Energy Research & Social Science 32 (2017) 76–85

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

A systematic review of strategies for overcoming the barriers to energy-efficient technologies in buildings

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ARTICLE INFO

Article history:
Received 12 August 2016
Received in revised form 11 March 2017
Accepted 15 March 2017
Available online 25 April 2017

Keywords:
Barriers to energy-efficient technologies
Reduction of fossil fuels
Environmental health
Building energy

ABSTRACT

The energy used to construct, operate and eventually demolish buildings has accounted for 40% of total energy used globally and 9% of the world's greenhouse emissions. When examining major energy consumers such as Europe or the United States, the amounts of energy used for buildings is even higher. The use of energy-efficient technologies (EETs), such as low-energy windows and programmable thermostats, have had many positive results, including long-term energy reductions, a healthier living environment, the creation of jobs, and better quality housing. Unfortunately, there continue to be barriers to the use of EETs. While there are dozens of strategies for overcoming these barriers, many have gotten overlooked or lost. This paper provides a review of the literature that has focused on barriers to the use of EETs and strategies for overcoming these barriers. The method used for identifying relevant literature was a systematic search of scholarly publications addressing barriers and/or strategies for EET use. A theoretical framework is presented as a means of organizing the literature. The framework includes three broad groups of barriers: knowledge of EETs, access to EETs, and desire to use EETs. Strategies for overcoming the barriers are likewise organized and described.

1. Introduction

The energy used to construct, operate and eventually demolish buildings has accounted for 40% of total energy used globally and 9% of the world's greenhouse emissions [28,1]. When examining major energy consumers, the amounts of energy used for buildings is even higher. For example, in the European Union (EU) 42% of its energy consumption results from buildings and 35% of its greenhouse gas (GHG) emissions [20,30], and, in the United States (U.S.), at least half of the electricity used and 36% of the nation's GHG emissions are associated with buildings. The use of energy-efficient technologies (EETs), such as low-energy windows, programmable thermostats, highly efficient ventilation systems, and the like, have assisted in the reduction of energy consumption. However, unless significant changes are made, it is projected that by 2020 residential GHG emissions will increase by 21% [2].

Estimates suggest that a sustainably designed building consumes 26% less energy than a traditional building (General Service Administration, GSA, 2008). Further, it has been estimated that, in the U.S. alone, energy consumption is now roughly half of what it would have been if levels of energy efficiency had remained unchanged [50]. Where there has been an EET upgrade in buildings (e.g., new energy-efficient vinyl siding for buildings, new energy-efficient windows, cleaner energy source for heating and cooling), there has been a stimulation in construction activity and creation of jobs. This can result in better quality housing, a healthier living environment and long-term energy cost reductions [42]; Rifkin, 2011; [3,14]. Further, the reduction of a building's energy consumption can save building owners and users money by lowering energy expenses, attracting tenants, commanding higher rents and sale prices, and can improve occupant health and well-being through cleaner energy sources for heating and cooling [37,51]. The reduction in energy use can also result in a reduction in a nation's dependency on imported energy and strengthen its strategic position [81].

The amount of energy consumed by buildings depends upon the extent to which EETs are used, from the building's design, to its construction, operation, maintenance and eventual demolition and recycling (i.e., the buildings life cycle). Unfortunately, EETs are not

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http://dx.doi.org/10.1016/j.erss.2017.03.010
2214-6296/

always adopted by architects, builders, owners, building maintenance workers, persons occupying the buildings, etc. In such cases, potential reductions in energy use are not realized which raises important questions: What barriers are preventing the use of EETs throughout the life cycle of buildings? And, what specific strategies are currently available to overcome these barriers? The purpose of this paper is to provide an extensive review of the literature that addresses these pertinent questions. The literature is organized within a conceptual framework that focuses on the barriers and strategies for EET use.

2. Methods used for identifying literature

The focus of the literature search was on scholarly publications that examined the use of EETs, barriers to their use, and strategies for overcoming the barriers. Most of the literature data bases were found in Ebsco Host and Proquest. Databases used within Ebsco Host included: Business Source Complete, Energy and Power Source, Environment Complete, Eric, GreenFILE, Health Source: Nursing/Academic Edition, Medline, Military and Government Collection, Psychology and Behavioral Science Collection, Science and Technology Collection, and SocINDEX. Data bases provided in Proquest but not Ebsco Host included: ABI/INFORM Global; Art, Design and Architecture; British Periodicals; Dissertations and Theses at UNT; Proquest Dissertations and Theses Global; GeoRef; Political Science Database; SciTech Premium Collection; and Sociology Abstract. Other sources of publications included Google Scholar, ScienceDirect, and SAGE Journals on Line. Key phrases that were searched included: barriers to energy efficient technology use, overcoming barriers to energy efficient technologies, energy use in buildings, sustainable strategies, energy technology innovation, energy technology barriers, energy technology adoption, sustainable design practices, sustainable design barriers, sustainable technology, energy efficiency, green building, Leadership in Energy and Environment Design (LEED), emissions reduction, zero carbon technologies, building energy use, and environmental sustainability. All scholarly publications from books, peer reviewed articles, and reports from both government and non-government organizations were considered for inclusion. The publications originated from a variety of countries including Australia, Austria, Brazil, Canada, China, Germany, Ghana, India, Kenya, Netherlands, Nigeria, Scotland, Sri Lanka, Sweden, Thailand, the United Kingdom, and the United States. Due to the large number of available articles and limited space for the literature review, only those that had a primary focus on barriers to EET use and/or strategies for overcoming barriers were included.

3. A conceptual framework for the use of EETs related to buildings

Fig. 1 displays a conceptual framework for understanding the use of EETs. As important as EETs appear to be, there are at least three types of barriers to their use: knowledge, access, and intent to use EETs. Provided below is a closer examination of these major barriers followed by a catalogue of strategies that have or can be used to overcome them.

3.1. Barriers to EET use

3.1.1. Knowledge

Knowledge refers to information used by those who can incorporate EETs into a building's life cycle, including owners, architects, general managers, building operators, occupants and the like (referred collectively as potential users). Discussions on the importance of knowledge have centered on three areas (Fig. 1). First is the knowledge that EETs provide an advantage. Unless the advantages of EETs are known, potential users will have no incentive to use them [59,65,16,60]. Further, Levi and Lawn [55] have noted that organizations sometimes limit the use of EETs because they use standard accounting procedures that are unable to recognize the financial advantages. Likewise, those financing the construction of a building may not be aware of the advantages of EETs or mistakenly believe that the existing methods for building are already efficient so that new EETs are seemingly unneeded [4,52,6]. Similarly, designers, project managers, and financial underwriting institutions may not be aware of the most recent studies showing the environmental, social, and economic advantages of various EETs [7,3]. Further, building users, such as residents, may not recognize the long-term financial savings offered by using EETs such as using a programmable thermostat.

Second is the knowledge that specific EETs exist. In some cases builders and users recognize that there is a need for EETs but lack awareness of or knowledge that specific EETs exist and are available for use. For example, Nduka and Ogunsanmi [60,p. 188] have noted in their survey of 150 Nigerian professionals responsible for the construction of buildings that the barriers affecting the use of EETs included a "lack of awareness." Saraswat and Shukul [70,p. 23], surveyed 75 builders in Vadodara City, India and found that

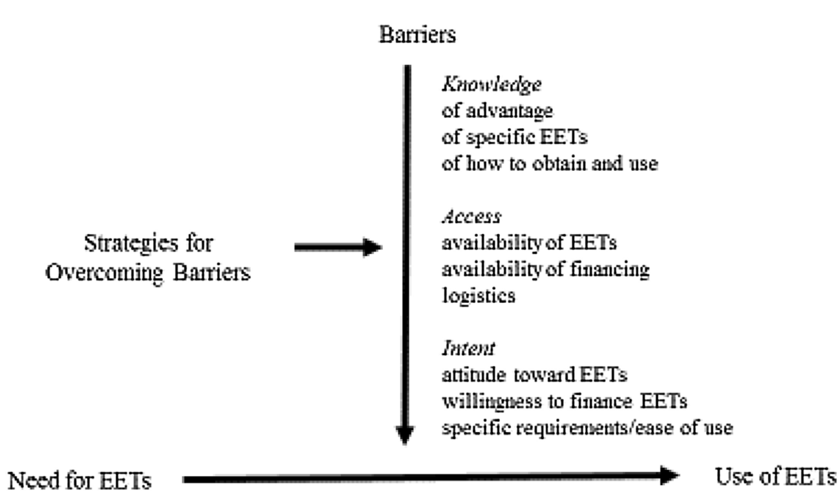

Fig. 1. Conceptual Framework Displaying Barriers to the Use of Energy Efficient Technologies (EETs) Within Buildings.

"More than one-half of the builders had low extent of exposure to various sources of information." Without knowledge that the EET exists, potential users will not use it [15].

A third knowledge area is awareness of how to obtain and use EETs. EETs are less likely to be incorporated into a building's life cycle if those who would buy and/or use them do not know how to obtain them, lack technical knowledge to implement them or believe that obtaining and using them would be difficult [70,5]. Where EETs are difficult to use, there is likely to be confusion by users and subsequently a lack of commitment to implementing them [67,29]. Similarly, where the EET is complex, it can be difficult to use and subsequently may be avoided [68]. While the knowledge barriers appear to be having less influence on EET use than in years past, they can still be a significant deterrent.

3.1.2. Access

An access barrier exists when factors external to the potential EET user prevent the person from accessing an EET. Researchers have focused on at least three types of access barriers (Fig. 1). One is the availability of EETs. A potential EET user, whether a general contractor or an occupant, cannot use a particular EET if the supply does not match the demand [7]. Similarly, in some cases, the EET is limited to a specific geographic location, making it inaccessible to some. For example, the use of wind energy is not practical in geographic locations that experience low wind volumes. In other cases the EET has been designed for a specific type of building and not accessible to all types or cannot be used in older buildings that lack certain infrastructures. Further, some EETs have only been laboratory tested to confirm basic performance and code compliance. Consequently, general contractors may question the viability of these EETs given their lack of field testing [7].

The second access barrier is the cost of EETs and available financing. In some situations, the cost of EETs are prohibitively expensive. Where the cost is within reach, a lack of financing can make the EET inaccessible [9]. For example, Bangdome-Dery and Kootin-Sanwu [16], in a review of EET barriers in Ghana, ranked the cost of EETs as the number one barrier to EET use. Williams and Dair [5], in their study of developments in England, found that real and perceived costs were among the barriers to EET use. And, in the U.S., Federal Housing and Urban Development rules do not always allow for adjustments to the amount of money provided to public housing authorities resulting in their inability to purchase desirable EETs for their public housing [29].

In the private sector, financial backing to pay for EETs may be difficult to obtain where the financial savings from the EETs have not been clearly established due to a lack of historical tracking of savings. In these cases, lenders often treat energy savings projections skeptically and refuse to include funds for EETs when calculating loan size for constructing or refurbishing a building [29]. Instead, they use traditional industry standards and focus on construction costs without attention to EETs and their potential cost savings as well as environmental benefits [7]; Lausten, 2008; [3]. Further, even where the financial payoffs have been clearly shown, financing is sometimes difficult to obtain as lenders (e.g., banks, non-banking financial institutions, private investors, or institutional investors) see EET savings as only a small share of the overall revenue/expense of the building and therefore not worth the investment [15,29]. Or, the financer may want to see a return on the EET investment within a few years and historical tracking suggests the return would take longer. A related barrier to financing includes the confusion that can come from trying to decipher the many public and private funding programs for supporting EETs to determine what they offer and what is best for a particular owner or builder. In these cases, owners and builders sometimes give up rather than attempt to understand the funding programs.

Another financial disincentive is referred to as "split incentives." In this case, those who would pay for the EETs to be incorporated within a building, such as owners and building contractors, would not reap all the financial rewards. While they might be able to reap some financial benefit through a higher sale value of the building, much of the financial benefit would be enjoyed by those eventually using the building and paying lower heating and cooling bills. To the extent that the builder can only reap a portion of the financial benefit, she/he is likely to question the financial viability of the EETs, resulting in less desire to use them.

Transaction costs have also been identified as a financial barrier to EET use. Transaction costs are those not directly involved in the construction or renovation of a building, but are unavoidable and sometimes unforeseeable costs emerging from the investigation of EETs and contracting activities required to procure them. More specifically, transaction costs can occur as a result of (1) searching for information related to EETs; (2) developing collaborations and partnerships; (3) negotiating during the procurement process and contract development; and (4) monitoring of contractual agreements and follow-up of installed EETs and their performance, e.g., energy and cost. These hidden costs in securing EETs can make them unaffordable [48,67,55].

A third access barrier, logistics, can exist even when availability and financing barriers are overcome. Logistics refers to the detailed coordination of operations involving multiple people, facilities, or supplies. Of course, the use some EETs, such as a programmable thermostat, may require very little logistics. However, as van Bueren and Priemus [6,p.83] have noted, in their study of EETs in the Netherlands, the implementation of EETs sometimes requires "...the support of multiple actors at various places and times in the decision-making process." This involves the logistics associated with transportation, material handling, and warehousing as well as the coordination and collaboration needed to successfully obtain the EETs [70,35,63]. For example, the equipment associated with energy-efficient building materials or heating, cooling, and/or ventilation systems may not be locally available. The more coordination and collaboration and, subsequently, time involved in obtaining these materials and equipment, the less likely the builder will incorporate these EETs. As Rohracher [11,p. 138] has noted, "sustainable buildings require (to varying extent) high-tech components, which are supplied by specialized companies (building control technologies, windows, heating systems, use of solar energy, transparent insulation materials, heat recovery systems, etc.)." While the logistics for obtaining EETs appear to be much improved from 15 years ago, they can still be a deterrent.

The logistical steps taken to secure EETs have been described as a juridical planning process as well as a physical design process [63,81,51]. In the juridical planning process, legal procedures must be followed, often based on local rules and regulations of a city or neighborhood. Here again, many EETs, such as a building's insulation, may have no local rules associated with it. On the other hand, other EETs, such as those related to building construction, may require satisfying certain rules and regulations, and the acquisition of government permits all of which add to the difficulty in acquiring the EETs. Steps within the physical design process focus on the formulation of a plan for implementing EETs, which can include clarifying the EETs' requirements and developing a construction plan.

Thus, logistics requires coordination and collaboration between varied persons that may include town planners, owners, architects, suppliers, project managers, electricians, and the like. A lack of coordination and collaboration can result in the EET not being implemented, or missed opportunities to implement EETs, or implementation but not maximizing the EETs intended design [63,81,51].

3.1.3. Intent

Intent to use available EETs refers to the potential user's (e.g., architect, builder, occupant) interest in and willingness to obtain EETs. A potential EET user may have the knowledge of and access to EETs but lack an intent or desire to use them, resulting in EETs going unused. For example, Ralph and Stubbs [67,p. 71] have highlighted the importance of intent through their survey of Australian and English university professionals by concluding that "…individuals, committed to the goal of a more sustainable world, play a vital role in the success of integrating environmental sustainability into universities." Symes and Pauels (1999) came to similar conclusions and noted from their case study in Manchester, England that the intent to implement innovations is directly related to the acceptance of the innovation by those involved in its implementation.

At least three groups of intent barriers were found in the literature (Fig. 1). If the EET has little appeal to the potential user, it is less likely to be used. Factors that can reduce appeal include cultural and individual characteristics, reference groups, and communication behaviors. The culture of people influences their beliefs, morals, and values. Some cultures are less inclined to perceive EETs as desirable and subsequently less likely to make efforts to use them [73,58,57,16,36,45]. Similarly, the norms and habits of a culture tend to influence member behavior so that where these tend to ignore EETs, there will be less desire to use them [59,45]. For example, a recent study in China found that cultural norms influenced people's intentions to adopt renewable energy technologies [21].

Culture can also be found within organizations. Some organizational cultures recognize the need for EETs and attempt to use them while others largely ignore them [43,67,11]. Organizational characteristics that have been associated with a lack of desire to use EETs include internal organizational structures that are rigid, formal, and centralized [55].

The individual characteristics found to influence the appeal to use EETs have included socioeconomic, personality, and lifestyle characteristics. Socioeconomic characteristics that have been found to create barriers to EET desirability include low education, low socio-economic status, and an inability to control one's economic resources [44,13,69]. Personality barriers include negative attitudes toward change, resistance to innovations, a closed belief system, a lack of faith in science, inability to cope with uncertainty and deal with abstractions, preference for the security of the status quo, tendency to be introverted, and a perception of oneself verses the world [82,22,34,55,68]. Lifestyle barriers have been described as those held by people who have become accustomed to a way of living that does not include EETs. For those lifestyles, EETs will be avoided if they interfere with the preferred lifestyle [58,3,69]. For example, a home buyer may choose to spend her/his limited building funds on amenities such as a larger or more attractive kitchen rather than on EETs such as energy efficient windows.

Reference groups and communication behaviors have also been described as affecting the appeal/desirability of EETs and subsequently the intent to use them. Research has shown that individuals often turn to friends, colleagues, other trusted individuals, and informal and formal leaders for information about EETs and for assistance in deciding on the value of an EET [12,22,7,26,69]. Further, research suggests that the opinions of informal and formal leaders, in particular, play a special role in influencing people's opinions about EETs [34,55]. Other researchers have reported that decisions to reject or accept EETs are sometimes collective in nature and center on strong social ties to a reference group with the individual members adhering to group decisions [25,68].

The influence of reference groups have also been reported at the organizational level, where the management within an organization scrutinizes the decisions of other organizations within their professional network before making their own choice to reject or adopt an EET [67,34]. Closely tied to the influence of reference groups is communication behavior. Those who communicate less with others and are more isolated have been found to value EETs less [40,34]. Further, where poor communication of details about the EET exists, potential users can become confused and subsequently lose interest in the EET [7,68].

A second group of intent barriers centers on the willingness to finance EETs. In this case, financing is not an access barrier because financing is accessible. However, as an intent barrier, the potential user either questions whether a particular EET is a good financial investment or has concluded that it is not [70,16,60]. In such cases, there is typically a lack of clear evidence and predictability that a new EET is cost effective, which, in turn, reduces desirability for the EET [15,57,63,10]. For example, the return on investment of a set of solar panels may be 10 years and, at the same time, the life of the solar panels may be 10 years, bringing into question the financial viability of purchasing the solar panels. In other cases, use of an EET may require special equipment, expertise or training which, in turn, can require delays in construction and/or extra costs. These conditions can deter interest in using EETs among builders (Lausten, 2008; [5,3]). Further, the development of EETs are often motivated by opportunities to improve the environment and health and less motivated by profit margins [70]. In these cases, the EETs are sometimes not economically competitive with more traditional energy sources and subsequently avoided by some potential users [15].

At an organizational level, intent can be reduced as a result of an organization's internal financial systems using traditional accounting procedures that make it difficult to financially justify the purchase of EETs. For instance, the long-term economic benefits of using EETs may be ignored when calculating the initial cost of adoption and implementation. Further, within organizations there are often competing priorities for limited resources and, when the long-term financial advantages are not apparent, the EET receives a low priority [67]. Still another financial disincentive noted above is "split incentives." When this occurs, those who have the financial resources to pay for the ETs lack an incentive to do so because they would reap only a portion of the financial rewards. Paying for the costs of the EETs but sharing the rewards with those eventually using the building is deemed undesirable. Finally, when there is dispersed and/or complex building ownership, the owners themselves may not agree on the financial viability of EETs [29,15].

The managers of utility companies are a unique group of potential EET users who may see no appeal to using EETs. Utility company managers often have business plans that focus on increasing the sale of their product, i.e., energy. If the majority of their revenues are derived from usage charges (as opposed to a monthly per-customer charge), implementing EETs can result in a loss of revenue. If the loss is absorbed by the utility without a cost recovery mechanism and with little or no reduction in marginal production costs, EET use can result in a loss of profit. On the other hand, King, et al. [47,p. 1] have concluded from their study of utility companies that "when energy efficiency can defer large capital expenditures that pose financial risks, utilities have a strong long-term financial incentive to promote efficiency that can outweigh any short-term financial disincentive."

A third group of factors reducing intent is related to the EET's specific requirements/ease of use, including the ease with which it can be implemented and used. The potential user may be aware of the EET, have access to it, perceive value in using it but feel its requirements make it too difficult or cumbersome to use and therefore undesirable [9,70,72,57,11,3]. In such cases, the EET may require routine cleaning and maintainance or simply not be designed with the potential user in mind. Factors contributing to this situation have included rigid government regulations and EET developers who have made no attempt to tailor EETs to potential users [29,7,76,78,80].

The need for extensive training is another specific EET requirement that can reduce the desire to adopt the EET. Where training is not easily obtainable, the potential user becomes discouraged [10]. In this regard, Rocha et al. [25] have associated geographic location with a lack of training and subsequently intent. They found rural areas to lack easy access to training with the result being less interest in those EETs requiring training. Similarly, Webber [80] has noted that rural areas lack the ability to transfer information easily and quickly and Lim et al. [56] found that rural areas of China experienced more barriers to EET use than urban areas.

4. A catalog of strategies for overcoming barriers to EET use

Strategies for overcoming barriers range from methods that inform potential users about the advantages of EETs, to those that can make EETs more accessible, to those that increase the desirability for EETs (Fig. 1). These strategies often vary depending on whether they are associated with a financer, owner, designer, builder, manager/operator, or occupant [34].

4.1. Strategies for overcoming knowledge barriers

The conceptual framework identifies three knowledge barriers including a lack of knowledge regarding the advantages of EETs, the existence of specific EETs, and the available procedures for obtaining and using them (Fig. 1).

4.1.1. Unaware of EET advantages

At least four strategies have been used to make EET advantages more visible. These include education/training programs, reference groups, communication channels, and sensitivity to how new EETs are introduced to potential users/financers. **Education/training programs** are offered to "expedite" the knowledge among potential EET users. For example, Hankinson and Breytenbach [35] conducted semi-structured interviews with practicing interior designers and architects within the Kwa Zulu Natal region in South Africa and concluded that education and experience were directly related to understanding the advantages of EETs. One means of expediting education and training is for organizations to provide a staff-like person who pulls together relevant EET requirements and benefits, as well as responds to requests for information. In other cases, organizations, such as the Center for Energy Technology in Chicago, U.S., can provide this service to owners [29]. Further, potential users of EETs may receive education and training as a result of (1) seminars and short courses [62], (2) continuing education through workshops, professional association meetings, and national conferences [10,51], (3) the creation of opportunities for designers and builders to interact with one another, [3] (4) public school courses that focus on the environment and EET advantages [51], and (5) relevant information provided through journals and magazines [46,71,70].

General managers and building operators have also gained knowledge of EET advantages through energy audits that provide valuable information about equipment and systems that can use EETs to reduce energy consumption [64,77]. In this regard, the U.S. Department of Energy is spending millions of dollars to help cities evaluate their energy programs and use this information to teach owners and builders about the advantages of various EETs [79,83]. Further, some localities require disclosure of a building's "energy use intensity," a numeric metric measured on a square foot basis which can help building managers and occupants see the energy saved where EETs are implemented [49]. At the occupant level, research has found that providing regular feedback to users about their energy use, such as through "smart sub-metering" or "efficiency labeling" helps teach them the financial and energy-saving advantages of EETs. Such feedback is reported to be best when it is simple and clear. This goes beyond earlier unsuccessful attempts that simply tried to point out specific EETs that could reduce energy consumption [59,77]; Lausten et al., 2008; [69,65].

Reference groups are a second major strategy used to overcome a lack of knowledge about EET advantages. These include peers and leaders but also national and government programs/organizations. Peer-to-peer and informal network learning can occur at all stages of a buildings life whether potential financers, building operators, or occupants [46]. Similarly, informal and formal leaders typically have the attention of others and therefore can use the opportunity to inform/teach others about EET advantages [67]. National programs can bring EET advantages to the attention of users/financers as well, such as through U.K's Energy Performance Certificate and the U.S. Leadership in Energy and Environment Design (LEED) program and the Green Globes program [52,46]. Similarly, some private corporations, non-profit organizations, neighborhood organizations and the like have chosen to highlight EET advantages for their peers and communities [69].

Important to the effectiveness of education and training programs and reference groups is **open communication** for the easy transfer of information. Open communication of information occurs through written works, person-to-person interaction, and marketing modalities such as websites, magazines, newspapers, television, radio and demonstrations that highlight EET advantages [78,26]. Closely tied to open communication is **how an EET is introduced.** If the introduction of a new EET to the building community is made with little fanfare, the result can be scant adoption or use of the EET. On the other hand, if the introduction is framed effectively with the assistance of reference groups and open communication channels; financers, builders, and users alike can gain knowledge of the EET advantages and subsequently be more likely to purchase and use them [24,76,38]. How to effectively frame messages that share knowledge about EETs has received a lot of attention in the literature with little agreement on the most effective framing methods. Some framing strategies focus on providing economic information regarding specific EETs while others focus on providing environmental knowledges. Xu et al. [82] have suggested that the most appropriate framing strategy for sharing knowledge may vary depending on the characteristics of the EET users being addressed.

4.1.2. Unaware of specific EETs

The strategies for educating people about the existence of specific EETs largely mirror those used to bring attention to the advantages of EETs. Those noted above include strategies for educating and training, for utilizing reference groups, using open communication channels, and smartly introducing new EETs. McKay and Carson [10] have noted that these variety of strategies are sometimes addressed within Market Transformation Programs developed in the U.S. by state agencies. Further, **standards and regulations at all levels of government** can bring attention to specific EETs. In some cases, building standards are set and enforced by federal regulations and encouraged through programs such as LEED. In other cases, local communities set and enforce regulations, typically through city councils or regional governments. These government standards and regulations bring specific EETs to the attention of financers, builders, and other potential users [14]; Lausten, 2008; [17,3]. In this regard, Egmond et al. [26] have found that in the Netherlands government attempts to highlight specific EETs have had positive effects. Further, the European Union (EU) has passed the Directive on Energy Performance of Buildings which sets the target dates of 2018 for all publically owned buildings and 2020 for all new buildings to be energy self-sustaining with energy to be produced on-site or by nearby renewable energy systems. Such a directive can be expected to draw much attention to EETs among contractors, builders and other potential users working within the EU and seeking to meet the Directive [19]. Similarly, U.S. federal buildings have been required to implement EETs in their design, construction, operation, and eventual demolition since 2009, encouraging builders to learn of the various EETs available [66]. Finally, also valuable are centralized **clearinghouses** that provide information on specific EETs [51].

4.1.3. Unaware of how to obtain and use EETs

Here again, many of the strategies described above for informing people about the existence of specific EETs and their advantages, can be used. Additional strategies for obtaining and using EETs include building guidelines, conferences/workshops, the use of "integrators," best practices, pilot studies, and demonstrations. **Building Guidelines** have tended to focus on engineering codes that provide guidelines for using EETs [51]. These are offered by organizations such as the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and the American Society for Testing and Materials (ASTM). **Conferences and workshops** are valuable education and training tools that can, in addition to bringing knowledge about specific EETs and their advantages, provide steps that help in obtaining and using them [58]. The use of **"integrators"** has been encouraged by The World Business Council for Sustainable Development (WBCSD). Integrators use their knowledge and management skills of the building industry and housing market to assist building owners and managers in obtaining and using EETs [46,25]. The **"best practices"** strategy provides examples of how EETs were effectively obtained and used by successful building owners, general contractors and the like, as well as showing how problems were overcome or avoided [29,71,57]. Similarly, **pilot studies**, such as those conducted by the National Renewable Energy Laboratory, show steps taken, mistakes made, and successes realized in obtaining and using EETs [31].

Demonstrations assist in learning how to successfully use EETs. Such demonstrations have been provided by the U.S. Department of Energy's National Renewable Energy Laboratory [66]. Demonstrations have been reported to be most effective when they are established in the specific geographic/climatic zone of potential users wanting to adopt EETs. In the case of residential housing, they are particularly effective when mirroring the types and monetary values of housing that is expected to incorporate the EETs [62]. Demonstrations that are made available by building owners who use EETs in their own buildings are also particularly effective at showing how to obtain and use EETs. It is important to note that one-time demonstrations have been reported to be detrimental in cases where they have distorted or left out facts about EETs. This includes a lack of details regarding first time purchases, continuous use, and ready replacement after the EETs life ends. Without these details, the potential user will still have important questions to be answered.

4.2. Strategies for overcoming access barriers

The conceptual framework specifies three access barriers: lack of availability, lack of EET financing, and the logistics of obtaining EETs.

4.2.1. Lack of EET availability

Strategies for making EETs more available largely center on government programs, private and non-profit grants, revised government rules and regulations that can assist the growth of EETs, and private research and development capabilities to make EETs for buildings increasingly available. **Government programs**, for example, include the U.S. DOE Weatherization Assistance Program that offers grants to states, territories, and some Indian tribes to make EETs available to low-income households [79]. The EPC [29] has reported that in 2012, the U.S. Housing and Urban Development distributed $23 million, in part, to make new EETs more available in multifamily buildings. At the state level, some states are providing liaison services to assist owners in gaining access to EETs. Similarly, some local utilities or weatherization providers in the U.S. provide potential users smart devices such as smart meters or direct control devices. At the same time, **non-profit and private grants** are being made available to support the production of existing EETs and the development of new ones.

Revised government rules and regulations include those of the U.S. Housing and Urban Development where rules have been modified to allow EETs to be more available to public housing. Further, revisions are also being considered to assist with EET implementation [29]. At the same time, private organizations are focusing **research and development** on new and improved EETs for buildings and on strategies for overcoming barriers associated with confined use to specific types of buildings so that they can be more widely used.

4.2.2. Lack of EET financing

There are at least six strategies that have been used for increasing the availability of EET financing. **Energy Service Companies** (ESCOs) and **Energy Service Contractors** raise money for investments in EETs that are based on future savings. That is, ESCOs allow for the money that will be saved, as a result of using EETs in new or renovated buildings, to be used to offset the cost of financing, installing, and/or operating those EETs. Organizations and building owners turn to ESCOs because ESCOs have extensive design and implementation experience in integrating EETs and because they provide a financial guarantee to project lenders that the energy savings generated will cover the debt service. Barriers to the use of ESCOs include the difficulty in measuring savings and calculating payments and the uniqueness of the performance contracts that can be at odds with the accounting systems used in government projects. Hui [39] has noted that in Hong Kong ESCOs are most often used for owner-occupied or single-tenant buildings, such as hospitals, hotels, and universities because their air-conditioning and heating systems are a large percentage of their total energy consumption and leave much room for cost savings. Nix [61,p. 20] has found that in India ESCOs have provided a proven and recognized procurement method for reducing the operating costs and environmental impacts of buildings at low risk to property owners.

Government tax and other financial programs are also being used to assist owners/users of buildings to better afford EETs [4,3]. For example, Fuerst et al. [32] have reported that the Energy Performance Certificate ratings on residential prices in Wales have resulted in statistically significant discounts. The Property Assessed Clean Energy Financing program in the U.S., has allowed owners to purchase EETs, receive 100% financing, and repay the debt over a period of up to 20 years as a property tax assessment. Unfortunately, in the U.S., tax policies have been complex and in some cases may have discouraged investment in EETs. For example, "passive loss rules" in the U.S. Internal Revenue Service Code may present a barrier rather than a strategy by limiting investment in small rental properties [29]. **Government and foundation grants** have been initiated to support research and development that are also focused on reducing the costs of EETs [29]. For example, the U.S. Department of Energy is funding research not only to make solar power more assessable but also to reduce the costs of solar panels.

Subsidies and low-interest loans are another strategy for providing financial assistance by reducing the cost of EETs [72]. This includes financial assistance from all levels of government to builders and home owners who adopt EETs. The EPC [29] estimates that in 2012 U.S. federal and state funding for state-administered, low-income, residential energy efficiency programs totaled almost

$1.3 billion. Subsidies and low interest loans are also offered by non-profit community organizations such as the New York City Energy Efficiency Corporation.

Electric and gas utility **incentive programs** have been used to make EETs more affordable [4]. Similarly, the U.S. Housing and Urban Development (HUD) Mark to Market Green Initiative provides financial incentives to private owners of HUD public housing units in order to encourage the use of EETs. Some government and non-profit organizations such as the Center for Neighborhood Technology in Chicago and the Community Preservation Corporation in New York offer "**one-stop shopping**" as an incentive to building owners [29]. One-stop shopping can assist them in making sense of the numerous and fragmented financial opportunities while at the same time securing third-party financing for EETs. Otherwise, when there are multiple sources of funding for which a building might be eligible and the owner has no single point of contact to assist in the navigation of these programs, the "hassle factor" has been reported to be overwhelming [29]. Other financial incentive programs include reimbursement of expenditures incurred during the purchase of EETs, providing credits based on the value of saved energy (e.g., "Green Credits"), and energy price discounts for EET users. Other financial mechanisms that can ease the way to affordability include leasing, venture capital, micro-credit, and loan guarantees [15].

4.2.3. Lack of effective logistics

A variety of strategies were identified for overcoming communication, coordination, and other logistic barriers to using EETs. van Bueren and Priemus [6] have suggested **placing coordination efforts in the hands of one or a few persons.** These persons must be well educated in both the juridical planning and physical design processes so that they can take responsibility for anticipating and solving coordination problems before they develop. Closely associated with the use of coordinators is the use of **extensive pre-project planning** designed to address anticipated logistics issues [57,81,10]. Similarly, **clearly specified contracts** can help avoid logistics problems by clarifying all special compliance requirements that are associated with the EET, including any specifics in the design, construction, commissioning, or documentation [3]. Model contract forms, covering an entire building, are available from a variety of industry groups such as the Associated General Contractors of America and the American Institute of Architects [63]. Additional strategies, noted above, include the use of **social networks**, **best practices**, and the availability of **grants and low-interest loans** for educating and training personnel in the logistical issues, including juridical and physical design planning as well as potential communication and coordination problems [29].

4.3. Strategies for overcoming intent barriers

The conceptual framework specifies three barriers that reduce the desire/intent to use EETS: attitudes toward the use of EETs, willingness to finance EETs, and the difficulties in implementing/using EETs.

4.3.1. Ambivalent or negative attitudes toward the use of EETs

As noted above, factors that affect attitudes toward EETs include cultural and individual characteristics, communication behavior and reference groups. A variety of strategies were identified for overcoming cultural and personal barriers. These center largely on three strategies: education, government intervention, and commercialization. **Education** can be used for more than simply informing potential users of the existence and value of EETs, as described above. It can also been used as a technique for behavioral modification in attempts to change people's attitudes, beliefs, and values and subsequently their norms and behaviors related to EETs. Moezzi and Janda [58,p. 34] have noted that ". . .education about energy use over the past decade has often focused on trying to ensure that people believe in climate change, promoting the idea that changes in how one acts and especially what one buys are personal responsibilities to help mitigate—or even 'prevent'—climate change." Egmond et al. [26,p. 1471] have described the purpose of such education as "informing, persuading, convincing or tempting." In this regard, education techniques have included **college offerings, conferences,** and **positive feedback** focused on the advantages of using EETs. This "information-deficit model" for behavioral change has received mixed reviews. In some cases, providing pertinent information has appeared to influence the beliefs and behaviors of individuals and their cultures. In other cases, providing pertinent information has been unable to gain the attention of influential people or reference groups. Further, at a broader level, providing pertinent information has not always been able to convince the population that making behavioral changes will have the desired long-term effects on cost savings, the environment, and health [58,55].

Government programs have also been cited as a stimulus for cultural changes in both personal as well as organizational norms and behaviors [35]. For example, Crabtree and Hes [24] have reported that government legislation and regulation in two major Australian cities have resulted in a higher use of EETs in buildings. In the U.S., the Green Building Council's LEED program encourages high energy efficiencies in buildings [44]. As potential users learn of the EETs contributing to energy efficiencies, positive attitudes and subsequent cultural norms in favor of EETs can develop. Other government techniques that have encouraged behavior change include **webinars** that offer information about the latest advancements in EETs, **awards** for using EETs, **subsidies**, and **tax incentives** [26]; Lausten, 2008; [34,33,53,74,46].

More forceful government approaches to culture change can require people and organizations to follow specific **rules and regulations** related to EET use. For example, Beerepoot and Beerepoot [17] have found that stricter government regulations in Holland have acted as an incentive to the use of EETs in the Dutch residential building sector. And, Cohen and Hulten [23] have described the positive influence of government auto emission regulations on people's attitudes towards energy efficiency. Further, government policies can highlight the advantages of **energy conservation**. While energy efficiency focuses on reducing energy consumption by using less energy for a specific service (e.g., using energy efficient cars), energy conservation focuses on reducing energy consumption by using less of a specific service (e.g., driving fewer miles). Government programs, such as those noted above, can encourage energy conservation.

Programs of private and non-profit organizations have also been influential. For example, Johansson [44] has described the influence of the National Association of Home Builders and the American Institute of Architects on guidelines for green buildings in the U.S. that have subsequently encouraged change in attitudes and behaviors. Stone [75] has emphasized the value of **think-tanks** in promoting new ideas. Further, Rocha et al. [25] have described how several Brazilian for-profit organizations have been successful at promoting EETs.

Commercialization is another strategy used to change cultural attitudes and beliefs about EETs [15]. The purpose of commercialization is, in many cases, to create changes in people's attitudes, beliefs, and values about a product such that people will desire and subsequently purchase the product. Further, those selling the EETs will ideally gain a profit, leading to less reliance on subsidies and other forms of EET support. Steps in the commercialization process include identification of potential users, designing products desirable to them, coordinating stakeholders (e.g., financers, developers, owners, suppliers), developing EET specific business plans designed to encourage use of EETs, and providing post-adoption support. Balachandra, et al. (2010) have examined the successes of EET commercialization and found that, while some EETs have become profitable, conventional technologies still have a strong grip on energy markets and often trump attempts to commercialize EETs.

Other strategies, noted above. include communication behaviors and training. **Communication behaviors** can inhibit pro EET attitudes where individuals are isolated and have relatively little communication with others [34]. Strategies for improving communication and subsequently pro EET attitudes include the use of the **mass media** such as television, radio, newspapers, magazines and the internet to get the word out about the advantages of EETs and reduce confusion [68]. The **training of "opinion" leaders** has been used as an effective strategy, particularly when the leaders have the ear of a group of people. These include presidents, directors, and others in powerful organizational positions who can influence attitudes and dictate behavior [67]. For example, the EPC [29] has noted the influence of elected officials who learned of the benefits of EETs and subsequently created policies producing pro EET attitudes among potential users [55]. Two other strategies linked to leaders include providing **financial incentives to social and organizational leaders** and making these leaders aware of **financial incentives available for their followers**. These include rewards for leaders who get others to use EETs and subsidies brought to the attention of leaders who then make them known to their followers [52].

Social networks, noted above, can also be used to increase the desire to use EETs. These include specific neighborhoods, residents of an apartment complex, people living within a finite geographic area, or perhaps specific minority groups who do not speak the native language [22,26]. Research has found that social networks can directly influence the speed at which new innovations, such as new EETs, are circulated [68]. In this regard, Rocha et al. [25] in their study of EET implementation within Brazilian industries found "social ties" to be important. Closely tied to social networks is the influence of **neighbors**. When a neighbor adopts EETs, others in the neighborhood will be more likely to do the same [54,68]. **Professional networks**, such as professional associations and institutes, are another type of reference group that has influenced the spread of pro-EET attitudes. Leung [54,p. 32] has found that professional networks facilitate: ". . .a high level of knowledge exchange, interpersonal communication, mutual influence and network activities." Further, Schweber and Harty [71], in their study of the use of energy-efficient reinforced concrete in France, the United Kingdom, and the U.S., found that pro-EET attitudes were spread within such networks.

Social and professional networks can be particularly effective strategies for promoting **peer pressure**. That is, there is pressure within a network or group to "keep up with the Joneses." For example, the EPC [29,p. 28] has noted that in some U.S. cities: "Enough building owners have erected photovoltaic panels, replaced their lighting, and installed energy management systems so that their competitors have taken note and perceive that tenants may soon prefer such appurtenances in their buildings." Rogers et al. [8] has reported that peer pressure can be so great as to change a "personal" innovation-decision into a "collective" innovation-decision. In these cases, a majority of members of a group, whether social or professional, decide to pursue a particular action or activity as a result of peer pressure within the group.

4.3.2. Willingness to finance EETs

Potential users may have access to the financial resources needed to invest in EETs but lack the willingness or desire to finance them. Financers and owners may question the value of EET benefits and, in particular, whether they are worth the time and energy that would be needed to obtain available financing or whether they are worth the subsequent costs of using the EET [15]. A variety of strategies, noted above, have been used to increase the willingness to finance EETs These include **providing information and education** [59], **demonstrations, best practices,** and **trialability** [34,15,71]. Further, Fri and Savitz [31] have noted the value of combining **feedback** with trialability. Through feedback from using an EET, potential users are able to see any positive financial, environmental, and health benefits and consequently will have less concern for the financial burdens that might be experienced in obtaining and using it [65,41]. Finally, in the special case of utility companies, **government incentives** and the use of **special rate mechanisms** can remove many, if not all, of the disincentives that limit the attractiveness of utility investment in energy efficiency [47].

The specific requirements/ease of use can serve to produce positive attitudes where the requirements for EET implementation and use are relatively simple and avoid complexity [34,72]. In this regard, Levi and Lawn [55] have noted the advantages of **incremental verses radical innovations**. The specific requirements of EETs with an incremental character are only moderately different from what the user is accustomed too while radical technology requirements are very different and often viewed as relatively complex and/or incompatible with the potential user's existing experiences.

Several strategies, noted above, have been used to reduce EET requirements and make them easier to use. These include **consulting with peers, demonstrations,** and **best practices.** Peers can assist potential users in understanding how the EET is implemented and increase its ease of use [25,68]. Likewise, demonstrations and best practices can assist potential users in becoming more familiar with specific EET requirements. Other strategies include the provision of **implementation procedures that can be easily modified** to match the skill level and preferences of the potential user whether a general contractor, building manager, or occupant [55]. Other strategies include providing implementation **instructions that are clear and easy to understand** and providing **consultation services** during the implementation stage [58,26].

5. Conclusions

The literature review demonstrates that there has been a great deal of effort placed on understanding how to incorporate EETs within the design, construction, operation, and eventual demolition of buildings. Researchers and theorists have identified dozens of barriers to using EETs and have offered a variety of strategies for overcoming the barriers. To provide some organization to the literature, a conceptual framework includes three types of barriers: knowledge, access, and intent. Roughly 33% of the articles reviewed for this article focused primarily on knowledge barriers, 22% on access barriers and 45% on intent barriers. The articles, focused on knowledge, emphasized the importance of training and educating the users of EETs on the existence of EETs, their purposes, advantages, and how to obtain and use them. Articles, focused primarily on access, highlighted parts of the world where accessibility is still a major issue, provided direction on how to obtain financing, discussed the continued issues surrounding costs, and highlighted coordination and communication issues that must be addressed in order to access EETs. Articles examining intent covered a wide range of topics that influence a potential user's desire to use EETs, including the effects of culture, socioeconomic characteristics of potential users, influence of social groups, and the importance of government intervention through strategies such as regulations and tax incentives.

Virtually all of the articles reviewed were in agreement that EET use within buildings is, at the least, desirable and at most essential. On the other hand, the articles did not agree on how to make this happen. Some focused primarily on "getting the word out" about the many EETs available, viewing this as most important to EET use. Others believed that new funding mechanisms are the crucial strategy needed. Still others were more focused on how to get people interested in and willing to use EETs, whether in the design and construction of a building, living in one, or during a buildings demolition.

Research questions still to be answered include: Which barriers are contributing most to the lack of EET use? And, which strategies are most effective at overcoming the barriers? Unfortunately, these two questions are not as simple as they appear. For example, the literature suggests that the importance of a barrier depends on the specific location and country of interest (e.g., differences in cultures and beliefs). Likewise, a strategy that works in one location or country may not work in another. What is clear is that much research is needed to provide more scientific evaluations of the barriers to EET use and evaluations of the various strategies focused on overcoming barriers and enhancing the use of EETs.

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