipment to a higher efficiency, this opinion would be considered biased and eliminated from purview.

Retrofit Specific Section

This section of the interviews queried the experts on the specifics of the retrofit process. The goal of this section was to identify better execution strategies for the proposed functions of the system. Thus, this section helped identify methods of measure selection, shortlisting and prioritizing measures, and identifying categories of information that need to be provided for the installation of shortlisted measures; altogether, it set up a standard protocol for the retrofit process.

Since the goal was to develop a standard protocol of retrofit implementation, the questions revolved around trying to find the techniques experts use when they encounter real retrofit situations.

Questions included:

- Approach taken to identify measures.
- Methods used to shortlist and prioritize measures.
- Technology and equipment they would use to audit a home.
- List of measures that the experts do not believe are safe or possible for the homeowners to install themselves.
- Building science aspects that need to be considered while selecting measures.
- Homeowner motivations in deciding to energy retrofit their home.
- Categories of information necessary to install a measure properly.

The interviews, overall, were a learning curve for the researcher. Each interview provided new insights into the way the experts work. The new knowledge gained by the researcher led to improvements in the questions asked in subsequent interviews. Hence, the interviews do not all contain the same set of questions but may be different. For more information about the interviews please refer to Appendix 2.

4.3.3 Extracted Knowledge

The expert interviews provided useful information for developing the framework of the QBES. The answers at the end of the query process were analyzed and inferences were made. An explanation of the extracted knowledge is presented below.

4.3.3.1 Identify Retrofit Measures

First, the interviews confirmed that each component of the home must be analyzed to determine whether it needs to be upgraded to a higher efficiency, similar to the manner that was assumed for the preliminary framework. In addition to analyzing the needs of the home, the needs of the occupants must also be given importance. Experts felt that in many situations, the homeowners may not have decided on energy retrofits to garner the energy savings. For example, some homes might experience issues of discomfort such as cold drafts, high or low humidity, external noise, lack of a uniform temperature throughout the home, and more. Experts stated that homeowners have often approached them to solve some of these issues. In such situations, it becomes imperative to solve those problems first, before proceeding to the identification of energy improvements for the home.

Solving each of the problems mentioned above can actually produce an increase in the thermal performance of the home. Consider, for example, a home with cold drafts and low humidity.

Experts feel that these phenomena are caused by air-leakage in the home. If there are leaks in the home that allow the entry of cold outside air into a warm, conditioned space, this draft of air could pose two problems. First, the spot of air leakage will become significantly colder than the other areas in the home, thereby causing temperature variances within the home. Second, the cold outside air is drier than the conditioned interior air, reducing inside humidity significantly. The method of fixing these problems would be to seal the uncontrolled air leaks; trying to solve this comfort issue by sealing the leaks will also save energy. Thus, by taking the dual approach of satisfying user needs and conserving energy, the user's motivation greatly increases, while the increased energy efficiency of the home intensifies large scale adoption of home energy retrofits.

4.3.3.2 Shortlist and Prioritize Measures

The interviews confirmed that the right method to follow in this refined framework is a cost effective approach that will shortlist and prioritize measures to fit the user's budget. However, the experts cautioned that several other aspects also need to be taken into consideration when determining and prioritizing the shortlist:

- **Consideration of interactions between building components to prioritize measures:** The building behaves as a system, with interactions between components affecting their energy performance. For example, if it is observed that neither the thermal envelope in a home is energy efficient nor the heating system is of state-of-the-art efficiency, then two measures are derived: a) Upgrade the thermal envelope, and b) Upgrade the efficiency of the heating system. If these measures are implemented with the thermal envelope being upgraded first, then the efficiency of the heating system is increased; the homeowner could downsize the heating system from its original size. This would also cause the new system to run many fewer cycles than it would have to with an inefficient thermal envelope. Thus, prioritization must take component interaction into consideration.

- **Consideration of user needs in shortlisting and prioritization:**

User needs must be considered when shortlisting and prioritizing, so that end-users are satisfied with the money spent, and are motivated to further retrofit their home in the future. Consider the example of window replacement. Most experts were of the opinion that upgrading existing windows to high performance windows offers a very low return on investment, taking several years to pay back. However, if a home has damaged windows that cause a security threat and need to be replaced, then this measure should be implemented to satisfy the immediate need of the user, although it may not be the most cost effective measure.

- **Analysis of energy savings by building energy simulation software**:

In the preliminary framework, the energy savings of measures were assessed using formulae or tables available in literature. This method of analysis, however, was found to cause some difficulties. The experts felt that the tables may produce a highly inaccurate evaluation of the energy savings. Another problem with such an approach is that equipment resizing is difficult. To avoid these problems, the experts felt that energy savings are best analyzed through building simulation software. These simulations provide a fairly accurate idea of potential energy savings for specific measures. They also provide instant feedback on the possible downsizing of heating and cooling systems.

- **Health and safety issues in shortlisting and prioritizing measures:**

Many home energy improvement measures have health and safety issues associated with them. Consider the following examples:

1) If the home contains asbestos, then an energy contractor who attempts to air seal and insulate the attic faces the risk of agitating the asbestos fibers, posing a risk for both him/herself and the occupant.
2) If the home is made excessively airtight by air-sealing, and the home contains naturally vented combustion appliances, then there is a risk of back drafts from flue gases, increasing the carbon monoxide levels in the home, and causing health risks.

In such scenarios, energy improvement measures must only be performed after the health and safety issues are removed or abated. As seen in the above examples, asbestos must be abated prior to air-sealing and insulating the attic and naturally vented appliances may have to be replaced by closed combustion appliances before air-sealing the home.

4.3.3.3 Provide Expert Advice on Installation

The preliminary framework identified the need to provide information related to the proper installation of measures. One of the goals of expert interviews was to identify categories of information that must be provided to installers of measures. The experts feel that these categories, identified at the end of the interview process, will encompass most of the information required for proper installation:

- Installation techniques
- Level of installation difficulty

- Installer skill level
- Installer safety
- Material selection and procurement
- Other factors

Installation Techniques

Any retrofit technology or measure, irrespective of its efficiency, can only perform optimally if installed in an appropriate manner. Most trade contractors are used to certain conventional installation procedures. If a technology demands unfamiliar installation techniques, however, the installer must have access to a knowledgebase of such information. This research aims to provide the framework for such a knowledgebase. Experts feel that it is very important to provide the installer with a step-by-step procedure to install measures.

Level of Installation Difficulty

This information will help the user identify the level of difficulty of an installation. This will help homeowners determine if the measures can be installed by themselves without expensive equipment; the measures need expensive equipment but can be installed by the homeowner; or the homeowner must seek a professional to perform the installation.

Three levels of difficulty have been identified:

a) Easy/(Do-It-Yourself) DIY

b) DIY with certain tools and precautions

c) Very Difficult/Needs professional installation

Installer Skill

In some cases, measures can only be installed by an installer who meets a certain skill requirement. Skills are defined by training, certification and licenses. For highly sensitive measures, in which the health of occupants or safety of installers could be in danger, the system must recommend installers who have the training or certification to install the measures in a way that does not compromise health and safety. For example, if asbestos has to be abated in a home before an EE upgrade, the action must only be performed by a professional who has undergone training and is certified to abate it. Another example would be work that can only be performed by a licensed professional, such as mechanical, electrical and plumbing work.

Installer Safety

In some cases, installers can encounter issues in the home that may compromise their safety. Examples include asbestos, lead paint, injury due to special situations in the home, etc. Thus, installers have to be informed about those issues, and strategies must be suggested to overcome them, so that measures can be installed in a safe manner.

Material Selection and Procurement

As with construction in general, home energy retrofits contain measures that can be installed with different materials and products. However, not all products fit a specific case. Thus, users must be provided with information about products and materials that are implementable in specific situations. For example, if thermal insulation is exposed, it must be fire resistant, as compared with insulation that is concealed within a cavity.

In addition to material selection, procurement information is necessary. Some materials or products may require long lead times to procure, and knowing this can help the installer to schedule the retrofit process better.

Other Factors

In addition to the factors mentioned above, there may be other factors of information that could be necessary in many situations. These factors may not fall into any given classification, but they will be specific to certain situations. Such factors, if and when they arise, will fall within the "Other Factors" category.

The overall knowledge extracted through expert interviews is summarized in Figure 4.3. The extracted knowledge related to the identification of retrofit measures and shortlisting are grouped together in the model, under the heading "Measure Selection."

4.4 Refined Framework of a Query-Based Expert System

Section 4.3 identified the information that was extracted from the expert interviews. This section shows how this extracted information can be implemented to develop the final framework of the query-based expert system. As mentioned earlier, the final framework performs the same functions identified in the preliminary framework—identifying retrofit measures, shortlisting and prioritizing measures, and providing expert advice on installation. However, the execution of those functions will be different.

Measure Selection

1. Decisions must be made within user budget with cost effective prioritization.
2. Measures must be analyzed using computer energy modeling.
3. Interactions between building components must be considered.
4. User motivation for retrofits must be addressed.
5. The user must be provided with post occupancy health & safety information.

Construction/Installation Knowledge Categories

A. Techniques

B. Installer Skill

C. Installer Safety

D. Material Selection and Procurement

E. Other Factors

Figure 4.3: Extracted Knowledge from Expert Interviews

4.4.1 Implementation of Expert Knowledge and Inputs from Other Tasks

Section 4.3 provided a description of the knowledge acquisition process and the knowledge acquired through the expert interviews. The summary of extracted knowledge was presented in Figure 4.3. The implementation of that extracted knowledge is presented in this section, to develop a framework, as shown in Figure 4.5.

4.4.1.1 Identify Retrofit Measures

In the preliminary framework, measures were identified through a query process. The user would supply information about existing conditions of the home and, based on the existing inefficiencies, the system would consider upgrade possibilities.

In the refined framework, in addition to analyzing the needs of the home, the system will analyze the needs of the user. Thus, the system will take a dual approach of analyzing homeowner needs as well as home upgrade needs.

In addition, this function of the expert system will receive inputs from tasks 6.1 and 7.1 of this project.

Task 6.1 is the market characterization project; it aims to identify the dominant archetypes of homes in the Great Lakes Region of USA. The dominant archetypes will then be tested, and a prescriptive package of measures will be pinpointed for the archetypes. Thus, when Task 6.1 is complete, the system may apply this prescriptive package to a home, if it falls within the identified archetype. This would avoid a lengthy query session with the user, identifying existing conditions of the home in order to suggest measures.

Alternately, Task 6.2 attempts to identify the key stakeholders in the value chain of home energy retrofits, and works to collect information about the needs of those stakeholders, to implement user-targeted retrofits. Thus, Task 6.2 will also help to systematically identify homeowner needs, and use it in the identification of measures.

4.4.1.2 Shortlist and Prioritize Measures

There are several changes in the execution of this function from the preliminary framework. First, energy savings will now be determined using an energy simulation tool, which will work in the system's background. This energy savings will help the system to prioritize measures, based on the measures' cost effectiveness and how they fit the user's budget. Second, the system now considers homeowner needs as a priority when shortlisting and prioritizing measures. Thus, even if one measure is found to be less cost effective than another, it will have a higher priority if it falls within the needs of the user. Third, the system will now consider the interaction between components of the home. In the interviews with experts, it was found that the major, energy-related interactions occur among the thermal envelope, lighting, and heating and cooling components. In order to analyze these interactions, measures identified in Step I (Identify Retrofit Measures) will have to be divided into three types:

- Type I – Thermal Envelope Measures
- Type II – Heating and Cooling Measures
- Type III – Stand-Alone Measures

As the name suggests, stand-alone measures are those that have limited or no interaction with the energy performance of other components. Examples would include major non-HVAC appliances.

Once these measures are divided in this form, they will have to be sequenced. The sequencing is shown in Figure 4.4.

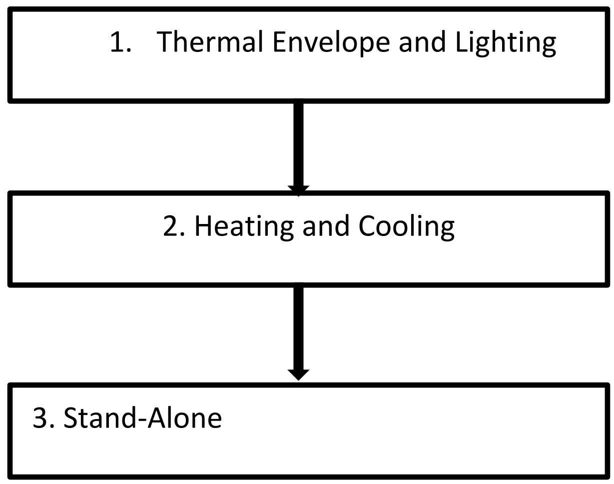


Figure 4.4: Prioritization Based on System Interaction

Finally, the refined framework will provide health- and safety-related information, if it is applicable for a measure, and strategies to help mitigate these issues. The system will also provide the cost for mitigation. The total cost of the measure will be the sum of the cost of the measure and the cost of mitigation. The user will then be given the following options:

a) *If the cost of mitigation exceeds the user's budget, the measure may be eliminated:*

In many cases, the cost of abatement may far exceed the user's budget; hence, the particular measure may be eliminated even if it might provide a high return on investment.

b) If mitigation work is performed, then the cost must be included with the cost of the measure to know the actual payback.

If the user decides to go ahead with the abatement and installation of the measure, the cost must now be the sum of abatement and installation. The return on investment and payback must now be calculated based on this total cost, to obtain realistic estimates.

c) *The benefits of such mitigation must be indicated, even if these cannot be monetized.*

Though the cost of implementing such measures is much higher than normal, the associated benefits may be high. The benefits can sometimes be monetized (if they lead to energy savings), sometimes they cannot (if they produce health and safety benefits).Whatever the nature of the benefits, users must be informed of them so they can make the appropriate choices.

4.4.1.3 Provide Expert Advice on Installation

The final function of the refined framework is to provide installation-related information. At the preliminary stage of the framework, this function was defined, but the categories of information to be provided to the user were still unknown. These categories were identified through the expert interviews, and explained in detail in previous sections of this Chapter. The categories of information are:

- Installation techniques
- Level of installation difficulty
- Installer skill level
- Installer safety
- Material selection and procurement
- Other factors

Task 7.1 also aims to identify quality control strategies for the installation of retrofit measures. Thus, Task 7.1 will provide input into Function 3 (Provide expert advice on installation) of the framework.

4.4.2 Integration of Database and Knowledgebase for Final Framework Development

This section shows how this knowledge can be integrated with quantitative knowledge to produce the final framework. In this framework, quantitative knowledge will play a significant part in the following areas:

1. **Cost Effective Prioritization**

Two types of information are necessary to shortlist and prioritize measures based on cost-effectiveness: energy savings and cost. The energy savings will come from the simulation tool, while cost will come from the NREM database. Both of these are quantitative sources of information. If a home is defined in the simulation tool, and a measure is simulated, the tool will instantly provide the energy savings for that measure. Similarly, the NREM database contains cost data for a comprehensive list of measures that can be used for a home energy retrofit. The list of measures is found in Table 4.2.

2. **Providing Installation Advice**

The third function of the framework is to provide installation advice for identified measures. Three sources of information provide necessary information for this function:

a) Expert knowledge

b) Input from Task 7.1

c) Published information and existing Building America resources.

Inputs from “a” and “b” have been explained above, and are both quantitative and qualitative in nature. Source “c” will be the major source of quantitative information providing input for installation information. In Chapter 3 of this report, an elaborate exploration of the existing Building America databases and information portal was conducted. It was observed that these sources contain useful information related to installation. This, combined with other sources of published information on installation, will provide a good source of quantitative information necessary to performing the third function of the framework. The refined framework, as explained in this section, is summarized the model shown in Figure 4.5.

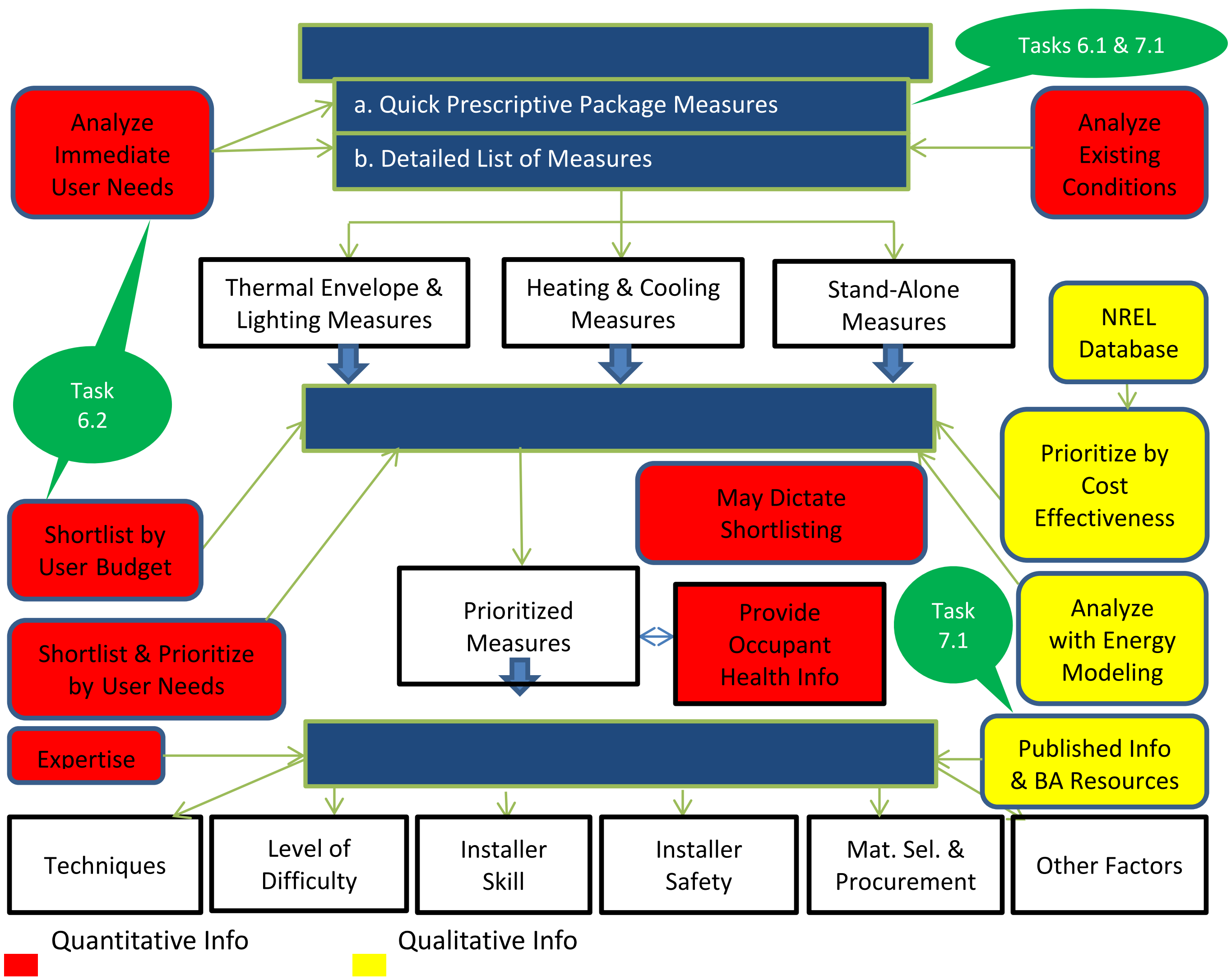


Figure 4.5: Model of Refined Framework

4.5 Chapter Summary

This chapter developed the framework for the Query-Based Expert System. The chapter began with a description of the architecture of a query-based expert system. The architecture included definitions, parts, qualitative knowledge and its acquisition, quantitative knowledge, and integration of qualitative knowledge and quantitative data.

The chapter then developed a preliminary framework for the expert system, which defined the functions that the actual system must perform.

The final part of the chapter developed the framework of the expert system by building upon the preliminary framework, and suggested refined methods of executing the functions based on expert interviews. The chapter gave a detailed explanation of the interview process, information acquired from interviews, and implementation of the information in developing the final framework. The framework also demonstrated the integration of existing quantitative databases and inputs from other tasks in the project.

CHAPTER 5

WORKING EXAMPLE OF QUERY-BASED EXPERT SYSTEM

5.1 Overview

Chapter 4 of this report developed the framework of a query-based expert system. The process began with the development of a preliminary framework, which was refined through expert interviews to develop the final framework. Chapter 4 also demonstrated the integration between qualitative knowledge and existing quantitative data, such as the NREM database and Building America's publications. Finally, the chapter showed how the expert system may connect to other tasks of the Cost Effective Energy Retrofit project.

This chapter aims to illustrate the functioning of the expert system within the layout of the framework. The working of the illustrative model will correspond with the process map shown in Figure 4.6. Hence, the illustration will query users about their needs and existing efficiencies of the home to identify upgrade measures. Once identified, the measures will be shortlisted and prioritized based on cost effectiveness, user budget and user needs. Finally the user will be provided with installation advice for the shortlisted measures.

The example is based on a hypothetical scenario wherein a home built in 1910, and measuring 2143 square feet of finished area, has to be energy retrofitted. The home contains three bedrooms and two bathrooms. The hypothetical homeowner has a retrofit budget of $8,000 and is queried by the system to elicit the necessary information. Figure 5.1 shows the Building Energy Optimization (BEopt) software used for an energy analysis image of the exterior of the home (Christensen et al. 2005).

It is to be noted that the data used for the examples are for demonstration purposes only. The researcher does not guarantee their accuracy.

Figure 5.1: BEopt Image of the Exterior of Hypothetical Home

5.2 Identification of Retrofit Measures

The following section attempts to identify measures to increase the energy efficiency of the home based on a user query process. In includes queries to identify user needs and needs of the building.

5.2.1 Identification of User Needs

As proved earlier, homeowners may have specific needs that have to be fulfilled before identifying energy efficiency upgrades. Examples of such user needs are queried in the following section.

Q.1: How long do you intend to live in your present home? *Answer: 10 Years*
Q.2: Which ones of the following components of your home require immediate replacement? • Windows • Dishwasher • Refrigerator • Clothes Washer • Clothes Dryer *Answer: Dishwasher*

5.2.2 Identification of Existing Efficiencies of Building Components

The existing efficiencies of the building components need to be identified to know the upgrade possibilities. Examples of queries to identify upgrade possibilities are given below:

Walls

Q.1: What is the nature of the walls of your home? • Wood Stud • Double Stud • CMU • ICF • Other *Answer: Wood Stud*
Q.2: Enter size and spacing of studs in the following format A x B; X” o.c *Answer: 2 x 4; 16” o.c*
Q.3: Enter R value of the insulation *Answer: 13*

Attic

Q.4: Is your attic insulated *Answer: No*

Roofing

Q.5: Choose the roofing material of your home from the following list;

- Asphalt Shingles
- Tile
- Metal
- Galvanized Steel

Answer: Asphalt Shingles

Q.6: Enter the color of the shingles from the following list:

- Dark
- Medium
- Light
- White or Cool Colors

Answer: White or Cool Colors

Q.7: Does your roof have a radiant barrier?

Answer: Yes

Slab

Q.8: Is your slab insulated?

Answer: Yes

Below Grade

Q.9: Identify the nature of your home below grade

Answer: Unvented crawlspace 4' high

Q.10: Is your crawlspace insulated?

Answer: No

Window

Q.11: Enter the window area of your home *Answer: 350 square feet*
Q.12: Enter the window type from the following options: • Single Pane • Double Clear • Low-e *Answer: Single Pane*

Major Appliances

Q.14: Is your refrigerator standard or Energy Star? *Answer: Energy Star*
Q.15: Is your cooking range standard or Energy Star? *Answer: Energy Star*
Q.16: Is your clothes washer standard or Energy Star? *Answer: Energy Star*
Q.17: Is your clothes dryer standard or Energy Star? *Answer: Energy Star*

Lighting

Q.18: Enter the percentage of lights that are CFL *Answer: 0%*

Space Conditioning

Q.19: Does your home have an air-conditioner? *Answer: Yes*
Q.20: Enter the SEER of your air-conditioner *Answer: 15*
Q.21: Select the nature of your space heating system from the following list: • Furnace • Hydronic Heating • Heat Pump *Answer: Furnace*
Q.22: Enter the fuel type, AFUE and size of your furnace in the following format: Fuel; AFUE%; Size (k BTU/h) *Answer: Gas; 80%; 150 k BTU/h*

Water Heating

Q.23: Enter the fuel type and Efficiency Factor (EF) of your water heater in the following format Fuel; EF% *Answer: Electric; 95%*

5.2.2 Identified Retrofit Measures

At the end of the query process, several measures, shown in Table 5.1, were identified for the home. The measures are divided into the following three categories:

a. Stand-Alone

b. Thermal Envelope and Lighting

c. Heating and Cooling

Table 5.1: List of Identified Measures

Stand Alone Measures	Thermal Envelope and Lighting Measures	Heating and Cooling Measures
Install a new Energy Star rated dishwasher	Air-seal and insulate attic to R-60 Air-seal and insulate crawlspace walls to R-19 Upgrade existing windows to U-value of 0.87 Upgrade existing lighting to 100% CFL	Upgrade existing gas furnace to 93% AFUE

5.3 Shortlisting and Prioritizing Measures

The second function of the expert system is to shortlist and prioritizes measures to fit the user's budget. This section demonstrates how the system will shortlist and prioritize measures based on user needs, cost effectiveness, and health and safety considerations.

5.3.1 Shortlisting and Prioritizing Based on User Needs

During the query process to identify user needs, the system identified the following needs:

User does not intend to spend more than ten years in the home.

User needs an immediate replacement of the dishwasher as it is non-functional.

To satisfy these needs, the system will first reject any measure with a payback greater than ten years. Second, the system will prioritize measures to include the dishwasher as a number one priority; it will be selected even if its payback is greater than ten years.

5.3.2 Shortlisting and Prioritizing Based on Cost Effectiveness

Once measures have been identified, based on user needs, the next step involves shortlisting and prioritizing measures based on cost effectiveness. This is done by determining the energy savings of measures using computer simulation, then performing a cost-effective calculation based on the results from the simulation and other information from quantitative sources. The following sections demonstrate how this is achieved.

5.3.2.1 Computer Simulation

The energy saving for the identified measures were calculated using Building Energy Optimization (BEopt) computer software (Christensen et al. 2005). Energy consumption was determined for an annual period. The unit of energy consumption was in US Dollars. Version 0.9.5.2 Beta of BEopt was used. The simulation was performed as follows:

Step I. The home was modeled in its existing condition, to find its energy consumption per year.

Step II. Each identified measure was upgraded separately to find its individual impact on the total energy consumption. The individual impacts are denoted by the first seven bars on the energy consumption graph shown in Figure 5.2

Step III. The home was modeled by removing the heating load. This is denoted by bar 8 in Figure 5.2. This revealed the total heating cost of the un-retrofitted home. The heating cost is calculated as follows:

UH = UF – UWH…. (i)

Where
UH = Total energy consumption for heating the un-retrofitted home
UF = Total energy consumption of the un-retrofitted home with heating load
UWH = Total energy consumption of un-retrofitted home without heating load

Step IV. The home was modeled by inputting all the selected measures. This is denoted by bar 9 on Figure 5.2. At the end of this step, BEopt recommended a smaller heating system. It suggested a reduction in size from 150 k BTU/h to 70 k BTU/h.

Step V. The home was modeled by inputting the entire thermal envelope and lighting measures but removing the heating load. This was done to show the cost of heating the fully retrofitted home. The heating cost is calculated as follows:

RH = RF – RWH…. (ii)

Where

RH = Total energy consumption for heating the retrofitted home

RF = Total energy consumption of the retrofitted home with heating load

RWH = Total energy consumption of the retrofitted home without heating load

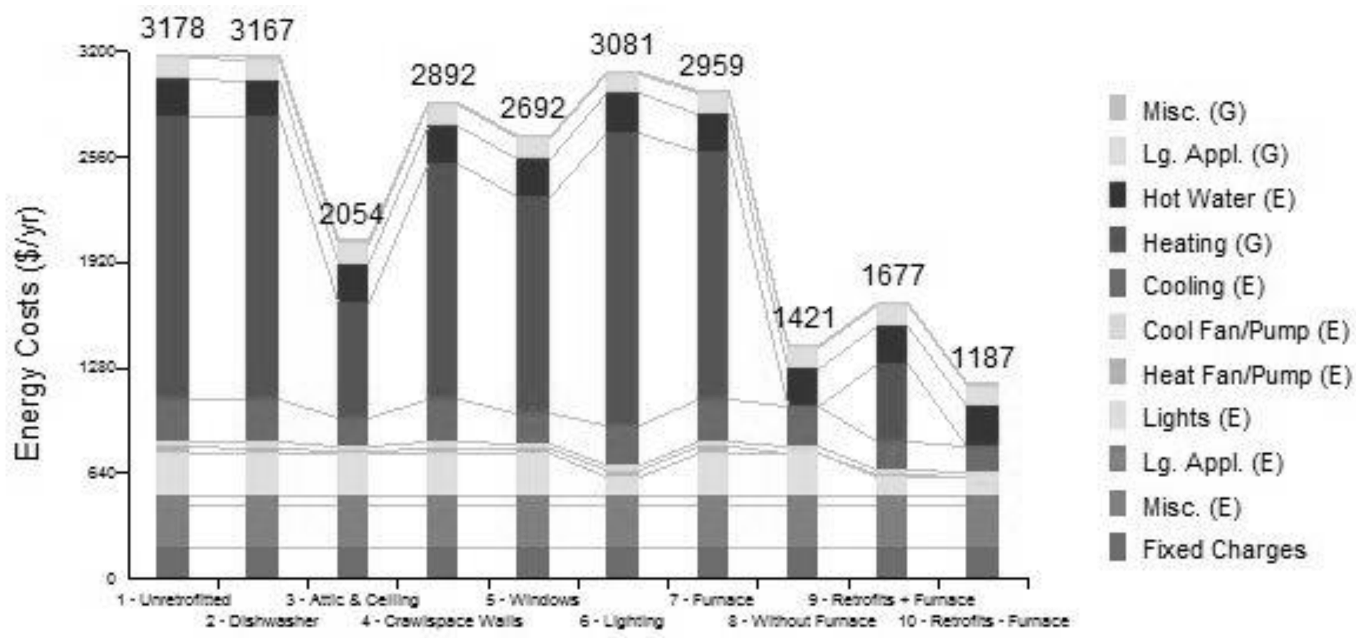


Figure 5.2: Energy Consumption Graph from BEopt Simulation

5.3.2.2 Cost Effectiveness Calculation

The cost effectiveness of each measure was calculated.

Population of Measure Data

First, Table 5.2 was populated with the relevant data for each measure as follows:

Column D: The cost for each measure was calculated from the NREM database.

Column E: Incentive amounts were assumed.

Column F: Effective cost was calculated as

EC = C – **I**…. (iii)

Where:
EC = Effective Cost
C – Original Cost
I – Incentive Amount

Column G: Annual loan payments were calculated using an online loan calculator. It was assumed that the entire effective cost of the measure was funded by loans with a term of ten years and a fixed annual percentage rate (APR) of 7%.

Column H: Annual energy savings were calculated as follows:

The annual energy consumption after implementing each measure was subtracted individually from the total energy consumption of the un-retrofitted home. Thus, bars 2 to 7 were subtracted individually from bar 1 of Figure 5.2, to obtain the individual energy savings of each measure.

Column I: Effective Return was calculated as:

$$\mathbf{X = ES - L} \ldots \text{(iv)}$$

Where:
X – Effective Return
ES – Effective Cost
L – Annual Loan Payment

Column J: Simple payback was calculated as:

$$\mathbf{P = C/ES} \ldots \text{(v)}$$

Where:
P – Simple Payback
C – Effective Cost
ES – Annual Energy Savings

Table 5.2: Data for Cost Effective Calculations (Individual Analysis)

A	B	C	D	E	F	G	H	I	J
Measure	Existing Efficiency	Upgrade Efficiency	Cost ($) (From NREL DB)	Incentive Amount ($)	Effective Cost ($)	Annual Loan Payment ($) (L) (Term = 10 years) APR = 7%	Annual Energy Savings ($) (ES)	Effective Return ($) (X)=ES-L	Simple Payback (Years)
Air-seal and insulate attic	Un-insulated	R=60	3675.2	50	3625.2	505.08	1124	618.9	3.2
Air-seal and insulate crawlspace wall	Un-insulated	R=19	1416.8	50	1366.8	190.44	286	95.56	4.7
Upgrade existing windows to higher efficiency	U=0.869	U=0.298	11900	237	11663	1625.04	486	-1139	23.9
Upgrade existing lighting to 100% CFL	0% CFL	100% CFL	210	30	180	25.08	97	71.9	1.8
Install Energy Star dishwasher	Standard	Energy Star	810	0	810	112.8	11	-101.8	73.6
Upgrade existing gas furnace to higher efficiency (Size 150 k BTU/h)	80% AFUE	93% AFUE	4950	450	4500	627	219	-408	20.5

User Need, Thermal Envelope and Lighting Improvement Analysis and Iteration

The iteration to shortlist and prioritize measures based on user needs and cost effectiveness is performed in this way:

Three measures are identified whose payback is greater than ten years

Upgrade existing windows to higher efficiency

Install Energy Star dishwasher

Upgrade existing gas furnace to higher efficiency

Out of these, only windows are rejected because

Installing a new dishwasher is an immediate user need

Gas furnace has not been analyzed for its interactions with the thermal envelope and lighting measures, so its actual upgrade possibility has not yet been realized. This will be performed in Section 5.3.3.3.

Iteration

1. Pick the immediate user need (Upgrade existing dishwasher)

Cost of Measure = $810

Remaining Budget = 8,000 – 810 = $7,190

2. Pick the highest effective return (ES-L) (Air-seal and Insulate Attic)

Cost of Measure = $3,625

Remaining Budget = 7,190 – 3,625 = $3,565

3. Pick the next highest effective return (ES-L) (Upgrade Existing Lighting to 100% CFL)

Cost of Measure = $180

Remaining Budget = 3,565 -180 = $3,385

4. Pick the next highest effective return (ES-L) (Air seal and insulate crawlspace walls)

Cost of Measure = $1,366

Remaining Budget = 3,385 – 1,366 = $2,019

Thermal Envelope, Lighting, and Heating and Cooling Measures (Combined Analysis and Iteration)

The iteration of the thermal envelope and lighting measures was performed in Section 5.3.2.2. The next step is to combine all the shortlisted thermal envelope and lighting measures, and analyze them in combination with the furnace. This will help the system decide if the furnace can be downsized to fit the improved thermal envelope. Table 5.3 gives the data for individual shortlisted measures, accompanied by the altered information of the reduced furnace. The reduced size of the furnace was suggested by BEopt.

Table 5.3: Data for Cost Effective Calculations (Combined Analysis)

A	B	C	D	E	F	G	H	I	J
Measure	Existing Efficiency	Upgrade Efficiency	Cost ($) (From NREL DB)	Incentive Amount ($)	Effective Cost ($)	Annual Loan Payment ($) (L) (Term = 10 years) APR = 7%	Annual Energy Savings ($) (ES)	Effective Return ($) (X)=ES-L	Simple Payback (Years)
Air-seal and insulate attic	Un-insulated	R=60	3675.2	50	3625.2	505.0	1124	618.9	3.2
Air-seal and insulate crawlspace wall	Un-insulated	R=19	1416.8	50	1366.8	190.4	286	95.5	4.7
Upgrade existing lighting to 100% CFL	0% CFL	100% CFL	210	30	180	25.0	97	71.9	1.8
Upgrade existing gas furnace to higher efficiency (Size 70 k BTU/h)	80% AFUE	93% AFUE	2310	450	1860	259	1090	830.8	1.7

Table 5.2 illustrates the reduction in size of the furnace from the previous 150 k BTU/h to 70 k BTU/h. Thus, the cost of the new furnace is now reduced from $4,950 to $2,310. The new heating energy savings is calculated by subtracting equation (i) from Equation (ii). The reduced

cost and increased efficiency, due to a reduced number of cycles, decreased the payback from 20.5 years to 1.7 years, making it a suitable measure for implementation. Thus, this section helped demonstrate the necessity of considering interactions between building components.

The iteration for the heating and cooling measures were calculated as follows:

Iteration

Pick the highest effective return (ES-L) – Upgrade Existing Furnace

Cost of Measure = $1860

Remaining Budget = $2,019 – 1,860 = $159

There are no other measures identifiable for the remaining user budget. The final shortlisted measures are shown in Table 5.4.

Table 5.4: Shortlisted Measures

Stand Alone Measures	Thermal Envelope and Lighting Measures	Heating and Cooling Measures
Install a new Energy Star rated dishwasher	Air-seal and Insulate attic to R-60 Air-seal and insulate crawlspace walls to R-19 Upgrade existing lighting to 100% CFL	Install a new 70 k BTU/h gas furnace which is 93% efficient

Priority List

The list of measures has to be prioritized in the following manner:

Install the dishwasher

Install all the thermal envelope and lighting measures

Install the downsized, higher efficiency furnace

5.3.3 Shortlisting and Prioritizing Based on Health and Safety Considerations

A very important part of home energy retrofits is the identification and mitigation of possible health hazards to occupants, post-retrofit. Section 4.4.3.2 of this report highlighted the importance of health and safety considerations. Thus, in this model, the health and safety issues will be addressed in this way:

Two of the shortlisted measures may have possible health impacts on the occupants

Air-seal and insulate attic

Air-seal and insulate crawlspace walls

5.3.3.1 Warnings

The system would provide health warnings to the user in the following manner:

“The above measures may increase the carbon monoxide levels inside the home. Perform a blower door test, post-retrofit. If the CO levels are below ASHRAE 62.2 Indoor Environmental Quality (IAQ) standards then:

Consider replacing existing atmospheric vented combustion appliances to sealed-vented appliances and

Install mechanical ventilation in the home to meet the ACH requirements of ASHRAE 62.2 IAQ standards.”

“Considering the age of your home, it is highly likely that the home uses a knob and tube type of electrical wiring. If this is found to be true, then rewire the home. If this is not done prior to installing the attic insulation, the excessive heat generated by this type of wiring may result in a fire hazard.”

5.3.3.2 Cost of Mitigation

The system will provide the following information to the user:

“The cost of mitigating the above hazards may be high. For example, the cost of rewiring your home is estimated to be about $22,000 including labor and material. The new parameters for attic air-sealing and insulation changes as follows:”

Total cost – $22,000 + $3,625 = $25,625

Annual loan payment – $3,570

Effective Return –$ -2,446

Simple Payback – 22.79 years

Thus, the system leaves the decision of whether to implement this measure to the user. The benefits of implementing this measure are laid out.

5.3.3.3 Benefits

Although this measure has a high initial cost, which would increase the payback to 22 years, this measure has the following benefits:

Reduces the risk of electric shocks.

Reduces the risk of fire.

Insulating the attic causes the heating and cooling systems to operate more efficiently, providing extra savings.

5.4 Expert Advice on Installation

The final step in the model is to provide expert advice on installation in several categories:

Installation Techniques

Level of Difficulty

Installer Skill

Installer safety

Material selection and Procurement

Other factors

Only one of the shortlisted measures, attic air sealing and insulation, was selected here for demonstration purposes. Its installation advice is listed within the six categories.

5.4.1 Air-sealing and Insulation of Attic

The air-sealing and insulation of the attic is to be performed in the following manner:

5.4.1.1 Installation techniques

Leaks in the roof must be fixed first.

Bathroom fans must be vented out, if they are vented into the attic.

There should be good lighting and the installers must communicate well among themselves for a safer operation.

Hire a professional to conduct a blower door test on the home.

While the blower door is running, you can check for air-leaks with the smoke generator and thermal camera.

The **easiest** places to air-seal are: 90% of the interior top plates, light boxes, wire holes, gable end exterior top plates, plumbing stacks, exhaust fans, knee-walls and chimney, weather-strip attic access, and can lights.

The **difficult** areas to air-seal would be the thermal boundaries, hard-to-reach interior top plates, exterior top plates, bulkheads, skylights and exterior soffits.

For more details, refer to the following document at the Building Science website. The link to the document is provided below:

Name: Attic Air-Sealing Guide and Details

Author: Joseph Lstiburek

Published by: www.buildingscience.com

http://www.buildingscience.com/documents/guides-and-manuals/gm-attic-air-sealing-guide/view

5.4.1.2 Level of Difficulty

The level of difficulty identified for this measure is 3 (Very Difficult/ Needs Trained Professional. The system will also provide details of the scale of difficulty:

“What does a level of difficulty 3 mean?

The scale of difficulty is:

1 – Easy/DIY

2 – DIY with certain tools and precautions

3 – Very Difficult/ Needs professional

In normal cases, this installation would be a level of difficulty 2, which means you could install it yourself with certain tools. However, considering the age of your home, the system has identified potential H&S issues, which need to be mitigated by a trained professional. Thus, it has given it a level 3.”

5.4.1.3 Installer Skill

This operation is best performed by trained professionals.

Certifications from reputed agencies such as BPI and RESNET are a good way to identify well-trained professionals.

Rewiring must be done by a licensed electrician.

Vermiculite insulation must be eliminated by a professional trained to perform such an operation.

Contact your State Dept. of Health for more information.

5.4.1.4 Installer Safety

If the house has active knob and tube wiring, rewiring must be done. Figure 5.3 shows knob and tube wiring.

The house should be tested for vermiculite insulation. If present, it must be removed by a trained professional.

Be aware of protruding nails in the roof.

If you suffer from claustrophobia, avoid performing this function by yourself; hire a professional.

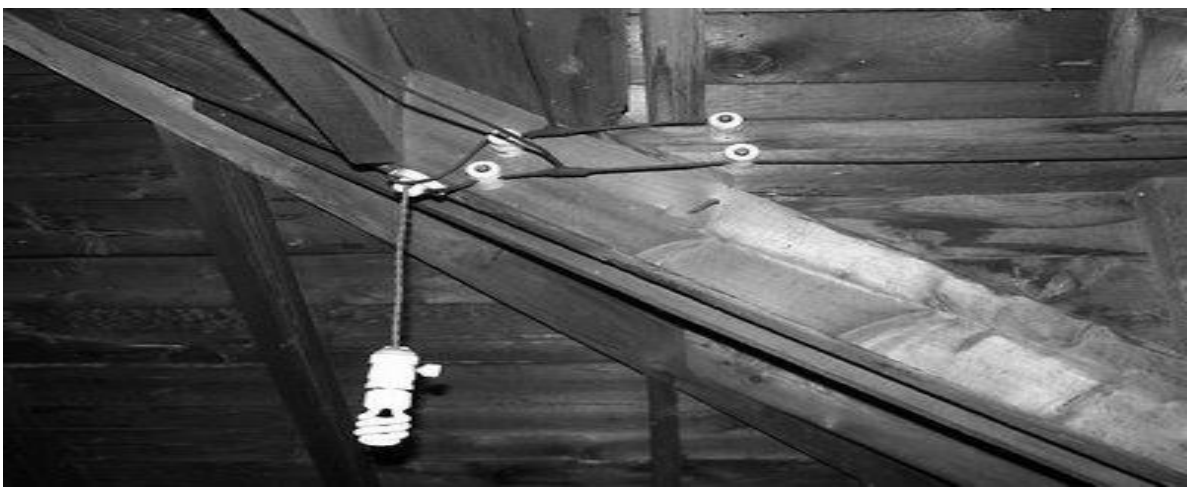


Figure 5.3: Knob and Tube Wiring (source: http://doverprojects.blogspot.com/2008/11/knob-and- tube-wiring-replacing-for.html)

5.4.1.5 Material Selection and Procurement

The materials to be used for the above operation could be the following:

Spray foam (1 part foam).

Foam board or 2 part foam can be used for attic ceiling and floor.

For chimney's, use metal flashing and fire caulk for fire safety.

Use Baffles to provide ventilation for the attic.

All of the above materials may be procured at the nearest lumberyard. Figures 5.4 and 5.5 show images of spray foam insulation and attic ventilation baffles.

Figure 5.4: Spray Foam Insulation (source: http://www.certainteed.com/products/insulation/spray-foam-insulation)

Figure 5.5: Attic Ventilation Baffles (source: http://www.peaktoprairie.com/?D=206)

5.5 Chapter Summary

This chapter illustrated the functioning of the expert system within the layout of the framework established in Chapter 4 of this report. The workings of the illustrative model corresponded with the process map shown in Figure 4.6.

The illustration model queried users to find their needs and the existing efficiencies of the home, so as to identify upgrade measures. Once identified, the measures were shortlisted and prioritized based on cost effectiveness, user budget and user needs. Finally, the user was provided with installation advice for the shortlisted measures.

The quantitative resources used in this model were the NREM database to determine the cost of measures, and the BEopt energy simulation tool to determine the energy savings of measures.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Overview

This chapter presents a summary of the research, and an overview of the generated outputs. The overview of the research will be discussed first, followed by a review of the objectives and methodology used to achieve the end results. Finally, the chapter will look at areas of future research.

This research developed the framework for a query-based expert system that homeowners can use to find customized information related to energy efficient measures for retrofitting their existing homes. To achieve this goal, the research developed the frameworks of a quantitative database and a qualitative knowledgebase, which were integrated to develop the final framework of the system. The framework then demonstrated a working example, using a hypothetical retrofit scenario.

Chapter 1 presented the research need, goal, objectives and work steps, as well as the scope and limitations. Literature related to this research was summarized in Chapter 2. Chapter 3 studied barriers related to home energy retrofits, together with the future steps required to remove them, examined the existing Building America information portal, and developed the framework of a quantitative database of retrofit measures. Chapter 4 developed the framework of a qualitative knowledgebase of retrofit measures by conducting interviews with experts, such as home energy auditors and retrofit trade contractors. Finally, Chapter 5 demonstrated a working example of the expert system framework.

6.2 Summary of the Objectives

The overall goal of this research is to promote the implementation of EE retrofits in existing homes by developing an information system, such as a query-based expert system, which would greatly reduce the cost and effort of acquiring the appropriate information. This would help increase homeowners' motivations to make their homes energy efficient. This section summarizes the work performed to achieve the research objectives.

Objective 1: Barriers and Catalysts

Identify barriers and catalysts for improving EE in existing buildings and homes, and form the basis of the information categories/entity sets of the quantitative database.

Chapter 3 discussed a literature-based study of the existing barriers and catalysts in the overall issue of implementing home energy retrofits. This classification was only done for academic purposes; for use in future research that will be built upon this research. Thus, this classification did not influence the categories of information defined for the database framework. The three categories of overall issues are:

Innovation in Construction

General Home Retrofit

Energy Efficiency/Building America

A literature-based study of the barriers and catalysts in the construction issues of home energy retrofits followed. These barrier categories became the categories of information required for the database framework.

The barriers identified in the overall issues of construction were categorized under appropriate topics; these topics then formed the information categories/entities of the quantitative database. Barriers and future steps were classified under four broad areas:

- Performance
- Cost Issues
- CM/Installation issues
- Other Issues

The first three areas of classification were used to identify categories of information for the quantitative database. Other Issues was only created for academic purposes. Thus, the categories of information are comprised of the broad areas of Performance, Cost Issues, and CM/Installation Issues.

Objective 2: Database and Knowledgebase

This objective was aimed at developing the frameworks of both the quantitative database and the qualitative knowledgebase. These are the two most important parts of a query-based expert system. The quantitative database was developed in Chapter 3 and the qualitative database in Chapter 4. The development methodology was comprised of two sub-objectives.

2a: Investigate the existing Building America Website and National Residential Efficiency (NREM) database, and propose ways to utilize the latter as the database of EE retrofit information.

This sub-objective looked the existing Building America information portal and its main databases to see how they could be modified for use as a comprehensive quantitative database of EE retrofit information.

The Building America information portal was studied to determine whether databases related to any category of construction issues already exist. The study looked at all parts of the Building America information portal, including publications, external links and databases. Two major databases providing information related to energy retrofits were found: the Database of State Incentives for Renewables and Efficiency **(**DSIRE**)** and the NREM database (DSIRE 2010 & NREL 2010). These databases provide information about the costs and financial incentives of retrofit measures.

A comprehensive category list of construction issues was created to determine the final categories of information to be added to the proposed quantitative database. The categories of cost and incentives, found to already exist in the Building America portal, were deleted from the comprehensive list to develop the final list of categories of information to be added to the new database.

2b: Develop the framework for a qualitative, experienced-based knowledgebase by interviewing trade contractors and energy auditors.

To achieve this objective, a preliminary framework of the knowledgebase, which suggested the desired functions of the system, was developed. The preliminary framework was derived from literature and the existing knowledge of the researcher. Three broad functions were outlined:

- Identify Retrofit Measures
- Shortlist and Prioritize Measures
- Provide Expert Advice Related to the Installation of Shortlisted and Prioritized Measures

Next, to refine these functions and find the best possible ways to execute them, the researcher conducted interviews with energy auditors and trade contractors. The expert interviews were then analyzed to extract relevant information for the QBES framework. The analysis suggested changes to the methods of execution for the suggested functions, although the preliminary functions remained as the basis for the final framework. The changes are shown in Figure 4.4.

Objective 3: Query-based Expert System Framework

3a: Develop the overall framework for a query-based expert system that combines qualitative knowledge and quantitative data to support decision-making/expert advice on retrofit measures.

3b: Demonstrate a working example of the query-based expert system.

The final step in the development of the query-based expert system involved the integration of the quantitative database and the qualitative knowledgebase, along with other tasks of the Cost Effective Energy Retrofit project (larger project funded by the Building America program). This final framework is shown in Figure 4.6.

Finally, a working example demonstrated the functioning of the expert system framework. This was done in Chapter 5 of this report.

6.3 Inferences and Observations

At the end of the research, which involved developing the framework of a query-based expert system, several inferences and observations were made. These inferences and observations, listed below, include suggestions for improving the performance of the actual expert system that may be developed upon this framework.

If an expert system is made available to homeowners, free of charge in a web-based format, it will reduce the cost associated with finding information on energy efficient retrofits. This reduced cost and time will encourage homeowners to use the right information in deciding upon retrofit practices, increasing the overall energy efficiency of their homes.

The experts who were interviewed suggested that if such a system were to be implemented by a reputable agency such as the government, it would add to the credibility of the information it provides. This information could then be used by actual experts in the field to support their decisions, and the advice they provide to homeowners.

Developers of such an expert system must perform adequate research on the answering capabilities of users. The researcher feels that this might be a major hurdle faced by such a system. Hence, methods have to be developed for homeowners to be able to answer queries in a satisfactory manner. This might be achieved by educating them about key aspects of their home, and providing tips and suggestions to help them identify the existing conditions of the home.

The system should be developed in a manner that allows simplicity of use. Experts feel that homeowners might be put off if the system is too complicated.

The system must have sufficient graphics, including pictures and videos, to support its advice. Experts who were interviewed felt that such a representation of information would increase user interest.

The system must have a feedback mechanism to allow users to suggest changes and improvements. This would allow for constant updates to the system.

6.4 Plans for Future Research

The framework of this query-based expert system, developed as part of this research, is meant to be a foundation upon which an actual system will be developed over the next few years. The plans for future years of research are:

Year 1: First, the quantitative database portion of the expert system will be derived from existing databases. Thus, such databases must be studied in detail and they must be integrated with the expert system developed upon this framework. Second, the expert system to be developed from this framework is to be developed upon an Exsys Corvid® platform (EXSYS 2011). Hence, this framework will need to be customized to suit the platform.

Year 2: The framework will be finalized with inputs from other tasks of this project. Following this, the actual knowledge acquisition from experts will begin. This knowledge will be used to populate the knowledgebase of the system. Finally, a pilot expert system will be developed upon the Exsys Corvid® platform.

Year 3: A fully functional expert system will be developed upon the Exsys Corvid® platform. Thus, this system will have a fully populated quantitative database and qualitative knowledgebase.

Year 4: This will be the final year of this project. The plans for year 4 include training, education and demonstration of the system. Additionally, plans to upload this system in a web-based format will be explored.

6.5 Chapter Summary

This chapter summarized the work done in this research, developing the framework of a query-based expert system. The research was conducted in four stages:

Develop the framework of a quantitative database.

Develop the framework of a qualitative knowledgebase.

Integrate the database and knowledgebase to develop the framework of the query-based expert system.

Demonstrate a working example of the query-based expert system.

The chapter also provided inferences and observations to assist in the future development of a query-based expert system upon this framework, with yearly plans.

Appendix 1

Summary of Barriers and Future Steps

(References: Jaffe & Stavins 1994, Koebel et al. 2003, NAHB 1991, Listokin et al. 2001, PATH 2002, Golovo and Eto 1996, RESNET 2010 b and NREL 2010 b)

		IV	HR	BA/EA
PERFORMANCE				
		IV	HR	BA/EA
	Potential Energy Savings			
	Barriers			
1	Benefits of implementing energy savings are difficult to quantify. There is need to empirically document the incremental benefits.			X
2	Limited access to energy utility data for consumers and contractors.			X
3	Need to estimate savings predictions for retrofits that are crucial for auditors and program-scale efficiency efforts.			X
	Difficult to know expected efficiency of current space conditioning equipment; need library/database of performance expectations for different makes and models. Manufacturers do not have incentive to provide this information.			
	Future Steps			
1	Need to estimate savings predictions for retrofits that are crucial for auditors and program-scale efficiency efforts.			
2	Behavioral information/questions - people need to know how much they will save by the use of automated home energy management systems and have faith in the information.			X
	Potential Health Impacts			
	Barriers			
1	Health risks are inherent in retrofits		X	X
2	Resolving health and safety issues do not have paybacks.??		X	X
3	Wood burning fireplaces cannot be made safe, but is an attraction for homeowners			X
4	The health risks have not been completely mapped and, consequently, the solutions have not been identified.			X
5	Policies for procedural and administrative solutions that will enable the federal government to address the weatherization and health hazards in more homes are currently lacking.			X
6	Liability issues may exist for someone who performs an audit.			
7	Lack of guidelines on energy retrofit of enclosures with warnings related to moisture issues.			X
	Future Steps			
1	Significant questions exist on the appropriate amount of ventilation. The questions need to be answered with a more scientific basis than currently exists.		X	X

2	Filtration of ventilation air must be addressed		X	X
COST ISSUES				
Financing				
Barriers				
1	Lack of lender reliability in energy savings.			X
2	Energy efficient mortgages have not become popular.			X
3	Distinct difference between cost and value in market, driving supply and demand that reduces value of energy efficient features.			X
4	Lack of consistent lender understanding of "green," and other confusing terms.			X
5	There is a general lack of funding options for energy efficiency improvements and the existing options are underutilized and still maturing.			X
6	An innovation is required to be accepted not only by project participants but by the insurance and finance industries involved in the project.	X		
7	Inadequate capital for deployment as in some cases the initial cost of deployment of an innovation could be high.			
Future Steps				
1	Need to use information to quantify energy efficiency more effectively on standard appraisal forms.			X
2	Need to use public funds to provide permanent mortgage loan discounts.			X
3	Need for education/outreach for lenders, appraisers and public.			X
4	Need to involve banking community in energy efficiency program development.			X
5	Need to engage appraisal industry with tools that enable them to recognize energy efficient building features and compare similar properties with energy efficient design/features.			X
6	Need to develop proper financial instruments to fund projects.			X
7	Need for turnkey financing.		X	X
Incentives				
Barriers				
1	The structure of the incentive available determines how many retrofit measures people buy. The cost of access exceeds the value of the benefit.			X
2	Limited funding for both tenant and contractor.		X	X
3	PACE (Property Assessed Clean Energy) loans have been put on hold: an example of fleeting financing models and mechanisms.			X
4	There exists confusion about rebates/tax credits.			X
5	Access to information and funding – even if consumers find a rebate that will help them, they may not have enough money to cover the remaining cost.			X

6	Factory built homes require different rebate programs, but it is a vastly underserved market.			X
CM/INSTALLATION ISSUES				
Building Energy Codes & Regulations				
Barriers				
1	New government regulations e.g. EPAs "Lead Abatement Rule" will cause many difficulties for contractors.		X	X
2	Electrical code does not properly account for retrofit of cavities with knob and tube wiring.		X	X
3	International Residential Code (IRC) currently discourages construction of walls with exterior insulated sheathing and vinyl siding (no OSB sheathing) due to structural concerns. These walls can only be constructed if a professional engineer stamps the plans.		X	X
4	International Code Council (ICC) does not provide "Evaluation Services" for processes, only products.		X	X
5	Building codes are highly diverse, varying from locality to locality. An innovation may be accepted by one code but rejected by another.	X	X	
6	Excessive building codes relevant to renovation especially historic preservation add to the unpredictability of estimating costs for rehab. Thus the contractor pool is usually limited, decreasing competition and increasing costs.		X	
7	In rehabilitation which involves federal subsidy, the "Davis Bacon" requirements will have to be met adding to regulatory requirements.		X	
8	Renovation work involves many environmental hazards such as lead paint, asbestos abatement, radon, etc.		X	
Future Steps				
1	Need to continue to push for code change allowing exterior insulated sheathing with vinyl siding.		X	X
2	Need to increase awareness of, and enhance code support addressing construction details and processes.			X
Product Availability Cost & Specs				
Barriers				
1	DOE test equipment standards currently have issues.			X
2	Need for supplemental dehumidification independent from cooling in low-sensible-gain houses in humid climates.			X
3	The labeling on equipment may not be easily understood by an average consumer.			X
4	High first costs leading to long payback time.			X
5	Lack of infrastructure for ease of maintenance.			X

6	Some technologies are not suited for universal installation methods	X		X
7	Difficult to know expected efficiency of current space conditioning equipment; need library/database of performance expectations for different makes and models. Manufacturers do not have incentive to provide this information.			X
Future Steps				
1	Need to develop simulated rating tool and spreadsheet tool to derive detailed product specifications and inputs.			X
2	Need to develop a low cost "Energy Recovery Ventilation" with own distribution system.			X
3	Consumers need to know how much they will save by the use of automated home energy management systems and have faith in the information.			X
Skill Level of Contractors				
Barriers				
1	Estimates provided by retrofit subcontractors are high due to the lack of understanding of the requirements.		X	X
2	Retrofit contractors and subcontractors are not properly trained.		X	X
3	Any innovation would require changes in business practices and installation techniques by trade contractors. However there is inadequate education and training avenues to implement such changes.	X	X	X
4	Inadequate skill of professional consultants.		X	X
5	Reliance on smaller trade contractors for most of the renovation work. This problem is aggravated because the management skill level required for renovation is higher than for new construction but the skilled, bigger contractors are mainly involved in new construction.		X	X
6	Liability issues may exist for someone who performs an audit.			X
Future Steps				
1	New emphasis on retrofits and energy efficiency creates a greater need for training and new kinds of specific certification.		X	X
2	New ENERGY STAR specifications have created the opportunity to require full building science training and performance on homes using the ENERGY STAR label.			X
3	Opportunity to provide high quality, on-demand training for builders and contractors doing the retrofit work.			X
4	Compulsory training and certification should be required.			X
5	Need to develop strategies to train all of the necessary people who will be doing the work.		X	X
8	Contractors need to offer performance guarantees			X
9	Need to have a team of people for comprehensive improvements. Homeowners do not know how to coordinate this.		X	X
10	Need for supplemental dehumidification independent from cooling in low-sensible-gain houses in humid climates.			X

Installation Procedures				
Barriers				
1	Current HVAC equipment has installation issues.			X
2	Implementing new home strategies, such as mechanical ventilation, in retrofit applications is challenging.	X	X	X
Future Steps				
1	Energy efficiency retrofits of foundation, crawl spaces, walls in masonry buildings, and roof systems have aspects that need further research.			X
2	Significant questions exist on the appropriate amount of ventilation. The questions must be answered with a more scientific basis than currently exists.		X	X
3	Filtration of ventilation air must be addressed.		X	X
4	Maintenance issues must be addressed, along with the role of air inlets or trickle vents.			X
5	Wider understanding is needed of when and where "exhaust only" ventilation is (and is not) appropriate.			X
6	Need to invest in the determination of scientifically valid necessary ventilation rates in both new and existing homes.		X	X
7	Need to evaluate ventilation distribution systems.		X	X
Safety Hazards				
Barriers				
1	Documentation on how to remove lead paint from exterior systems is lacking.		X	X
2	The risks have not been completely mapped and, consequently, the solutions have not been identified.		X	X
3	Estimates provided by retrofit subcontractors are high due to the lack of understanding of the safety requirements.		X	X
4	Energy efficiency retrofits of foundation, crawl spaces, walls in masonry buildings, and roof systems have safety aspects that need further research.			X
5	Assessment of scope and impact of the health hazards and the consistency in how crews respond is lacking.			X
Future Steps				
1	Recommend policy, procedural and administrative solutions that will enable the federal government to address the weatherization and health hazards in more homes.			X
Project Planning Time +Costs				
Barriers				
1	Participants in the retrofit process lack integration.	X		X
2	The process of renovation is a lot more unpredictable when compared to new construction because the process has to cater to a lot of unique features of the		X	X

	existing building, hence requiring more intensive management than new construction.			
Quality Management (QA+QC)				
Barriers				
1	Quality is sometimes sacrificed for cost	X	X	X
2	Need to standardize the work that is performed and enforced by everybody on the team.		X	X
3	Builders and remodelers need help with operational efficiencies and product quality/differentiation that can be addressed by total quality assurance.		X	X
4	Significant energy improvements are possible, and require total quality management systems to be consistent, particularly in larger organizations.			X
5	Builders and remodelers often don't know where to start, and suffer from an inability to change organizational culture.		X	X
6	Need to clearly define and measure quality with sound building science as a foundation (reference to DOE Builders Challenge Quality Criteria).			X
7	Need to quantify risk in terms of cost/occurrence/legal risk.			X
8	There is a dire lack of performance standards or certification to distinguish a good product from a bad one. This leads to unreliability and lack of trust in an innovation.	X	X	
9	Regulatory requirements demand new rehabilitation work to be up to the same standards as new construction. Sometimes, meeting this requirement is a near impossibility.		X	
Future Steps				
1	Need to provide education and outreach			X
2	Checklists are both a good system for consistent level of performance and a liability.			X
3	Prove that Building America program work is successful (through measuring energy/money/CO2 savings).			X
4	Quality assurance needs improvement.			X
5	Need standards for retrofit validation (test-in/test-out).			X
6	Need quality impacts and feedback for all stakeholders.			X
7	Retrofits with super quality assurance are building trust.			X
8	Contractors need to offer performance guarantees			X
9	Need to establish more laboratory and field-testing of equipment			X
INFORMATION RELATED ISSUES				
Barriers				
1	Information is out there, it's just not getting to the right people.			X
7	Privacy concerns make it easy for utilities to refuse to share data.			X
3	The risks have not been completely mapped and, consequently, the solutions			X

	have not been identified.			
4	Auditors have differing opinions on proper retrofits and fund allocation.			X
5	Liability issues may exist for someone who performs an audit.			X
6	Retrofit process has many stakeholders and communication between parties is tedious and complex.			X
7	Construction industry is dominated by small firms. Small firms are generally known to be slower than larger firms in adapting to new technology.	X		
8	Limited funds for research	X		
9	Once research on new technologies and ideas have been performed in government and university labs, there is a lack of means to move them to the field where they could be ultimately deployed.	X		
10	There is insufficient flow of information between project participants within the industry and between the industry and product manufacturers.	X		
11	Energy efficiency information given by Federal agencies lack consistency.			
12	The information available on energy efficient products and systems including availability, cost, manufacturers, and potential energy savings are scattered and difficult to find.			
13	In some cases powerful manufacturers of EE technology prevent more energy efficient competitors from selling their product.			
Future Steps				
1	Existing information needs to be aggregated, indexed and distributed.			X
2	Need to develop national standards for building performance to enhance education for all stakeholders.			X
MARKET AND CONSUMER MOTIVATION ISSUES				
Barriers				
1	With savings accounts and Certificates of Deposits (CD) likely to earn 1%-3%, and instability of stock markets over the last few years, selling the benefits of energy efficiency by emphasizing the Rate on Investment should be an easy sell for homebuilders and a no-brainer for homebuyers.			X
2	Saving energy may be low on the list of priorities when a homeowner decides to make changes to his/her home (usually comes after financial, comfort and other values).			X
3	Homeowners want home improvements to be visible to neighbors and guests, which most energy improvements are not.			X
4	Too many products are presented with claims of efficiency. Homeowners do not know how to distinguish between truly efficient products and those using efficiency claims solely as a marketing device.			X
5	Supporters, such as realtors and appraisers, lack an education in energy efficient homes and have yet to establish a standard method of presenting the benefits of energy efficiency to their customers.			X
6	Energy costs and mortgages are presented separately and the value of energy savings is overshadowed by the cost of mortgage payments.			X
7	Distrust of the construction/insulation industry.			X

8	Consumers don't know value of audit – energy audits are not advertised well.			X
9	Not embracing the 'makeover' concept – don't see reason to change.			X
10	Construction industry is highly cyclic, that is, the volume of construction activity is highly dependent on the economy. Thus companies might be hesitant to accept innovation because of the unpredictability of profits.	X		
11	Homebuyers resist acceptance to innovation.	X		
12	Buildings have a very long service life; during this period there could be a large number of changes in its ownership acting as an impediment to change.	X		
13	Most construction projects are fixed price projects. In such cases designers and constructers find themselves at a highly opposing position preventing either side from innovating or accepting innovations	X		
14	Manufacturers of EE technologies have their self-interests in advertisement leading to a lot of misinformation on their part.			
15	Consumers are misinformed about the benefits of energy efficient remodeling; hence do not view it as a wise option.			
16	Consumers do not seem to be driven by social consciousness to conserve energy.			
17	A major concern for remodelers when faced with innovative technology is the uncertainty they face with respect to the revenues and profit.			
18	Remodelers are skeptical about the consumer demand for energy efficient solutions.			
19	Incentives for energy conservation are misplaced in some cases, that is, the entity that would benefit from home energy efficiency is not the financial decision maker to invest in it. This is commonly seen in rental homes.			
20	Homeowners, especially builders tend to reduce the first cost of home building and hence opt for low efficiency features for the home			
21	Wood burning fireplaces cannot be made safe, but is an attraction for homeowners		X	X
	Future Steps			
1	Decisions to make changes to a home usually coincide with major life events (new children, new job, sending children to college, etc.). Policies related to energy retrofits should focus on aligning with personal decisions.			X
2	Homeowners do not want to be overwhelmed with number of metrics telling them how good or bad their homes are with energy efficiency. They need to be provided with a single energy label in a context that they can understand and assign some value to.			X
3	Need to design programs around the people, not the houses. Align energy benefits with homeowner preferences for comfort, convenience, health, functionality, security, economics and control.			X
4	Provide information on retrofit costs and savings to sources that homeowners contact and trust, e.g., contractors, home improvement outlets, etc.			X
5	Need to start by addressing likely adopters; look at age group, income, and energy usage.			X
6	Need to investigate the renovation decision-making process in specific populations and contexts.			X
7	Marketing is important – if agent markets house as 'green,' can increase premium by approximately 14%.			X

8	Millions of renovations occur every year and energy efficiency improving measures would be easy to incorporate during renovation. It is difficult to encourage energy efficiency improvements after major renovation.			X

Appendix 2
(Expert Interviews)

Interview Questions

Professional Type: (HVAC Contractor + Energy Auditor)

6/9/11

General Questions

1. What is the type of business your firm is involved in?
a. Energy Auditing
b. General Contracting
c. Both
d. Others (please specify)

Answer: I own two companies. Our companies do both auditing and general contracting work.

2. What is your role in the firm?

Answer: I am the chief auditor and owner of the company and I manage the work in the General Contracting

3. How many home energy retrofits has your firm done?
a. 1-20
b. 20 – 50
c. Above 50

Answer: Above 50

4. As a contractor what aspects of home energy retrofit do you perform?

a. What services do you prefer to do and why?

b. What services do you do with your own forces and which ones are subcontracted out?

c. Which of your services have a higher profit margin?

Answer:

a. We prefer HVAC related work such as design of ductwork and installation of equipment and ductwork. The reason for this is that our company has several years of experience mainly in the HVAC. We also have the infrastructure to perform HVAC related work.

b. HVAC related work is always done by our workforce. We occasionally subcontract out insulation work and also if there is some work related to the retrofit but does not fall in our expertise e.g. electrical and plumbing work

c. HVAC

5. What specific jobs are you licensed/certified for?

Answer: We are licensed builders i.e. we are licensed to perform all aspects related to retrofit work including insulation, HVAC, appliances, air – sealing etc.

6. What is your major geographical region of operation?
Answer: South-West Michigan

7. Do you belong to any professional associations related to home energy efficiency?
Answer: BPI, RESNET, Efficiency First, Air-Conditioning Contractors of America

Home Energy Retrofit Specific Questions

Identifying Measures

1. Given a scenario where you go to a home and have to make recommendation for measures and you do not have means to perform testing on the home, explain in a step by step manner what methods you will use to make that decision. Note that the homeowner is highly informed about the home including equipment efficiencies, insulation levels, age of home and systems, construction type etc., and will provide you with that information
Answer:

- For air sealing, it is impossible to suggest the right amount of sealing without performing the blower door test to find out the CFM of air flow. It is also a health and safety issue so we will have to perform the combustion testing of appliances to ensure that there is adequate ventilation so as to keep the carbon content in the air below 8 ppm.
- For equipment and appliance related measures, we can go around looking at the efficiencies of the equipment and appliances, check the insulation levels, type of lighting etc. Sometimes the efficiency of equipment will not be readily available. In such cases we would use some empirical methods to analyze the efficiency e.g. the furnace is vented with a plastic pipe, the efficiency should be 90% or greater, if it is vented with a metal pipe, the efficiency will be less than 80%. Note that HVAC equipment upgrade may not produce the best return on investment (ROI).
- Next, we have certain which we can use to find the ROI on the non-equipment related measures such as thermal insulation.

2. What are some of the conditions you have when you select an energy efficient product for a home?
Answer:

- Safety ratings and efficiency ratings e.g. Gas Appliance Manufacturers Association (GAMA) ratings for gas equipment
- Properties of material e.g. for insulation we would check the flame spread, smoke spread, right type of material, R-values etc.

- Industry ratings

3. Different homes have different retrofit needs. What aspects of the home will determine the need?
Answer: Construction type, previously performed retrofits and age

4. If you identified aspects of the home that determines the need in Q 3, what will be the major points of distinction? E.g. if you believe the architectural type of the home will affect the retrofit need, then please mention the dominant archetypes in the Michigan area and what each archetype will need? Similarly, provide time periods in which there is a significant difference in energy efficiency of the building, hence varied needs
Answer: Some dominant archetypes in MI that come to mind are

- Cape Cod
- Ranch homes
- Bungalow

Determining the differences in energy performance of homes is a whole 9-yard by itself. It will not be possible to provide that information in this setting.

5. Consider the decision making model identified in the preliminary framework of the expert system and state your suggestions to make it more effective. Explain how this model may work for non-equipment based measures e.g. air sealing, insulation etc.
Answer: I think this is a right approach to go about developing the system. The existing efficiency and age of the systems are some of the methods we use to determine the necessity to replace systems. In addition, this method may also be useful for thermal insulation and other non-equipment based measures. However, a lot of care has to be taken to suggest improvements in insulation as, the rate of energy savings will decrease as the amount of insulation is increased. We usually suggest at least 14 in of insulation because above that, the potential for savings is not very much.

Shortlisting and Prioritizing Measures

6. What are some of the most common questions that homeowners have for you when they decide to retrofit their homes?
Answer: A lot of times, homeowners have a lot of ideas and sometimes misconceptions about the energy saving potential of certain measures. They usually get this information from manufacturer advertisement. So they want us to implement those measures. But many times these are just misconceptions, for example, EE windows are identified as a great energy saving measure however, in reality, this measure has a very long payback period.

7. What are the major motivating factors for home owners to pursue home energy retrofits?
Answer:

- Comfort
- Energy Savings
- Cost
- Return on investment

8. What are some of the measures that provide the greatest return on investment for a home owner?
Answer: Air-sealing

9. What are some external factors which increase the cost of the retrofit operation? What steps can homeowners take to reduce such costs?
Answer: The biggest cost that comes to mind is, when a home owner decides to implement a certain measure, there may be other measures that will have to be implemented to ensure health and safety or proper performance of the desired measure. This is some additional cost that the homeowner must be prepared for. The best example of this is "air-sealing". To implement air sealing, the homeowner may first have to replace their furnaces and combustion water heaters which are atmospherically vented, otherwise the air tightness may cause reverse drafts which could be dangerous.

10. Give the order of importance from the list below that home owners expect from a retrofit measure:
a. Cost of Measure
b. Return on Investment
c. Comfort
Answer: In my opinion, return on investment and comfort would rank equally for a homeowner. The cost of the measure would be second in terms of priority

Installation Advice

11. Provide a list of installation strategies for foundation wall insulation.
Answer:

- This is an often un-insulated portion of existing homes and any insulation is better than no insulation.
- It is best to insulate foundations on the exterior, but in existing homes it often makes more sense to insulation the interior.
- This measure can affect air tightness so a blower door test and combustion safety testing should be considered.

- Any insulation left exposed should have a class 1 fire rating.
- Insulation in living spaces should be covered with drywall, plywood or similar fire resistant material.
- Any serious moisture or drainage issues should be taken care of before insulating a foundation.
- Crawl space floors should have a vapor barrier installed when insulating.
- If the foundation is being repaired due to moisture or movement it may be a good time to insulate as well.
- Finishing all or part of the basement is a great time to insulate on the interior.

12. Provide general categories of information you think are necessary for an installer
Answer:

- The installers must be aware of the techniques of installation including proper precautions to protect them from accidents or accidental exposure to harmful substances.
- They must know what appropriate materials to use in different situations
- They must be aware that certain tasks such as MEP or HVAC may require a license to install.

13. What is a list of measures that you would recommend to be installed by a certified or licensed professional?
Answer: If a measure has the potential to harm the health of occupants post retrofit, I would recommend that it be performed by a trained professional. Air-Sealing is a great example. It if one of the easiest measures to install but unless roper testing before and after is done, it could result in serious health hazards for occupants. In addition to occupant’s health, the safety of installers too is important. Thus if the home is old and may contain hazardous material such as asbestos or lead paint, it is best installed by a trained professional who will take the necessary precautions.

Any work relating to mechanical, electrical and HVAC need to be performed by a professional with the appropriate license.

Interview Questions

Professional Type: (HVAC Contractor)

6/14/11

General Questions

1. What is the name and type of business your firm is involved in?
a. Energy Auditing
b. General Contracting
c. Both
d. Others (please specify)

Answer: We were residential and commercial HVAC contractor.

2. What is your role in the firm?

Answer: I was the CEO. My duties included management, sales and system design

3. How many home energy retrofits has your firm done?
a. 1-20
b. 20 – 50
c. Above 50

Answer: More than 400 jobs per year for the past 30 years

4. As a contractor what aspects of home energy retrofit do you perform?

a. What services do you prefer to do and why?

b. What services do you do with your own forces and which ones are subcontracted out?

c. Which of your services have a higher profit margin?

Answer: We only did HVAC related design and installation. We had a background in HVAC. Sometimes, if there was electrical work related to HVAC, we subcontracted it out as we didn't possess an electrical license. A/C installation and design was the most profitable as there was fewer competition.

5. What specific jobs are you licensed/certified for?

Answer: HVACR. However we never performed any refrigeration work.

6. What is your major geographical region of operation?

Answer: 45 mile radius of Lansing, 90% was within a 30 mile radius.

7. Do you belong to any professional associations?

Answer: ASHRAE, ACCA (Air Conditioning Contractors Association of America), RSES (Refrigeration Service Engineering Society)

Home Energy Retrofit Specific Questions

Identifying Measures

8. Given a scenario where you go to a home and have to make recommendation for measures, explain in a step by step manner what methods you will use to make that decision. Note that the homeowner is highly informed about the home including equipment efficiencies, insulation levels, age of home and systems, construction type etc., and will provide you with that information.

Answer:

i. Go to the attic to visually inspect insulation.

ii. Inspect the plans of the home if they have them

iii. Ask if they know the amount of sidewall insulation present. The answer to this question is usually no.

iv. Remove the receptacle and probe with a coat hanger to check the level of insulation.

v. We then check the nature of windows

vi. We next go to the basement to check for insulation on the walls and ceiling of the basement.

vii. Evaluate the duct system and furnace. If the home has a hydronic heating system, we would evaluate the boiler and the piping.

vii. Next we measure the area of the envelope components including area of insulated surface, area of windows etc.

viii. We evaluate the electrical circuits to check the capacity of the circuits check the capacity to handle the new HVAC systems.

ix. Perform a heat-loss and heat-gain calculation based on the information collected above.

x. Estimate the operating cost of new system vs existing system

<u>Method of calculating the operating cost is as follows:</u>

Whole year’s gas consumption – (July’s consumption x 12) = Estimated heating related gas consumption for a year.

9. What are some of the conditions you have when you select an energy efficient product for a home?

Answer: The BTU capacity necessary for the home. AGA ratings (American Gas Association)

10. Different homes have different retrofit needs. What aspects of the home will determine the need?

Answer: E.g. is it the construction type, architectural type, age of the home etc.?

Construction Type, age of the home and how well the home has been maintained.

11. Consider the decision making model identified in Table 1 and state your suggestions to make it more effective. Explain how this model may work for non-equipment based measures e.g. air sealing, insulation etc.

Answer: This model seems to work well for equipment based measures. It will also work well for non-equipment based measures if you find a way for the homeowner to supply you with information related to the existing condition of the home. E.g. amount of insulation present, air-tightness of the home etc.

Shortlisting and Prioritizing Measures

12. What are some of the most common questions that homeowners have for you when they decide to retrofit their homes?

Answer:

- How much is it going to cost?
- How long is the warranty?
- Why is your labor price higher than your competitors?

13. What are the major motivating factors for home owners to pursue home energy retrofits?

Answer:

- High operating costs
- Environmental Concern

14. What are some of the measures that provide the greatest return on investment for a home owner?

Answer: Air-sealing

Installation Advice

15. Provide a list of installation strategies for HVAC equipment upgrade.

Answer:

- It is important to choose a high efficiency unit (95 AFUE or better for furnaces and Boilers, 16 SEER for A/C units)
- It is also important that the unit be sized properly. Especially if the home has been insulated and sealed an accurate load calculation should be done. Improperly sized equipment can waste energy and cause comfort problems.
- Replacing equipment is a good time to make sure that distribution systems are properly designed and sized (hydronic or forced air.) Air ducts should be properly sized, sealed and

insulated where necessary. Hydronic systems should have properly sized radiators and consider zoning the system.

- For water heaters apply the same rule of thumb as heating and cooling, reduce the load with low flow fixtures and insulating hot water lines before sizing the unit.
- For combustion safety purposes choose units with sealed combustion or at least an induced draft. Make sure to do combustion safety testing on any atmospherically drafted appliance.
- Work being done in crawl spaces and attics can be a good time to seal and insulate duct work in these spaces or replace equipment located there. Sealing and insulating duct work should be done before adding insulation.

Interview Questions

Professional Type: (Contractor + Energy Auditor)

6/21/11

General Questions

1. What is the type of business your firm is involved in?

a. Energy Auditing

b. General Contracting

c. Both

d. Others (please specify)

Answer: We are primarily RESNET certified home energy auditors but recently started performing retrofit contracting as well.

2. What is your role in the firm?

Answer: Owner, operator and auditor; I also train my employees.

3. How many home energy retrofits has your firm done?

Answer: More than 400 audits so far. We have performed about 50 retrofit contracting jobs in the last one year.

4. As a contractor what aspects of home energy retrofit do you perform?

a. What services do you prefer to do and why?

b. What services do you do with your own forces and which ones are subcontracted out?

Answer:

a. We were specialized in injection foam insulation since about a year ago, however since last fall we began doing all aspects of retrofit contracting of a home. We have even started doing spray foam insulation since Spring 2011

b. We subcontract out furnaces, boilers, DHW and windows

5. What specific jobs are you licensed/certified for?

Answer: Certified as a HERS rater and licensed as a builder

6. What is your major geographical region of operation?

Answer: Western MI

7. Do you belong to any professional associations?

Answer: RESNET and BPI

Home Energy Retrofit Specific Questions

Identifying Measures

8. Given a scenario where you go to a home and have to make recommendation for measures, explain in a step by step manner what methods you will use to make that decision. Note that the homeowner is highly informed about the home including equipment efficiencies, insulation levels, age of home and systems, construction type etc., and will provide you with that information. Please provide method for suggesting measures based on testing and measures which can be identified by non-testing means.
Answer:

i. Learn the concerns of the homeowner including comfort issues, high cost of utility bill issues etc.
ii. Then we proceed to the attic and check the insulation level. We then check to see if the attic and ducts contains harmful material such asbestos which could get airborne if the blower door test is performed

iii. Look at the existing equipment and note the age, efficiency, potential for health hazards such as wood burning fireplaces, live asbestos, combustion safety etc.

iv. Perform the blower door test and infra-red camera test

v. Run the results on the Rem/Rate software and determine the performance of the home including possibilities for implementation of measures.

vi. Explain the results of the audit to the homeowner

9. What are some of the conditions you have when you select an energy efficient product for a home?
Answer: Check to see if it works in its intended manner and meets the requirements of the current code

10. Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, architectural type, age of the home etc.?
Answer: Age, architectural style, type of construction and previously performed retrofits

11. Consider the decision making model identified in Table 1 and state your suggestions to make it more effective. Explain how this model may work for non-equipment based measures e.g. air sealing, insulation etc.
Answer: Firstly, I think this system would work. However, through my years of experience with homeowners, I found that very few really care about the energy efficiency of their home. Comfort is important to them and they accept energy savings as a bonus with comfort. Hence I wonder if they would be willing to spend the time in answering all the questions you proposed. I believe their limited attention span can be captured by some graphical output such as a HERS

index to know how their home fares in comparison to similar homes. Overall I think the homeowner must not be allowed to think that this tool is a replacement for proper auditing and installation with a sound building science approach.

12. Explain what the age of equipment identified in Table 1 should be to consider replacement.

Answer: I think insulation can hold good for several years, however, appliances and HVAC equipment may not hold good for more than 20 years.

Shortlisting and Prioritizing Measures

13. What are some of the most common questions that homeowners have for you when they decide to retrofit their homes?

Answer: Most of the time homeowners are misled by advertisers of EE products into believing that implementation of their product will have a short payback, however this is not true e.g. windows have a payback of about 40 years but homeowners think they would save a lot if they change their windows. Hence most of homeowner questions are related to the advertisements and how much they can save if they implemented those measures. Most of the questions are about windows, geothermal heating, tank-less water heaters etc.

14. What are the major motivating factors for home owners to pursue home energy retrofits?

Answer: Comfort

15. What measure according to you provides the greatest return on investment for a home owner?

Answer: Insulating basement walls

16. From the list of measure provided in Table 1, prioritize the measures based on what you feel is the best sequential approach to achieve the best results.

Answer: The overall category based prioritization will be as follows

Air-seal first, then add thermal insulation and finally upgrade existing heating and cooling equipment.

The above method of prioritization is important for the following reasons:

- Once insulation is packed in place it would be impossible to perform air-sealing next, hence air-sealing must be done first.
- Enclosure insulation must be performed before HVAC because, the performance of the thermal envelope will determine the size of the HVAC system required. In older homes, most of the HVAC systems are over-sized and hence upgrading the same size HVAC to a higher efficiency will not make sense if the thermal performance has been improved. Thus the existing system can be replaced with a smaller, high efficiency system. The overall cycles of running are also reduced because of the enhanced envelope performance

17. Is there a method of quantifying annual energy savings of measures in terms of cost savings? If yes, please provide the methods to determine annual energy savings for each measure.

Answer: HVAC and appliances can be quantified with the help of tables and other literature. It is difficult to quantify enclosure related measures; however Rem/Rate does this function

18. Give the order of importance from the list below that home owners expect from a retrofit measure:

a. Return on Investment

b. Comfort

c. Health and Safety

Answer: According to me, this will be the order or priority:

1. Comfort
2. Return on Investment and
3. Time of installation
4. Very small percentage think of health and safety

Installation Advice

19. Provide a list of installation strategies for above grade wall insulation.

Answer: This can be labor intensive to upgrade useless done as part of another project. If there is no insulation in the walls it can be worth the effort because it is often the largest surface area of the home's envelope.

Injection foam insulation is excellent upgrade to existing cavity insulation because it is easy to install. The following points must be taken into consideration:

- This measure can affect air tightness so a blower door test and combustion safety testing should be considered.
- In homes built before 1978 lead base paint may be present, be sure to take appropriate precautions.
- Some older siding products contained asbestos, again take appropriate precautions.
- Putting new siding on a house is probably the perfect time to upgrade wall insulation.
- If the exterior walls are opened up during an interior remodel it good time to insulate that area.

20. Provide a list of safety precaution that have to be taken by the installer of retrofits

Answer:

- Asbestos

- Lead Paint
- Mold
- Injury due to special conditions in the home

Professional Type: (Contractor + Energy Auditor)

Location: Midland, MI

6/30/11

General Questions

1. What is the type of business your firm is involved in?
a. Energy Auditing
b. General Contracting
c. Both
d. Others (please specify)
Answer: Both energy auditing and retrofit contracting

2. What is your role in the firm?
Answer: I am the owner and operator

3. How many home energy retrofits has your firm done?
a. 1-20
b. 20 – 50
c. Above 50
Answer: 1 - 20

4. As a contractor what aspects of home energy retrofit do you perform?
a. What services do you prefer to do and why?

b. What services do you do with your own forces and which ones are subcontracted out?

c. Which of your services have a higher profit margin?
Answer: As a contractor I perform general contracting for home energy retrofit

a) Air-Sealing because I find it the most interesting.
b) We perform all measures ourselves except HVAC related work.
c) Performing a whole house retrofit is the most profitable. Among individual measures, I think thermal insulation provides the highest profit.

5. What specific jobs are you licensed/certified for?
Answer: I am a licensed residential builder

6. What is your major geographical region of operation?

Answer: Mostly the Midland area of Michigan

7. Do you belong to any professional associations?

Answer: I belong to two professional associations Midland and State Home Builders Association and Residential Energy Services Network (RESNET)

Home Energy Retrofit Specific Questions

Identifying Measures

8. What are the major motivating factors for home owners to perform energy retrofits?

Answer: In a sequential order from most to least motivating, the following factors motivate homeowners to perform energy retrofits.

a. Reduction in energy consumption

b. Contributing to environmental sustainability

c. Maximizing comfort in the home

d. Maximizing durability of the structure

9. Provide a step by step method you use to perform the energy audit

Answer:

a. Firstly, I analyze the air leaks in the home by performing a blower-door test

b. I then check for potential energy loses in the home by checking the thermal envelope with an infrared camera

c. Next I check the efficiencies of major appliances, HVAC equipment, domestic hot water heater, water taps and faucets, etc.

d. I then take physical measurements of the thermal envelope

e. Once I go back to my office, I input my observations into building simulation tool to identify possible measures that can be implemented to save energy.

f. I submit this report along with my personal comments to the homeowner for their decision.

Shortlisting and Prioritizing Measures

10. Once you identify measures in a home, how would you prioritize their implementation?

Answer: Measures must be prioritized in the following manner:

- Upgrade the lighting of the home to CFL. This is a quick and cost effective retrofit strategy

- Reduce the heating and cooling loads by upgrading the efficiency of the thermal envelope. This is done by air-sealing uncontrolled leakages and adding thermal insulation at the thermal boundary.
- Next, the ducts of the heating and cooling system must be properly installed and balanced so the delivery of heat or conditioned air in uniform throughout the home. Then ducts must be sealed with mastic. Do not use duct-tape to seal the ducts.
- Next heating and cooling measure can be upgraded to higher efficiency systems. At this point they could also be downsized to fit the upgraded thermal envelope.
- I personally do not recommend upgrading existing appliances or windows unless they are non-functional as these improvements have very little effect on the energy performance of a home

11. How do you predict the energy savings of a measure?

Answer: My building energy simulation tool does the energy saving predictions.

12. Provide some cost effective ways to perform retrofits

Answer: The most cost effective method to perform home energy retrofits is to combine it with other remodeling work that the home is in immediate need of. For example, If the existing siding of the home has to be replaced, then it must not be done without first installing thermal insulation. If the windows of a home are non-functional and pose a security or comfort risk, then they may be replaced with a high performance window.

13. Provide a list of post occupancy health issues that needs to be dealt with in home energy retrofits

The following health issues have to be dealt with during retrofits

- *Combustion Safety:* If the home contains naturally vented appliances i.e. appliances that draw combustion air from the interior of the home and the home is too airtight, back-drafting of flue gases can occur, increasing carbon monoxide levels in the home, causing a health hazard to occupants
- *Moisture Management:* Care must be taken that retrofits do not cause moisture infiltration in the home. Additionally, if moisture issues exist, they must be resolved so that molds are not formed.

Installation Advice

14. Provide a list of installation strategies for attic insulation.

Answer:

- This can be the most cost effective insulation to add due to the fact that it’s usually easy to install, as it does not affect any finished surfaces.
- The ceiling should be air sealed before adding insulation.

- Lose fill insulation is generally tighter and more consistent than batt insulation.
- Sealing and insulating duct work in the space should be done before adding insulation.
- This measure can affect air tightness so a blower door test and combustion safety testing should be considered.
- Electrical wiring should be updated before it is covered with insulation.

15. What are a list of measures that you would recommend to be installed by a certified or licensed professional?

Answer: I would recommend insulation and air-sealing work to be installed by a RESNET or BPI trained professional. Any work relating to mechanical, electrical and HVAC need to be performed by a professional with the appropriate license.

16. Provide a list of safety precaution that have to be taken by the installer of retrofits

Answer: The following are some of the things that installers need to be aware of and take necessary precautions if present

- Mold
- Lead paint
- Asbestos
- Vermiculite insulation
- Risk of electrical shocks if knob and tube wiring is present

Interview Questions

Professional Type: (Energy Auditor)

Date: 7/1/11

General Questions

1. What is of business your firm is involved in?

a. Energy Auditing

b. General Contracting

c. Both

d. Others (please specify)

Answer: We are RESNET certified home energy auditors.

2. What is your role in the firm?

Answer: Owner, president.

3. How many home energy retrofits has your firm done?

Answer: At least 1800

4. What specific jobs are you licensed/certified for?

Answer: Licensed RESNET auditor

5. What is your major geographical region of operation?

Answer: Western MI

6. Do you belong to any professional associations?

Answer: RESNET

Home Energy Retrofit Specific Questions

Identifying Measures

7. What are the major motivating factors for home owners to perform energy retrofits?

Answer: In a sequential order from most to least motivating, the following factors motivate homeowners to perform energy retrofits.

a. Reduction in energy consumption

b. Maximizing comfort in the home

8. Provide a step by step method you use to perform the energy audit

Answer:

a. Obtain one year's history of utility bills

b. Discuss the needs of family to find their likes and dislikes, problems, motivations, lifestyle etc.

c. Take measurements of the house including windows

d. Analyze insulation systems

e. Perform infra-red camera imaging

f. Survey all equipment sizing and efficiency, and appliance efficiencies

g. Carry all information obtained to my office where I perform computer energy

h. Obtain the computer reports and combine it with my own observations to produce a 10-15 page report of possible upgrade strategies

Shortlisting and Prioritizing Measures

9. Once you identify measures in a home, how would you prioritize their implementation?

Answer: Measures must be prioritized in the following manner:

- Reduce the heating and cooling loads by upgrading the efficiency of the thermal envelope.
- Next heating and cooling measure can be downsized and upgraded to higher efficiency
- Consider upgrade of existing appliances to Energy Star

10. How do you predict the energy savings of a measure?

Answer: With the help of building energy simulation

11. Provide some cost effective ways to perform retrofits

Answer: The most cost effective way of performing retrofits is to air-seal uncontrolled leakages and insulate the attic and the rim joist.

12. Provide a list of post occupancy health issues that needs to be dealt with in home energy retrofits

Answer: The following health issues have to be dealt with during retrofits

- *Air tightness:* If the home is too airtight, it can cause problems related to health of occupants. To avoid this, air-sealing operations must be tested out to ensure that there is at least one air change every three hours
- *Knob and Tube Wiring:* Knob and Tube wiring is usually found in homes older than 1920. If this wiring is covered by attic insulation, it could result in a fire.
- *Combustion Safety:* If the home contains naturally vented appliances i.e. appliances that draw combustion air from the interior of the home and the home is too airtight, back-drafting of flue gases can occur, increasing carbon monoxide levels in the home, causing a health hazard to occupants

Professional Type: (Contractor + Energy Auditor)

Location: Lansing, MI

7/9/11

General Questions:

1. What is the type of business your firm is involved in?

e. Energy Auditing

f. General Contracting

g. Both

h. Others (please specify)

Answer: Both energy auditing and retrofit contracting

2. What is your role in the firm?

Answer: I am the owner

3. How many home energy retrofits has your firm done?

a. 1-20

b. 20 – 50

c. Above 50

Answer: My firm is relatively new, but I worked in the area of home energy retrofits, before establishing my firm. I have done over 400 energy audits and 40 retrofit installation works.

4. As a contractor what aspects of home energy retrofit do you perform?

a. What services do you prefer to do and why?

b. What services do you do with your own forces and which ones are subcontracted out?

c. Which of your services have a higher profit margin?

Answer: As a contractor I mainly perform air-sealing, insulation and ductwork.

d) Air-Sealing because I find I think it is very challenging.

e) We perform air-sealing, insulation and ductwork ourselves. We subcontract out siding, roofing, HVAC and, Mechanical Electrical Plumbing (MEP) work.

f) Insulation is profitable as it is easy to install and has far fewer unknowns than some other work.

5. What specific jobs are you licensed/certified for?

Answer: I am a licensed residential builder. I am certified by BPI and am also a LEED AP

6. What is your major geographical region of operation?
Answer: Mostly Michigan

7. Do you belong to any professional associations?
Answer: None

Home Energy Retrofit Specific Questions

Installation Advice

8. Provide a list of installation strategies for attic air sealing and insulation.

Answer:

- If the house is too tight, mechanical ventilation must be provided and possibly eliminate atmospheric -vented equipment.
- If the siding on the home is to be replaced adding house wrap or air-barrier can reduce air leakage. While the blower door is running, you can check for air-leaks with the smoke generator and thermal camera.
- The **easiest** places to air-seal are: 90% of the interior top plates, light boxes, wire holes, gable end exterior top plates, plumbing stacks, exhaust fans, knee-walls, chimney, weather-strip attic access and can lights
- The **difficult** areas would be thermal boundaries, hard to reach interior top plates, exterior top plates, bulkheads, skylights, exterior soffits.

Materials:

- Spray foam (1 part foam)
- Foam board
- 2 part foam
- For chimney's use metal flashing and fire caulk for fire safety.

Precautions:

- Be aware of protruding nails in the roof
- The measure can cause claustrophobia
- Have good lighting and communication for safer operation.
- Wear respirator masks to protect from dust.
- Use planks across the rafters to prevent falling through the roof
- Check for vermiculite insulation and knob-and –tube wiring.
- Add a CFL before air-sealing can lights

9. Provide a list of installation strategies for crawlspace air sealing and insulation.

- Seal up crawl-space and basement windows
- Air seal rim joist, sill plates, open core blocks, spigots, dryer vents, HVAC vents and cracks in foundation.
- Use paint to reduce porosity of concrete after mitigating moisture issues.
- The **difficult** areas would be interior balloon framed walls because it is difficult to find them.

Material:

- Spray foam (1 part foam)
- Foam board 2 part foam,
- For chimney's use metal flashing and fire caulk for fire safety.

Precautions:

- Clear work area from all stored material in basement
- Clean the rim joist area
- Watch out for gas lines, water heater and other equipment
- All the precautions for attic air-sealing and insulation may also apply in this case.

10. Provide a list of installation strategies for duct improvement.

Answer:

- Seal the supply and cold air returns, add or take away a supply.
- Adding more return ducts can increase the efficiency or balance the system
- Insulate ducts in unconditioned spaces

Material:

- Mastic Tape
- Duct Mastic
- High temperature caulk to seal combustion appliance flues

Precautions:

- Use of the right materials at the right place
- Fresh air intake must be at least 10 feet away from combustion equipment to prevent the possible pollution of the fresh air.

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