State-of-the-Art Review of Window Retrofit Options for Energy Saving in Single Family Dwellings

Tim Ariosto[1] and Ali M. Memari[2]

[1]Ph.D. Candidate, Department of Architectural Engineering, The Pennsylvania State University. 104 Engineering Unit A, University Park, PA, 16802. Email: tma5011@psu.edu

[2]Professor, Department of Architectural Engineering and Department of Civil and Environmental Engineering, The Pennsylvania State University, 222 Sackett Building, University Park, PA 16802. Email: memari@engr.psu.edu

ABSTRACT

The study presented here involved the investigation of several different window retrofit solutions for energy efficiency. The criteria used to compare each system were Thermal Improvement, Thermal Comfort, Condensation Potential, Impact on Daylighting, Air Leakage, Cost, Ease of Operation, and Aesthetics. This paper introduces various methods for retrofit of existing windows, presents their attributes, and compares various options based on the stated criteria.

INTRODUCTION

According to the 2011 Buildings Energy Data Book (US DOE, 2011), buildings use approximately 40% of the nation's energy consumption. Approximately 56% of this energy is used for space heating, cooling, and lighting applications, while 25-35% of this energy is wasted due to inefficient windows. All of these factors are directly impacted by the building envelope (Totten and Pazera, 2010). In addition to other functions (Kazmierczak, 2010; Sanders, 2006), successful building envelopes shield occupants from outside weather conditions, whether that be excessive hot temperatures in the summer or extremely cold temperatures in the winter, as well as provide a connection to the outside in terms of natural lighting and views.

Fenestration systems are a key element in achieving these goals, although they are always the weakest link in terms of thermal performance (Oldfield et al. 2009). This is primarily due to the extremely high U-value found in windows in comparison to wall systems. In addition, glazing systems can have a significant impact on energy savings through daylighting. For example, Johnson et al. (1984) found that fenestration can reduce total building peak demand by up to 14-15%.

One of the major challenges facing homeowners is the high capital cost associated with fenestration upgrades. This is particularly problematic since the energy savings associated with replacing windows with their higher efficiency counterparts is typically relatively small. The payback period for replacing single glazed windows with double glazed windows can be as long as 50 years for cold climates. This payback period will also increase as the quality of the existing windows increases. When double glazed uncoated windows are replaced with triple glazed units with argon fill and a low e coating, the payback period is typically around 100 years for cold climates (Guler et al., 2001). Another study conducted by Frey et al. (2012) demonstrated that high performance window upgrades have a return of investment (ROI) of only between 1.2-1.8% based on climate, which translates to a simple payback period of 55-83 years. Therefore, for most homeowners it is necessary to determine low cost methods of reducing heat flow through their windows.

The goal of this study is to evaluate retrofit strategies along with ratings of energy performance. The paper starts with an investigation of the performance of several different window retrofit solutions (a.k.a window attachments). This includes a description of each method as well as an indication of the cost of each method, the expected thermal improvement, as well as any potential risks that may be involved. A ranking will then be presented that can be helpful to aid homeowners in selecting a glazing system.

PARAMETERS OF THE STUDY

Several criteria are considered in this paper, including quantitative issues such as Thermal Improvement, Comfort, Cost, Condensation Potential, Impact on Daylighting, and Air Leakage as well as qualitative issues such as Ease of Operation, and Aesthetics.

Thermal Improvement

One of the most important criteria for energy management is the thermal improvement provided by a window attachment system. When considering thermal improvement, there are two basic aspects that should be considered. The first is the increase in U-value. The second aspect is how well it reduces solar heat gain.

The thermal performance of each window attachment is measured in terms of the improvement obtained in comparison to a double glazed window, based on manufacturer data or other scientific studies. Percent improvement is determined using the equation below.

$$\frac{Improved\ Performance - Orginal\ Performance}{Original\ Performance} \times 100\%$$

Comfort

The two components that will affect comfort are inside air temperature and the Mean Radiant Temperature (MRT). The MRT is determined by weighing the effects (by area, spatial relationship, and difference in temperature as compared to the skin of a person in the space) of each object in a space. When the MRT is warmer than the occupant's skin temperature, that person will "feel" warm. On the other hand, when the MRT is cooler than the occupant's skin temperature, they will "feel" cold.

The MRT of a window is a property that is based on variables such as room furnishings, the size and location of the window in that space, as well as regional climate characteristics such as outside temperature, humidity, and wind speed. For this study, the window attachments are rated as improving the thermal comfort, reducing the thermal comfort, or having no effect on the thermal comfort with all other variables being equal.

Condensation Potential

Condensation occurs when moist air contacts a surface with a temperature below its dew point. For fenestration, this will usually involve interior air condensing on the interior surface of a cold glazing unit, typically near the frame. Excessive condensation can result in mold growth or rot in the window frame and sill. In addition, condensate on windows in particularly cold climates has the potential to freeze the window shut, creating possible egress issues. Condensation typically occurs as a result of poorly insulated windows. Generally speaking, exterior window attachments that result in an increased glazing temperature will have a lower risk of condensation, while interior attachments that lower the temperature of the glazing will have an increased risk of condensation. Interior window treatments that either completely seal out moist air from the surface of the windows or allow for increased levels of ventilation will have less condensation. In this study, window attachments are rated as having an increased or a decreased risk of condensation.

Impact on Daylight

Most window attachments have some effect on the visual transmittance of the window assembly. When opaque attachments that significantly reduce the daylighting potential of an interior space are used, increased energy is required for lighting. This may offset any energy savings depending on the requirements of the space. Each window attachment is rated as having no impact, minimal impact, or significant impact on the daylighting potential of a space.

Air Leakage

There are two major routes in which outside air can infiltrate through windows. The first is between the sash and the jamb, while the second is between the jamb and the wall. The ability of a window attachment to reduce air leakage is judged based on how effective it is at preventing air leakage through each of these locations.

Cost

Since window attachments are all retrofit solutions for residential construction, the cost of all materials come from sources available to the common homeowner such as home improvement centers. When appropriate, installation costs are included.

Ease of Operation

The most successful window attachments will not become an inconvenience to the homeowner in order to operate. A window attachment that is difficult to use will be ignored by the occupant, rendering it useless, or may be used incorrectly, potentially resulting in an increase in energy use. Window attachments will be rated as requiring no work, minimal work, some work, or significant work.

Aesthetics

The aesthetic impact of a window attachment is the hardest criteria to weigh against the others. An exterior window attachment may affect the street appeal of a home or the interior feel of a room. The severity of any positive or negative impact is subjective on the part of the occupant. Therefore, each window attachment is rated as having "minimal to no aesthetic effect" or "substantial aesthetic effect."

EXTERIOR WINDOW ATTACHMENTS

OPERABLE SHUTTERS

Although exterior shutters on new homes are typically inoperable, existing primarily for aesthetic purposes, older homes typically have operable shutters. These shutters provide protection for the glazing as well as an effective means of solar heat gain prevention. They can fold from the sides, top, or bottom as well as slide into place on tracks. Shutter performance will vary based on material (wood, aluminum, and steel) and style (louvered, raised paneled, board-n-batten, bahama, or accordion type.)

Shutters with louvers can be an effective means of reducing the solar heat gain into the building as well as limiting the effect of night sky radiation. However, exterior shutters will be an ineffective means of insulation unless a mechanism is in place to provide sealing around the perimeter of the shutter. For best performance, light filtering shutters should be closed in daylight hours for solar heat gain reduction during the summer. In the winter, shutters should be open for passive solar heating during the day, then closed at night to prevent heat losses.

Bahama style shutters (e.g. www.shutterkings.com/extbahama.htm) are particularly effective at creating a shading effect for the window. A variation of this style of shutters could be designed with hinges at the bottom and a reflecting surface facing the window. This system would be used to reflect sunlight further into the building for daylighting and passive solar heat gain. A highly insulating material such as rigid foam insulation could also be used to reduce heat loss through the windows at night. A compressive seal could be utilized to insure that no air leaks through the windows when the shutters are closed.

INSULATING ROLLING SHUTTERS

Exterior insulated shutters (e.g. www.rollac.com) are a variation of the accordion shutters comprised of interlocking slats that completely cover the outside of a window when closed and retract to fit inside of a valence at the top of the window when open. The slats usually slide inside of weather sealed track and are operated with either an electric motor or a pulley system. Although they are primarily used for storm protection, units with an insulated core can also offer significant thermal improvement.

STORM WINDOWS

A storm window (e.g. www.larsondoors.com/storm_windows/) in its most basic form is an additional window system installed on the exterior of the existing window system. Storm windows are classified as Two-Track, Triple Track, Two-Track Sliding, and Basement. Storm windows can result in a substantial increase in thermal efficiency, which can be further improved when low- e coating is used, as well as reductions in air leakage and condensation risk.

WINDOW SCREENS

Insect screens are a common element of most residential window systems. Although the screens provide some shading effect; their presence is not taken into account with performance values for window systems. In addition to providing shading, they also slow the convective heat flow at the surface of the window.

PLASTIC WRAP ON WINDOW SCREENS

Plastic wrap can be used to cover the outside of window insect screens to create an inexpensive, easy to install alternative to storm windows. This method creates an additional airspace on the exterior side of the sashes. The thermal improvement in with this system would be greater than the 7% improvement obtained through using insect screens alone, but not as great as the 55% obtained through the use of exterior storm windows. A 20% improvement is assumed. This system does reduce air leakage, however drafts could seep between the edges of the insect screen and the jambs due to the lack of weather-stripping.

INTERIOR WINDOW ATTACHMENTS

CONVENTIONAL BLINDS

This system (e.g. http://www.levolor.com/products/metal-blinds/) uses individual flat slats, generally made of aluminum, wood, or vinyl, that can be adjusted to block light and solar heat gain While aluminum blinds are typically thin (6-9 gauge), wood and vinyl blinds can be as thick as ¼". In particularly humid climates, condensation may be an issue for wood blinds. Therefore, moisture resistant blind should be used.

INSULATING BLINDS

This system (e.g. www.levolor.com/products/cellular-shades/) uses a dual cell design that creates an air gap which provides additional insulation. Some more advanced models have edge tracks to limit the air movement around the blinds, which boosts the thermal performance of the system. Other designs have a reflective polyester layer on the side of the blind facing the window.

INTERIOR SHUTTERS

Interior shutters (e.g. www.horizonshutters.com/traditional-shutters) act similarly to blinds, except they are completely opened by swinging the shutter out of place. In addition, the angle of the shutters is adjusted manually or using an adjustment rod. The shutters are typically composed of wood or vinyl, with each slat being in the ¼" range. Although store bought models tend to be very expensive; do-it-yourself, highly insulated designs can easily be made for a low cost. However, as thermal performance increases, proper weather stripping is essential to prevent condensation.

ROLLER SHADES

The shades (e.g. http://www.levolor.com/products/roman-shades/) can be installed on either the interior or exterior of the building. The shades are pulled down as needed to block light and solar heat gain. They are stored in either a valence above the window or have a "Roman Shade" setup in which fabric folds up at the top. They are available in a variety of different materials and colors with varying transparencies.

CURTAINS AND DRAPERIES

Curtains and draperies (e.g. www.thermalwindowcurtains.com/) are common features of many homes. They are made with a variety of different materials in various styles and are typically used primarily for decoration. Although curtains will always be an effective method of shading, they will also be an effective insulator assuming the perimeter of the curtains can be sealed when closed, the fabric has an air barrier layer and is heavy enough to provide insulation (Langdon, 1980.) The use of a foil, reflective backing will result in additional savings. Condensation risk will be high, so a fabric should be selected which is effective at preventing moisture transport.

LOW EMISSIVITY FILMS

Low emissivity coatings (e.g. www.gilafilms.com/en/Residential-Window-Film.aspx) are usually applied to glass at the manufacturing stage for newer windows. However, many older homes still use uncoated glass. In these cases, a low emissivity film can be applied to the existing glass without the need for skilled labor. Although these films will not improve the insulation of the window, they will decrease solar heat gain as well as transport of long wave radiation (heat) from the interior pane outward.

PLASTIC WRAP AROUND WINDOW FRAMES

Plastic wrap can be used to cover the entire window frame on the interior of the building. Double-sided tape is used to attach the plastic to the outside of the window frames and a hair dryer is subsequently used to stretch the plastic tight. As an alternative, bubble wrap can be used to obtain even greater improvement in thermal performance, albeit at a greater loss to transparency.

DRAFT SNAKES

“Draft Snakes” are a fabric tube filled with rice or a similar fill. When placed along a window sill, they serve to block any drafts that are entering the space. They are only intended to prevent drafts that occur along the base of the window or a door. In addition, they will only be effective for leaky windows. Although they will not impact the sides of the sashes, they can effectively stop air leakage through the top or bottom sash of double-hung window.

DISCUSSION

A summary of the preliminary key performance characteristics of the retrofit options introduced is shown in Table 1. As can be seen, the thermal improvement ranged from 0 for systems that primarily focus on shading and SHG reduction, to 696% for custom made, highly systems which are capable of providing an air seal around the window. The cost for each system ranged from as little about two dollars to $600 for a 30”x60” window opening.

The systems were then ranked in order to compare the relative benefit of each system from a thermal improvement standpoint. The percent improvement for each system was divided by the cost of retrofitting a single window. This value was then normalized based on the worst performing system. Therefore, systems with a higher rank will perform better per dollar invested.

It was found that the rolling shutters ranked worst according to this criteria, whereas the custom made, interior shutters performed best. One of the more surprising results is how cost effective systems such as plastic wrap around window frames are. These types of systems also do not require any work on the part of the occupant beyond the initial installation.

Another important point to note is that many of the effective systems require some form of additional work to be done on the part of the occupant beyond basic installation. Systems such as curtains and draperies will be drastically less effective if measures are not taken to thoroughly seal around the edges. Many of these systems, including shutters, insulating shutters, curtains/draperies, and insulating blinds must be opened or closed throughout the day to allow for passive heating and daylighting as appropriate. If this effort is not taken with these systems, the true performance of the system will not be reached.

Table 1: Summary of performance characteristics for each window attachment

	Thermal Improvement	Comfort	Condensation Risk	Retrofit Cost for 30"x60" Window	Impact on Daylighting	Air Leakage	Ease of Operation	Aesthetic Impact	Rank
Shutters	up to 532% for custom designs[1]	Improved	Reduced	$100 [2]	Significant	Potentially reduced	Significant work required	Substantial	114.00
Roller Shutters	28%[3]	Improved	Reduced	$600 [4]	Significant	Reduced	Potentially significant work required	Substantial	1.00
Storm Windows	121%[1]	Improved	Reduced	$108.74 [5]	No Impact	Reduced by 5.7-8.6%[6]	Minimal work required	Substantial	23.84
Window Screens	7%[7]	Slight Improvement	Marginally Reduced	$5.04 [5]	Minimal	Ineffective	Minimal work required	Minimal	29.76
Plastic Wrap on Window Screens	20%	Improved	Reduced	$1.99 [5]	No	Potentially reduced	Requires work for yearly installation	Minimal	215.36
Conventional Blinds	Used for SHG reduction	Improved	Increased	$43-$151 [5]	Significant depending on use	Ineffective	Some work required	Substantial	N/A
Insulating Blinds	60%[1]	Improved	Increased	$110 [5]	Significant depending on use	Potentially reduced	Some work required	Substantial	11.69
Interior Shutters	up to 696% for custom designs[1]	Significant Improvement	Potentially Significant Increase	$21.29 (DIY) - $478 (High end wood shutters)[5]	Significant based on use and design	Reduced	Some work required	Substantial	700.53
Roller Shades	Used for SHG reduction	Improved	Increased	$128-$278[5]	Significant based on use and design	Ineffective	Some work required	Substantial	N/A
Curtains and Draperies	38%[1]	Improved	Potentiall Significant Increase	$29.98 [5]	Significant based on use and design	Potentially reduced	Some work required	Substantial	27.16
Low Emissivity Films	Used for SHG reduction	Improved	No effect	$12.60 [5]	Minimal	Ineffective	Some work for initial installation	Potentially substantial based on	N/A
Plastic Wrap on Window Frames	24% [1]	Improved	No effect	$1.99 [5]	No	Signficantly reduced	Some work for yearly installation	Minimal	258.44
Draft Snakes	N/A	N/A	N/A	$6.97 [5]	N/A	Signficantly reduced	Minimal work required	Minimal	N/A

[1] Craven et al., 2011
[2] http://architecturaldepot.com/louver0shutters.html
[3] ATi, 2009
[4] Personal Correspondance with Stefan Poetsch (Rollac)
[5] Lowes
[6] Drumeller et al., 2007
[7] Brunger et al., 1999

CONCLUSIONS

The study involved the review and comparison of several different window retrofit solutions. Five of these solutions are located on the exterior of the building, while eight are located on the interior. Each solution was investigated based on available information for thermal improvement, comfort, condensation risk, cost, impact on daylighting, air leakage, ease of operation, and aesthetic impact. Finally, each solution was ranked based on the percent thermal improvement per dollar cost. Several important conclusions can be reached based on this study.

- Interior window attachments are prone to have an increased risk of condensation, whereas exterior attachments are likely to have a reduced risk of condensation.
- For window attachments to be effective at improving thermal insulation, they must be made of a robust, highly insulative, non-air permeable material that can be sealed along the perimeter of the attachment and the window.
- When homeowners seek to perform energy saving retrofits, they should begin with simple low cost systems such as wrapping their window frames in plastic wrap.

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INFORMATION BARRIERS IN HOME ENERGY RETROFIT ADOPTION: RESEARCH IN PROGRESS

Duah, D Y. A.[1] and Syal, M.[2]

[1]Doctoral Candidate and Fulbright Scholar, Construction Management Program, School of Planning, Design, and Construction. Michigan State University: and Faculty Member, Department of Architecture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. duahdani@msu.edu
[2]Professor, Construction Management Program, School of Planning, Design, and Construction, Michigan State University. syalm@msu.edu

ABSTRACT
Generally, buildings, especially residential ones, are a major consumer of energy. The majority of the housing stock consists of existing homes, a large number of which is energy inefficient. Retrofitting existing homes to make them energy efficient has huge economic, social, and environmental benefits.

Though the benefits and opportunities for home energy retrofits (HER) are fairly well established, its adoption has faced huge obstacles. One estimate of market penetration for HER programs puts it at less than 2%.

The research identified lack of information as an important barrier to the adoption of HER. It also identified two types of information barriers as quantitative information and expert knowledge. The need for information to accelerate HER adoption and promotion of HER among homeowners were also emphasized. Finally, the research explored the integration of various information categories for future development of an intelligent decision support system framework.

1.0 OVERVIEW
In general, buildings, particularly residential ones, are one of the major consumers of energy. Compared with other sectors such as transportation and industry, the building sector consumes a major share of energy. Buildings today are responsible for more than 40% of global energy used and a third of global greenhouse gas emissions both in developed and developing countries (UNEP 2009). In the United States, buildings consume 72% of electricity, 36% of natural gas and 40% of all energy use. The average household in the United States spends at least $2,000 a year on energy bills, over half of which goes to heating and cooling. Out of the total energy consumption in an average household, 50% goes to space heating, 27% to run appliances, 19% to heat water and 4% to air conditioning. The majority of the housing stock consists of existing homes and a large number of these homes are energy inefficient (EIA 2008 cited by USEPA 2009; Energy Star 2012).

Energy efficiency (EE) practice refers to increasing or maintaining a given level of service while decreasing the energy used to provide that service. Usually, an upfront capital investment in the use or installation of energy saving devices is required and savings usually pay off the initial expense. For instance, efficiency reduces the demand for electricity without reducing or interfering with the performance of an electrical appliance and without reducing the comfort or convenience that the appliance provides. Common instances of energy upgrades include the replacing of incandescent light bulbs with compact fluorescent lamps (CFLs); or buying Energy Star appliances, light fixtures, and windows (IEA 2011; LBNL 2012).

Increasing investments in EE in buildings is one of the most constructive, cost-effective ways toward addressing challenges with sustainability as it is can lower energy bills, reduce demand for fossil fuels, help control rising energy costs, enhance electric and natural gas system reliability, help reduce air pollutants and greenhouse gases, and increase the value and competitiveness of buildings (Johnson Controls 2012; USEPA 2006). Evidence from studies around the world continues to support the hypothesis that EE measures and programs result in highly cost-effective investments, using even the narrowest criteria (Clinch & Healy 2003).

1.1 Home Energy Retrofit (HER)

Retrofitting a building requires the replacement or upgrade of old building systems with new energy saving technology and processes. An EE retrofit by definition is any improvement made to an existing structure, which provides an increase in the overall EE of the building, or home. Examples of EE retrofits include air-sealing a building's thermal boundary, installing dense-pack cellulose insulation, loose-fill cellulose insulation etc. (Fulton *et al.* 2012; SME 2012).

The building sector has the most potential for delivering significant and cost-effective GHG emission reductions (UNEP 2009). Existing buildings consume more than 70% of electricity and produce more than a third of the greenhouse gas pollution in the U.S. Reducing the energy demand of buildings is vital to nurturing a clean energy economy that generates sustainable, high quality jobs and reduces our dependence on imported fossil fuels (EERE 2011). Investment in building EE, through retrofitting and other strategies, is emerging as a high priority in a growing number of cities and states throughout the U.S. because it simultaneously meets environmental protection, economic development, and social goals (ISC 2009). In addition, though there has been numerous research efforts related to EE in new home construction in the U.S., with over 130 million existing homes compared to an annual addition of about half a million to two million new homes, energy retrofit of existing homes can have a greater impact on saving energy (AHS 2009; BA 2010). This research concentrated on retrofitting existing homes to increase their EE.

2.0 LACK OF ADOPTION/ IMPLEMENTATION OF HOME ENERGY RETROFITS

Though the benefits and opportunities for HER are fairly well established, its adoption has faced huge obstacles. For instance, in 2007, the approximately 150 EE-related loan programs in the U.S. reached less than 0.1% of their potential customers (Fuller *et al.* 2010; Ho & Hays 2010). Generally considered a successful residential EE effort, a report by Fuller *et al.* (2010) on findings from a 1980–1992 Bonneville Power Administration Program that provided free audits and highly subsidized retrofits indicates that, the program only motivated 5 percent of eligible customers to have an audit. Evidence from the Residential Conservation Service, a subsidized audit program established in the late 1970s, suggests that of the audits offered by utilities to their customers at $50 or less, only 3–5% usually responded (Tonn & Berry 1986). Another estimate of the market penetration for HER programs is less than 2% (Neme *et al.* 2011).

The low patronage of EE and HER has led to what is referred to as the “efficiency gap” where the EE of buildings, equipment, and appliances in use is far less than what is technically attainable (OTA–U.S. Congress 1993). Even though unified and systematic information is required to perform effective retrofits, most of this information is scattered and difficult to find (PATH 2002). In a recent Pan-European survey, respondents agreed that neither cost nor technology was the problem, but rather a lack of information about the available technologies and their benefits to consumers (Commission 2005). Bonsall *et al.* (2011) posit that, results from the Commission's survey are by no means atypical and that of all the market barriers, information is continually cited as most influential to future uptake.

Research literature has shown that lack of information for retrofit decision making is one of the main reasons offered for the efficiency gap. The lack of information may be particularly important for owners of older existing buildings who do not have the expertise to assess HER options and may not know how to improve EE (Palmer et. al 2011). In order encourage the adoption of HER strategies in the U.S. this information barrier must be overcome.

The main objective of this research is to investigate the information related barriers leading to low adoption rates of HER and to explore the integration of various information categories for future development of an intelligent decision support system (IDSS) framework.

3.0 NEED FOR INFORMATION TO ACCELERATE HOME ENERGY RETROFIT (HER) ADOPTION

The Building America (BA) Program has identified the importance of information flow in HER as one of the key issues in its adoption. Having reached a consensus on the necessity of information flow, BA notes the following (NREL 2010b): (1) information is necessary to quantify EE in appraisal forms; (2) there is a lack of understanding of energy efficient terminology in the industry; (3) there is a lack of documentation to remove lead paint from exteriors; (4) information is out there, but it is not getting into the hands of the right people; (5) there is a lack of information to protect trade contractors from liability.

The following are some of the specific instances in the literature that point to information barriers to HER implementation thus necessitating the need for information in order to accelerate the adoption of HER.

Information for Stakeholders

BA has identified the skepticism of consumers and homeowners about EE claims due to market misinformation and false claims of EE as an important barrier to the penetration of market-ready energy solutions (NREL 2010a, NREL 2010b). In addition, regarding marketing and occupant behavior in retrofits, BA notes that, renovating and building energy-efficient homes is only part of the challenge and that convincing homeowners and investors to pay for energy improvements, and operate their homes efficiently, presents an additional challenge. Bianchi (2011) posits that, BA research is not accessible in a format that is most useful to stakeholders. An important conclusion drawn at a BA expert meeting on poor implementation of condensing boilers on a large scale was that, there was lack of information on optimum installation strategies and insufficient training for installers and designers (Aspen Publishers 2010).

Delay in Dissemination of Research Results

Though dissemination is an issue often raised by researchers, it is hardly seriously addressed (Crosswaite & Curtice 1994). According to Basch *et al.* (1986) dissemination can be described as deliberate efforts to spread an innovation. Ensuring the best possible use of research results is a means of demanding accountability from researchers (Crosswaite & Curtice 1994). Key reasons related to delay in disseminating/implementing research results into practice includes:

- Lack timely availability of information at the point of decision making (Haines & Donald 1998, Sorrel *et al.* 2004)
- Lack of understanding of the process of diffusion of innovation in the residential building industry (Koebel *et al.* 2003)
- Influence of powerful entities towards inhibiting the introduction of innovative cost effective solutions by smaller competitors (Golove & Eto 1996)

In a Pan-European survey, on the question of how funds could be targeted in supporting research towards investment in EE technologies, participants overwhelmingly responded that it would be better spent on demonstrating and validating the potential of current technology, thus avoiding the situation where good solutions stay in closed boxes without delivering results (Commission 2005).

Lack of a Standard Protocol and Unified Source of Information

A standard protocol is required to provide consistency in the means and methods used by home energy efficiency professionals, such as trade contractors and energy auditors. Standardized professional training programs, certification and an industry review/comment platform will support the growth of the energy retrofit industry by providing skilled and credentialed workforce (PATH 2002, EERE 2012, NREL 2012). One of the barriers identified to the large-scale implementation of EE in existing homes is the lack of standard protocol to dictate the methods used by home EE 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 (PATH 2002).

Need for Experts in Home Energy Retrofits

The involvement of experts in home energy retrofits is inevitable. Homeowners may not be aware of the inefficiency of their homes and the availability and benefits of energy retrofits. Specific opportunities for improving the EE of a building are typically more difficult for homeowners to evaluate on their own since they lack the expertise to do so. Thus, information provided by experts such as energy auditors is not only useful, but have an important role to play in filling the information gap that exists on building EE. Homeowners have a perceived distrust of energy auditors especially those with contracting interests. They are also confused about the conflicting information available in published sources and hence need the help of experts (Komor et al 1989; NREL 2010a; Palmer et *al.* 2011; PATH 2002).

The above noted discussion identifies the information related barriers. It also emphasizes the need to promote HER among homeowners and for information to accelerate HER adoption.

4.0 INFORMATION TYPES IN HOME ENERGY RETROFITS

To undertake a HER, homeowners seek information from a variety of sources such as: word of mouth, trade contractors, retrofit contractors, energy auditors, retail and lumber yard employees, how-to books and the internet, Federal and state government resources, television and radio shows, non-technical newspapers and magazines, utility companies, print advertisements, cost databases.

Based on literature review, these information sources can be put into two broad categories of information: expert knowledge/expert advice and quantitative /published information. These two information categories are utilized by stakeholders such as consumers, energy auditors, retrofit contractors, trade contractors, designers, developers, etc. for retrofit decisions (See Figure 1).

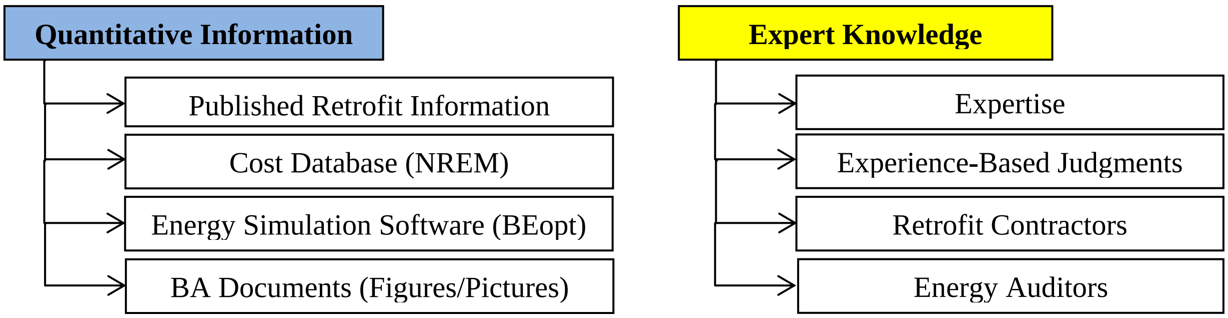

Figure 1: Two Key Information Categories/Sources

The first category has been termed as "quantitative information." This category includes information related to the task domain that is typically found in published sources and commonly agreed upon by those knowledgeable in the particular field (Palmquist 1996; Turban 2005; Syal 2011). Examples include: published information about retrofit technologies, cost information from databases such as the national residential efficiency measures (NREM) database, energy simulation reports from simulation software such as building energy optimization (BEopt), and information available in BA documents (NREL 2010b, USDOE 2010b).

The second category of information can be termed as "expert knowledge" and is also known as expert advice or qualitative information. This category includes information that can be defined as the knowledge of good practice, good judgment, and plausible reasoning in the field (Palmquist 1996; Turban 2005; Syal 2011). Examples include: expertise and experience-based judgment of retrofit contractors and/or energy auditors.

Within the context of the information categories identified and the lack of adoption and broad implementation of HER leading to low patronage of energy retrofits, the above-noted two information categories relate to the two barriers: "information barrier" and "expertise barrier". Understanding of the two information categories will help remove these barriers.

4.1 Sources of Quantitative Information

Several construction and home EE-related information portals and databases currently exist. This section summarizes the existing literature on information portals and databases used in the HER industry and other construction-related industries and a few examples are presented here.

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

Developed by integrating several USDOE databases of building retrofit measures into a unified national database, the database is a public, centralized resource of home retrofit measures and costs. It is mainly designed to assist users decide on the most cost-effective retrofit measure(s) for HERs. It allows constant feedback from users to improve its effectiveness. The database obtains input from two sources: data from retrofit programs and data from public feedback, both of which are monitored by the database administrator.

Building America (BA) Portal

This was developed as a useful portal for providing information to the public. The layout of the BA portal mainly includes: (1) information about the BA program including research teams, current research, and future goals and deployment strategies; (2) technical and scholarly publications related to home EE; (3) links to building science educational institutions and curricula; (4) information related to EE technologies, measures, and best practices; (5) sources of EE incentives; (6) links to other EE databases such as the NREM database; (7) search portal useful for quick retrieval of specific data.

Energy Star Portal

The Energy Star Program is a joint program of the US Environmental Protection Agency and the US Department of Energy (USDOE). It was created to protect the environment through energy efficient products and measures (Energy Star 2010). The program's information portal contains the following information: (1) products and measure to increase home EE; (2) tool that assesses the energy performance of a home. Data required to run the tool are "location of the home" and "past energy consumption"; (3) tool that suggests retrofit strategies for increased energy performance, based on the location of the home and its typical features; (4) links to other EE databases; (5) search portal useful for quick retrieval of specific data; (6) scholarly and technical publications related to home EE.

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

Established in 1995, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council which is funded by the USDOE and 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 and provides three areas of information for both Federal and State resources: (1) Financial Incentives; (2) Rules, Regulations and Policies; and (3) Related Programs and Initiatives.

4.2 Sources of Expert Knowledge

Within the HER industry, many sources of expert knowledge exist and pursued by homeowners. This section discusses three main sources which include: HER professionals, homeowner's self-acquired knowledge, and knowledge from a prepackaged source such as an expert system.

HER Professionals

In order to make informed decisions about which energy retrofit measures to select, homeowners need the help of competent and trained professionals who are certified to give them accurate, trustworthy, and comprehensive information specific to their home (EnergyARM 2009). One way of obtaining this information is by conducting an energy assessment of the home. Energy retrofits employed without initial measurement and analysis can produce unacceptable results thus there is a need for energy professionals to estimate a proposed retrofit's energy savings and prioritize the retrofits in descending order of their cost effectiveness (Krigger & Dorsi 2009).

As a result of the need to have a standardized protocol and harmonized training for energy professionals, the USDOE in 2012 funded guidelines for home energy professionals. The certifications focus on the most common jobs in the home energy upgrade industry: energy auditor, retrofit contractor, and quality control inspector (EERE 2012).

Homeowner's Self-Knowledge

In order to perform energy retrofits, the needs, preferences, and budget of the homeowner is a major consideration. Homeowners who undertake energy retrofits have different levels of expertise and these ranges from novices to experts. The lack of access to information however generally inhibits how much knowledge the homeowner may possess. The level of expertise of homeowners range from doing simple tasks such as: installing light bulbs or installing wall insulation to difficult tasks including blowing insulation into an attic, performing an energy audit, or testing the home to ensure it meets the quality standard. Homeowners generally have limited self-knowledge and usually rely on the expertise of HER professionals.

Expert Systems (ES)

An ES is a branch of artificial intelligence that can be used to solve problems that generally require human expertise. The basic concept of ES is to capture and organize the enormous task-specific knowledge derived from the experts (expertise) in a computer. Users can recall the stored expert knowledge through the computer for specific advice in solving a problem. The computer can arrive at a specific conclusion by means of inferences and then provide advice or necessary logic in the same way a human expert would (Warzawski 1985; Turban et al. 2005).

5.0 INTEGRATION OF TWO INFORMATION CATEGORIES AND FUTURE PLANS TO DEVELOP INTELLIGENT DECISION SUPPORT SYSTEM (IDSS) FRAMEWORK

For effective HER decision-making, it is important that the above noted information categories – expert knowledge and quantitative information, work in an integrated fashion. Figure 2 shows the integration of the two information categories and the layout served as the early thinking for the proposed development of the IDSS framework.

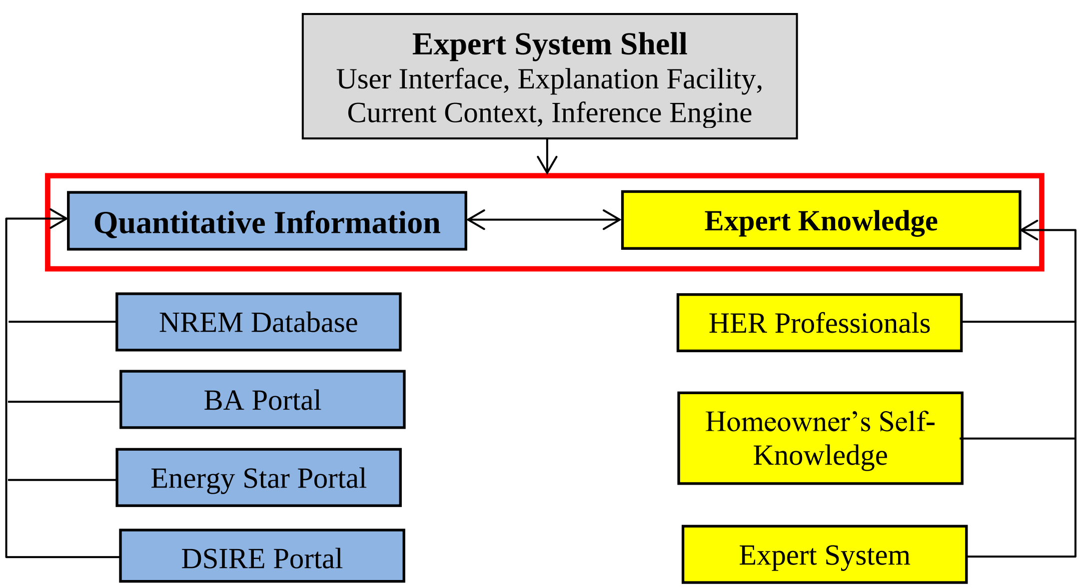

Figure 2: Integration of Information Categories – Early Thinking for Proposed IDSS

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