Residential and Commercial Buildings | 3

Revidential and commercial buildings in the United States use about $180 billion worth of energy per year for space heating and cooling, lighting, water heating, and other energy services. Passive solar architecture,[2] daylighting, and certain other renewable energy technologies (RETs) can cost-effectively reduce energy use in new buildings by 15 to 20 percent. Together with energy efficiency improvements,[3] these technologies can provide roughly 50 percent energy savings in new buildings compared with their conventional counterparts (see figure 3-1). These RETs can save money, reduce the need for new energy supplies, and provide substantial environmental benefits.

What Has Changed?

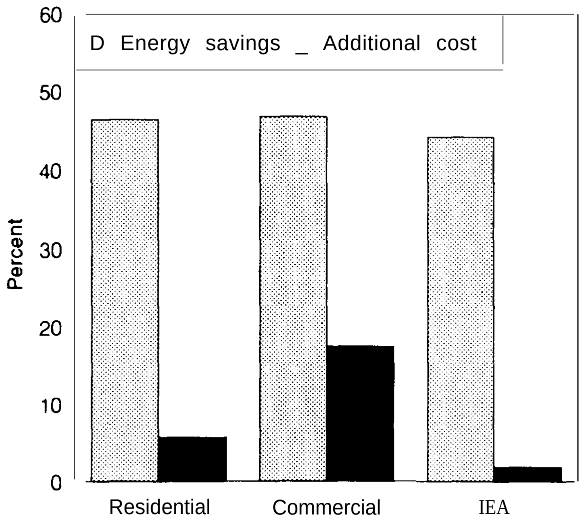
In the early 1970s, energy was not a very important consideration in building design or operation. Relatively little was known about building energy flows, market challenges to use of RETs, or effective policy responses. Following the 1973-74 oil embargo, build-

[1] U s Department of Energy, Energy Information Administration, *Annual* Energy Re-iew *1993*, DOE/EIA-0384(93) (Washington, DC: July 1994), pp. 55, 77.

[2] A more descriptive term is *building-integrated solar energy,* but the traditional term *passive solar* is used here.

[3] In comparison, previous work by the Office of Technology Assessment showed that cost-effective, commercially available efficiency improvements by themselves could reduce new building energy use to two-thirds that of conventional buildings. When the provisions of the Energy Policy Act of 1992 are fully implemented, a portion of these efficiency improvements will be captured. See U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency, OTA- E-5 18* (Washington, DC: U.S. Government Printing Office, May 1992); "Energy Policy Act of 1992," Conference Report 102-1018, Oct. 5, 1992.

FIGURE 3-1: Energy Savings and Additional Construction Costs of Passive Solar Designs Compared with Conventional Forms



NOTE Average energy savings are depicted for 20 residential buildings and 12 commercial buildings studied in the United Slates as well as 40 buildings studied by the International Energy Agency The buildings were experimental models use of the data obtained from these studies now allows better performance and lower costs than those shown here

SOURCES Solar Energy Research Institute Passive *Solar Homes 20 Case Studies SERI/SP-271 -2473* (Golden, CO December 1984), Burt Kosar Rittelmann Associates and Min Kantrowifz Associates *Commercial Vuilding Design Integrating Climate, Comfort, and Cost (New*York NY Van Nostrand Reinhold Co 1987) and International Energy Agency *Passive and Hybrid Solar Commercial Buildings Basic Case Studies,* Task XI (Washington DC U S Government Printing Off Ice 1992)

ing energy research, development. and demonstration (RD&D) was launched in parallel with supports such as tax credits for commercializing largely unproven technologies. Much was learned from both the failures and the successes that followed.

Two decades later, we now have a substantial base of proven technologies and practical policy experience of what works and what does not. Many valuable technologies are in the RD&D pipeline. The design and construction of well-performing passive solar buildings have been conclusively demonstrated. Window technology has improved dramatically in recent years as multiple glazings, low-emissivity coatings, and other technologies have penetrated the market: further improvements such as gas- filled[4] glazings are now appearing. Sophisticated lighting controls that integrate artificial lights with daylight are now available commercially. Improved materials and designs are appearing in solar water heaters. These are only a few of the many advances. Some estimate that more than 200,000 residential and 15.000 commercial buildings using passive architecture have been built[5] and 1.8 million solar water heaters have been produced.[6] Although there arc serious market challenges hindering adoption of these technologies. they are now better understood and policies have been developed to deal with them (see box 3-1). Many, however, still primarily remember the frequent overselling of the technology during the 1970s and early 1980s.

| Potential Roles

The residential and commercial sectors use roughly 35 percent of U.S. primary energy and 65 percent of U.S. electricity (see box 3-2). In addition to potential direct energy and financial savings to the building owner,[7] incorporating RETs for space heating and cooling, water heating, and daylighting may shift and or reduce peak loads on utilities, potentially providing important demand-side management (DSM) benefuts and cost savings for the utility. Reducing fossil energy use can also provide environmental benefits.

[4]Including either argon or krypton.

[5]J Douglas Balcomb (cd,), *Passive Solar Buildings* (Cambridge, MA: MIT press. 1992).

[6]Kenneth G. Sheinkoff, *Progress in Solar Energy Technologies and Applications: An Authoritative Review* (Boulder. CO: American Solar Energy Society, January 1994).

[7]Where time-of-use metering is used, the building owner may capture some of the demand-side management peak load reduction benefits.

BOX 3-1: National Policy Influencing Renewable Energy Use in Buildings

Several federal acts currently Influence the use of RETs in buildings Section 912 of the Housing and Community Development Act of 1992[1] established the Solar Assistance Financing Entity (SAFE) to help finance the use of renewable and energy-efficient technologies in buildings. This law also established the energy-efficient mortgage pilot program under sections 513 and 914

The Energy Policy Act of 1992[2] requires consideration of RETs in energy standards for new federal buildings, in residential energy efficiency guidelines, in lighting, and in the energy-efficient mortgage pilot program

Many other programs, including Community Development Block Grants and Comprehensive Housing Assistance Plans, Influence energy use in buildings and might greate greater consideration to RETs in the future

[1] U S Congress House of Representatives *Housing and Community Development Act of 1992* Conference Report 102-1017 (Washington DC U S Government Printing Off Ice, 1992)

[2] U S Congress House of Representatives, *Energy Policy Act of 1992*, Conference Report 102-1018 (Washington DC U S Government Printing Off Ice 1992)

Principal Themes

Three broad themes are addressed in this chapter:

1. the principles and performance of various RETs[8] for heating and cooling, ventilation, lighting, water heating, and other energy needs in new[9] residential and commercial buildings [10];
2. market challenges in the design, construction, sale, and ownership of buildings using RETs, and past experience in addressing these challenges; and
3. policy options associated with further RD&D and commercialization of RETs for buildings.

INTRODUCTION

Renewable energy has been used to heat, cool, and light buildings since humanity first moved indoors. Clerestories[11] were used more than 3,000 years ago by the Egyptians to daylight their temples at Karnak. The Remans designed their buildings with a variety of passive solar features: windows to capture sunlight for heating in the

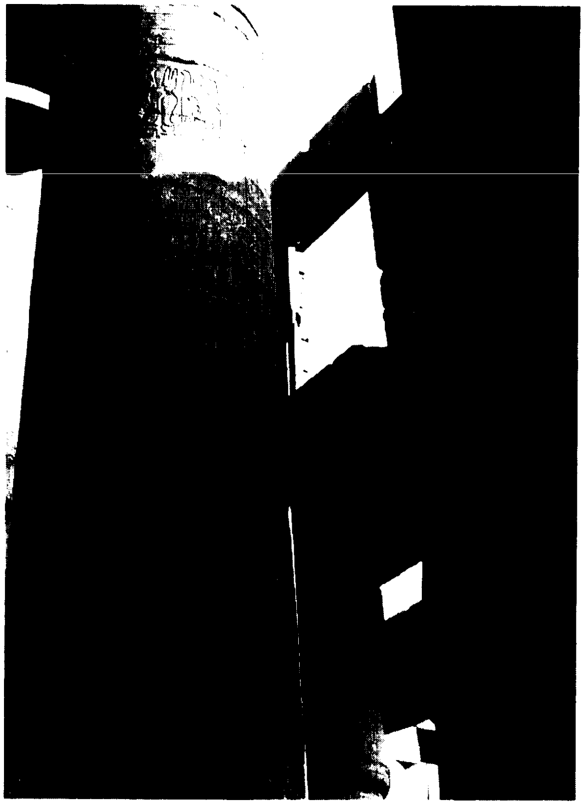
[8]Although the following discussion emphasizes the potential role of renewable energy in buildings, no distinction should be made in practice between the contributions of renewable energy and energy efficiency. Buildings should be designed on an integrated basis, considering all the potential efficiency and renewable energy benefits, and combining them in the most cost-effective and highest architectural- and amenity-value form possible.

[9]Only new construction is examined here. Renewable energy retrofits of existing buildings are also possible, but are often not as cost-effective as designing and building renewable technologies into new construction. Some retrofits, such as cooling load avoidance and ventilation air preheat, may be cost-effective in some cases.

[10]Note that industrial buildings (i.e., where manufacturing takes place) also offer significant opportunities for using RETs to supply space heating and cooling, lighting, and other energy needs. Many of the RETs used in commercial buildings can be adapted to these industrial building applications. Industrial buildings, however, are not explicitly included in the discussion here nor in the summary statistics because the Energy Information Administration separates residential and commercial buildings from industrial energy uses.

[11]*Clerestories* are windows located at the top of high walls and designed to cast light deep into interior spaces.

MARSHA FENN OTA STAFF



Clerestory at the temple of Karnak, Egypt

winter, carefully sized overhangs for shading in the summer, heavy masonry (thermal mass)[12] construction to moderate day-night temperature swings, and clerestories to cast light deep into the building. At the same time, they developed a remarkable body of law to protect citizens' rights to access the sun yet not block their neighbors' access.[13] In Iran, wind towers, the shape of the roof, evaporative cooling, and carefully placed plantings were used to control overheating.[14] Many early Renaissance cathedrals have carefully designed clerestories to provide sufficient light to define the interior without letting in so much light as to cause glare or overheating.[15]

These same elements—siting, landscaping, proper placement and design of windows, overhangs, clerestories, thermal mass, and others—are characteristic of solar architecture today (see figure 3-2), and can be adapted to a wide variety of architectural styles. With modern materials and design tools, these solar architectural techniques have become much more effective.

The processes of solar heating, ventilation, thermal storage, evaporation, and radiative cooling occur naturally in buildings. The way we design and position our buildings, size and orient their windows, and landscape the property all impact these energy flows. Thus, the question is not whether renewable energy can influence fossil energy consumption in our homes and offices-it already does. The question is whether energy flows are allowed to cause problems such as overheating and glare or are employed instead to deliver useful services. Achieving this goal requires careful tradeoffs between a variety of design parameters. Thoughtful, balanced design can provide substantial financial, energy, and aesthetic benefits; poor design or overreaching to reduce conventional energy use can increase costs and decrease building comfort and performance.

Historically, buildings were designed for the local climate and natural daylighting. Many were, however, uncomfortable and poorly lit due to insufficient design knowledge, lack of insulation, and low-quality windows. Then, plentiful and inexpensive supplies of fossil fuels and electricity provided architects a degree of freedom they had never before known (and habitants a degree of comfort never before experienced), Building designs gradually changed to reflect abstract visions rather than the reality of the local climate. Energy use for heating, cooling, and lighting buildings increased accordingly. The first oil crisis of 1973 re-

[12] Thermal mass means the heat storage capability of a material multiplied by its mass (weight). A wood frame wall has a low heat storage capacity, whereas a solid masonry wall has a high heat storage capacity.

[13] Dian Favro, "Roman Solar Legislation," *Passive Solar Journal*, vol. 2, No. 2, 1983, pp. 90-98.

[14] Mehdi N. Bahadori, "Passive Cooling Systems in Iranian Architecture," *Scientific American*, vol. 238, 1978, pp. 144-154.

[15] Richard G. Stein, *Architecture and Energy* (Garden City, NY: Anchor Press, 1978).

BOX 3-2: Energy Use in Buildinç

Energy use in buidings has changed substantially in both form and function during the past several decades Primary[1] energy use in residential and commercial buildings totaled 29 exajoules in 1990 (figure 1-11 in chapter 1) Of this, about one-half went to space heating and cooling, one-fifth to Iightlng, and one-tenth to water heating (figure 3-3) These proportions change significantly with the type of building, its use, and its occupants Total buiding energy use in the United States has Increased (figure 3-4)—there are more people, more households, and more offices-while energy use per unit area (commercial) or per person (residential)[2] has roughly stabilized over the past decade due to a variety of efficiency Improvements The sources of energy have changed dramatically Use of fuel 011 has dropped since the 1973011 embargo, and natural gas has largely made up the difference (figure 3-4) At the same time, new loads have appeared Electron/c office equipment has sharply Increased plug loads[3] in commercial buildings[4] and programs such as the “Energy Star Computer” have been launched in response Utility demand-side management programs are gaining momentum as they grapple with peak loads due to air conditioning during summer heat waves, as well as try to reduce overall consumption Building energy use will continue to change due to technological advances, population growth, economic growth, demographic changes, and many other factors, perhaps including global warming

[1] This breakdown assigns generation transmission and distribution losses Incurred by the electricity sector proportionately to the end use that actually consumed the electricity

[2] Residential energy use dropped about 20 percent between 1972 and 1982 and has since roughly stabilized

[3] These are loads on wall outlets due to plugging in computers, printers, photocopiers, fax machines and so forth These loads are distinct from lighting loads which are wired into place when the building is constructed

[4] L Norford et al Electricity Use in Information Technologies " *Annual Review of Energy,* vol 15, 1990 pp 423-453

versed that trend and generated a wave of interest in again using renewable energy to heat, cool, and light buildings: that reversal lasted little longer than high oil prices.

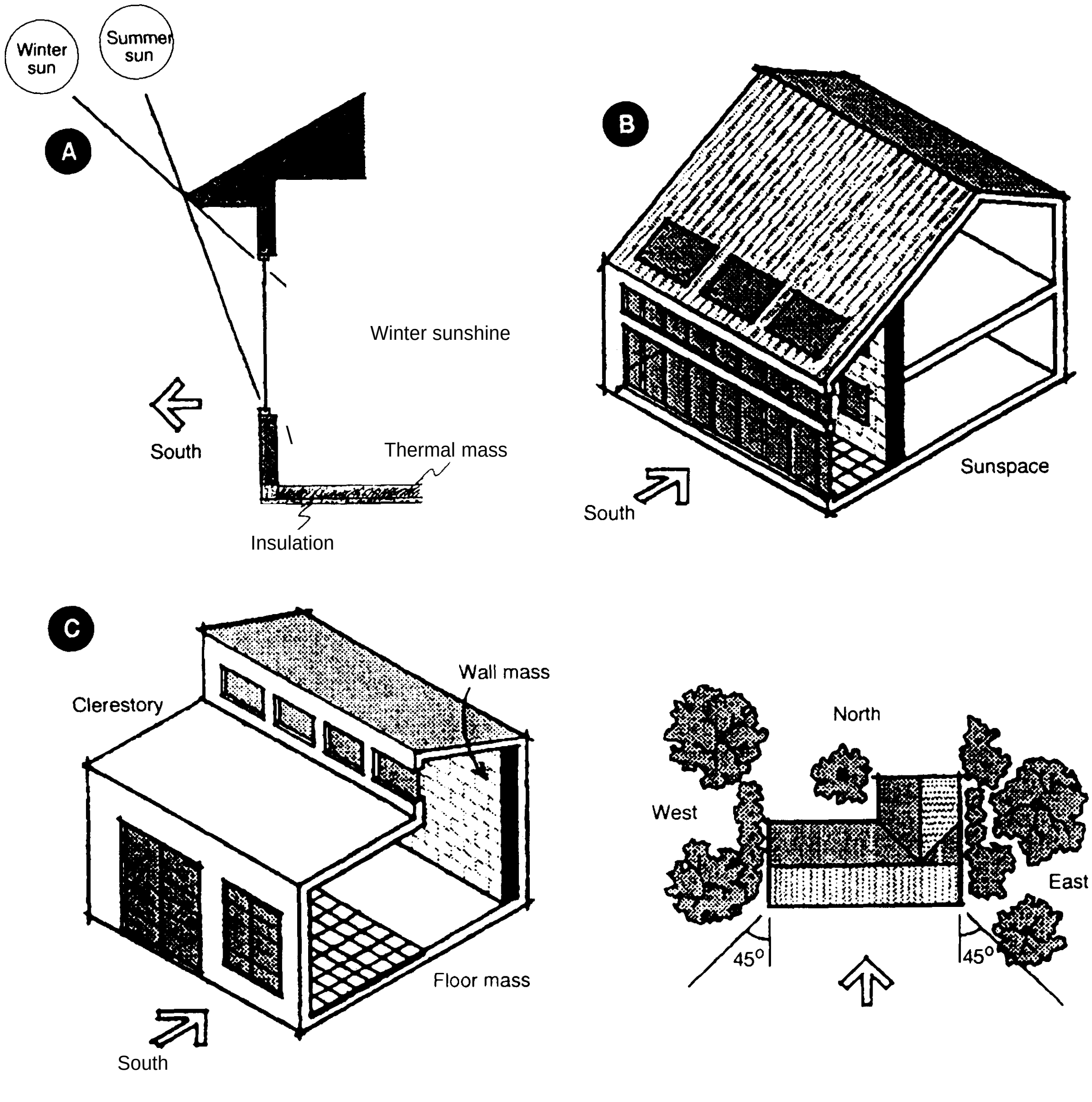
RENEWABLE ENERGY TECHNOLOGIES

The total energy performance of a building is a complex process, dominated by the continuous interaction among the building's internal sensible and latent[16] heat gains and losses, solar inputs, thermal storage, radiant heat transfer, and air movement: the external environment; and other factors. Conventional space conditioning systems have been designed simply to overpower the natural forces both heating and cooling our buildings, resulting in considerable expenditures for equipment and fuel. The process of maintaining a comfortable environment efficiently is a more subtle and site-specific undertaking.

Renewable energy technologies for buildings take several approaches in providing energy services. Generally the most cost-effective RETs for space heating, cool ing, and lighting are passive architecture and daylighting. These strategies use the building itself—walls, windows. overhangs, thermal mass—to capture. store, and distribute renewable energy. This approach requires careful design but uses little or no additional material—hence its frequent cost-effectiveness. Active systems use discrete collectors on the roof or near the building to capture sunlight and pipe the energy where it can heat the building (or domestic hot wa-

[16] Sensible heat is what we physically feel when we touch a hot object: latent heat is the energy required to evaporate a quantity of water. As used here, latent heat refers to the large amount of moisture or humidity that can be exchanged among a building's materials, indoor air, and the outside. High levels of humidity contribute substantially to occupant discomfort and increase building cooling loads.

FIGURE 3-2: Principal Design Elements of Passive Solar Architecture



NOTE: A. Solar architecture uses windows to capture sunlight for winter heating, carefully sized overhangs for summer shading, and in some cases, thermal mass (bricks, masonry) to moderate day-night temperature swings. B. Sunspaces provide passive solar heating and bright living space. C. Clerestories contribute to lighting and winter heating. D. Trees and other landscaping can shade east and west windows from summer sun.

SOURCE: Adapted from Passive Solar Industries Council and National Renewable Energy Laboratory, *Passive Solar Design Strategies: Guidelines for Home Builders* (Washington, DC and Golden, CO: 1991).

BOX 3-3: Additional Renewable Energy Technologies

A variety of other renewable energy technologies can provide useful energy services for buildings but have not been considered in detail in the course of this assessment. These Include wood heating and geothermal heat pumps

Wood Heat

Wood heating can be cost-effective where low-cost, reliable sources of wood are used 117 well-designed and well-built wood stoves Domestic wood stoves can, however, produce relatively high levels of smoke that may lead to local air pollution Catalytic combustors have reduced this air pollution problem while generally Increasing stove efficiencies

Geothermal Heat Pumps

Most heat pumps use air as a heat source or sink. The problem with this is that when heating or cooling is needed the most, the air is at its coldest or hottest which makes the air-coupled heat pump work harder and reduces its efficiency [1] Geothermal heat pumps, however are coupled to the relatively constant ground temperature by long pipes in the ground to collect heat for heating or to cool the fluid in the pipes for air conditioning The moderate ground temperatures allow geothermal heat pumps to run more efficiently typically using about two-thirds as much electricity as standard air-coupled heat pumps and less than half as much as an electric resistance heater combined with a conventional air conditioner Burying the pipes does cost more however and simple payback times for this additional cost are typically on the order of six years.

[1] It may, in fact, be cut out at times and electric resistance heating used as backup

ter) or drive a cooling systcm. These systems are cost-effective only in particular circumstancres because of the large quantities of expensive add-on materials required. Of increasing interest systems that are integrated into the building shell itself, including ventilation air preheat and photovoltaics. By integrating these systems into the building, the amount of epensive add-on material required can be minimized and the system made more cost-effective. Othcr RETs are discussed in box 3-3.

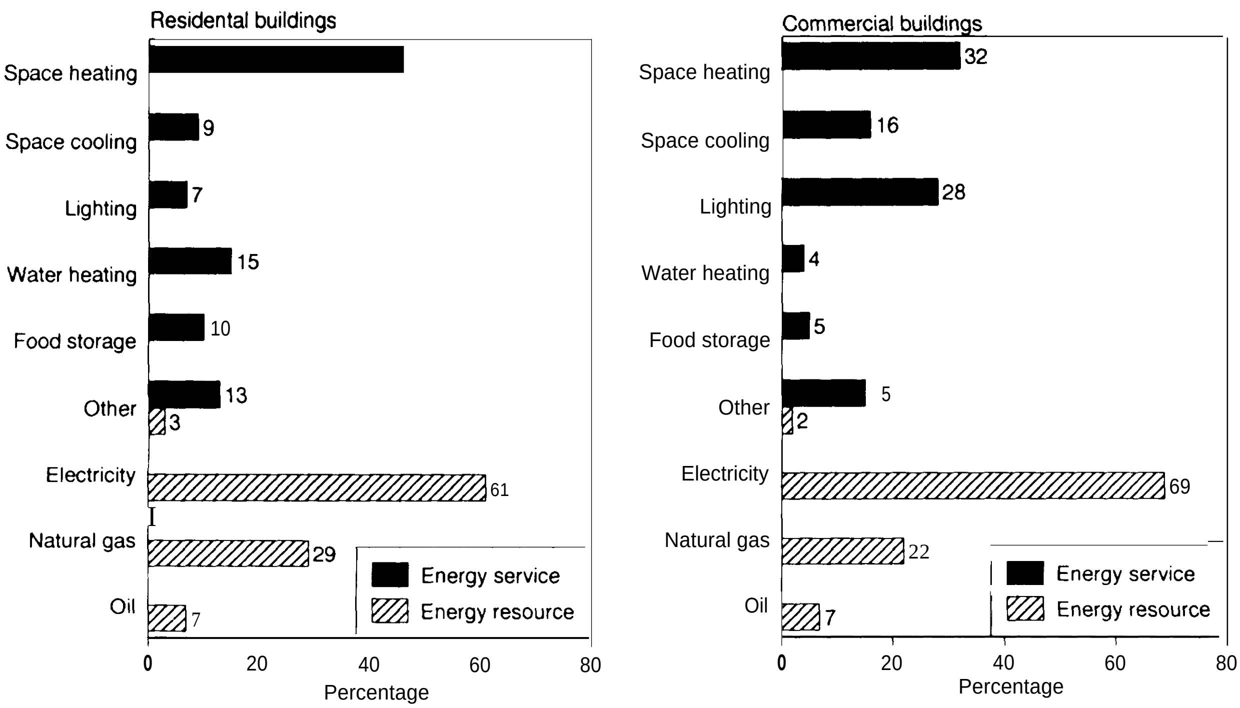
Because the environment, construction, usage, and energy demand patterns for buildings differ (see figure 3-3), renewable strategies tend to be context -dependent: a strategy designed for a building used for manufacturing may not be applicable in a comparably sized and built adjacent warehouse. Similarly, a RET strategy used for a small office building may not be applicable in a nearby residence. These energy use patterns have also changed significantly over time, particularly with increasing use of electricity (see figure 3-4).

Passive Architecture[17]

Renewable energy technologies to provide space heating, cooling, ventilation, and lighting energy services can take many forms in residential and commercial buildings. Passive heating and cooling technologies use the building itself to capture sunlight for heat and/or light and to reject heat from the building. This includes windows to let in

[17] For reviews of passive architecture, see Bruce Anderson (ed)., *Solar Building Architecture* (Cambridge, MA: MIT Press, 1990); Jeffrey Cook (ed.), *Passive Cooling* (Cambridge, MA: MIT Press, 1989); Balcomb (ed.), op. cit., footnote 5; American Solar Energy Society, "Proceedings of the National Passive Solar Conferences," various years; and references therein.

FIGURE 3-3: Energy Services and Supplies in U.S. Residential and Commercial Buildings



NOTE: Energy use by particular buildings varies greatly by the type of building, occupancy region, climate, and many other factors

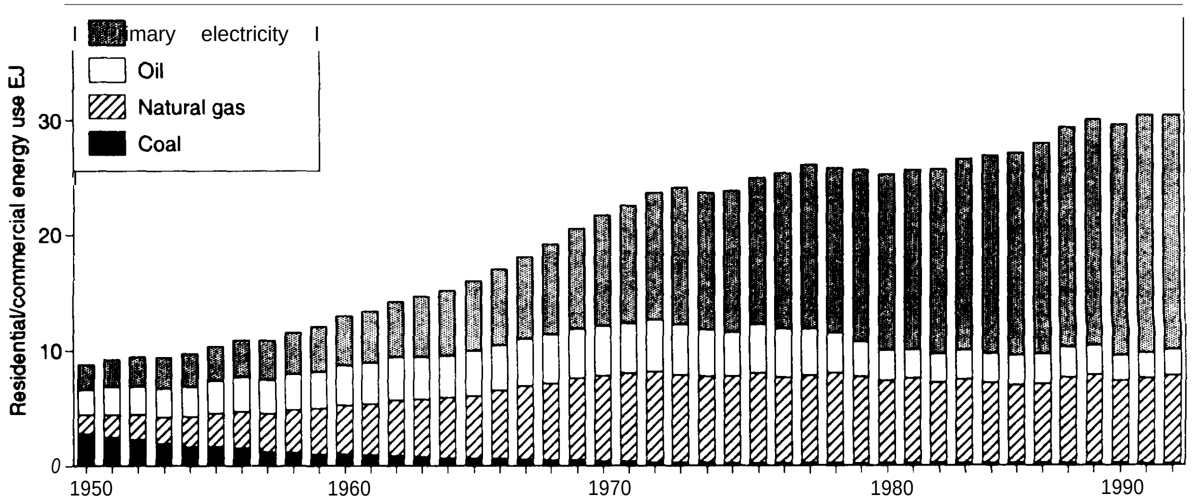
SOURCES: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1992*, DOE/EIA-0384(92) (Washington, DC: June 1993); and U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518 (Washington, DC: U.S. Government Printing Off Ice May 1992)

light for both heating and lighting; overhangs to block the summer sun and minimize cooling requirements, ventilation to reject unwanted heat or provide fresh air, and thermal mass such as bricks or concrete to store heat for use (winter) or to absorb heat for removal (summer) at some other time during the day.

Window technology and placement are critical for capturing solar energy in the winter and rejecting it in the summer; improvements in window technology over the past decade allow this to be done much more effectively than in the past (see box 3-4). Once the window captures heat, thermal mass [18] and interior air movements determine how effectively this heat is used. In recent years, passive design has emphasized "sun-tempering," which rearranges windows in the building to improve solar gain and lighting but (over the entire building) may require little additional window area and little or no additional thermal mass. This avoids the cost of adding thermal mass; it also reduces design complexity by avoiding the difficulty of properly coupling incoming sunlight to the thermal mass. Most conventional construction, in fact, has moved toward the use of lighter weight materials. Even traditional elements such as brick fireplaces are today commonly made of metal with a relatively lightweight brick veneer over it

[18] Thermal mass can moderate interior temperature swings.

FIGURE 3-4: Total Energy Use in U.S. Buildings, 1950-92, by Energy Supply Type



SOURCE: U.S. Department of Energy, Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384(92) (Washington, DC: June 1993)

to provide the appearance of solidity; this type of construction reduces the usefulness of a fireplace as thermal mass.

As south-facing window area is increased, more sunlight is admitted into the space and the use of thermal mass gradually becomes more important to minimize overheating and moderate day-night temperature swings. Overheating and glare were frequent complaints in early passive homes, but they can now generally be avoided with proper design.

These same architectural elements can provide summer cooling. Overhangs[19] can shade south-facing windows from the summer sun, thermal mass can moderate temperature swings and can be used to absorb heat during the day for release outside at night,[20] and properly sited operable windows and open floor plans can provide effective cross ventilation. Other techniques used include shading by properly placed and selected trees or other landscaping, night cooling,[21] and others. In the dry Southwest, evaporative cooling can be effective and has long been used;[22] for the humid Southeast, desiccant moisture removal systems are being developed because moisture removal is a prime problem.[23]

A key element in cost-effectiveness for these technologies is to employ the same elements normally used to construct a building, but configure

[19] Including awnings and trellises.

[20] This will generally be accomplished with ventilation at night to circulate cooler night air.

[21] This can include ventilation with night air or radiation to the night sky—both coupled to thermal mass (including earth coupling) to remove heat absorbed by the thermal mass during the day.

[22] As the name implies, evaporative cooling uses the evaporation of water to absorb heat and cool the air. When the cooler, more humid air is discharged directly into the living space, the system is often known as a "swamp chiller." Alternatively, heat exchangers can be used, with the humidified air blown outside after it first cools off dry interior air via a heat exchanger. This prevents excessive moisture input into interior spaces.

[23] Desiccant removal systems use drying agents to absorb water from the interior air and then use solar energy to heat the agent and drive off the moisture, releasing it to the outside.

BOX 3-4: Advanced Window Technologie

Approximately 15 exajoules (EJ) of primary energy are used annually to heat and cool buidings; roughly one-quarter of this energy demand due to undesirable heat losses or gains through windows,[1] When the first 011 crisis occurred in 1973, approximately 70 percent of new windows sold in the United States were single glazed with an insulating value of R-1 [2] If an average building life of 40 years is assumed, such windows would result in the lifetime loss of more than 100 EJ worth more than $1 trillion [3] Following the first energy crisis, changes in building codes and other factors resulted by 1990 in the market shifting largely (80 percent) to double-glazed windows with an insulating value of R-2 Such windows cut energy loss in half.

Beginning in 1976, researchers at Lawrence Berkeley Laboratory began work to Improve window performance Low-emissivity (low-E) windows with special coatings to reduce heat loss were their first major focus The $2-million federal Investment leveraged some $100 million in private Investment in low-E film production technology,[4] This work produced windows with a thermal resistivity of R-3, and with low-conductivty gases, R-4, with energy savings of two-thirds and three-quarters, respectively, compared with single-glazed windows The first significant sales of low-E windows occurred in 1984 following a variety of ongoing federal supports and outreach to manufacturers; they now account for one-third of residential window sales A number of other technologies have been developed subsequently and are now in various stages of commercialization, Transparent insulation and electronically controlled coatings[5] are under development and promise substantial further Improvements in window performance,

In parallel, Lawrence Berkeley Laboratory has developed a computer design tool called Window 4.0, more than 3,000 copies have now been distributed. It is used extensively by manufacturers to design more energy-efficient windows and by Industry for the window rating and labeling system.

[1] R Bevington and A Rosenfeld, "Energy for Buildings and Homes, ' *Scientific American*, vol 263, No 3, September 1990, p 80

[2] R-1 refers 10 the resistance to heat flow, R-1 is a resistivity of 1 square foot-hour-°F/Btu

[3] This assumes that 70 percent of the windows of the total building stock are single-glazed, in fact. the fraction that was single-glazed at that time was likely to be significantly higher The dollar value is basedon the overall energy costs for buildings, the fraction of energy use lost by windows, and a 40-year building life

[4] Howard S Geller et al "The Importance of Government-Supported Research and Development in Advancing Energy Efficiency in the United States Buildings Sector" *Electricity Efficient End-Use and New Generation Technologies, and Their Planning Implications*, Thomas B Johansson et al (eds) (Lund, Sweden Lund University Press, 1989)

[5] Electrochromic windows Researchers are also examining thermochromic (responsive to temperature) and photochromic (responsive to light) coatings

them in ways that better control natural energy flows. Thus, windows on the east and west side are minimized-they tend to provide little net winter heat but significant summer overheating—and the equivalent window area is moved to the south side where it can provide winter heating. A fireplace might be positioned so that it receives direct sunlight in the winter and thus can provide some thermal mass benefits. Passive design must **be** used in conjunction with a full complement of cost-effective energy efficiency techniques, careful siting and landscaping, and other aids. These design techniques are subtle, but effective.

Passive heating, cooling, and lighting (see below) require careful and sophisticated architectural design; they are design-intensive rather than material-intensive. The development, testing, and distribution of effective computer design tools and the provision of additional supports at the design stage may therefore be important for effective and widespread use of these technologies.

In some circumstances, however, the careful "tuning" of passive design performance may also cause difficulties. For example, passive solar and daylit designs may sometimes be less amenable than conventionally heated buildings to subsequent modifications to suit the tastes of new owners. New owners of passive homes have sometimes covered interior mass floors with carpet, mass walls with wallboard, or made other changes that reduced the effectiveness of carefully tuned interior designs. Similarly, offices may raise existing or build new walls to increase worker privacy that at the same time disrupt the natural flow of solar heated air through the building or block daylight. On the other hand, unlike conventional structures, passive buildings can often remain habitable (and are less susceptible to freezing damage) during power and fuel disruptions in severe cold or hot spells. Further, passive design features do not generally wear out the way conventional heating, cooling, or lighting equipment does.

Properly designed and built, the reduction in heating and cooling loads made possible through passive solar design can allow conventional heating and cooling equipment to be downsized, in part offsetting any additional cost of RETs. Overall cost and performance results from a number of case studies of carefully monitored buildings across the United States are shown in figure 3-1. These buildings demonstrated significant energy savings, averaging roughly 50 percent energy savings for efficiency and renewable energy contributions combined, compared with conventional designs, and at relatively little increase in construction cost. The overall cost of saving energy by using these technologies is substantially lower than current or projected costs of conventional fuels, as indicated in the example supply curve of figure 3-5. These opportunities can be found throughout the United States and offer prospective owners of new residential and commercial buildings large cost and energy savings.

Daylighting[24]

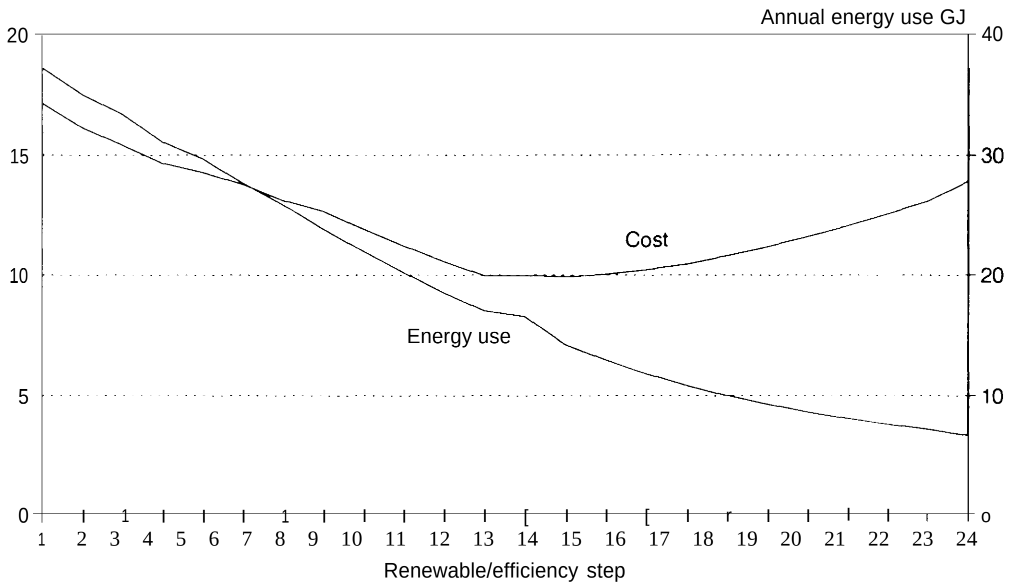
Daylighting is the process of letting light in from the outside and integrating it with interior electric lighting (o provide high-quality, glare-free, lowl-energy-use lighting for occupants. This includes adding high windows, clerestories, and skylights or roof monitors to cast light deep into the building's interior: atria to provide lighting in the core of a large building: and appropriately placed walls, screens, reflectors, and luminaires to diffuse daylight.

Both direct and diffuse sunlight can be used for daylighting. Direct sunlight is highly directional, very intense, and often variable from moment to moment (e.g., as clouds pass by). It is used for dayligh only after it has been diffused by passage through a diffusing window or fixture or after it has been reflected off an interior (nonmirror) surface. Direct sunlight may also be used for interior spaces where light must be "piped" in.[25] Diffuse sunlight is light that has been scattered by the atmosphere and comes from the entire sky. Although it is less intense than direct sunlight, it is much less directional and variable from moment to moment. Daylighting strategies often rely more

[24] See, e.g., J. Douglas Balcomb, "Daylighting," ISPRA Course on Passive Solar Technologies for Buildings in Mediterranean Climates, Kefalonia, Greece, Oct. 17-21, 1988; C. Ben[on et al., Lawrence Berkeley Laboratory, "Control System Performance in a Modern Daylighted Office Building," LB L-3061 1, October 1990; D. Arasteh et al., Lawrence Berkeley Laboratory, "Cooling Energy and Cost Savings with Daylighting in a Hot and Humid Climate," LBL- 19734, July 1985; and G. Sweitzer et al., Lawrence Berkeley Laboratory, "Effects of Low-Emissivity Glazings on Energy Use Patterns in Nonresidential Daylighted Buildings" LBL-2 1577, December 1986. Extensive literature on daylighting can be found m American Solar Energy Society, op. cit., footnote 17. For practical hands-on guides. see, e.g., Wayne Place and Thomas C. Howard, North Carolina Alternative Energy Corp., "Daylighting Multistory Office Buildings," 1990; and Wayne Place and Thomas C. Howard, North Carolina Alternative Energy Corp., "Daylighting Classroom Buildings," 1991.

[25] If not diffused by a diffusing window, fixture, or reflector, direct sunlight tends to be used sparingly and then primarily to accent Internal design. In this context, note that simply allowing light in from large expanses of glass on modem office facades can result in glare and require high levels of artificial light as a counterbalance.

FIGURE 3-5: Representative Building Energy Supply Curve



NOTE: Estimated life-cycle cost and energy use are shown for a series (1-24) of renewable energy and energy efficiency improvements in a residential building in Albuquerque, NM, using electric resistance heating. Improvements include increases in wall, ceiling, and perimeter insulation (steps 1-5, 13); higher quality windows (steps 6-7, 14, 24); and increases in window area, placement, and associated features (8-12, 15-23). At roughly steps 12-13, life-cycle costs reach a minimum, with energy use about half the base case electric resistance heated household. The cost of saving electricity varies from around 8¢/kWh at step 2, to 4¢/kWh at step 12, to 75¢/kWh at step 24. A similar analysis for natural gas shows a supply curve that is nearly flat to steps 12-13—i.e., gas and solar heating cost the same at current low gas prices—and then becomes more expensive for solar heating after step 13. In this case, although solar heating does not have a decisive direct cost advantage over low-cost natural gas, it does reduce exposure to the risk of future gas price increase, will improve building habitability during cold spells if gas is cut off, and reduces environmental impacts.

SOURCE: Adapted from Robert W. Jones et al., "Residential Energy Standards for New Mexico," Seventeenth National Passive Solar Conference, Cocoa Beach, FL, June 13-18, 1992.

heavily on diffuse sunlight because of its higher lighting quality and stability.

Because daylight provides more visible light than heat compared with artificial lighting, it can also reduce air conditioning loads.[26] Overall, the energy savings from daylighting strategies is heavily dependent on the relationship between lighting and cooling electricity saved, or additional heating energy consumed. This relationship va-

[26]Diffuse sunlight is roughly twice as efficient as standard fluorescent bulbs and nearly six times as efficient as incandescent bulbs in terms of lighting service per unit thermal input into the building. Thus, admitting 1 watt of diffuse sunlight can allow a decrease in the fluorescent lighting load by 2 watts, and also decrease the air conditioning load by 0.5 watts (if a coefficient performance of 2 is assumed), for a net savings of 2.5 watts of electricity per watt of sunlight. This benefit is decreasing as artificial lighting becomes more efficient and lighting design reduces unnecessarily high lighting levels.

ries widely from region to region and from building to building within regions.[27]

Daylighting is of particular interest in office buildings where lighting is a very large energy demand; internal heat gains predominate so that cooling is needed over much of the year (and so daylight can reduce cooling loads); and architecture has already moved toward glass exteriors and interior atria.[28] Daylighting is also of great interest for schools. Properly designed, daylighting can provide 50 to 75 percent of the light needed during daytime hours. Daylighting must be integrated with heating and cooling design elements to achieve optimal overall performance. Windows used for day lighting can be placed to provide passive solar heating in the winter and to avoid summer solar gains. Controls to dim or turn off artificial lights are usually required to achieve the full potential savings of daylighting.[30]

Solar Water Heaters

Solar water heaters use panels or tanks exposed to the sun to warm water for domestic or service use (solar domestic hot water, SDHW)[31] or for swimming pools.[32] Early adoption was fueled by a number of forces, including emerging environmentalism, fear of high fuel prices, and government tax credits. With the expiration of the federal tax credit in 1985, the solar thermal (including the solar water heater) market experienced considerable downsizing, from 225 manufacturcrs in 1984 to 98 in 1986 and 45 today.[33] Overall, an estimated 1.8 million systems have been produced since the 1970s.[34]

Solar pool heaters are a low-temperature application, typically operating around 80°F (27°C), and thus can be quite efficient without using an insulating glass or plastic cover, or other insulation. This allows them to be very low cost with average wholesale prices in 1992 of $27/m^2 ($2.50/ft^2).[35] Solar pool heaters are cost-effective over a fairly wide range of conditions and have developed into a significant market. Sales increased 11 percent from 1991 to 1992 and accounted for nearly 90 percent of the solar thermal collector market.[36]

SDHW is a medium-temperature application. typically operating around 120°F (50°C). These temperatures require insulating glass or plastic

[27] The relationship between cooling and heating loads depends dramatically on the length and severity of the heating and cooling seasons. The length of these seasons for a particular building depends on the assumed base case amount of heat that is generated within the building (e.g., by people, lights, and computers) and the degree to which this amount is changed by decreasing the lighting load. Thus, daylighting would save proportionately more energy in a densely packed office building or restaurant, with large internal heat gains and a long cooling season, than in a warehouse, with little internal gain and a shorter cooling season.

[28] Balcomb, op. cit., footnote 24.

[29] Mike Nicklas, Innovative Design; J. Douglas Balcomb, National Renewable Energy Laboratory; and Mark Kelley, Building Science Engineering, personal communication, Apr. 13, 1994.

[30] In general, however daylighting is desirable where it can provide superior lighting for a large portion of the time. Otherwise, daylighting does not become the norm and people override the lighting controls too frequently. Nicklas, op. cit., footnote 29.

[31] This refers to hot water used for household purposes (e. g., washing and bathing).

[32] Solar water heaters can be either passive, in which the flow of water (or other fluid) is driven by natural temperature differences generated by solar heating, or active, in which the flow of water (or other fluid) is driven by an electric pump powered by the utility grid or by an adjacent photovoltaic system.

[33] Downsizing actually began in 1979, but experienced its biggest jump between 1984 and 1986. U.S. Department of Energy, Energy Information Adminstration, *Solar Collector Manufacturing Activity 1992*, DOE EIA-0174(92) (Washington, DC", November 1993).

[34] Sheinkoff, op. cit., footnote 6.

[35] Energy Information Administration, op. cit., footnote 33.

[36] Total solar thermal collector shipments in 1992 were about 7 million square feet.

covers, side and back insulation, and other techniques to reduce heat loss and improve efficiency.[37] The greater material intensity and complexity of these collectors raise wholesale prices for the collector alone into the range of \$100/m2 (\$1 0/ft^2).[38] Overall costs are typically in the neighborhood of \$200/m^2 for all of the hardware, \$ 100/m2 for installation, and up to \$300/m^2 for overhead, profit, and marketing costs.[39] This gives a total installed cost in the range of \$300/m^2 to \$600/m^2 (\$30/ft^2 to \$60/ft^2).[40] Typical systems are *4* to 8 m^2 in area, depending on the climate, and deliver roughly 30 to 40 MJ/day of energy. This is equivalent to about 8 to 12 kWh of electricity with a value of \$0.80 to \$1.20/day at high electricity rates.[41] The simple payback may then be as low as six years in some select areas compared with electric water heating,[42] but it is not generally cost-competitive compared with natural gas systems at current prices.[43]

Large-scale production and installation of solar water heaters might allow significant price decreases through economies of scale and learning and by reducing marketing and other overheads. Although there are enough cost-effective uses of SDHW to justify large-scale manufacturing and installation, the market has been slow to develop due to a variety of market challenges.

Sola water heaters may also sometimes be made more cost-effective by considering their use in utility demand-side management (DSM) programs. Although water heating is a large energy demand (see figure 3-3), utility DSM programs must instead focus on the extent to which water heating contributes to the utility's peak electricity demand; this varies by region and time of year. As an example of it not being cost-effective, studies by Florida Power and Light found that electric water heaters only contributed an average of about 0.2 kW each to the peak load. Overall program costs and ratepayer impact concerns then made solar water heater DSM investment incentives not cost-effective (see box 3-5).

In areas with large coincident peaks between electric water heating loads and utility loads, utility incentives for SDHW systems may be cost-effective.[44] In response to this DSM opportunity, Edison Electric Institute, the American Public Power Association, and the Department of Energy established the Utility Solar Water (USH$_2$0) Program to assist in the development and expansion of utility programs for residential and commercial solar water heating. The intent is both to reduce utility demand in regions where the SDHW option is cost-effective and to aggregate markets for SDHW so as to allow manufacturing and installation scaleup and thus help drive costs down.

As with passive systems, the cost-effectiveness of SDHW might be assisted by developing de-

[37] These include spectrally selective absorber surfaces and vacuum jackets.

[38] Energy Information Administration, Op. cit., footnote 33.

[39] Henry (Greg) Peebles 111, American Energy Technologies, Inc., personal communication, May 26, 1994.

[40] In Comparison, one manufacturer estimated costs t. be typically 25 percent for the collector and related hardware, 25 percent for marketing and advertisement, 15 percent for installation, and 35 percent for overhead and profit.

[41] This ignores storage losses and the value of the electric water heater tank, and assumes a high value of 10¢/kWh for residential electricity.

[42] This assumes the higher cost of \$600/m^2 for a smaller 4 m^2 system installed in a favorable climate, a high level of del ivered energy, and high electricity rates.

[43] Batch and thermosyphon water heaters are particularly cost-effective, in Some cases even when measured against natural gas.

[44] See e.g., Clifford S. Murley and Donald E. Osborn, "SMUD's Residential and Commercial Solar Domestic Hot Water Programs," paper presented at the American Solar Energy Society Solar 94 Conference, San Jose, CA, June 1994. A detailed study across the entire United States found a wide variation in coincidence between hot water demand and utility loads, ranging from 12 to 78 percent in the summer to O to 36 percent in the winter, depending on the region. See S.F. Ahmed and J. Estoque, *Solar Hot Water Manual for Electric Utilities: Domestic Hot Water Systems*, EPRI EM-4965 (Palo Alto, CA: Electric Power Research Institute, December 1986).

BOX 3-5: Consideration of Solar Water Heaters as a DSM Measure by Florida Power and Light[1]

Florida Power and Light (FPL) began prowding front-end payments of up to $400 for solar domestic water heaters (SDHW) in 1982 Installations under this program grew steadily to almost 14000 in 1985 before collapsing to less than 1,000 by 1987 when federal tax credits were withdrawn Overall FPL provided support for almost 41,000 solar water heaters between 1982 and 1990

In response to the Florida Public Service Commission, FPL developed a demand-side management plan in 1990 On reviewing the payment for domestic solar water heaters, FPL found that, in fact, there were benefits of only 75@ for every dollar spent The reason was that few people took hot showers in the late afternoon when FPL experienced its peak electricity demand, so substituting SDHW reduced the peak load little and saved FPL little Investment On the other hand during off peak times, electric water heaters consumed large amounts of power --1 ,500 kWh per year—and so contributed substantially to FPL revenues

Despite these results, FPL ultimately petitioned the Commission to continue its SDHW Incentive payment program because of FPLs concern that many of the benefits of renewable (e g , environmental benefits, fuel diversity, continued support for the embryonic solar Industry) were not captured in the cost-benefit analysis

At the same time, FPL discovered in its review of the SDHW program that swimming pool pumps had a high load during the late-afternoon peak period Subsequent analysis found that photovoltaic-powered pool pumps had a benefit-cost ratio of 1 2 (i.e., 20 percent net benefits) An Incentive program for photovoltaic-powered pool pumps is now under study.

[1] Steven R Sim Residential Solar DSM Programs at Florida Power and Light " *Solar Age* September-October 1991 pp 23-25

signs that are integrated into the building shell, reducing overall material and construction requirements. Homeowner costs may also be reduced by incorporating the costs of the system into the home mortgage—amortizing SDHW costs over 30 years and allowing interest charges to be deducted from tax payments.

Active Space Heating and Cooling[45]

Active space heating and cooling systems use discrete solar collectors—large panels glazed with glass or clear plastic---on the roof or beside the structure to capture sunlight and pipe the energy where it can heat a building or drive a cooling system.

Active space heating and cooling systems are cost-effective for only a 1 imited range of applications.[46] The primary difficulty with active systems is that large costly areas are required to collect the relatively low-energy-intensity solar resource. It is difficult to do this cost-effectively with discrete dedicated material- and labor- intensive collectors. In contrast. the cost-effectiveness of passive architecture is largely the consequence of being able to use elements of the building it-

[45] For classic descriptions of active systems, see John A. Duffie and William A. Beckman, *Solar Engineering of Thermal Processes*, 2nd Ed. (New York, NY: John Wiley & Sons, 1991); and Bruce D. Hunn et al. (eds.), *Engineering Principles and Concepts for Active Solar Systems* (Golden, CO: Solar Energy Research Institute, July 1987).

[46] U. S, Department of Energy, "Renewable Energy Technology Evolution Rationales," draft, Oct. 5, 1990; and American Solar Energy Society, *Progress in Solar Energy Technologies and Applications: An Authoritative Review* (Boulder, CO: January 1994).

self—at little or no additional material or labor cost—to perform the collection function.

Several recent efforts have focused on reducing the material intensity of active solar systems by integrating the collector into the building shell. For example, solar collectors are being developed that heat ventilation air before it enters a building.[47] These collectors form part of the building wall. Because ventilation air is a low-temperature application (roughly 65° to 70°F) and because air is pulled through the collector to the inside (minimizing heat losses), glass or plastic covers are not needed for insulation as is common for somewhat higher temperature applications (such as solar domestic hot water heaters). These factors minimize the use of additional materials. At the same time, low temperatures also mean that these systems can be relatively high inefficiency. This technology received one of the prestigious R&D 100 awards from *Research and Development* magazine for 1994. Ventilation preheat may become a more important consideration as new air quality standards for buildings are implemented,[48] and these technologies appear likely to be cost-effective in some colder climate applications.

Landscaping and Tree Planting[49]

The summer and winter temperatures of urban areas tend to be higher than rural surroundings because asphalt, concrete, and other construction materials absorb and hold large amounts of heat, and because there is little vegetation for shade or to transpire moisture and thus lower urban temperatures.[50] In some cooling-dominated climates, shading and reflective surfaces may help cool buildings.[51] For example, the National Academy of Sciences estimates that planting trees and lightening the color of roads and buildings could reduce U.S. air conditioning use by about 25 percent.[52] Likewise, absorptive surfaces and properly designed landscaping can help reduce heating requirements in other areas.

In response to this opportunity, several tree planting programs have recently been initiated or considered, including utility demand-side management programs. Little is known at this point about the overall cost-effectiveness of these efforts.[53] Balancing the potential energy and peak electric capacity savings (which require further research themselves) are outreach, planting costs, maintenance, water use, risk of loss of trees, and other factors. In addition, there are concerns about root growth into sidewalks, sewers, and foundations, among other issues. The location of trees around a house and in any urban environment must be carefully considered so as to help rather than hinder passive performance in all seasons.

47 Charles F. Kutscher and Craig B. Christensen, "Unglazed Transpired Solar Collectors," *Advances in Solar Energy*, Karl W. Boer (cd.) (Boulder, CO: American Solar Energy Society, 1992); and Charles E. Kutscher, "Unglazed Transpired Solar Collectors," *Solar Today*, August 1992, pp. 21-22.

48 In the past, ventilation air heating was generally not a separately identified load. Over the past two decades, however, residential and commercial buildings have been made substantially more airtight in order to increase efficiency; consequently, ventilation air heating is becoming a more identifiable load. With new concerns over air quality and higher ventilation rates under American Society of Heating, Refrigeration, and Air Conditioning Engineers's new standards, ventilation air heating is likely to become an important energy demand and may account for roughly 5 to 15 percent of building energy demand.

49 U.S. Environmental Protection Agency, *Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored surfacing* (Washington, DC: 1992).

50 Urban heat island effects may, however, benefit winter heating. On the other hand, trees can provide important wind shielding from winter winds and reduce building heat loss, but winter shading even by bare branches can reduce winter heat gain substantially.

51 Care must be taken, however, that light surfaces do not reflect into adjacent windows and increase glare and cooling requirements.

52 National Academy of Sciences, *Policy Implications of Greenhouse Warming* (Washington, DC: National Academy press, 1991).

53 E. Gregory McPherson, "Evaluating the Cost Effectiveness of Shade Trees for Demand-Side Management," *The Electricity Journal*, November 1993, pp. 57-65.

Much further RD&D is needed to better understand all these issues.

The potential in urban cores is less clear because of the density and scale of construction. Further research and carefully monitored demonstrations are needed to clarify this potential. Carbon sequestration and air quality benefits, as well as aesthetic benefits, are potentially also provided by suburban and urban tree planting programs. By one estimate, a 5°F (3°C) reduction in the daily high temperature of Los Angeles by using light-colored surfaces on roads and buildings and by planting trees could reduce smog episodes by one-third.[54]

Integrated Design

All of these technologies—passive or active solar heating and cooling, daylighting, efficiency improvements, and others—must be considered in an integrated fashion. Adding sufficient window area to heat a poorly insulated building in the winter may require such large amounts of thermal mass to reduce day-night temperature swings that it is not cost-effective, whereas adding a small amount of window area to a well-insulated building may provide highly cost-effective heating. Thermal mass considered only for its winter heating benefits may not be cost-effective, but when considered for its summer air conditioning peak load shifting as well, it may be quite desirable.

Integrated building design is very important for achieving high performance in these systems.[55] Integrated design considers a wide range of cost and performance tradeoffs across all aspects of the building's design in order to deliver the highest quality building services—thermal comfort, lighting, clean air, aesthetics—at the lowest possible life-cycle cost. Adequate consideration of all these factors is a very design-intensive process. Consequently, the lack of capable computer design tools to aid the architect and builder in this process is an important factor that has limited penetration of these technologies. Improved knowledge of building physics and the widespread availability of powerful personal computers are now opening up, for the first time, the possibility of sophisticated, integrated building design.

RD&D AND COMMERCIALIZATION

For RETs to make a substantial contribution to energy needs in the buildings sector a variety of RD&D and commercialization issues must be addressed. RD&D needs are examined briefly here, followed by a detailed look at several key commercialization challenges.

Research, Development, and Demonstration

Although several of these renewable energy technologies are moderately mature, further R&D is needed in areas such as monitoring systems; computer-aided design tools for integrating daylighting, passive solar heating and cooling, and other attributes in building design; more intelligent lighting controls to better integrate artificial lighting with daylighting availability; electronically adjustable and spectrally selective windows; and improved materials for active and passive solar heating elements. These and other potential areas for further RD&D are summarized in table 3-1.

Past Experiences[56]

Research, development, and demonstration of RETs for buildings has been supported by federal and state policies and programs for some two de-

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54 Lawrence Berkeley Laboratory, "Heat Islands and How To Cool Them," *Center for Building Science News*, spring 1994.

55 J. Douglas Balcomb, "Integrated Design," paper presented at the Symposium on Solar Energy and Buildings, Athens, Greece, Dec. 8-10, 1993.

56 The discussion on experience is based on J. Douglas Balcomb, *Passive Renewable Energy: What's Holding Us Up? What Should Be Done?* (Boulder, CO: National Renewable Energy Laboratory, July, 1992); and personal communications with contributors as listed in the front of this report.

TABLE 3-1: Research and Development Needs

Materials	Insulants, particularly transparent Insulants such as aerogels Electronically adjustable spectrally selective windows, Improved lighting controls for Integrating daylighting and artificial lights Improved and longer life gaskets and sealants Phase-change materials, Desiccants for cooling systems. Selective surfaces Improved catalysts for small-scale biomass combustion emissions control Air-to-air heat exchanger materials
Building physics	Passive cooling techniques, Incuding radiant cooling Perimeter daylighting systems, allowing deeper penetration of perimeter spaces Atria design for better daylighting and thermal performance Basic heat transfer and natural convection air-flow research to improve performance and comfort Moisture absorption and desorption in building materials Duct design
Whole buildings	Testing advanced concepts in buildings, Performance monitoring of solar buildings Model land-use controls to encourage proper subdivision/site design
Human comfort research	Determining what makes people comfortable or uncomfortable with respect to temperature, humidity, lighting, and other factors within a building.
Design tools	Improved residential and commercial building design tools that perform Integrated analysis, including daylighting and window design, space heating, space cooling, and utility demand-side management Development of simplified design tools for the design and construction community. Validation of design tools

SOURCE Off Ice of Technology Assessment, 1995

cades. This support has led to important developments in many aspects of passive and active solar design; a variety of efficient lighting and tippliance technologies;[57] low-emissivity window coatings[58] and other window technology improvements, including the development of design tools;[59] radiant barrier technology; ventilative and desiccant cooling; and other technologies. Not all projects were successful, of course, but the overall track record has been good.

Support has also been provided for a number of demonstrations and field monitoring. The Department of Energy (DOE) Passive Solar Commercial Buildings Program supported the design of *21*

57 Howard S. Geller et al., "The Importance of Government-Supported Research and Development in Ad\ ancing Energy Efficiency in the United States Buildings Sector," *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications*, Thomas B. Johansson et al. (eds.) (Lund, Sweden: Lund University Press, 1989).

58 By one estimate, the return on [his technology—national savings to federal investment-hus been 7,000 to l See ibid.

59 Of particular note is the Lawrence Berkeley Laboratory Window 4.0 and other window design tools.

commercial buildings throughout the United States and monitored the cost and performance of 12 of them.[60] Energy and operating expenses were cut in half with, on average, no net increase in construction costs. Overall, 1ighting energy was reduced 65 percent, cooling 65 percent, and heating 44 percent compared with standard construction (figure 3-1). Detailed surveys found occupants highly satisfied with the buildings, particularly the daylighting. Key factors contributing to success included federal use of private parties to design, construct, and use the buildings, with the federal role limited to bringing the parties together, absorbing the additional cost of designing the buildings, and monitoring building cost and performance. This program helped train numerous architects, engineers, and builders: provided demonstrable proof that the concepts worked; and helped leverage the construction of many other passive buildings.

Similarly, the Class B Residential Passive Solar Performance Monitoring Program conducted by the Solar Energy Research Institute (SERI—now known as the National Renewable Energy Laboratory) took detailed data (about 20 data points an hour) for about 60 passive houses over an extended period.[61] These data showed that the passive systems provided more than half of the net heating load of these buildings and gave insights into how they worked as well as what did not work. This program provided reliable documentation and support for these technologies and data to aid researchers in improving these designs further. Some believe this to be one of the most valuable programs of the period because it provided detailed information to designers and engineers on what worked, what did not work, and why.

Some programs were, however, less successful, particularly those that attempted to push inappropriate or immature technology into the market. For example, a number of active solar cooling systems using different technologies were designed and built as demonstrations. A few were technically successful, but many never operated and none were ever close to being cost-effective or developing a self-sustaining market. The development of cooling systems is important for much of the United States, as well as much of the developing world. Before such technology pushes are attempted, however, realistic technologies must be chosen and the research and development (R&D) must be focused on ultimately providing commercially viable products.

RD&D Funding

Overall federal funding for such RD&D programs is listed in table 1-4 and has been in the range of $2 million to $5 million per year in recent years. In comparison, annual private and public expenditures for energy to heat, cool, light, and provide other energy services for residential and commercial buildings are roughly $180 billion annually.[62] If a 10-percent overall energy savings could be realized in the longer term by using RETs in buildings---one-half to two-thirds the potential—$18 billion would be saved annually, without even considering growth in the stock of buildings or increases in energy prices. This amount is roughly 4,000 to 10,000 times recent federal expenditures

[60] Burt Hill Kosar Rittelmann Associates and Min Kantrowitz Associates, *Commercial Bul/ding Design: Integrating Climate, Comfort, and Cost* (New York, NY: Van Nostrand Reinhold Co., 1987); and U.S. Department of Energy, *Project Summaries: Passive Solar Commercial Buildings Program* (Washington, DC 1982).

[61] Solar Energy Research Institute, *Passive Solar Homes: 20 Case Studies*, SERI/SP-27 I -2473 (Golden, CO: December 1984); and Solar Energy Research Institute, *Passive Solar Manufactured Buildings: Design, Construction, and Class B Results*, SERI/SP-27 1-2059 (Golden, CO: December 1984).

[62] Energy Information Administration, op. cit. footnote 1

on RD&D in these technologies. A 10-percent savings in the buildings sector corresponds roughly to reducing total U.S. primary energy use by about 3.5 percent.[63]

In comparison, coal currently supplies about 23 percent of total U.S. energy and 54 percent of U.S. electricity. Fully implemented, the clean coal program would reduce U.S. energy use by about 4.3 percent,[64] as well as substantially reducing emissions of sulfur and nitrogen oxides (SO_x and NO_x).[65] (RETs in buildings would have a substantially smaller direct impact on emissions of SO_x and NO_x.)

While annual appropriations for RETs in buildings have been $2 million to $5 million in recent years, those for the clean coal program have typically been in the $400 million to $500 million range, roughly 100 times greater. Although these calculations are crude and the programs are not directly comparable in many respects, these estimates do give an order-of-magnitude comparison of the relative benefits and costs of these programs. A much more detailed analysis of the relative long-term value of these and other programs would be useful.

Commercialization Overview

A variety of market challenges limits the commercialization of RETs in the buildings sector. These challenges must be addressed if a significant share of cost-effective applications of RETs in buildings are to be developed.[66] Such actions are particularly important in the buildings sector because of several factors: the large amount of energy consumed and the corresponding environmental impacts of fossil energy use; the very long lifetime of buildings and the inherent difficulty and cost of modifying them after construction; and important interconnections with other sectors, particularly electricity.

There is a large literature for the buildings sector discussing the extent to which various challenges to commercialization and/or observed consumer behavior actually represent market distortions and barriers.[67] For example, studies of energy efficiency investments consistently find implicit discount rates of 20 to 800 percent, compared with market rates of 10 percent real and less.[68] Some believe that this discrepancy indicates substantial market distortions and barriers;

[63] In solar buildings, there may be small additional emissions for the production of additional glass, cement, and so forth. A total life-cycle estimate of emissions is needed, but is not done here.

[64] It would raise electricity-generation efficiencies from the current 35 percent to roughly 45 percent. Since electricity accounts for about 85 percent of coal use and is 23 percent of total national energy use, the improvement in efficiency corresponds to national energy savings of 4.3 percent when fully implemented at today's rate, without considering future changes in the mix or number of generating plants.

[65] Emissions reductions of 90 percent are a research goal.

[66] Although cost-effectiveness as discussed here is based only on market prices for energy, it may be useful to include environmental and other externalities in this cost-effectiveness criterion to the extent possible. These issues are not addressed in the discussion here for the buildings sector but are discussed for electricity in chapter 6.

[67] Most of this literature focuses on energy efficiency and related investments. See, e.g., Alan H. Sanstad et al., *On the Economic Analysis Of Problems in Energy Efficiency: Market Barriers, Market Failures, and Policy Implications, LBL-32652* (Berkeley, CA: Lawrence Berkeley Laboratory, Energy Analysis Program, January 1993); J.A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," *Bell Journal of Economics*, vol. 10, 1979, pp. 33-54; H. Ruderman et al., "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," *The Energy Journal*, vol. 8, No. 1, 1987. pp. 10 I- 124; Harry Chemoff, "Individual Purchase Criteria for Energy-Related Durables: The Misuse of Life Cycle Cost," *The Energy Journal, vol. 4, No. 4,* October 1983, pp. 81-86; Fereidoon P. Sioshansi, "The Myths and Facts of Energy Efficiency," *Energy Policy*, April 1991, pp. 231 -243; and Kevin A. Hassett and Gilbert E. Metcalf, "Energy Conservation Investment: Do Consumers Discount the Future Correctly?" *Energy Policy, vol. 21,* June 1993, pp. 7 IO-716. The references In these papers, particularly that@ Sanstad et al., provide a very extensive guide to the literature.

[68] Hausman, op. cit., footnote 67; and Ruderman et al., op. cit., footnOte 67.

others believe that this represents legitimate consumer sensitivity to the risk and uncertainties of investing in energy-efficient equipment.[69] Regardless of the cause of these investment patterns, there appears to be a need to find mechanisms that reduce the gap between what is cost-effective from the societal perspective and what is currently invested in by the individual. The focus here is on the practical ways in which various factors may limit the commercialization of RETs in the buildings sector, rather than a theoretic] discussion of what does or does not constitute a market distortion.

Market challenges to the use of RETs in buildings occur at every step of design, construction, sale. ownership, and energy costing.

Design

Passive solar buildings are general] y more design-intensive than conventional buildings. Low margins on design fees and short time frames for completing designs, the frequent lack of training, and the lack of capable design tools and other supports tend to deter architects from pursuing such design-intensive options. There may also be little or no reward to the architect for pursuing an energy-conscious design.

Decisions on purchasing RETs require comparisons across many attributes, such as first cost, performance, appearance, and convenience. These attributes often overshadow energy considerations. For example, the builder may realize a higher profit margin or quicker sale by adding an extra bathroom or jacuzzi rather than by investing in additional insulation or adding passive solar design features to reduce life-cycle costs and improve overall societal costs and benefits. These considerations strongly influence design and particularly the time that is devoted to different aspects of design.

Renewable energy technologies may also change the amenity value of a building. Some may object, for example, to the appearance of a (non integrated) solar water heater on a rooftop. others may appreciate the warmth and light of a sun-tempered living room. In other cases. passive solar design may not--or may be (misperceived to not—fit in with the local architecture and thus be less desirable to some potential buyers. For example, brick colonial houses may be able to incorporate modest levels of passive solar techniques, but extensive use would be difficult without changing appearances. Builders consequently may hesitate to introduce passive solar features.[70] However, some analysts believe that effective passive solar designs exist for almost any architectural style, including brick colonials.[7]

Strategies to address the design challenge of passive solar include developing design tools and guidelines, providing design assistance and Supporting information exchange, supporting the education and training of architects and engineers in these technologies, and establishing design competitions and awards.[72]

Design Tools and Guidelines

The development of capable and user-friendly computer design tools would address to varying degrees all of the design challenges noted above, particularly the lack of time or resources to develop design-intensive passive solar architecture or adapt it to various architectural styles. This poten-

[69] Hassett and Metcalf, op. cit., footnote 67.

[70] Ron Nick Jon National Association of Home Builders, personal communication. July 23, 1992.

[71] Nicklas, op. cit., footnote 29; Kelley, op. cit., footnote 29.

[72] Several of those interviewed by the Office of Technology Assessment also raised concerns about the liability of the architectural firm should anything—even unrelated to the RET—go wrong m a building it designed using RETs, as well as the more general concern that an architect cannot "experiment" on a client. A possible response would be to support the development of standard practice guidelines or standards for the use of RETs in buildings through an organization such as the American Society for Heating, Refrigeration, and Air Conditioning Engineers whose standards are widely recognized and accepted. This would reduce both the liability and the "experimentation" concerns. Further analysis of these issues is needed.

DON AITKEN

Neuffer Construction homes m Reno, Nevada, use passive design techniques to reduce energy use by 35 to 50 percent compared with conventional homes

tial is largely untapped. The buildings sector—architects, engineers, builders, equipment manufacturers—tends to be highly fragmented, with relatively few resources devoted to RD&D, developing design tools, or transferring information. Some recent work has begun to focus on this issue (see box 3-6).

Such passive solar design tools should explicitly interface with the computer-aided design (CAD) tools now widely used to design commercial buildings. This would ultimately allow a variet y of performance calculat ions and optimizations to run in the background while the building is designed on CAD. (Such tools are especially needed for the earliest design stages, when the architect is just beginning to sketch his/her *vision* for the building.) Similar development is needed for the residential sector. It is important, however, that design tools be validated on an ongoing basis against actual building performance.[73]

Past experience with the development of design tools has been quite positive. Useful design tools developed with federal funding and distributed to the buildings industry include the "Passive Solar Design Strategies: Guidelines for Home Building" by the National Renewable Energy Laboratory and Passive Solar Industries Council, the Solar Load Ratio Method of Los Alamos, computer programs such as DOE-2[74] and Window-4 by Lawrence Berkeley Laboratory, and the F-Chart method of the University of Wisconsin. These tools have been very useful to many designers and researchers in the buildings sector.

Design Assistance and Information Exchange

The ongoing collection of data from actual monitored field demonstrations of technologies and the conversion of those data to information usable by practitioners can potentially play a key role in supporting design work and validating various design approaches. This was shown to be an important part of past federal support of RET development for buildings, as discussed above for the DOE Passive Solar Commercial Buildings Program and the Class B Residential Passive Solar Performance Monitoring Program. Such monitoring efforts virtually ceased in 1982.

The federal government has also played a vital role in supporting valuable information exchange. For example, 18 Passive Solar Conferences have been held in the United States. The first was sponsored by the U.S. Energy Research and Development Agency (ERDA)[75] and organized by the Los Alamos National Laboratory solar group in 1976. Since then, these conferences have been organized by the American Solar Energy Society with some funding from DOE and others. Similarly, there have been international Passive and Low-Energy Architecture Conferences held annually since 1982 with some federal support. The *Passive Solar Journal* was also launched by a single $85,000

[73] For example, theoretical models often break down when critical parameters such as air infiltration rates are simply guessed or when practical construction techniques compromise performance (e.g., by creating thermal short circuits between the building interior and exterior).

74 Although admittedly user unfriendly, DOE-2 has played an important role in providing a technically oriented design audience with an important tool for understanding energy flow in buildings. Lawrence Berkeley Laboratory, with funding from the Electric Power Research Institute and DOE, is developing a user-friendly, interactive version of this energy-simulation software.

[75] ERDA was a forerunner of the Department of Energy.

BOX 3-6: Passive Solar Design Strategies: Guidelines for Home Building

The lack of high-quallty user-friendly computer tools for passive building design has been a serious constraint on more widespread use of these systems In response, researchers at the National Renewable Energy Laboratory and the Passive Solar Industries Council, in a five-year collaborate effort, have developed a computer tool, Passive Solar Design Strategies: *Gudelines for Home Building,* with support from the Department of Energy It has been distributed widely through the Pass-we Solar Industries Council To date, more than 100 versions of these guidelines have been generated for different Iocalities, and nearly 50 workshops have been held with more than 3,000 attendees The response has been good with almost 100 known passive homes constructed using these guidelines or the accompanying software called *Builder Guide* A similar program is now under development for small commercial buildings.

Further development and dissemination of these design tools could fill an Important gap in making passive designs a viable option for designers and builders

SOURCES J Douglas Balcomb National Renewable Energy Laboratory personal communications, March 1994 Helen English Passive Solar Industries Council personal communications March 1994

federal grant.[76] These efforts were a primary source of in format ion and a meet ing ground for researchers. architects, builders, financiers, and policymakers.

Education and Training

For RETs to be designed and built into buildings, architects and engineers must be trained in the technology. Education and training thus play an important role if solar buildings industry is to develop.

Past experiences have shown both the benefits and the risks of depending on federal assistance for education and training support. For example, the masters of science (MS) program at Trinity University in San Antonio is noted by some as having produced a particularly fine group of well-educated solar engineers and technologies. This program received considerable support from the DOE Solar Program in the late 1970s and early 1980s, but then folded in the mid- 1980s when funding dried up. In contrast, the School of Architecture at Arizona State Universit y has maintained an MS solar design program for more than two decades with essential y no federal support. This has greatly limited its resources, but has also protected it from arbitrary shifts in federal funding.

Design Competitions and Awards

Design competitions can potentially be used to stimulate interest in RETs for buildings, and numerous small awards can be given for better designs. Such programs could be structured so that there are many winners—perhaps half of the entrants, while the awards vary from a few thousand dollars for residential buildings to a few tens of thousands for commercial buildings. These amounts would be sufficient to cover a substantial portion of the additional design costs of including RETs in the building, while keeping overall program costs relatively low.

Past experience with such design competitions has been positive. DOE and the Department of Housing and Urban Development (HUD) collaborated in holding three rounds of passive solar design competitions in the late 1970s and early 1980s. Awards were given to the best designs, based on performance and architectural quality,

[76] Support ended, howev cr, before this publication became self-supporting; it is no longer published.

and covered the additional cost of designing a passive home and entering the competition.[77] Only a few hundred awards were given out, but the interest generated led to the construction of thousands of passive solar homes.[78] These competitions also pushed designers to develop better quantitative analysis tools for passive design and encouraged their more widespread use in the private sector. A number of construction practices now becoming standard were derived in part from these competitions and related demonstrations, including better-insulated walls and roofs, improved windows and doors, airtightening techniques, and foundation insulation.

Construction

In 1990, the residential construction industry built 1.4 million new homes, two-thirds of which were single family. This industry consists of about 100,000 firms with an average of five employees each. Small firms, however, built only 13 percent of new housing units; firms that build more than 100 units per year account for two-thirds of new housing units and may be better able to use new designs. In general, however, the industry is highly fragmented, which makes the introduction of new design and construction practices difficult.[79] This problem is compounded by the highly fragmented local codes and standards to which buildings must be constructed. As a trade industry, practices are generally learned by experience, which also contributes to the long times for change within the industry.

Some have argued that laying out a new subdivision to maximize the potential solar gain may reduce the number of homes that will fit in a tract, potentially raising prices and lowering developer revenues. Others note that lots can be laid out as desired; those most suitable for passive solar can have appropriate designs built on them, while others can place less emphasis on passive solar and more on efficiency.[80]

Construction bidding (by building contractors) is almost always done on a competitive first-cost basis rather than a life-cycle cost basis. Higher real or perceived upfront costs may then deter investment in RETs. Construction budgeting (by owners or architect/engineering firms) is usually done on a first-cost basis as well, but sometimes is based on life-cycle cost.

Strategies to address the construction challenge include supporting the construction of demonstration buildings and monitoring their performance carefully; supporting information exchange; establishing solar equipment rating and certification; encouraging utility investment; developing voluntary or mandatory building energy rating systems, codes, and standards; and giving “golden carrots” to manufacturers.

Demonstrations

Demonstration buildings and detailed performance monitoring can provide builders with visible, physical proof that a technology works. These demonstrations differ from the RD&D efforts described above in that they would not feature new or unproven technologies, but instead would serve as showcases for commercially viable technologies that builders and potential users could see and touch.

Information Exchange

Information programs can play an important role in generating interest among potential builders of

77 California Energy Commission, “Solar Gain: Winners of the Passive Solar Design Competition,” February 1980; and Franklin Research Center, “The First Passive Solar Home Awards,” prepared for the U.S. Department of Housing and Urban Development, January 1979.

78 J. Douglas Balcomb, National Renewable Energy Laboratory, personal communication, February 1994.

79 Office of Technology Assessment, op. cit., footnote 3.

80 Jeffrey Cook, Arizona State University; Mike Nicklas, Innovative Design; and Mary-Margaret Jenior, U.S. Department of Energy, personal communications, Apr. 3, 1994. Mark Kelley, Building Science Engineering, personal communication, Apr. 13, 1994.

passive solar buildings or other RETs in the buildings sector and educating them as to what works and what does not.

Solar Equipment Rating and Certification

Private sector equipment rating and certification systems have sprung up widely where large markets exist; establishing such systems where markets are young or small is more difficult. Such rating and certification programs can increase consumer confidence and reduce the risk of "quick-buck" operations that damage the industry's reputation; they can help standardize technology evaluations; and they can provide a means of comparing technologies. These benefits can be important to a young and struggling industry.

Several equipment rating and certification systems have been initiated with assistance from federal and state governments. A system for rating windows has been developed by the National Fenestration Rating Council and Lawrence Berkeley Laboratory. Solar water heaters are rated under the Solar Rating and Certification Corporation, an independent nonprofit corporation formed in 1980 by the Solar Energy Industries Association and the Interstate Solar Coordination Council, which represents state governments and publicly owned utilities.[81] Rating and certification could be extended to other products, particularly those used in passive applications such as daylighting systems and integrated lighting controls, and integrated mechanical systems.

Utility Investment

Utilities could potentially benefit substantially from RETs by reducing overall load, reducing peak loads, and shifting peak loads to offpeak hours. The cost-effectiveness of these DSM applications depends on the location, the particular building load, the utility load, the RET, and other factors. Utility DSM programs have grown rapidly to exploit the potential for improvements in energy efficiency. Because of internal procedures, Public Utility Commission directives, or other factors, however, many utility DSM programs may not adequately consider RETs. Factors such as the Ratepayer Impact Test may also play a role in reducing support for RET DSM programs[82] (see box 3-7). To overcome this potential shortsightedness requires specific recognition of the role of renewable as a DSM measure. This is primarily a state public utility regulatory commission issue. Potential federal roles might include supporting case studies, developing generic model DSM programs that can be adjusted by region, and providing information transfer of needed baseline data.

Building Energy Rating Systems, Codes, and Standards

Improvements in building energy performance could be achieved with building energy rating systems or with codes and standards.

Building energy rating systems could be used to provide reliable information on the expected energy costs of a particular building. This would provide potential buyers or renters with useful information for making their decision. As a first step, sellers of existing properties might be encouraged (or required) to inform potential buyers of the building's energy bills for the previous 12 months. For new construction, other methods of determining energy costs are needed. For example, Home Energy Rating Systems are at various stages of pilot demonstration and are described briefly in box 3-8.

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81 "Solar Rating & Certification Corporation Presents OG-300-89: The Most Comprehensive Guide on Solar Water Heating Systems," *Solar Industry Journal*, fourth quarter, 1990, p. 36.

82 For more detailed discussions of this issue, see David Moskovitz et al., *Increasing the Efficiency of Electricity Production and Use: Barriers and Strategies* (Washington, DC: American Council for an Energy Efficient Economy, November 1991); and James F. Deegan, "The TRC and RIM Tests, How They Got That Way, and When To Apply Them," *The Electricity Journal*, November 1993, pp. 41-45.

BOX 3-7: Consideration of Passive Solar Homes at Sierra Pacific Power Company[1]

[1] Donald Aitken and Paul Bony, "Passive Solar Production Housing and the Utilities," *Solar Today,* March/April 1993, pp 23-26
[2] The higher cost is due to additional features provided

Codes and standards might be used to mandate certain minimum building energy performance standards; these in turn would rely on renewable and energy-efficient technologies for implementation. The key to this is developing guidelines by region and building type that list reasonable energy budgets and goals.[83] At least 40 countries now have voluntary or mandatory standards for energy use in new buildings.[84]

Whether or not codes and standards are preferable to market mechanisms depends on many factors, including the flexibility allowed by the codes and standards as implemented, the cost-effectiveness of codes/standards or market mechanisms, and the influence of market challenges described in this section and the effectiveness of market mechanisms in overcoming them. For example, the disjuncture between owner and tenant, or the consumer's perception of risk and uncertainty,[85] may overwhelm many market mechanisms and require the use of codes and standards or other nonmarket approaches if there is to be rapid market penetration by cost-effective technologies.

Codes and standards are often problematic in practice. It maybe difficult to properly account for integrated design, the variability of building types and orientations, or a variety of other factors within the constraints of prescriptive standards. Performance standards can be difficult to enforce:

[83] A history of building codes and standards is provided in Office of Technology Assessment, Op. cit., footnote 3, pp. 107-109. These codes are now being reviewed and updated under the Energy Policy Act of 1992, sections 101, 102, 104, and elsewhere.

[84] Kathryn B. Janda and John F. Busch, "Worldwide Status of Energy Standards fOr Buildings," *Energy, vol.* 19, No. 1, 1994, pp. 27-44.

[85] Hassett and Metcalf, op. cit., footnote 67.

BOX 3-8: Home Energy Rating Systems and Energy-Efficient Mortgages[1]

Home Energy Rating Systems (HERS) are being developed to provide a reliable tool for predicting the energy use of residences; Energy-Efficient Mortgages (EEMs) will incorporate consideration of energy costs when underwriting mortgages. Thus, purchasers of low-energy-use homes will more easily qualify for a mortgage[2] or will qualify for a larger loan than those who purchase inefficient homes.

Efforts to develop HERS and EEMs go back to about 1980, but the programs had been relatively inactive. The current national effort began in 1990 with the National Affordable Housing Act and in 1991 with the National Energy Strategy. In 1992, the Departments of Energy and Housing and Urban Development, and 25 stakeholder groups released "A Blueprint for Action" calling for voluntary HERS and EEMs and providing a framework for HERS-EEMs programs, including criteria for qualifying for a loan, default rate data collection and use, lender indemnification, property evaluation, rating system validation, quality control, public information programs, and builder and lender training. Work to further define each of these and other issues is proceeding.

The National Energy Policy Act, the Housing and Community Development Act,[3] and the Veteran Home Loan Program Amendments,[4] all signed in 1992, accelerated the HERS-EEMs effort The Housing and Community Development Act, in particular, requires the establishment of a five-state pilot EEM program and work is proceeding

HERS and EEMs represent an Important step forward Results from pilot projects should prowde valuable Information on how to make them more effective and determine their true potential

[1] The principal source for this box is Barbara C Farhar and Jan Eckert *Energy-Efficient Mortgages and Home Energy Rating Systems A Report on the Nation's Progress* NREL/TP-461-*5478* (Golden, CO National Renewable Energy Laboratory September 1 993)

[2] By one estimate some 250 000 families might qualify for a first-tme home 'oar under EEMs who would otherwise be excluded under todays system, which does not consider energy use in loan qualification criteria See ibid

[3] U S Congress Housing and Community Development Act of 1992, Conference Report 102-1017 Oct 5 1992

[4] The Veterans Home Loan Amendments (Title 38, section 9) establishes a nationwide loan guarantee program—for loans up to $6000 in some circumstances—for energy efficiency improvements to an existing home owned and occupied by a veteran

officials charged with enforcing building codes, for example, are generally more concerned with health and safety—they will not be aware of a higher energy bill, but if a deadly fire occurs in a building they inspected, they will see and hear about it on the news and in the office. Officials are often already overcommitted, and energy codes and standards tend to be complex, potentially requiring considerable additional attention.[86] Technically, codes and standards often significantly lag best practice and are slow to incorporate technological improvements. Codes and standards may nevertheless be an important tool in ensuring a minimum level of performance.

Where codes and standards are used, state and local governments generally play the lead role; the federal government can also tighten energy-related codes and standards and work with state or

[86] In many cases, however, code enforcement depends more on the architect, engineering (A/E) firm than on inspectors. When an A/E submits a set of construction documents for a building permit, it is representing that the documents are in compliance with all applicable regulations. Building officials can check only limited aspects of any plan to verify code compliance. Therefore, if compliance with an energy standard is required, A/Es are obligated to comply, just as they are with fire safety provisions. Of course, training is still needed to provide the A/E with the knowledge needed to understand and comply with the requirement. This is not intended to minimize the importance of code review or of training code officials, but one need not rely solely on code officials to achieve compliance. Harry Gordon, Burt Hill Kosar Rittelmann Associates, personal communication, Apr. 25, 1994.

local government to improve model building codes. Providing an overall energy code and allowing substantial flexibility within it can give designers and builders more opportunities to cost-effectively and market-effectively meet the standard; however, such flexibility also increases the complexity of enforcement, compared with the use of prescriptive codes with simple checkoffs. For example, the California Energy Commission Title 24 Building Standards are noted for their allowance of passive solar design techniques to offset heavier use of insulation; however, they also require complex technical documentation. Title 24 also lags technically in some areas. For example, it has yet to incorporate low-emissivity coatings on windows.

Where codes and standards are pursued, it is also helpful to provide support for validating and adopting particular design strategies that meet the overall energy code requirement. Efficiency and renewable should be treated equally within codes and standards. If possible, however, it is generally preferable to use a carrot to improve building energy performance rather than the stick of codes and standards.

Golden Carrots

Manufacturers of RET equipment for buildings might be given cash awards in competitions to build the best-performing equipment. This has proven an effective approach in the development of efficient refrigerator designs, and would complement design competitions and awards for architects and builders.

| Sale

Individuals pursue several goals when making energy-relaed building investment decisions—for example, minimizing the time to make a decision, spending the least amount upfront, minimizing risk by obtaining the same item that worked before, or simply avoiding "hassle." Few pursue the goal of minimizing life-cycle costs, which RETs can help achieve.[87]

Individuals often lack a source of credible information needed to make sound energy-related investments. Vendors of solar systems may be viewed with suspicion because of early performance problems by some vendors in the field. Reliable information on actual field performance of various RETs is difficult to obtain, and RETs are often (misperceived as requiring discomfort or sacrifice, which limits their appeal.

Strategies to address these problems include information programs, field demonstrations, solar equipment rating and certification programs, utility encouragement of or investment in building RETs, building energy rating systems, and energy-efficient and renewable energy mortgages or other forms of financial support such as tax credits. Most of these have already been discussed briefly; the focus here is on various forms of financial supports.

RET Mortgages

RET mortgages would allow a potential home buyer to qualify for a higher loan by using expected future savings in energy costs to cover the higher mortgage payments. Several pilot programs for energy-efficient mortgages are now under development or in operation and will provide useful information to guide future efforts in this area. Energy efficiency mortgage pilot programs are described in box 3-8.

Tax Credits

Tax credits reduce the effective cost to an investor of an investment in an RET technology. There has been considerable experience with these financial supports.

Federal solar tax credits were enacted in 1978.[88] In response, markets for solar equipment

[87] Office of Technology Assessment, op. cit., footnote 3.

XX Energy Tax Act of 1978, Public Law 95.6] 8, Nov. 9, 1978. There are also a number of state tax credits, many of which continue today. State tax credits were not examined in the course of this assessment, but deserve detailed analysis to determine better what works and why.

grew rapidly. There were, however, unintended side effects. Equipment prices were often increased, and some of this solar equipment was poorly designed, poorly built, and poorly installed, which resulted in failures. The market grew so quickly with its intense, artificial fertilizing by tax credits that it had insufficient time to weed out poor products and establish reputable brands or dealers. The tax credits may also have been somewhat inequitable in that they tended to go toward individuals in higher income brackets that could afford the upfront investment. When the tax credits were withdrawn in 1985, the market crashed and numerous systems were left orphaned in the field. Some manufacturers survived, have persevered, and today market well-designed, high-performance systems.

In addition, the tax credits applied only to add-on equipment, not to passive design features—the most cost-effective approach—because it is very difficult to design tax credits so that they apply to the marginal investment in passive features. For example, when is a window a window and when is it a passive design element? This question indicates the difficulty of separately identifying what components of a passive solar design should qualify for a credit when they are intimate components of the building structure. Consequently, tax credits can be difficult to implement.

Improvements in technology may, in some cases, sidestep the problem of identifying passive solar value. For example, advances in window technology make high-performance windows energy savers, irrespective of their orientation. Tax credits might be provided for windows that perform better than a baseline standard, according to the ratings of the National Fenestration Rating Council.

Finally, the tax credits were expensive, and there has been considerable debate over their effectiveness in stimulating investment.[89] Recent work has indicated that tax credits are modestly effective in stimulating investment, but are strongly impacted by consumer perception of the risk of future energy costs versus sunk investment and other factors.[90] If targeted on specific, high-performmce but expensive technologies, tax credits may be effective in increasing sales, which in turn should reduce costs of manufacture.

Feebates

Rather than use a broad-based energy tax, a tax/rebate might be applied to new construction based on its estimated energy performance under building energy rating systems.[91] For example. buildings projected or measured[92] as requiring more energy than average might be taxed at a rate that increases with decreasing performance. These taxes would provide rebates. again on a sliding scale, for buildings expected to use less energy than average. This would avoid the equity issues inherent in a broad-based energy tax; it would also help address the problem of the sensitivity of buyers to upfront capital costs.

Although feebates have been proposed frequently in various sectors, they have not been used in the buildings sector. Pilot programs would be needed to demonstrate that building energy usc can be estimated reliably in practice and to address a host of technical. commercial, and institutional

[89] T.A. Cameron, "A Nested Logit Model of Energy Conservation Activity by Owners of Existing Single Family Dwellings," *Review of Economics and Statistics*, vol. 117, 1985, pp. 205-211, J.A. Dubin and S.E. Henson, "The Distributional Effects of the Federal Energy Tax Act," *Resources and Energy*, vol. 10, 1988, pp. 191-212; and M.J. Walsh, "Energy Tax Credits and Housing Improvement," *Energy Economics*, 1989, pp. 275-2X4.

[90] Hassett and Metcalf, op. cit., footnote 67; Kevin A. Hassett and Gilbert E. Metcalf, "Energy Tax Credits and Residential Conservation Investment," January 1993.

[91] It would be necessary to ensure the accuracy of building energy rating systems through ongoing monitoring of a random sampling of buildings.

[92] Measurements might be made of building airtightness and other factors to determine overall building performance.

issues. Although intriguing in concept, feebates require much more study and demonstration.

Ownership

Roughly one-third of housing and one-quarter of commercial building floor space is leased or rented rather than owned.[93] Landlords have little incentive to invest in RETs for buildings when the tenant pays for the energy consumed. Tenants have little incentive to invest in RETs since they have little expectation of remaining long enough to recoup their investment.

When trading off first-cost and energy savings, homeowners will often not invest in RETs unless they offer very short payback periods. Reasons for this sensitivity include the following:

- *Inability to recoup their investment.* Homeowners typically move every 6 to 10 years, If the resale market does not value RET investments, the owner must recoup the investment within this short ownership period, which encourages a desire for a quick payback.
- *Perceived high risk and low resale value.* Investment in RETs is perceived as presenting some risk for which the owner must be compensated by a higher return (or equivalently a shorter payback period). In particular, a residence is generally the largest purchase a consumer ever makes, and anything that might conceivably make the dwelling less marketable or otherwise increase consumer risk may then require a compensating "risk premium" payment.
- *Large sunk investment, risk, and uncertainty,* Investments in energy savings are sunk investments, and homeowners must be appropriately compensated for tying up so much of their capital in a "risky" illiquid investment. Given the wide fluctuations in energy costs, the option of waiting to invest may be viewed as reducing their risk. Technologies are also changing rapidly; early investment poses the risk of early technological obsolescence, so there may be advantages in waiting to invest.[94]

On the other hand, building owners also face risks by being so utterly dependent on outside sources of conventional energy. As witnessed over the past two decades, energy prices can skyrocket, subjecting the owner to unexpected costs over extended periods. This may be a particular problem for low-income people or fixed-income retirees. Further, should there be a disruption in energy supplies, buildings can quickly become uninhabitable. Such risks are not commonly considered in building design, construction, or ownership.

Strategies to address these problems include building energy rating systems; RET mortgages; financial supports, possibly including tax credits; utility encouragement of and investment in RETs; codes and standards; and feebates. These have been discussed above.

Energy Costs

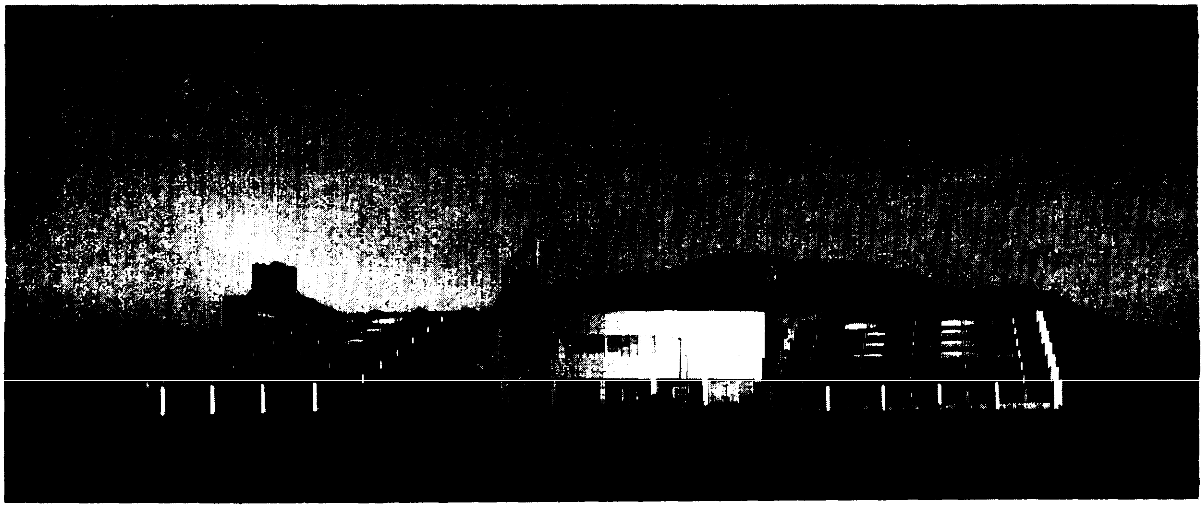
Energy costs, particularly for a business, often constitute only a small percentage of total operating costs and are much less than, for example, employee wages. Few businesses are willing to risk any disruption in energy-generated services—such as heating, cooling, or lighting—that might lower worker productivity. Although this concern is real, it may often be unfounded. Productivity studies have found that well-designed passive solar and efficient buildings can actually enhance productivity.[95]

The price of energy in the market today may not reflect the "true" societal cost of energy given the distribution of goods and services across the cur-

[93] Office of Technology Assessment, op. cit., footnote 3.

[94] Hassett and Metcalf, op. cit., footnote 67.

[95] Walter Kroner et al., *Using Advanced Office Technology To Increase Productivity* (Troy, NY: Center for Architectural Research, Rensselaer Polytechnique Institute, Troy, NY, 1992); and Joseph Romm and William Browning, "Greening the Building and the Bottom Line: Increased Productivity Through Energy Efficient Design," Asilomar Summer Study, American Council for an Energy Efficient Economy, 1994.



HEDRICH BLESSING

The Solar Energy Research Facility at the National Renewable Energy Laboratory in Golden, Colorado, uses a variety of passive and other technologies to reduce overall energy use by an estimated 30 to 40 percent compared with conventional buildings.

rent population or across generations, the risk of energy disruptions, uncertain y over future energ y costs, potential national security impacts, and environmental impacts.[96] These issues are discussed in more detail in chapter 6 in the context of the electricity sector.

Individually, designers. builders, and consumers are each responding logically within the constraints that they face; collectively, the net result is the construction of' many buildings that have much higher energy use than is necessary or cost-effective. This poses a variety of financial, risk, and environmental costs that are not now adequately incorporated in marketplace decision-making.

Strategies to address these problems include, in addition to those is ted above, energy and environmental externality taxes.

Energy and Environmental Taxes

The cost of energy could be raised to more accurately reflect the full costs of using it, including environmental and other external costs. For this to have any significant impact, however, it would best be combined with building energy rating systems and RET mortgages or other mechanisms. The overall impact for reasonable tax levels, however. is likely to be modest and will take a long time to occur because of the numerous market challenges noted above. In addition, a broad-based energy tax would fall more heavily on those who own or rent older and less well-built housing. Retrofitting housing can help reduce these costs and is an important policy in its own right, Retrofits, however, are not nearly as effective as incorporating RETs in new construction.

Federal Procurement

The federal government has considerable purchasing power because of its size, and this power can be used to increase the sales and distribution of RETs for buildings. In 1989. for example. the federal government spent $3.5 billion for energy used in its own buildings and another $4 billion

[96] The Price of energy may not even reflect the cost to deliver it within the existing accounting framework. Energy prices charged residences are averages and do not reflect the true cost of, for example, utility-generated power. particularly peak power. Time- of-use metering might better reflect systemwide costs of' providing power and offer additional incentives for consumer investment in RETs.

subsidizing energy use of low-income households.[97] This includes the roughly 500,000 office buildings owned or leased by the federal government, 1.4 million low-income housing units owned by the government, 9 million households for which the government subsidizes energy bills, and 422,000 military housing units. Incorporating RETs in existing or new federally owned or energy-subsidized buildings may offer an important opportunity to save taxpayer dollars where RETs can be cost-effective alternatives to conventional systems, while simultaneously providing meaningful acknowledgment of the value of these technologies.

Lessons Learned

Several other overall lessons can be noted from the history of past programs and policies. First, premature termination of many of the federal programs in building RETs in the early 1980s resulted in the loss of valuable data, the disbanding of highly productive research teams, and an abrupt halt to the momentum that had been developed. Second, although well intentioned, several of the commercialization programs did not usefully address the key market challenges discussed above; appropriate mechanisms to address these challenges remain elusive, and further experimentation is needed. Third, many of the technologies were initially oversold, promising cost and performance that could not be delivered.

An important difference now, compared with two decades ago when these efforts began, is that there is a foundation on which to build. Two decades ago, R&D was just getting under way, while commercialization of unknown technologies was being pushed at the same time. This led to many failures as well as many successes. Today, R&D and detailed field monitoring have shown what works and what does not. Commercialization efforts, therefore, have a base of proven technologies on which markets can be built, while RD&D can continue to provide new opportunities.

POLICY OPTIONS

There is already considerable experience with a variety of effective policies as well as some that are ineffective in developing and commercializing RETs for buildings. Some of this experience is discussed above, and a number of policy initiatives continue today (see box 3-l).

Current policies have been described throughout this chapter and in box 3-1. As for funding support, the total DOE fiscal year 1995 budget for solar buildings is $4.69 million up from $2 million in fiscal year 1992. This can be compared, however, to a high of $260 million (1 992 dollars) in 1978. Support will be used to develop solar water heater rating and certification procedures, improve their reliability, and demonstrate their use in utility DSM programs, and to examine a few advanced technologies, including the integration of photovoltaics into buildings—with funding of $500,000[98] in fiscal year 1995.

Almost no support is provided for high-leverage activities such as the development of design tools for passive solar buildings, and no support is provided for design competitions, which proved so successful in the late 1970s and early 1980s. Similarly, there is little or no support for RD&D in passive design, daylighting, field monitoring, or other potentially high-leverage activities discussed earlier. As a consequence, market penetration by RETs into the buildings sector is likely to continue to be slow, and numerous cost-effective opportunities for using RETs in buildings are likely to be lost.

Taking advantage of low-cost, high-leverage opportunities to greatly expand the development and use of RETs in buildings could help capture a significant portion of cost-effective applications and proportionally reduce the use of fossil fuels in

[97] U.S. Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Government: Government by Good Example?* OTA-*E-492* (Washington, DC: U.S. Government Printing Office, May 1991).

[98] This is part of the total request of $4.69 million.

buildings along with their attendant environmental impacts. Balanced against these potential benefits are, of course, some costs and risks, including increased direct federal expenditures (higher than present spending) and the risk of incurring unanticipated costs in attempting to further the use of RETs.[99] Federal expenditures would increase under this strategy but could be kept modest by targeting the highest leverage opportunities.

Policy options that might be considered as part of such a strategy are listed below. Most of these RD&D and education/information programs could be supported through DOE, with commercialization programs also supported through the Department of Housing and Urban Development and other agencies.

RD&D programs might include:

- *Collaborative research, development, demonstration, and field monitoring.* High-leverage R&D targets for RETs in buildings could be supported at significantly higher levels in cooperation with manufacturers and builders (see table 3- 1). Collaborative field demonstrations of promising near-commercial technologies with extensive performance monitoring could also be supported. Many of the best field performance data remain those collected under the DOE Passive Solar Commercial Buildings and the Class B Residential Passive Solar Performance Monitoring Programs over a decade ago, as described earlier. Building on this previous experience could have considerable value.
- *Golden carrots.* Increased support for the development of manufactured RETs for the buildings sector should also be considered. Current funding is limited to a small solar hot water heater program and a few others.[100] Such RD&D can be conducted collaboratively between the national labs and manufacturers. It might also be done by using private sector incentives such as the "golden carrot" award won by Whirlpool for the development of the high-efficiency refrigerator.[101]
- *Commercial demonstrations for builders and users.* Demonstrations of proven RETs in buildings could be built, with federal support for the difference in cost, if any, compared with conventional buildings. In contrast to the above R&D demonstrations, these buildings would not be testing new technologies. Instead, they would provide local builders and users examples of what is possible within particular market segments. Since many of the passive solar buildings constructed to date have been for an upscale clientele, these designs might best target low- and medium-income housing. Recent examples include the award winning "Esperanza del Sol" development[102] in Dallas, Texas, featuring three-bedroom homes for $80,000 and Neuffer Construction's Homes in Nevada.[103]

Design and information programs might include:

- *Design tools.* Passive solar and other RET design tools are slowly being developed today. In-

99 See, e.g., Linda Berry, *The Administrative Costs of Energy Conservation Programs,* ORNL/CON-294 (Oak Ridge, TN: Oak Ridge National Laboratory, November 1989).

100 This includes some work on unglazed transpired collectors and a small effort to integrate photovoltaics into buildings.

101 U.S. Congress, Office of Technology Assessment, *Energy Efficiency: Challenges and Opportunities for Electric Utilities,* OTA-E-561 (Washington, DC: U.S. Government Printing Office, September 1993).

102 This development received Edison Electric Institute's first E-Seal award for environmentally superior design. With estimated overall annual energy savings of 50 percent at an additional construction cost of 0.2 percent, this design has a payback time of less than one year. See Burke Miller Thayer, "Esperanza del Sol: Sustainable, Affordable Housing," *Solar Today,* May/June 1994, pp. 21-23.

103 Donald Aitkin and Paul Bony, "Passive Solar Production Housing and the Utilities," *Solar Today,* March/April 1993, pp. 23-26.

creased support would enable their more rapid development, and their integration into commercial CAD tools could provide a high-leverage means of encouraging the use of passive solar and daylighting strategies in commercial buildings. Similar development of design tools for the residential sector could be supported, building on work already done by the National Renewable Energy Laboratory, the Passive Solar Industries Council, Lawrence Berkeley Laboratory, and others.

- Design cornpelitions. Providing numerous but small prizes (sufficient to cover the additional cost of solar design) for the best solar designs has proven effective in the past, and could be restarted. This option complements the development of design tools and also provides a high-leverage means of encouraging the use of passive solar and daylighting designs in buildings.
- *Design assistance.* Design assistance could be provided to those who are interested in pursuing solar designs but lack sufficient technical means of doing so. This may be particularly important, for example, for small residential builders. A set of region-specific, high-performance solar designs for residences might also be developed, demonstrated (see above), and distributed as models. This strategy complements the development of design tools and the use of design competitions.
- *Education.* Support might be provided for the development of additional course materials on RETs for buildings at architecture schools and for the development of focused RET design programs such as those described above at Trinity University or Arizona State University.
- *Information programs.* Broad-based information programs might be developed to provide potential builders and users relevant information for encouraging use of RETs in buildings and for informing their decisionmaking.

Rating and standards programs might include:

- *Solar rating and certification programs.* Current solar rating and certification programs, such as those described earlier, might be expanded and strengthened to include more RETs.
- *Voluntary standards.* Support might be provided for the American Society of Heating, Refrigeration, and Air Conditioning Engineers or other professional organizations that help establish industry standards to develop guidelines and standards for best practice in solar design. This wouid give RETs in buildings higher visibility and credibility at relatively low cost.
- *Building codes and standards.* Building energy codes can help ensure that minimum energy performance standards are met; such codes have been used extensively in the United States.[104] Building codes might be further developed in support of RETs, recognizing the potential difficulties as discussed above.

Finance and commercialization programs might include:

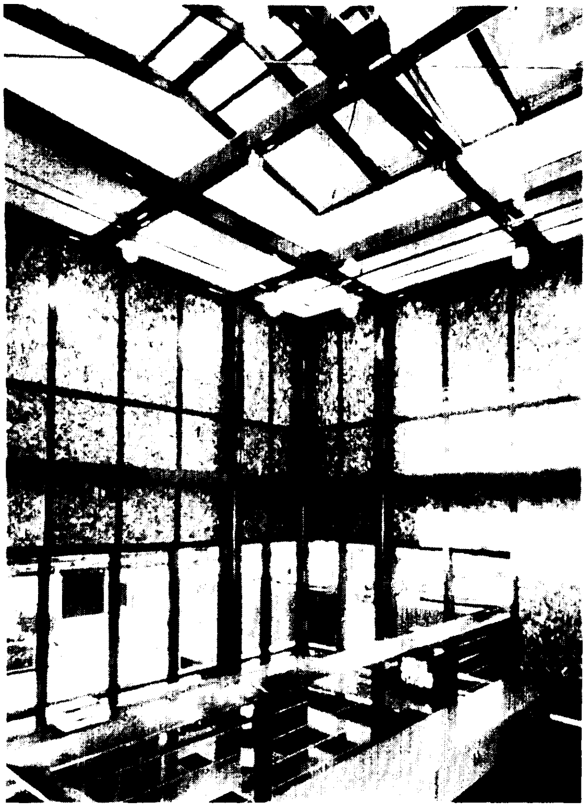
- *RET mortgages.* Energy-efficient mortgages are now under study in pilot programs (box 3-8). If the results of these efforts are positive, such programs might be expanded in their technical scope to more fully consider renewable and in their geographic scope to include a progressively larger portion of the United States.
- *Federal procurement.* All federal construction, purchase, or rental of residential, commercial, or other buildings could be based on life-cycle cost analyses (including external i ties) that consider efficiency and RET options, with mandated acquisition of the highest level of efficiency and RET technology projected to be cost-effective.
- *Utility investment,* Utility investment in RETs for buildings could be encouraged through supporting case studies to determine where, when. and to what extent RETs can provide DSM

[104] Office of Technology Assessment, op. cit., footnote 3.

benefits, including offsetting lighting, heating, and air conditioning loads. The current effort and the primary focus of the DOE Solar Buildings program is on utility DSM opportunities using solar water heaters, as described above.

Other types of policies designed to increase market competitiveness of RETs could include the following:

- Tax credits. Although tax credits were used during 1978-85 with mixed results, as described earlier, they might be combined with building energy rating systems, solar rating and certification programs, or other mechanisms to better target them toward technologies that are cost-effective over a wide range of circumstances. The design of these programs should also consider the lessons now being drawn from modern finance theory concerning the effectiveness and structure of tax credits.[105]
- *Fecbates.* Pilot projects might be considered to evaluate the potential of feebates as a means of reducing the upfront capital costs of investments in RETs in buildings.



ADVANCED PHOTOVOLTAIC SYSTEMS INC

Building-integrated PV system. The PV material in the skylight serves a multiple purpose: the skylight offsets interior artificial lighting as well as cooling to remove heat generated by artificial lights; the PV material coating the skylight generates electricity.

CROSSCUTTING ISSUES

Visions of the distributed utility (chapter 5) often project large numbers of photovoltaic (PV) cells or fuel cells in residential and commercial buildings. Integration of PVS into building structures may significantly lower PV balance-of-system costs; the use of distributed fuel cells might provide thermal benefits for space heating or hot water but would continue to use natural gas as a fuel for the near to mid-term with a transition to renewable fuels in the long term.[106] In both cases, these early markets might help ramp up production and allow further economics of scale and learning to be realized. Such economies might also cvcntually help fuel cells to penetrate transport markets.[107]

CONCLUSION

Renewable energy technologies arc available for residential and commercial buildings but are not yet widely utilized. As shown in this chapter,

[105] Hassett and Metcalf, op. cit., footnotes 67 and 90.

[106] A transition to renewable-generated hydrogen might be possible in the long term. Use of natural gas in the near to mid-term could then be part of a transition strategy to develop the distributed utility, capture cogeneration benefits, and reduce the price of fuel cells for other applications. See Joan M. Ogden and Joachim Nitsch, "Solar Hydrogen," *Renewable Energy: Sources for Fuels and Electricity*, Thomas B. Johansson et al. (eds.) (Washington, DC: Island Press, 1993).

[107] Note that the potential benefits depend on the type of fuel cell used. Chapter 4 describes a variety of potential paths for transport technologies, some of which use particular fuel cells such as the proton exchange membrane cell, The choice of technology within the buildings sector should, therefore, consider in part the potential synergisms with transport technologies.

greater utilization of these technologies could save money over the building's life cycle and reduce energy use. The indirect benefits of these technologies—particularly reduced environmental damage from fossil fuel use and reduced sensitivity to power and fuel cost increases or supply disruptions-could be considerable. There may also be a significant export market for these technologies, including spectrally selective and/ or electrochromic window coatings, lighting controls, building-integrated photovoltaics, and design tools. Past experience provides a number of lessons that may be used to refine policies intended to move these technologies into the buildings sector. A number of policies may offer significant leverage to move these technologies more rapidly into the marketplace with relatively little investment.