

*HOUSING EDUCATION AND RESIDENTIAL ENERGY EFFICIENCY: A REVIEW  
OF TECHNOLOGICAL AND ECONOMIC ASPECTS OF ENERGY CONSERVATION*

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*ABSTRACT*

*The importance of energy efficiency in the residential sector is highlighted by its relationship to community issues, including housing affordability and economic development. Negative impacts of wasteful energy consumption include the disproportionate effects of rising energy costs on low-income people and the transfer of dollars from local communities to energy-exporting economies. Housing professionals can play an important role in keeping households and communities apprised of the technology and economics of energy conservation. This paper is presented as a primer on these issues for the housing educator, from whom consumers can learn about options in energy efficiency and their associated investment aspects. Housing educators can also help community leaders to become aware of the importance of conservation for its economic impacts in a local economy. Ultimately, energy awareness will prepare households and communities for expected future price increases and contribute to the conservation of finite resources.*

*INTRODUCTION*

In spite of volatile market conditions responsible for fluctuating energy prices, oil remains a dwindling resource. Increased energy demand, especially in developing countries, could set the stage for another energy crisis (Flavin, 1985). At the state level in this country, price and availability of energy are important determinants of economic health. Where indigenous resources comprise a small amount of a state's energy supplies, energy dollars are transferred to export economies, reducing local expenditures for goods and services. Preventing this transfer through conservation actions increases household disposable income, which, through a multiplier effect, exerts substantial impacts on local sales, investments, jobs, and the local tax base (Fisher, 1980; Lewis, Youmans, Goldman, and Premer, 1979; Stebbins and Floyd, 1979). A strong relationship can, therefore, exist between energy efficiency and economic development in the various sectors of a community.

Despite incentives for households and communities, energy conservation measures in the residential sector are not implemented at levels consistent with available technology and utility energy survey recommendations (Driscoll, 1981). Reasons for this disparity include inappropriate price signals generated by volatile market conditions, the technical and complicated range of alternative conservation strategies, a general lack of awareness of the investment aspects of energy conservation, and misconceptions about externalities such as lowered air quality in general and radon gas in particular.

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*INNOVATION AND THE HOUSING INDUSTRY*

Advances in housing technology during the past decade have included a wide array of building practices and products that result in high levels of achievable thermal integrity in the built environment. Whether optimal levels are designed into newly constructed or rehabilitated homes depends on a number of interrelated factors within the residential sector, including the nature of the United States housing industry. The provision of residential shelter in this country is an activity with a vast number of participants, including landowners, developers, architects, government officials, laborers, lenders, realtors, tenants, and owners. The housing industry can be characterized as a highly fractionalized activity, involving many small producers and consumers (Schoen, Hirshberg, and Weingart, 1975).

The localized nature of housing markets and the increasing complexity of the technology of thermal integrity inhibit the diffusion of innovations. In addition, the high initial costs characteristic of low-energy homes restrict buyers, who are typically cost-sensitive, and lenders, who have no uniform basis for appraising the energy efficiency of homes and generally rely on conventional debt-to-income ratios for maximum mortgage amounts (Diez, 1986). These constraints on both the supply of and demand for energy efficiency have been addressed through demonstration programs for builders, low interest-rate loans for buyers, and secondary mortgage-market programs for lenders.

Progress has also been made in the development of home-energy rating systems, which would provide standard measures for evaluating the thermal performance of structures (National Institute of Building Sciences, 1985). Concurrent with these developments are indications that some groups of home buyers expect energy efficiency in the homes they buy (Fletcher and Woodcock, 1986). The energy-efficiency aspect of manufactured houses currently being imported to the United States from Sweden and other countries is considered by some observers to contribute to their popularity (Schipper, Meyers, and Kelly, 1985).

*DESIGN TRENDS*

The evolution of energy-efficient design in the residential sector of the United States can be considered to be in its third phase (Nisson and Dutt, 1985). The first phase began shortly after the 1973 Arab oil embargo. It was dominated by an interest in active solar systems. The high initial costs of the mechanical systems required by this approach and the large amounts of space necessary for energy collection and storage were drawbacks, especially in northern regions of the country. The second phase was marked by a resurgence of the centuries-old technique of passive solar design, in which solar energy collection, storage, and distribution systems are incorporated into the components of a structure. On a large scale, widespread diffusion of passive solar architecture has not been achieved for a number of reasons, including uncertainty about energy savings.

The focus of the third phase of energy-efficient design is on reducing the need for any type of heat source, whether it is oil, gas, electricity, or sunlight. The term *superinsulation* refers to a method of house construction that is unique--not because of the materials used, but because of the way they are used. Although there is no popular agreement regarding a precise definition for superinsulated housing, the term generally refers to extremely high levels of insulation materials in the building envelope, a continuous vapor retarder complemented by an infiltration barrier, and an effective ventilation system. Although a superinsulated house may cost as much as ten percent more to build

than a house of conventional construction, energy savings are very high. A superinsulated house can be designed to require as little as five percent of the heat required by its conventional counterpart. Furthermore, less uncertainty is associated with the savings achievable from superinsulation than those from solar designs because solar gain is less crucial to a house with a minimal annual heating load.

*The Thermal Envelope*

Comprising the supporting technology of energy-efficient design are components of the building skin and mechanical systems within the structure. The former category includes all elements of the thermal envelope. The latter consists of heating, cooling, and ventilating systems. Recent developments in both areas have increased the number of options that significantly affect energy consumption for space conditioning.

The barrier between the interior and exterior environments is formed by the building shell, or thermal envelope. Traditionally the focus of energy-conserving actions, thermal integrity of this component is relatively easy to upgrade in existing houses and is regulated by building codes in new construction. Factors influencing types and amounts of insulation used for particular applications include the structural characteristics of the dwelling, application details, and the local climate (ASHRAE Handbook, 1985).

In northern climates, the vapor retarder has long been considered an essential component of the thermal envelope. The installation of a 6-mil polyethylene layer between insulation and interior finish material has been standard practice in the construction of energy-efficient homes for years. General uncertainty about the long-term performance of polyethylene and the potential for vapor-retarder failure through degradation of this plastic have highlighted problems associated with this approach to moisture control in walls and attics (Lischkoff and Lstiburek, 1984). Recommendations for polyethylene vapor-retarder installation now include careful storage of the material before its actual application (Sieben, 1984). Of particular importance is the need to prevent its exposure to sunlight, because of the effect that ultraviolet rays have in breaking down polyethylene. Stretching the material too tightly when applying it to walls and ceilings can lead to eventual rips. All laps and edges should be sealed to prevent air leaks, and the plastic should never be punctured.

Current construction practices make it difficult to observe all the necessary safeguards when installing a polyethylene vapor retarder. Even if they are observed, however, questions about long-term effectiveness persist because of the tendency of polyethylene to become brittle with age, as well as the potential for punctures throughout the life of the structure. The very need for a plastic vapor retarder is also being questioned (Lischkoff and Lstiburek, 1985). Because the dominant transport mechanism of moisture through the building envelope is air movement, not diffusion, Canadian engineers now contend that the control of moisture is achieved more efficiently by preventing air movement through the envelope. The Airtight Drywall Approach (ADA) is a building technique that accomplishes this (Lischkoff and Lstiburek, 1986).

Instead of focusing on a plastic film vapor retarder, ADA achieves an effective air barrier, so that moisture-laden household air does not pass into the wall cavity or attic. Major air leaks that exist in conventional construction are prevented by placing foam and rubber gaskets between the subfloor and bottom plates, as well as between gypsum board and studs or joists. Instead of polyethylene, vapor-barrier paints are used in conjunction with ADA to achieve a

moisture diffusion barrier.

Test results for airtightness achieved through ADA have been impressive, and additional construction costs for the air barriers are minimal (about \$150 per house, but no polyethylene vapor retarder is used). Another advantage of ADA is visibility of the air/vapor barrier, so problems that may develop (such as a hole in the drywall) are easy to spot and repair, unlike a concealed plastic film. Although research on ADA is continuing, test results so far indicate that a more effective alternative to a polyethylene vapor retarder for moisture control is now available.

Of all the elements of the thermal envelope, windows characteristically exhibit the least resistance to heat flow, with even double-pane glazing losing heat up to 20 times faster than typically insulated wall (Nisson, 1984). The thermal performance of existing windows can be improved with additional panes of glass or plastic, caulking, and weatherstripping. Units can also be replaced with energy-efficient windows that take advantage of recent developments in glazing technology. New window systems offer higher resistance to heat flow through options that include low-emissivity and reflective coatings, gas-filled airspaces, and interpane baffles. Ongoing research into improving the thermal performance of glazing is resulting in "smart windows"—units with electronically switchable glazings and optical memories. Other strategies include the use of evacuated cavities and aerogels. These developments are predicted to result eventually in north-facing windows with R-values equivalent to insulated sidewalls.

#### *Mechanical Systems*

Inefficiencies have long been inherent in combustion-based central heating systems, particularly because of operating cycle losses that result from using heated air to maintain combustion and chimney draft. Other sources of inefficiency include system oversizing and distribution losses. Typical annual fuel utilization efficiencies (AFUE) for central-heating systems in the United States are about 75 percent (Mullen, 1984). Continuing developments in home-heating technology are resulting in new designs for highly efficient combustion-based hydronic and forced-air systems. Innovative features in this equipment include condensing heat exchangers, direct venting of combustion gases through plastic pipe instead of a chimney, and pulse combustion (Sadowski, 1984). Smaller sized units without distribution systems are available for low-energy homes (Dutt, 1985).

In comparison with other types of heating systems, lower equipment and installation costs of some types of electric heating systems contribute to their popularity, especially in new construction. In superinsulated houses, electric heat may be advantageous because it does not require combustion. When combustion equipment is installed in an airtight house, design issues that must be addressed include the provision of air to support the flame, exhausting of combustion products without compromising energy efficiency, and maintenance of indoor air quality. When a heating load for a home is minimal, as is the case with a superinsulated house, the consideration of these factors may lead to the selection of electric resistance heating.

Other types of electric heating systems are thermal storage units and heat pumps. A thermal storage heater consists of a cabinet that contains ceramic bricks heated with electric current during the hours of low fuel rates. Once charged, the bricks radiate heat without the use of current during the times of higher rates. This system represents a practical alternative to conventional electric resistance heating systems when discounted fuel rates are available to consumers during off-peak periods. In 1852, the heat pump was first purposed as a heating device by William Thompson (later known as Lord Kelvin), who referred

to his device as a "heat multiplier." A heat pump uses electricity to both heat and cool a dwelling. It generates more energy than it uses by removing heat from air, water, or the earth and making it available for water- or space-heating needs. The system operates on the principle that heat is available for such a transfer until temperatures drop to absolute zero (- 450°F). The operation of the heat pump can be reversed for cooling in the summer (Calm, 1984).

#### *Indoor Air Quality*

A consequence of an airtight house-design strategy is a reduction in the air-change rate between the indoor and outdoor environments. Products used in home-building materials and furnishings, as well as activities that take place in and around a house, all contribute to the quality of the air within it. Pollutants found in homes today include formaldehyde from particle board and plywood, nitrogen oxides from tobacco smoke and unvented gas-burning appliances, organic compounds released during the aging of synthetic materials, and radon gas from certain soils in contact with the house or water supply. In addition, moisture levels in houses with inadequate ventilation can be high enough to result in structural damage.

A conventionally constructed dwelling is not likely to be airtight, so intermittent ventilation is achieved through cracks around the sills, windows, and utility service openings. Dwellings, however, that have been extensively retrofitted, and properly constructed energy-efficient houses do not have these cracks. While they do ventilate a house, cracks also result in substantial heat losses through infiltration. Ventilation achieved through faults in the thermal envelope is never constant because it depends on wind speed and conditions of the building site. A better solution is controlled ventilation with an air-to-air heat exchanger. This device replaces the air in a house with fresh air from outside, and simultaneously recovers heat from the exhausted air. Excessive humidity is also removed from the dwelling during this process (U.S. Department of Energy, 1984).

Recent research into the quality of air within the built environment has resulted in an increased awareness of the potential for human exposure to radon, a colorless, odorless gas that occurs naturally in low concentrations all over the world. A radioactive product formed by the decay of uranium and radium, radon can be carried by air and water. Increased incidents of lung cancer are associated with high levels of exposure to the decay products of radon. Human exposure can occur through contact with contaminated air or water (Hanson, 1985).

Major factors affecting a home's radon level are: 1) strength of the radiation source, 2) permeability of soil on which the house is built, and 3) house ventilation rate. High radon levels have been measured along certain geologic formations in the United States. Within these areas, it has been observed that clay soils act as radon barriers, unlike porous gravel through which the gas can easily flow. Through suction pressure, a house pulls soil gases inside. This pressure varies among houses because of construction details and air-handling equipment, such as furnaces and fans.

Some simple construction techniques have been found to reduce radon levels (U.S. Environmental Protection Agency, 1986). These include sealing cracks in basement floors and walls, ventilation of crawl spaces and basement subfloors, and increasing the overall house ventilation rate with the use of an air-to-air heat exchanger. Treatment for radon-contaminated water consists of charcoal filters or aeration in closed, vented tanks.

Research efforts currently underway may provide insights into unanswered questions regarding the incidence and consequences of radon exposure. A continued educational effort targeted to builders and home owners is necessary to counter misconceptions about relationships between energy-efficient structures and indoor air pollutants that hinder energy-conservation efforts.

#### *ECONOMICS OF ENERGY EFFICIENCY*

Many of the systems described in the preceding sections involve considerable capital expenditures for durable goods, a factor that highlights the appropriateness of evaluating them as investments. While the payback-time analysis is a popular evaluation tool for this purpose, it can be misleading. When used as a basis for selecting among mutually exclusive investments, it does not necessarily lead to an alternative with the highest net present value (Brealey and Myers, 1981). Important elements missing from a payback calculation are benefits accrued beyond the break-even point, including effects on house value. For this reason, life-cycle costing, net present value, or return-on-investment analysis (Gates, 1983) are preferable evaluation tools.

A difficulty with projecting benefits of an investment in energy efficiency has been the lack of an empirical basis from which to determine capitalization effects, or changes in house value attributable to such investments. Research efforts in recent years have examined this issue. Although these studies were conducted in different markets using various measures for energy efficiency, a general conclusion is that a house value is positively related to thermal integrity. Calculated rates of return have compared favorably with other investment opportunities and capitalization effects have been observed (Laquatra, 1986).

Reliance on market forces to accomplish widespread diffusion of energy-efficient design requires that both buyers and sellers be fully informed about the projected space-heating consumption of a given house. Different systems for rating the energy efficiency of dwellings have been proposed (Hodges, 1984; National Institute of Building Sciences, 1985; Rosenfeld and Wagner, 1982) and would provide measures for comparing thermal integrity across houses and projecting future expenditures. However, empirical evidence supports the claim that households are not able to project net savings resulting from an investment in energy efficiency because of systematically biased measurement inaccuracies (Kempton and Montgomery, 1982). This situation justifies an educational effort in the areas of technology and savings calculations.

In owner-occupied housing, price signals to energy end-users are instrumental in achieving optimal levels of conservation because a clear relationship exists between investors and beneficiaries of energy-conservation measures. A number of institutional barriers in rental housing markets, however, are conducive to low levels of energy efficiency in units that, in many cases, are inhabited by those who can least afford anticipated energy price increases.

The problem of the split incentive in rental housing arises because those who make decisions about a building's level of energy efficiency are not the same people who use energy within that structure. State building codes resolve this problem in new construction by requiring that minimum standards for energy efficiency be met. For existing rental properties, however (many of which will be in existence well into the next century), owners can pass along energy-cost increases to tenants, regardless of inefficiencies in a building's thermal envelope and mechanical systems. Owners themselves may face financial barriers to implementing conservation measures because of cash flow problems, an inability to finance capital improvements, or rent control ordinances that limit rent

increases based on such improvements. In addition, technical barriers posed by peculiarities of multi-family dwellings and a general lack of understanding regarding certain aspects of these structures also contribute to an inefficient use of energy in rental housing markets (Office of Technology Assessment, 1982).

Because rental housing comprises a substantial portion of the housing stock of some communities, consequences of economic leakage through the loss of energy dollars from that sector may be significant. Community approaches to this issue have included tenant education programs, the provision of incentives to property owners, and regulation (Laquatra, 1987).

### *PROGRAM BUILDING*

The continuing existence of obstacles to energy efficiency in housing underscore the importance of ongoing efforts in research, teaching, and extension activities. Program areas should cover a wide range of issues, including employment, community economic development, and affordable housing.

The importance of housing information programs is discussed by Baird, Shoffner, Godwin, and Connell (1984), who conclude that such an effort is timely and beneficial for individuals and families. The technological and socio-economic aspects of energy efficiency are topics that can be easily integrated into ongoing housing education programs in secondary schools, colleges and universities, and Cooperative Extension. In particular, the localized nature of the network comprising the Extension system makes it well-suited for surmounting barriers to widespread diffusion of energy efficiency in the residential sector. Extension can and has played a leading role in the development of educational programs on particular aspects of design, technology, and socio-economics that are tailored to specific audiences, such as contractors, owners, owner-builders, and buyers.

The development and implementation of a comprehensive energy-education program are critical steps in eventually overcoming barriers to energy efficiency. Localized approaches can be targeted to individuals and families, groups and organizations, and public decision makers. Recognition of the demonstrated capabilities of energy-conserving technologies through policies that facilitate, rather than hinder, their use is a potential outcome of a community energy-education program.

The immediate challenge to housing educators is to make energy an interesting and important topic, regardless of the direction of price levels. A focus of programmatic efforts can be linkages between residential energy use and critical issues, including housing affordability and community economic development. Within Extension programs, such a scope can include policy education for community leaders to address problem areas, such as energy efficiency in a community's rental housing stock. Particular attention could be paid to situations faced by low- and moderate-income families that hinder investing in energy conservation, including lack of access to capital, heavy debt loads and strained family budgets, as well as the technical and often confusing array of available options. Because of the impacts of utility expenses on total shelter costs, energy efficiency is a significant aspect of affordable housing, in both existing buildings and new construction. Although patterns of energy use that result from the way structures are built and used are slow to change, impacts can be made through courses, demonstration projects, and mass media efforts.

A determined effort to maintain the importance of energy efficiency in the residential sector is an important task for housing educators and researchers, preparing households and community leaders for expected energy price increases.

Dollars that pay for energy imports could instead be spent in local businesses, and households could benefit through greater control over their energy expenditures.

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