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ABSTRACT

This monograph explores how architecture is influenced by and is responding to the global energy dilemma. Emphasis is placed on conservation techniques (using heavy insulation) and on passive solar construction (supplying most of a building's heating, cooling, and lighting requirements by sunlight). The basic problem is that architecture, like transportation, manufacturing, and agriculture, is heavily dependent on fossil fuels. It is estimated that approximately one-quarter of the world's energy supplies (two-thirds of which is derived directly or indirectly from oil and natural gas) is used for heating, cooling, and lighting buildings. Until recently, buildings in many countries were constructed with little or no concern for their energy efficiency or lifetime fuel costs. Building designers and researchers have recently become much more energy-conscious, due in large part to realization that paying for electricity is now the biggest expense in operating most large buildings. Also, the level of general awareness regarding energy use in buildings has risen rapidly as consumers, builders, real estate agents, and others have been exposed to education about climate conscious buildings. The conclusion is that the potential of energy-conscious improvements such as passive solar techniques and conservation for reducing dependence on expensive fossil fuel energy will be realized if designers, consumers, and regulatory agencies make an immediate and total commitment to make the transition to climate conscious buildings. Ways in which this transition can be accelerated include labeling of the fuel requirements of buildings by trade associations and local governments, provision of tax breaks for solar and other energy efficient homes, and establishment of energy standards for all new buildings. (DB)

Energy and Architecture: The Solar and Conservation Potential

Christopher Flavin

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The energy dilemma facing the world today has many facets. Transportation, manufacturing, and agriculture are all heavily dependent on expensive fossil fuels. The world's buildings are unfortunately no exception. The heating, cooling, and lighting of buildings now consumes nearly one-quarter of the world's annual energy supplies, and approximately two-thirds of this is derived directly or indirectly from oil and natural gas. The cost of providing fuel and power to this sector has escalated rapidly in recent years, and in many nations buildings have been forced to the front lines in the fight to reduce petroleum use.[1]

The energy problem, then, is in some measure an architectural problem. Modern buildings have until recently been constructed with little heed paid to their energy efficiency or lifetime fuel costs. The buildings sector, like other parts of the world economy, has been accustomed to low, subsidized fuel prices. The prevailing assumption was that efficiency of energy use was unimportant because technological developments would continue to keep fuel prices low. The price of this shortsightedness is borne by millions of consumers in their monthly fuel bills.

Throughout the fifties and sixties, the buildings in many countries were constructed with ever more voracious energy appetites. Lighting levels were increased, air conditioning systems were added, and builders continued to use single-pane windows and minimal insulation. The people who live and work in buildings contributed to the exorbitant energy use as well, setting thermostats too high in winter and too low in summer. The result was predictable: energy use in buildings increased more than 5 percent per year in many countries. The United States, which set the standard for "modern" buildings during the postwar period, is now clearly paying the consequences.

I wish to thank Ann Thrupp for her assistance with the research for this paper, and Jeffrey Cook, Darian Diachok, Keith Haggard, Michael Holtz, Scott Noll, and Dianne Shanks for their reviews of the manuscript.

6 Residential and commercial energy use in the US nearly tripled between 1950 and 1973, and the annual bill for providing fuel and power to those sectors now stands at over $100 billion.[2]

It is not for lack of know-how that the situation is so dismal. Relatively simple changes in design and construction techniques—some of them known to the ancients—could greatly lower the fuel requirements of buildings. And today, well-designed climate-sensitive buildings that use the sun's energy directly to heat the interior and provide light and that use natural breezes for cooling are reducing fuel bills by 75 to 100 percent, depending on the local climate. Good insulation and windows that face the equator are the basic features of such structures. Many are called "passive solar" buildings since most heating, cooling, and lighting requirements are supplied by sunlight, shading, and natural ventilation. Others rely more on the conservation technique of using very heavy insulation and are known as "low-energy" buildings. In practice these approaches are often used together in the same structure.

Energy-conscious design, once the domain of backyard inventors and counterculture enthusiasts, is now being practiced by top architectural firms and integrated into suburban communities. Major research efforts under way in more than a dozen countries are refining the state of the art, reducing costs, and starting to apply the new concepts to large commercial structures as well as private residences. Architects and engineers are reassessing the whole range of construction materials and techniques in their attempts to reduce the fuel requirements of buildings. They are also investigating ways to adapt the designs to retrofit existing buildings. The spectacular growth in these fields is rooted in some simple economics: climate-sensitive design is cost-effective at today's fuel prices. During the eighties, ignoring energy-saving principles of construction is like throwing money down the drain.

Knowledgeable observers are predicting that the next decade will see some of the most rapid and far-reaching changes in the history of architecture. As one pioneering solar architect noted recently, "traditionally, architecture has been a response to the times, and energy

"The next decade will see some of the most rapid and far-reaching changes in the history of architecture."

conservation is the issue of our time." Designers and builders face unprecedented challenges in the years ahead as they attempt to meet the needs of a fundamentally different energy situation. Opportunities for innovation will also be great, however, and it is conceivable that the forces of necessity will breathe new life into the architectural field.[3]

Already, a number of improvements have been made in the way the average building is designed and built. Better insulation and storm windows are among the measures that have dropped the heating requirements of new buildings in many countries by 20 percent or more in the last few years. The more ambitious design changes—that would reduce heating and cooling requirements by more than half—have not yet fully penetrated the construction industry. But in a few nations, the day that such designs really take hold is quite close. In the United States, in particular, some large building companies are actively developing passive solar prototypes, and attractive government financial incentives will soon pull them into the mass marketing of energy-saving buildings. Between 10,000 and 20,000 passive solar buildings currently stand in the US, but there could easily be more than a million by the mid-eighties. A challenging but reasonable goal for most countries would be to cut the energy requirements of *all* new buildings by 75 percent by 1990.[4]

The need for rapid change is difficult to underestimate. Buildings are long-term investments, and the house that was built with yesterday's $2-a-barrel oil in mind will still be standing when oil hits $50 a barrel in the not-too-distant future. Much of the world is still in the midst of an unprecedented housing boom that will last several more years, and large commercial buildings are being built even more rapidly. Improvements made today in design and construction techniques will have a disproportionately large effect on the comfort and economic attractiveness of the world's building stock at the turn of the century. Equally important are ongoing efforts to retrofit existing buildings with solar and conservation measures. Since 80 percent of the buildings in use today will still be around in the year 2000, it is essential that they be improved in response to the altered world energy situation. These changes will require substantial economic and institutional adjustments. But in the long run the benefits will unquestionably far outweigh the costs.

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Energy and Architecture

In this age of standardized buildings and mechanical heating and cooling systems, it is easy to forget that climate-conscious design was once the norm. In some parts of the world, it still is. The pueblos of the American Southwest, the adobe and thatch huts of equatorial Africa, and the cooling towers of Moslem Asia are all testimony to the simplicity and common sense inherent in passive solar design. Built without the aid of architects or engineers, these buildings cleverly use sunlight and natural breezes to heat and cool their interiors.

Over 2,000 years ago, Socrates observed that "in houses that look toward the south, the sun penetrates the portico in winter, while in summer the path of the sun is right over our heads and above the roof so there is shade." This basic idea—that the sun describes a lower and more southerly arc in winter than in summer (and a more northerly one in the southern hemisphere)—is applicable everywhere but the tropics near the equator. It is the central principle in all passive solar design. Two to three times as much sunlight strikes a south-facing wall in winter than in summer, making that the logical side on which to place windows. The house itself then becomes a solar collector.[5]

As Ken Butti and John Perlin point out in their book *A Golden Thread*, which documents the history of solar architecture, the Greeks were among the earliest passive solar designers. Many of their buildings were oriented to the south and had thick adobe or stone walls to keep out the summer heat. In the sunny Greek climate, it seems likely that the very simple design of those buildings provided all the heat necessary on two-thirds of the winter days. And several Greek cities were planned so that all buildings had exposure to the winter sun.[6]

Passive solar heating was also employed by the Romans, who picked up their knowledge of the basic concepts from the Greeks. The major energy source at the time was firewood and charcoal, but by the fourth century A.D. indigenous wood supplies had largely been stripped from the Italian peninsula. The pressure of fuel scarcity was a strong incentive for solar heating, and Roman architects slowly adapted solar design to the variety of conditions found throughout the Roman Empire. The Roman architect Vitruvius wrote that "it is obvious that designs for homes ought to conform to diversities of climate." Romans developed the first greenhouses as well as solar-heated bathhouses; floor plans indicate residences were organized so that rooms would be comfortable at the time they were most often occupied; and access to the sun was actually made a legal right under the Justinian Code of Law adopted in the sixth century A.D.[7]

Many other cultures developed equally successful climate-sensitive building styles. Homes in ancient China were generally built on the north side of courtyards, facing the south, and sunlight was admitted through wood lattice windows and rice paper. The Anasazi people of the American Southwest lived in mud or stone buildings constructed against overhanging cliffs that faced south. They were earth-sheltered dwellings, solar-heated in the winter and shaded in the summer, all without benefit of modern building materials or theories. More recently, the early settlers in New England built "salt box" houses that were carefully oriented to face the south. They were two-storied dwellings with most of the windows on the front, and a long, sloping roof on the north to provide protection from winter winds. It is an astonishingly sensible design for very cold climates and has been undergoing a revival in the seventies.[8]

Other forms of traditional architecture incorporate simple passive cooling techniques effectively. Throughout tropical Asia and South America, simple pole and thatch buildings are open on the sides to allow ample ventilation but are protected from the heat by a thatch roof. Thatch rivals fiber glass as an insulator, and is also found atop mud and straw buildings in sub-Saharan Africa. In Moslem Asia, cooling towers have been in use for a thousand years and help draw air into buildings, providing ventilation and relief from the hot summer climate.[9]

Since the beginning of the Industrial Revolution and the migration to the cities that accompanied it, traditional architectural forms have been abandoned by one culture after another. The climate-sensitive building designs that had been developed were not easy to adapt to cities, and the growth of urban populations encouraged a standardization of architectural styles, particularly in the low-cost housing needed for an expanding labor force. The amount of wood and coal required to heat the buildings of nineteenth-century Europe and North America increased rapidly. Although living conditions improved for many people, they deteriorated for millions of others; heating buildings became a major expense that not everyone could afford.

As modern architecture matured over the last century, energy considerations continued to take a back seat. Architect Richard Stein writes that "during the 1920s many of the most prophetic and influential architects projected the form of the future as being freed from the rigorous demands of climate and orientation." These pioneering designers embraced the notion of using mechanical systems and artificial lighting to provide for needs previously met by sunlight and natural ventilation. The convenience of modern heating and cooling systems and the relatively low cost of new fuels such as natural gas and electricity persuaded consumers as well as builders that worrying about energy efficiency was a waste of time.[10]

In more recent years, the fuel requirements of buildings have continued to grow, more than doubling worldwide between 1950 and 1970. Though a portion of this increase is accounted for by growth in the number of buildings, many structures are simply built to use more energy than those of the past. And because of an unprecedented housing boom, a disproportionately large share of the world's current building stock was constructed during these years. Many of the new building forms were pioneered by American designers and were quickly adopted in Europe and Japan during the postwar reconstruction period. More recently, they have been aggressively marketed throughout the Third World.[11]

There are several common reasons for the unnecessarily large fuel requirements of buildings around the world. Only half the residential buildings in Europe, for instance, have any insulation at all, and storm windows are a rarity there. In the United States, close to one-third of the residential housing stock has no insulation, and another 50 percent is inadequately insulated. In addition, the buildings in many countries, particularly those belonging to the poor, are loosely constructed and "leaky": tiny cracks around windows and in walls and attics can result in considerable heat loss. Another explanation for high fuel use is the usually random siting of buildings, which exposes them to heat-robbing winds in the winter and excessive sunlight in the summer.[12]

This lack of attention to climate-sensitive design or construction techniques, combined with energy-intensive heating, air conditioning, and lighting systems, has proved costly. The results are easily seen in the typical modern office building with its glass facades and mechanical "climate-control" systems in use every day of the year. It is not uncommon to have to turn on a quarter of an acre of lights to work at a few square feet of desk in these buildings. In private houses and apartments, the rapid spread of air conditioning has been the most important factor in increasing energy use in recent years. Though in many ways the architectural changes of the last 35 years have been a success, from a long-term energy perspective they have been a failure.

There are two main categories of buildings—residential and commercial—and both are big energy users. Together, the residential and commercial sectors account for between 20 and 40 percent of national energy use in most industrial countries. (See Table 1.) Of this, approximately four-fifths is used to heat, cool, and light buildings and the rest runs appliances and water heaters. Residential energy consumption exceeds commercial energy use in most countries by 20 to 100 percent, though the rapid growth of the service sector has meant commercial buildings take up an ever-increasing share.[13]

Table 1: Energy Use in Residential and Commercial Sectors in Selected Industrial Countries, 1978

Country	Residential and Commerical Energy Use	Share of Total National Energy Use	Residential and Commercial Energy Use Per Person
	(million tons of oil equivalent)	(percent)	(tons of oil equivalent)
United States	442.62	33	2.01
Canada	46.32	33	1.95
Sweden	12.95	38	1.56
Netherlands	21.04	39	1.50
West Germany	78.89	39	1.29
France	50.76	35	.95
United Kingdom	45.01	31	.81
Italy	31.80	30	.56
Japan	56.59	21	.49

Source: Organisation for Economic Co-operation and Development.

North Americans warmed to the new energy-intensive buildings earlier and more vigorously than Europeans did. Fuel use per person in the residential and commercial sectors is nearly twice as high in the US and Canada as in most of Europe. There are a number of explanations for this large disparity, including the more compact layout of European cities and the tendency of people there to be satisfied with warmer buildings in summer and cooler ones in winter. The industrial country with the best record is Japan, where the per capita fuel use in the buildings sector is only one-quarter of the U.S. level, due to the compactness of Japanese buildings and the nearly complete lack of central heating. It is also striking that in Sweden the fuel requirements of buildings are 25 percent lower than in North America, despite a harsher winter climate. Traditionally higher fuel prices and lower per capita incomes have meant that the energy used in buildings is treated less nonchalantly in Europe and Japan than in North America.

"Traditionally higher fuel prices and lower per capita incomes have meant that the energy used in buildings is treated less nonchalantly in Europe and Japan."

Energy use in the buildings sector has become a major problem in virtually all industrial countries, however, and none can afford to be complacent. In much of Europe, the proportion of national energy resources devoted to buildings is as high as or higher than that in the United States. The U.S. transportation sector claims a large share of available fuel, whereas elsewhere in the industrial world, industry and buildings account for the preponderance of fuel use. Furthermore, much of the energy used in buildings in these countries is supplied by petroleum, which makes their positions even more precarious. Nearly all the heating fuel in Japan and 80 percent of that used in France and West Germany is petroleum, compared with 44 percent in the US, where natural gas plays a much larger role. For Europe and Japan, therefore, buildings play a crucial role in any efforts to reduce burdensome OPEC oil bills.[14]

Similar data are unavailable for Eastern Europe and the Soviet Union, but the few figures that have been published indicate their buildings are comparable to those in Western Europe in terms of energy use. The winters are severe, and insulation levels are not particularly high. Petroleum and electricity use is, however, considerably lower in these countries. In the Soviet Union, one-quarter of residential energy needs are still met by firewood and central heating is relatively rare. These conditions are changing, however; as living standards improve, modern heating systems have been introduced and fossil fuel use has risen commensurately.[15]

The situation in the Third World varies widely depending on climate and stage of development. Many developing nations are located in the humid tropics, where buildings traditionally relied entirely on the sun for heating and on natural ventilation for cooling. In the more temperate developing countries in Central Asia and Latin America, firewood and charcoal have been and still are the most popular means of providing heat. However, in the last decade the cities of the developing world have attracted a large assortment of Western-style office and residential buildings. Built with little attention to the often tropical climate in a developing country, most of the new buildings require electricity-intensive mechanical cooling systems designed in the West. Since many developing countries lack both engineers and the spare parts needed to keep the systems running, the air conditioners frequently break down. It is not uncommon for people then to break the sealed windows in order to keep their offices from becoming stifling hot. So far, the heating, cooling, and lighting of buildings is not one of the major drains on Third World fuel supplies, as it amounts to less than 10 percent of the energy used in most nations. A major challenge in the future, however, will be to improve the miserable housing conditions in many developing countries without compounding their already desperate energy situation.[16]

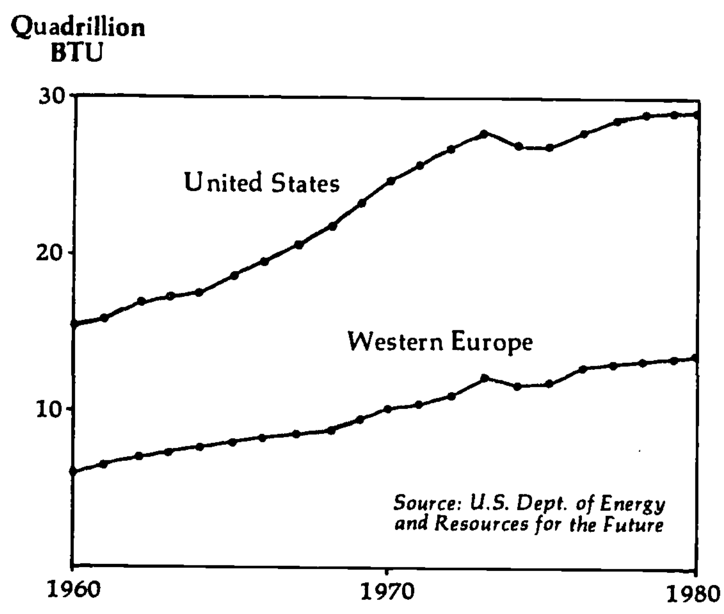

Figure 1: U.S. and European Energy Use in Residential and Commercial Sectors, 1960-80

In many nations there are signs that the energy performance of buildings has begun to improve since 1973, albeit slowly. The increase in energy use in the U.S. residential and commercial sectors dropped from a 5.1 percent annual growth rate in the sixties to approximately 2 percent in the late seventies. (See Figure 1.) Most of this improvement came from thermostats being set lower, adjustments of furnaces and air conditioners, and the addition of insulation to existing buildings. Even these simple measures, in combination with slowed economic growth, have been enough to stabilize the energy requirements of most buildings. The remaining annual increment comes from an increase in the number of buildings. Savings have been more impressive in Europe. Energy use in buildings is increasing at a 1 percent annual rate in West Germany, has leveled off in Great Britain, and is slowly falling in Sweden. This compares with growth rates that approached or exceeded 5 percent during the sixties.[17]

The improvements made so far have been predominantly a response to higher energy prices. The costs of electricity, heating oil, and natural gas have all risen at record rates since the mid-seventies, in marked contrast with the steady and declining prices of the sixties. In Japan, the real price of heating oil rose 75 percent between 1973 and 1976 and in Italy it more than doubled. In the United States, the real cost of heating many homes soared, with particularly severe increases for houses heated by oil. (See Table 2.) Lower income

Table 2: Average Annual Residential Heating Bill in the United States, By Fuel, 1960-80

Year	Oil	Natural Gas	Electricity
		(1980 dollars)	
1960	390	310	960
1970	360	250	630
1975	560	280	710
1980 (est.)	990	420	840

Source: Office of Technology Assessment and U.S. Department of Energy.

groups have been hit particularly hard. In its 1979 annual report, the Tennessee Valley Authority poignantly called attention to one of its customers who paid her electric bill with a social security check, "and walked out to face the month of February with less than $30." Though natural gas is still a relative bargain in the US, recent estimates indicate that price decontrol combined with supply constraints will make it nearly as expensive as heating oil by 1990.[18]

Similar increases have occurred in the cost of providing energy to commercial buildings. Paying for electricity is now the biggest expense in operating most large structures, and has helped boost monthly rents at a record pace. In both the commercial and the residential sector, building owners and renters frequently cannot afford not to conserve. In many countries, government conservation programs have begun to provide an additional impetus.[19]

As recently as 1970, economists and planners in many nations were predicting that residential and commercial energy use would more than double by the end of the century. Their predictions were an extrapolation of the trends from 1960 to 1970, which in 1980 seem like ancient history. The formerly unbroken curve of spiraling fuel use in buildings has now been interrupted nearly everywhere. Continuing price increases and the gradual response of consumers and the building industry are likely to cause a leveling off of the energy requirements of this sector during the next decade. The major unanswered question is whether architects, builders, and consumers can actually reduce the amount of fuel used in buildings by the end of the century. A growing body of evidence indicates they can.

Climate-Sensitive Design

A decade ago, builders and home renovators interested in cost-effective, energy-conscious building design would have been in a real bind. Basic data describing patterns of heat gain and loss in buildings were hard to come by, only a handful of architects had come up with innovative building plans, and financial information comparing various options was unavailable. Today the situation is

"The formerly unbroken curve of spiraling fuel use in buildings has now been interrupted nearly everywhere."

changing rapidly. Technical journals have appeared and conferences are scheduled in many countries, national and private laboratories are investing millions of dollars in the development of energy-saving materials and assemblies, and architectural plans are now available for everything from a low-energy office tower to a passive-solar mobile home.

The common goal behind these diverse efforts is to reduce the costly reliance of buildings on fossil fuels. The basic principles being applied are quite simple: by using insulating materials to slow the rate at which indoor temperatures adjust to extreme outdoor temperatures, by admitting as much sunlight as possible during the winter months, and by providing various means of shading during the summer, heating and cooling systems based on fossil fuels can be greatly reduced or even eliminated. Different designs are of course needed for different types of buildings, climates, and economic levels, but in most cases the underlying principles are similar. In recent years, the international exchange of data and reports has begun to assist the research efforts in many nations.

Glass (and more recently plastic) is the basic material that makes modern solar heating possible. Grecian solar houses must have lost heat almost as rapidly as it was collected, a process that is reduced with glass that readily transmits sunlight but that impedes thermal radiation, in effect trapping heat in the building. This phenomenon, known as the greenhouse effect, is familiar to anyone who has left a car in the sun on a cool day and returned to find it overheated. In its simplest form, passive solar heating consists of having most of a building's windows on its south side (or, in the southern hemisphere, on its north side). In this way, a large portion of the heating needs are supplied by the sun. Windows on the east, west, and north are minimized because they tend to lose more heat than they gain and because they can cause overheating problems in the summer. Many architects now design buildings to be elongated on an east-west axis in order to increase the area available for "solar gain" on the south. Properly siting a solar building is almost as important as the design. Access to the winter sun and protection from cold winds can be facilitated by correctly positioning the structure.[20]

18 The first modern solar house was built in Chicago in the thirties. It differed from a conventional house mainly in that it was carefully sited to take advantage of the sun and had a large window area on the south side. Similar buildings were constructed over the next two decades in Cambridge, Massachusetts, in Wallasey, England, and elsewhere. They attracted a great deal of attention and convinced some observers that a new physical principle had been discovered. *Business Week* suggested in 1940 that the Chicago house was the "newest threat to domestic fuels." Some of the early solar houses were successful and others were not, but over the years a few persistent designers continued to improve the state of the art.[21]

As research proceeded it became clear that retarding heat loss was as essential as admitting sunlight. The walls, roofs, and windows of conventional houses lose a great deal of heat during cold weather because of radiation and convection. Such a house, when heated only by the sun, cools rapidly after dark. Solar houses developed more recently in Europe and North America have included more than twice as much wall and attic insulation as conventional dwellings have. Most windows are double- or triple-glazed, and vestibules are often used to prevent a sudden loss of warm air when someone enters or leaves the building. In addition, strong emphasis is placed on tightness of construction so that the building has as few air gaps as possible. As much as half the heat loss in a conventional building occurs through direct infiltration of cold air.

Also integral to the success of a passive solar building is a method of heat storage. By using construction materials with substantial capacity to hold heat, a building's ability to store the sun's energy is increased. When the sun sets or when the furnace is turned off, the thermal mass slowly radiates heat, keeping the building warm. Several traditional building materials—including brick, concrete, adobe, and stone—perform this task well and help reduce temperature fluctuation in both winter and summer. In some structures these materials are used in walls that are then insulated on the outside so that the thermal mass is in the interior of the building. Additionally, thermal storage materials can be incorporated in large fireplaces, secondary walls built mainly to store heat, or in floors. Rock or gravel

"The beauty of passive solar design is that there are a great number of ways to harness the sun's energy effectively."

drainage underneath a dwelling can serve a dual role, acting as a large heat sink. Water is one of the best materials for storing warmth, and, though somewhat difficult to use in a building, can be incorporated in a "water wall" or used in a fish pond. Researchers at the New Alchemy Institute in Massachusetts maintain that aquaculture tanks located inside a greenhouse can pay back their cost in heat-storing capacity alone.[22]

In addition to providing heat during the winter months, a climate-sensitive building should be cool and well-ventilated in the summer. Fortunately many passive heating features such as good insulation and thermal storage help with passive cooling in the summer. Other features that are frequently employed include shades that protect south-facing windows from the high summer sun and ventilation systems that take advantage of natural breezes and thermal convection to keep air moving continuously through a building. Vegetation can be one of the best aids to passive cooling. Deciduous trees protect a house from the summer sun only and often provide a microclimate that is several degrees cooler than in surrounding areas. Pioneering work in this field was done in Japan and the U.S. Southwest. More advanced forms of passive cooling recently developed will play an important role in cooling large commercial buildings.[23]

The beauty of passive solar design is that, though the basic principles are simple, there are a great number of ways to harness the sun's energy effectively. Solar houses don't have to be identical, nor need they be dull. Bruce Anderson, chairman of Total Environmental Action and a solar design expert, notes that "the variety of climates and personal tastes will dictate a veritable plethora of unique solar home designs." Hundreds of different types of passive solar buildings have appeared in the last decade as architects attempt to translate the simple principles of energy-efficient housing into livable, reasonably priced, attractive buildings. Many of the most efficient new buildings look surprisingly conventional and would easily blend into any residential or commercial development.[24]

One of the more ingenious designs for solar heating involves the use of a thermal-storage wall placed several centimeters inside a large

20 expanse of glass on a building's south side. The wall, constructed of masonry or filled with water, is painted a dark color to absorb heat from the sun; heat collected during daylight hours is radiated to the rest of the house for many hours after sundown. This is known as a Trombe wall, named after Felix Trombe, who with Jacques Michel designed buildings using this technique at the French Solar Energy Laboratory in the late fifties and early sixties.[25]

Today, the Trombe wall is a well-established concept and variations on it can be found in many parts of the world, using different wall materials and thicknesses, various techniques of air circulation, and different amounts of insulation and thermal storage. In general, the Trombe wall is an extremely effective collector of solar energy. Its chief drawback is that the heat-storing wall is quite close to a window, causing considerable heat loss through radiation and requiring special thermal shades that are closed at night. An interesting variation on the Trombe wall was developed by Steve Baer in New Mexico in 1972. He mounted 138 barrels of water behind a south-facing window wall, providing effective, cheap thermal storage. Another house in that area uses 2,000 old wine bottles for storage.[26]

A related but distinct method of passive solar heating is the use of a greenhouse or "sunspace" on the south side of a building. An attached greenhouse serves as a natural solar collector that can be easily closed off from the rest of the building at night. It can be an interesting addition to a house and can extend the fresh vegetable season as well as providing heat. As with other passive solar systems, the importance of double or triple glass, tight construction, thermal mass, summer shading, and ventilation is clear. If well-designed and properly sited, a greenhouse can supply more than half a building's heating requirements in sunny climates. The chief advantage of the solar greenhouse is that it is an easy addition to conventional designs and is an attractive option for people who do not want to alter the basic form of their buildings.[27]

Other solar designers are catching the sun by moving underground, a seeming contradiction that in fact makes a great deal of sense.

Earth-sheltered buildings, whether they simply employ a sod roof or are constructed completely beneath the surface, use the earth as a natural insulator that damps out temperature fluctuations in both winter and summer. By exposing such buildings to the vicissitudes of the weather only on the sunny side, the sun's heat can be effectively collected and stored. Earth-topped roofs have the additional advantage of providing natural evaporative cooling in the summer. In some climates, watering the roof might be the only air conditioning necessary. Projects in the United States and Israel have done much to advance these designs. What is not yet clear is whether earth-sheltered buildings can be built cheaply and made attractive to large numbers of people. Right now, building underground is an expensive proposition, but some builders are convinced that the cost can be brought down substantially.[28]

Other types of climate-sensitive buildings have been developed in recent years and are being further refined by research teams and entrepreneurs. A house developed by Harold Hay in California uses an enclosed pool of water on the roof for heat collection as well as for radiative cooling. Another interesting concept, developed by Lee Porter Butler in California and by a Norwegian team, is called the double-envelope house. It incorporates a greenhouse on the south side and a continuous air space in the roof, north wall, and basement to supply heated air to various parts of the building. Both the roof pond design and the double-envelope house have been successful in some custom-built homes but their large-scale economic attractiveness remains to be determined.[29]

These bold, innovative research efforts are typical of the energy-efficient architecture field in 1980. New design ideas appear regularly, and older designs are being perfected and made less costly. The United States has provided much of the early leadership in climate-sensitive building, but other nations are gaining and may soon be on the cutting edge in particular areas of research. That different national areas of specialization have begun to develop in a field so young should not be surprising: climate is the key factor. Some designs are appropriate in northern, cloudy regions while others are better suited to areas with more sunlight year-round. Darian Diachok of the U.S.

Solar Energy Research Institute recently conducted an international passive architectural survey and notes: "Passive research is taking on a distinctly regional flavor. Individual countries are now making major strides in developing buildings that are economical in their climates."[30]

The different paths being pursued by U.S. and southern European designers as opposed to those in Canada and northern Europe illustrate this emerging regional focus. In the former areas, emphasis is placed on obtaining as much winter sunlight as possible. Using Trombe walls and various techniques of direct solar gain through south-facing windows, buildings in these regions can obtain most of their heating needs from sunlight. Designers focus on maximizing solar access as well as providing summer shading and ventilation.

Researchers in Canada and northern Europe are taking quite a different tack. Since the sun is present for only a few hours a day at midwinter and for much of that time is hidden by clouds, relying on sunlight for a large portion of heating needs would be hopeless. Instead, architects are designing super-insulated, very tightly constructed houses with relatively few windows. These buildings are wrapped in polyethylene plastic and special care is taken to seal all trouble spots, resulting in air infiltration that is one-tenth that of a conventional house. These buildings are called "low-energy" or "zero-energy" houses, denoting the fact that they require very little heating, even from the sun. In fact some of them rely as much on the body heat of the occupants and the waste heat from appliances as on heat from the sun, and auxiliary heating is needed only on the coldest of winter days. Typically, a low-energy house is fitted with an air-to-air heat exchanger—a small unit resembling an air conditioner that ventilates the building but prevents heat loss. Without this device the air could become unpleasant or even unhealthy as pollutants such as the radon found in concrete slowly accumulate.[31]

Leadership in low-energy building design is coming primarily from Austria, Canada, Denmark, and Sweden. Research results have been impressive so far. The test buildings appear to be efficient and economical: the Saskatchewan Conservation House in Canada, for example, uses double-wall construction, super-insulation, a heat exchanger, and south-facing windows to reduce heating requirements by 90 percent compared with a well-constructed conventional home. Some observers are predicting that such buildings will become the norm in northern latitude countries.[32]

Energy-conscious design is on yet another path in regions that must cope with a hotter climate. Passive cooling research in most countries, including the United States, is ten years behind that on heating. Australia, however, has conducted a major research effort under the auspices of the Commonwealth Scientific and Industrial Research Organization, and is now doing extensive work on evaporative and radiative cooling. The results of this research should assist other countries with hot climates. In the case of the Third World, this could be a significant contribution at a time when planners are contemplating the need to expand housing quickly in cities. According to some experts, it should soon be possible to construct all but the largest buildings without air conditioning in most parts of the world. Passive cooling and natural ventilation will keep such buildings comfortable.[33]

A separate regional focus is beginning to emerge in some tropical nations. In hot, humid climates, ventilation and dehumidification are essential for comfort, and evaporative cooling does not work well. Unfortunately research into these problems is not very far advanced. The developing countries located in the tropics have many pressing needs that compete for scarce capital resources, and international assistance agencies have been slow to respond to the need for work in this field. Malcolm Lillywhite of the Domestic Technology Institute in Colorado, who is an expert on energy needs in Africa, is confident that passive cooling can make a major contribution in tropical regions, but he maintains that a great deal more research is necessary, particularly at the village level.[34]

Most of the building-related research now under way in the Third World is concerned with the development of low-cost native construction materials to replace expensive imported ones. Such efforts need to begin incorporating thermal considerations. In the past, up-

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grading the traditional housing in many of these countries resulted in a steady deterioration in their livability. The tin roof that has spread throughout much of Africa is cheap and long-lasting, for instance, but it allows excessive heat buildup compared with a thatch roof. According to Lillywhite, the use of native insulating materials can greatly improve these buildings. India has initiated research programs that are looking into some of these problems; an effort to develop moisture-absorbing materials for dehumidification has been particularly successful.[35]

The bottom line in determining the success of various climate-sensitive designs will be their cost-effectiveness. This issue has received quite a bit of attention from economic analysts in recent years. Their calculations rest on a comparison of the costs of the solar and conservation features with the value of the fuel saved during the time the building will be occupied. Included in the equations are assumptions about interest rates, the rate of inflation, and the rate of fuel price escalation. Using these criteria, economists can determine a payback period for the money invested in energy-saving features as well as a life-cycle cost for the building. The basic conclusion of these economic analyses has been consistent: a well-designed solar or low-energy building almost always has a lower life-cycle cost than a conventional building does.[36]

Climate-sensitive buildings usually come out ahead in such calculations because they can often reduce fuel bills by 50 percent at little or no extra cost. For instance, a south-facing window costs no more than one that faces north, and a concrete floor that can store heat is cost-competitive with a wooden one. Options such as using two-by-six inch wall studs rather than two-by-fours to allow space for extra insulation or employing triple-glazed windows or night shades add only marginally to building costs. Other design possibilities—extensive glazing, a Trombe wall, or a large amount of thermal storage material—can be quite expensive, but if properly employed and suited to the climate of the area they can still be a financially sound investment.

"A nearly equal investment in conservation and solar measures would yield the lowest total cost over the life of the building."

The economic attractiveness of a climate-sensitive building also stems from the fact that expensive central heating and air conditioning systems are not needed in any but the largest buildings or in the most severe climates. Heating needs can be reduced so drastically that localized gas or electric heaters or wood stoves will often suffice. Residential building costs are often lowered by $1,000 or more by doing without air conditioners, furnaces, and heat distribution systems.[37]

Many economists caution that the cost-effectiveness of particular designs can vary greatly. Over the lifetime of a building it is possible to save a lot of money or to save only a little, depending on the climate, design choice, regional construction costs, and the price of auxiliary fuels. All the various solar and conservation features in a building reinforce each other, and it is essential that the best combination of features be chosen. For instance, designers of large commercial buildings have had a tendency to provide for a large amount of solar gain when in fact cooling costs are usually a higher portion of the structure's expense. An inappropriate design can in some cases actually increase fuel needs, and it certainly reduces the benefits that would otherwise accrue to the building's owner.[38]

Flexibility is now the watchword for designers interested in cost-effective solar buildings. Even within a particular region exclusive reliance on just one design principle is unlikely to consistently yield the "right" answer from a financial viewpoint. Douglas Balcomb of the Los Alamos Scientific Laboratory, a leading expert in the performance of passive solar systems, has found that a mix of passive solar and conservation methods is usually the best bet for the consumer. Using data from a house in Kansas, his analysis suggests that homeowners should initially invest in insulation and storm windows, but that beyond $800, investment in passive solar features should be pursued simultaneously. A nearly equal investment in conservation and passive solar measures, Balcomb found, would yield the lowest total cost over the life of the building. Putting the same money into either strategy alone would have resulted in considerably smaller savings.[39]

An important aspect of this flexible approach to design is that passive systems need not be exclusively passive. In most cases some form of auxiliary heating system makes sense, with the size of the system depending on climate and the local availability and cost of fuels. In regions where electricity or oil rather than natural gas is used, a higher fraction of solar heating is appropriate. And in many cases, it is a good idea to add non-passive features, such as a fan that moves heated or cooled air to other parts of a building. Fans and even active solar collector systems if properly integrated can improve the financial attractiveness of a climate-sensitive building. By most estimates, however, proper design is the best place to start when planning a building from the standpoint of its energy use. Pump-driven solar collectors, though highly effective for heating hot water, are usually an expensive method of heating a building's interior.[40]

The economics of the energy systems of buildings is still a relatively young science. Much work remains to be done so that planners, builders, and consumers can have detailed information on the long-run financial picture of a building they want to construct or purchase. The most important results are already in however. The world's buildings consume billions of dollars worth of fuel unnecessarily each year and fairly simple design changes could have eliminated much of that waste for a relatively small price. From now on, the economic evaluation of a building should include its probable life-cycle cost rather than just its initial expense so that the investments make economic sense in the long run. During the eighties, continuing to construct houses and commercial buildings such as those that dot the landscape today would be costly, both for individuals and for society as a whole.

Breaking Ground

The research and development efforts of numerous innovative architects, builders, and engineers over the last decade have laid the foundation for the transition to climate-sensitive, fuel-conserving buildings. The principles are simple, the necessary materials are

"A recent U.S. Government listing of solar design professionals included over 1,000 firms and individuals."

readily available, and the buildings are cost-effective at today's prices. The transition may be a gradual as well as a complicated one, however. Institutional barriers such as the complexity of the building industry and its necessarily acute attention to short-term financial considerations will make rapid change difficult. Alan Hirshberg of the consulting firm Booz, Allen, and Hamilton notes: "the building industry is very disaggregated and fragmented. You really need to go beyond the traditional research and development. You have to deal with that wide variety of players in the building industry process."[41]

With passive solar architecture, implementation will clearly be more difficult than the basic research. Among the challenges ahead are the education of a whole generation of architects, engineers, and builders; the integration of solar and conservation designs into subdivisions and housing developments; and the transformation of a commerical building industry that so far has been lagging behind. There are a number of signs that some of these changes are beginning to occur. If they continue, climate-conscious homes and offices could take off in a big way in the eighties.

One of the most encouraging developments is the growing interest of architects in solar design. Heating, cooling, and lighting needs have in recent decades been thought of as unrelated to the design of buildings, and they were often left to the engineers to resolve once the plans were complete. Today a growing number of architects are insisting that energy considerations play a major part in the design process. The early pioneers in climate-sensitive architecture, who often designed homes for their own use, have been joined by hundreds of others. In France, Sweden, and the United States, solar architects can be found in most regions, and plans for a custom-designed solar or low-energy building can be found nearly as easily as those for a conventional one. A recent U.S. Government listing of solar design professionals that covered engineers as well as architects included over 1,000 firms and individuals. Many of the companies are small, designing less than ten buildings a year. However, many solar designers are working to expand their business, and some are drawing up plans for houses that can be marketed to builders and developers.[42]

A more fundamental shift is also beginning to occur as energy considerations enter into the designs of many architects who are not specifically attempting to create climate-sensitive buildings. Here, the architectural schools are playing an important role. Many are for the first time requiring courses in the thermal performance of buildings and a few are actually teaching passive solar concepts. Often the students have led the faculty in insisting that energy issues be included in the curriculum.

Some of the leading schools in teaching energy-conscious architecture are the Massachusetts Institute of Technology, University of Oregon, and Arizona State University in the US; the Architectural Association in England; the University of Alberta in Canada; the University of Auckland in New Zealand; and the Technical University in Denmark. Much work remains to be done, however, to improve the educational process. Architecture professors Harrison Fraker and Donald Prowler are currently developing for use in a dozen U.S. schools of architecture curricula that will provide "a coherent framework for the inclusion of passive solar design methods and concepts in the architectural design process." One encouraging development in 1980 was the formation of the International Institute of Energy and Architecture. Its goals include furthering the worldwide exchange of data and encouraging the teaching of climate-sensitive design in schools of architecture everywhere.[43]

Architects are of course only the tip of the iceberg in the building industry. In the United States, several hundred thousand developers, builders, subcontractors, and suppliers erect more than one million single-family homes, apartments, and commercial buildings each year. Only 10 percent of these are custom-designed by architects. Building firms must assess the market for each particular project and then choose a design, building materials, and construction methods that appear to satisfy the wishes of their customers and that will provide a decent profit. Unfortunately, passive solar buildings are often thought of as unconventional and costly, a major deterrent to professional builders and developers. In today's real estate market, both single-family homes and commercial buildings are often built on a speculative basis, and the builder must be cautious not to come up with something that won't sell. Features that add cost to a speculative building are naturally shied away from since the selling price is the bottom line and builders don't have to worry about the home's heating bills.[44]

Despite these obstacles, some people within the building industry are beginning to take an interest in energy-conscious construction, particularly in the United States. In the last few years several firms that concentrate exclusively on passive solar construction have been set up. Many have been highly successful. Comunico, a company in New Mexico, has built a large number of custom-designed solar houses that use Trombe walls, attached greenhouses, and other techniques. Comunico is achieving 70 to 90 percent solar heating in the buildings it has constructed so far, and the group is now developing standardized solar homes that will be suitable for subdivisions. Another successful solar building firm is Green Mountain Homes of Vermont. Established in 1976, the company has built more than 200 solar houses and is now completing a home a week. Most of the components are prefabricated, and it is possible for prospective homeowners to buy the building as a kit and erect it themselves.[45]

Several other U.S. and Canadian firms are building solar houses in large numbers, and hundreds of smaller builders have entered the market. The day when passive solar architecture was mainly the domain of well-to-do owners of custom-designed homes is now ending. As solar builders adopt mass-production techniques and the preassembly of components, dramatic cost reductions are being realized. And one company is now offering a passive-solar mobile home for sale, opening up an entirely new market. Robert Naumann, an engineer with considerable experience with solar construction, echoes the conclusions of many solar entrepreneurs: "The profit margin can be very attractive when the builder keeps cost at a reasonable level. . . . in a progressive community with a good market these types of homes should always be successful." In no other part or the world has solar building taken hold quite so extensively as in North America, though in Denmark and Sweden the low-energy house may soon play an important role in the co-op dominated building markets in those countries.[46]

Since much of the initial resistance to solar design reflects builders' perceptions of market demand, the industry is beginning to respond as home buyers pay more attention to the energy characteristics of houses. Most builders, however, are reluctant to go out on a financial limb with untested designs. Solar building competitions and demonstration programs can help surmount this problem. Programs set up by the U.S. Departments of Energy and of Housing and Urban Development, as well as by state governments, have worked well thus far. Architects and builders have had the opportunity to test out design ideas with government financing and many have since begun to construct residential and commercial solar buildings for the private market. A major Common Market solar design competition now under way is expected to stimulate climate-sensitive building in Western Europe.[47]

Involving the entire building industry in energy-conserving construction will obviously take time, and a continuing flow of information will be essential. It is encouraging that trade associations are introducing educational programs and that industry publications now regularly carry articles emphasizing the need to save energy. Most informed observers seem to believe that government incentives such as low-interest financing and tax credits will also be essential, especially to open up the lower income housing market. Such programs can help shift the momentum of a rather entrenched industry and can encourage the slightly more costly attention to detail that is crucial if good designs are to result in good houses.

The next important step in the spread of climate-sensitive buildings is the use of these design concepts in housing developments and subdivisions. So far, there are few examples of such large-scale solar building projects, but indications are that many will get off the ground in the next few years. Developers are realizing that solar design and the promise of reduced fuel bills can be a strong selling point, and they are approaching design firms for solar blueprints. The few solar developments that have been constructed so far have been quite successful and are serving as models for other builders.[48]

"The industry is beginning to respond as home buyers pay more attention to the energy characteristics of houses."

Village Homes in Davis, California, is a 240-unit solar subdivision developed in the late seventies. While most of the houses appear at first glance to be quite conventional, they are all passively designed and are sited and landscaped so as to have full access to the winter sun. The members of the community are actively involved in the continuing planning of the Village Homes development, and an architectural review board ensures that one family's buildings and trees do not intrude on another's access to sunlight. The heating and cooling requirements of these buildings are 50 percent below those of a conventional development. Solar water heaters, extensive bike paths, and community gardens further enhance the energy efficiency and livability of this model community. Village Homes has been successful both from a comfort and a financial viewpoint, and it has drawn nationwide attention to the possibilities of solar developments.[49]

Several other solar subdivisions are now rising in various regions of the United States as well as in England and West Germany. They rely on a variety of building designs, but all emphasize the need to lay out streets and plan landscaping in a way that allows solar access. This is not always an easy task, particularly with small lots and with people's traditional expectations that homes should face the street. In addition, local zoning requirements can make proper siting nearly impossible. Solar developer Randle Shick, at work on a subdivision in Virginia, notes that "designing the site plan for this 10-acre tract for solar orientation was a challenge, but became a headache when county zoning requirements were confronted." In fact, one of the reasons for the success of the Village Homes project in California was the cooperation of the city council and its adoption of zoning and building codes that encouraged energy-efficient construction. With this sort of support, the proper siting of buildings can be relatively simple and could become standard practice in new subdivisions.[50]

Equally as important as designing energy-efficient subdivisions is the task of incorporating passive solar features into town houses, apartments, office buildings, and other high-density urban developments. Siting and orientation are more difficult in these cases, though

32 the advantages of shared walls and less floor space per person help reduce energy requirements. Unfortunately, only modest research efforts have been undertaken so far on climate-sensitive design for such buildings, and it will be some time before the field is as advanced as it is with detached single-family residences.

According to U.S. Department of Energy estimates, even conventional residences in high-density urban neighborhoods require on average 25 to 50 percent less heating energy than suburban-style houses do. The inclusion of passive solar features and conservation measures in town houses can make them an extraordinarily energy-efficient form of housing. Architect Peter Land of Illinois calls for a new emphasis on low-rise, high-density developments that he believes could lower energy and building costs simultaneously. Some of the town houses he has designed would be open to the south and be protected by other buildings on the east and west, and would include an interior patio to admit sunlight. Presumably, solar town houses could also profit from the heat-conserving techniques developed for low-energy houses in Canada and Scandinavia; since solar access is sometimes limited in cities, a high level of thermal insulation makes sense.[51]

A number of solar town houses and multi-family housing projects have been built in Europe in recent years. Italy has more than 2,500 solar housing units in place, most of them relying on relatively simple direct gain designs. One of the most ambitious projects is a planned energy-efficient town in Belgium that will include high-density solar buildings. That sort of comprehensive approach is needed in cities everywhere. Peter Pollock, an urban planner with the U.S. Solar Energy Research Institute, notes that compact cities and the use of solar technologies are compatible goals, but that they will require new initiatives by both developers and planners. Given the projected increases in city dwellers in many countries, a great deal of passive solar building in the future will have to be urban solar if it is to have a significant impact. In Europe and Japan in particular, relatively few single-family detached homes will be built in the coming years.[52]

High-rise apartment and office buildings also present unusual design problems that have yet to be fully addressed. There is less latitude in shaping such structures and providing shading. In addition, lighting and cooling in larger buildings usually requires more energy than heating does, so providing daylight and passive cooling for the occupants becomes a major consideration. Research on passive lighting is now under way, and engineer Douglas Bulleit notes that for large buildings "it very strongly appears that daylight is becoming the champion of passive design techniques." Experts in the field are confident that designs that incorporate the use of daylight can make climate-sensitive architecture as cost-effective for large commerical buildings as it is for single-family dwellings.[53]

One of the pioneering architects in the commerical building field is Harrison Fraker, who has developed a number of striking energy-efficient innovations. Among other projects, he has designed a fairly low-cost medical office complex in Princeton, New Jersey, that is expected to use 30 percent less energy than a conventional building. It will incorporate an atrium to provide light and heat, a natural ventilation system, and a roof topped with a rock bed and sprinklers to provide evaporative cooling at night. Another leader in energy-efficient design for large buildings is Gunnar Birkerts of Detroit, who developed a 14-story office building for IBM that was completed in 1979. The building incorporates much less glass than most modern buildings do, yet through an ingenious window design most of the office workers are provided with natural light. Furthermore, the IBM office building includes a unique two-toned facade that allows solar gain on one side but retards heat loss on the other. The world's largest passive solar office tower will soon be standing in Singapore. Designed by a U.S. firm, it will be 40 stories tall and is expected to have energy bills 38 percent below those of a comparable conventional building.[54]

Modern high-rise buildings are quite complex, and improving their energy characteristics is now one of the major research frontiers in climate-sensitive design. In large structures, designs that solve one energy problem can easily aggravate others, and integrating passive heating, cooling, and lighting into the same building requires complicated models, computer programs, and numerous trade-offs. In addition, most large buildings have mechanical systems to control the building's internal environment, and, while these can be made smaller in passive solar buildings, they cannot be eliminated. Energy-efficient design must therefore be integrated with the mechanical systems. One solar architect notes that "we design to provide comfort and lighting in a passive way for at least 50 percent [of the energy load] and then use the mechanical systems to handle only the extremes." Recently developed microelectronics-based control systems allow artificial lighting to be adjusted according to the availability of natural light and enable heating to be turned down when people leave a room. Large savings could also be realized by providing localized light and heat, making it unnecessary to switch on hundreds of square feet of lighting every time someone enters a room. And giving occupants some control over their own heating, cooling, and lighting could magnify these savings. The sealed window is one feature of modern office buildings that is ripe for elimination: windows that open would provide cooling breezes on many days when air conditioning is now required.[55]

Considerable research into many of these questions is still needed and is the focus of government support in some countries. In the United States, the Department of Energy is sponsoring a program in which a panel of experts is going through the design process with 30 different design teams, critiquing their plans and offering suggestions. The U.S. Government is also providing leadership by example: the Tennessee Valley Authority and the U.S. Solar Energy Research Institute will both soon be housed in passive solar complexes. Such projects will develop a reservoir of experience among private architects and should hasten the day when climate-sensitive design is a standard feature of commercial buildings. This is encouraging, since recent estimates indicate that fuel savings of more than 50 percent can be achieved on cost-competitive commercial structures, a level of performance that few designers have achieved yet. Though the savings possible in commercial buildings are not quite as great as those in store for residential structures, they are enough to have a substantial impact on world energy needs in the decades ahead.[56]

The Dilemma of Existing Buildings

One of the most difficult challenges ahead is improving the energy efficiency of existing structures. The majority of the buildings that will be in use in the year 2000 are already standing, and unless their gluttonous fuel appetites are curtailed they will continue to be an unhealthy drain on many countries' fuel supplies well into the next century. For many people, particularly low-income individuals without the financial resources to buy new homes, this is a vital issue. Unfortunately, the need to retrofit existing buildings with solar and conservation measures has received relatively little attention until recently.

Only 1 percent of most nations' buildings are torn down in a given year, and annual construction accounts on average for 2 to 3 percent of the building stock. So even if all the homes and commercial structures built between now and the year 2000 were solar buildings, they would constitute less than one-third of the total at the turn of the century. Relying on this process for a complete transformation of the building stock would take several additional decades. One possible strategy would be to accelerate the replacement of old inefficient buildings, but the cost would be staggering. It might also be counterproductive. Construction is an energy-intensive process, and it would be difficult to recoup the energy resources squandered in tearing down usable buildings.[57]

Making existing buildings more energy-efficient is thus the logical alternative. Though it is a more difficult, costly, and institutionally complex process than starting from scratch at the design stage, potential fuel savings from such a program in most countries are greater than for the most ambitious new construction programs. This is particularly true in parts of Europe where very few new buildings will be started over the next couple of decades.

The level of awareness regarding these problems is rising rapidly. Canada, France, Ireland, Sweden, and West Germany are among the many nations with ongoing research programs to determine the energy conservation potential in existing buildings. Needless to say, the potential varies widely and is lower in countries such as Sweden, where a rigorous climate and high fuel prices have encouraged energy-efficient construction for years. However, in most nations the energy-use record of existing buildings is miserable. Major problems include a lack of insulation and storm shutters and the widespread use of single-pane windows. Many buildings are simply leaky: weather stripping and caulking are either lacking or have badly deteriorated. In addition, the often random placement of windows can lead to excessive heat buildup in summer and net losses in winter.[58]

Researchers in Ireland, where the situation is particularly grim, have found that only 15 percent of residences have enough attic insulation and less than 5 percent have adequate insulation in the walls. In some regions of the United States, one-third of the buildings are uninsulated, and nearly all of the homes and offices built prior to 1970 have extremely inadequate insulation. As investigators in various countries begin to catalog the energy performances of existing buildings, they are finding the situation to be much the same. On the one hand these results are discouraging, but on the other hand it seems clear that a small investment in retrofit measures could in many cases result in major fuel savings.[59]

Conservation measures that have been taken in millions of residences in Europe and North America since 1973 have commonly resulted in a reduction of fuel bills by 10 percent or more. These programs usually include weather stripping, storm windows, insulation of the walls if there is a suitable space, and additional insulation of the attic. Savings can be much greater however. Researchers in West Germany believe that 30 to 50 percent savings could easily be realized in their residences using conventional conservation measures; in Switzerland, where existing buildings are already quite efficient, 30 percent savings are expected. In practice, only a few homeowners have been able to reduce fuel needs that much. The success of such programs varies considerably and depends of the skill with which the job is done, as well as on the type and condition of the building.[60]

> "Researchers in West Germany believe that 30 to 50 percent savings could easily be realized in their residences using conventional conservation measures."

Potential savings, however, are even greater than those realized in the most thorough conventional program. An interdisciplinary group of scientists at the Princeton Center for Energy and Environmental Studies conducted extensive experiments during the late seventies using 30 similar town houses in Twin Rivers, New Jersey. They found that fuel bills could be reduced by a full two-thirds through the use of a more comprehensive but still cost-effective program. Storm doors were added, new and more efficient storm windows were developed, and some windows were fitted with insulating shutters to be closed at night. In addition, a tracer test and infrared scan were used to locate remaining sources of air infiltration, which were then caulked and weather-stripped.[61]

According to the Princeton investigators, the key to the success of their program was the thorough evaluation they conducted beforehand of each building's performance. Remedying the thermal deficiencies of an existing house is a complex process in which all of the various problems must be addressed at once. The Princeton scientists found, for instance, that in many houses leaks in the attic were causing warm air to bypass the insulation, which helps explain why conventional insulation retrofits sometimes result in little improvement. Effective retrofit programs will require trained personnel who can evaluate a building's performance and then specify a range of cost-effective measures.[62]

On some buildings, even more extensive retrofits may be needed. In the past it has been common practice to construct masonry buildings without insulation. Since brick does conduct heat, even a thick brick wall will allow considerable heat losses. Unfortunately there is no easy way to insulate such a wall: common fiber glass or foam insulation must somehow be supported and sealed off from the interior. One possibility is to build a false interior wall next to the existing masonry one and then fill the space with insulation. But this both requires expensive interior finishing work and diminishes the living space in the building. A more effective means of adding insulation has, however, been developed that involves spraying polyurethane foam on the outside of the building and then covering it with a finishing material. One advantage of this technique is that the existing masonry wall can then serve as a collector of warmth inside the building and help diminish temperature fluctuations. Though the procedure is relatively expensive, research results indicate that it is cost-effective for many masonry buildings in cold climates.[63]

Some builders and homeowners have taken the additional step of converting conventional buildings into passive solar ones. Such a process is actually quite feasible with certain types of buildings that happen to be properly sited and landscaped. The most frequent sort of passive solar retrofit is a solar greenhouse that can be attached to the south side of a building without replacing existing walls. It often makes sense to place vents in the walls and add a fan to circulate the captured heat. In the United States, solar greenhouses have become one of the most popular forms of home improvement; thousands were constructed during the late seventies and there is every sign that the interest of homeowners will continue. A number of firms now market prefabricated solar greenhouses, making it possible to "solarize" a house for $2,000 to $3,000.[64]

Other types of passive solar retrofit are also feasible in many cases. A Trombe wall can be created by adding glazing just outside a south-facing masonry wall, or clerestory windows can be added to the roof to admit more sunlight. Often such measures require substantial structural changes, and it is important to make sure that they are cost-effective before beginning the work. Some of the most successful applications of these more complex retrofits have been in large commercial buildings. Many older schools, factories, and warehouses in the northeastern United States have uninsulated south-facing brick walls that are ideal for conversion to Trombe walls. A recent study by the National Bureau of Standards found that in many cases these retrofits are financially sound, especially if it is possible to do the conversion without substantially altering the building's structure.[65]

The move to retrofit existing buildings has been quite widespread over the last few years. In the United States, close to 20 million private residences have been retrofitted with attic insulation since 1973, a figure that represents one-quarter of the nation's housing stock. Sales of insulating materials are one gauge of the improve-

"The most frequent sort of passive solar retrofit is a solar greenhouse that can be attached to the south side of a building without replacing existing walls."

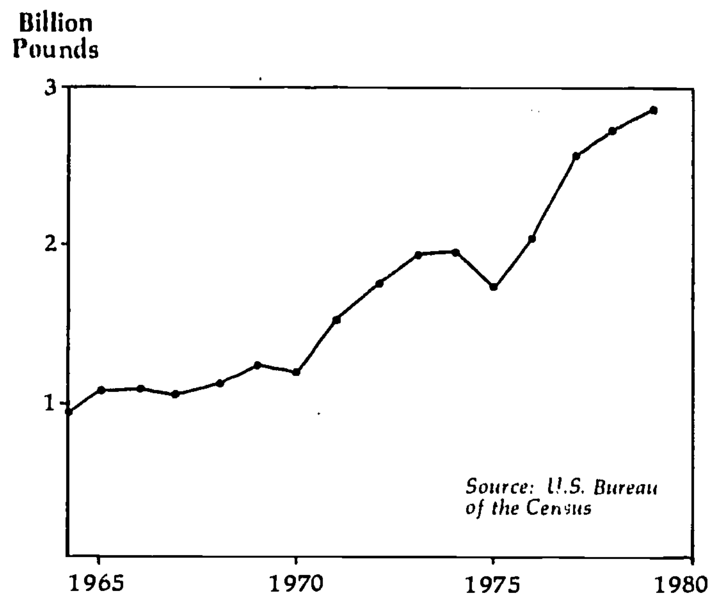

Figure 2: U.S. Shipments of Fiber Glass Insulation, 1964-79

ments being made: in the United States, shipments of fiber glass insulation have more than doubled since the early seventies. (See Figure 2.) The increase is due to higher insulation levels in new houses as well as to millions of retrofits. Similar trends are reported in Europe. These figures are impressive, but they are only a harbinger of the immense fuel savings that can be achieved in existing buildings.[66]

The challenges that lie ahead include the development of standards and procedures for determining which retrofit measures should be used on a particular building and the introduction of much more

40 extensive retrofits than those that have become standard so far. In addition, there are disturbing signs that the low-income groups who could benefit most from fuel-saving improvements to their homes and apartments are being priced out of the retrofit market. In all these areas, well-designed government programs can play a crucial role in speeding the transition to energy-efficient buildings. Informational and economic barriers are preventing homeowners from making improvements that are in their long-term financial interest. For a relatively small sum, governments can eliminate some of those hurdles. A number of such programs have recently been started.

In the United States, the problem of dilapidated, inefficient residences of the poor has reached crisis proportions in recent years. Many families in the cold Northeast now spend half their income on heating oil. A national weatherization program for low-income households was included in the 1976 Energy Conservation and Production Act, and the Department of Energy provides approximately $200 million each year to state governments for individual weatherization programs. These efforts have been only partially successful, however. Many of the state programs started quite slowly, and finding sufficient workers and training them has been a problem. In addition, there are serious doubts about whether the funds allocated are sufficient, considering the magnitude of the job ahead. By the end of 1979, only 650,000 low-income houses had been weatherized—less than 5 percent of the 14 million homes that were eligible. It is estimated that no more than 3 percent of eligible houses can be retrofitted annually, so that it will take over 30 years to weatherize the entire low-income housing stock. And even those that have been reached are receiving only partial retrofits.[67]

These programs are a first step down a path that can lead to vast improvements in the energy efficiency of the world's buildings. Two significant changes will be crucial, however, to an effective U.S. effort and to the development of similar programs in other countries. First, more money should be allocated, so that the majority of households can be reached during the next decade. Programs that merely dent a problem of this size encourage apathy and do not get the sort of political visibility that is essential if they are to thrive. More importantly, institutional innovations are needed at the regional and local levels to bring more private contractors as well as skilled workers into the programs. Local community groups in the United States have often had much more success with low-income weatherization than has the national program, which illustrates the importance of grass-roots support and the need to adapt such efforts to the real needs and aspirations of a community.

Another serious gap that is slowing the retrofit process is an informational one. Even wealthy homeowners and commercial operators have great difficulty finding someone to provide a comprehensive assessment of the energy performance of their buildings and to recommend improvements. To fill this chasm, Princeton physicist and energy expert Robert Williams suggests a new profession of "house doctor" be created—"one who can quickly identify the important thermal attributes of a building and who is thoroughly familiar with effective retrofits on most types of housing in the region." The procedure would be intelligence-intensive rather than materials- or labor-intensive. Strict educational and certification standards would of course be necessary to ensure the success of such a program, partly because consumer confidence would be essential. Williams suggests that the house doctor be equipped to make minor on-the-spot retrofits that could save 15 to 20 percent on space heating and that would serve as additional incentive to have the energy audit done. In most cases, the simple retrofits would involve minor furnace adjustments and the use of a little tape or insulation to plug air leaks. More extensive improvements such as adding insulating shutters or even a solar greenhouse would be left to the consumer's discretion after detailed information on cost and the expected payback period had been supplied.[68]

In the United States, a variety of home energy audit programs have been available since 1975, most of them sponsored by utility companies or by state or local governments. The new programs apparently contributed to the recent upsurge in home weatherization, but most are far from having the sophistication or effectiveness of the proposed house doctor system. In fact, many of the audits are done by mail, relying on a homeowner's own assessment of the building's energy-related characteristics. As a result, few of these audits come close to recommending an optimal package of retrofit improvements. Most do not recommend passive solar additions at all, nor do they provide help in locating contractors or obtaining financing.

Among this spotty mosaic of audit programs there are a few bright exceptions. Two of the best are being sponsored by utilities in Oregon and by the Tennessee Valley Authority (TVA). In each case, free and comprehensive home energy audits are backed up with information on special financing arrangements and on contractors to perform the job. The TVA program also provides interest-free loans for conservation measures, while the state of Oregon has utilities finance the retrofits themselves. Other utilities with ambitious home energy auditing programs include Pacific Gas and Electric and Southern California Edison, both of which are being pushed along by a conservation-minded California Public Utilities Commission. Even General Public Utilities Corporation, the company that owns the Three Mile Island nuclear power facilities, has in the aftermath of that disaster started a conservation program that includes energy audits and minor insulation jobs done free of charge. It seems certain that this will be a safer investment than some of its earlier ones.[69]

These efforts are little more than pilot projects, however, for a more comprehensive national program scheduled to begin in 1981. The new Residential Conservation Service (RCS), to be run by the U.S. Department of Energy, will direct the states to develop programs under which utility companies will conduct energy audits and arrange the financing and installation of conservation and solar retrofit measures. Comprehensive training manuals are being prepared and the energy auditors will have to meet state qualification standards. The Residential Conservation Service has the potential to develop into one of the nation's most important new energy initiatives. Its planners anticipate that the audits could approach the effectiveness of the house doctor concept and that as many as 20 million residences will be audited over the next five years.[70]

There are unfortunately a number of weak links in the Residential Conservation Service that could prevent its achieving a full measure of success anytime soon. Most of the implementation and enforcement responsibilities will fall on the states, and while some plan to welcome the new program with open arms, others have served notice that they will enforce the RCS only reluctantly. Superficial audits, a lack of advertising, or failure to follow up on the initial audit could prevent the RCS from having much impact on the energy efficiency of a particular state's housing stock. And, lamentably, the program will not apply to rental or multi-family housing units where a large number of lower income people live, particularly in cities. This presents a serious equity problem since some of the people most in need of the savings the RCS could deliver will not be involved in the scheme. This gap needs to be filled, and Congress is already considering broadening the service's coverage.

Other questions surrounding the Residential Conservation Service involve the future role of public utility companies, since they will soon be forced to move beyond their position as marketers of fuel and electricity to one of being responsible for a range of energy services. Many will be encouraged by the states to finance weatherization for their customers by including the charges in the rate base, just as they would an investment in a new power plant. It will be a fundamental change for the industry, yet one that makes a lot of financial sense. It now costs considerably more to provide extra fuel or to build a new power plant than it does to supply the same amount of energy through conservation measures. This new departure nonetheless raises disturbing questions about conflict of interest and the possible monopolization of energy supplies by utilities. Particularly today, with overcapacity prevalent in much of the electric utility industry, there is some doubt about how eager the companies will be to promote a further cutback in demand. One thing is clear: public utility commissions will have to be ever more vigilant in their efforts to ensure that the utilities' actions serve their customers' best interests.[71]

These are all serious concerns, and it would probably be wise to consider the Residential Conservation Service a test program that may have to be substantially improved upon. One important challenge will be to ensure that the utility conservation programs work with existing low-income weatherization efforts so that the programs reinforce each other. Improving the energy efficiency of poor people's homes should be a major priority of all energy audit and retrofit efforts. With well-integrated programs that have community support and that are revised over the years, the potential for improving the world's buildings is immense. Such efforts can demonstrate that existing buildings are in effect a major source of energy, and that tapping that source can provide substantial economic benefits.

Building to Save Energy

The transition to an era of fuel-conserving buildings appears to be reaching a takeoff point less than a decade after the process began. Architect George Way echoes the forecasts of many observers when he states, "I am optimistic that passive technologies will soon become part of the mainstream of architectural practice." The dedication and enthusiasm of the pioneers in this booming new field are impressive. They are quite confident that the groundwork is in place to reduce the energy problem in buildings to negligible dimensions by the turn of the century. Hundreds of economic, political, and institutional hurdles remain to be leaped, however, before there is a fundamental transformation of the buildings landscape.[72]

A recent study by the Commission for the European Communities summed up the situation well. "The potential for fuel savings in this sector is both the most promising and the most uncertain," the authors observed. They went on to note that continuation of the progress made since 1973 in improving the efficiency of buildings depends upon very decentralized decisions and numerous institutional factors. The institutional considerations include a range of past government policies that actually fostered energy wastage in buildings through fuel price subsidization, the promotion of least-cost housing, and other measures. The U.S. Government alone spent more than $200 billion over the last 60 years subsidizing the development

"Improving the energy efficiency of poor people's homes should be a major priority of all energy audit and retrofit efforts."

of conventional forms of energy, which helped make inefficient buildings economically viable.[73]

In the years ahead, innovative government policies in league with the best efforts of private industry will be essential to counter the momentum of earlier practices and to surmount the institutional barriers within the building industry. This is particularly true in an era when soaring prices and capital scarcity encourage short-term economic decisions that take little account of long-term costs to society as a whole. The world's cities are now full of buildings that will simply be too expensive to use in 20 years' time. The effectiveness of new government policies will be crucial in determining the speed of the transition process and in ensuring that the houses and apartments of low-income groups are not left behind. So far, the United States has been the leader in developing innovative government programs to deal with these problems. If successful, it seems likely that these programs will serve as models for other countries to emulate and improve upon.

The introduction of energy standards for new buildings is one of the most common ways national and local governments have tried to influence energy use since 1973. The new laws usually specify certain construction practices, such as insulation levels, and are added to existing building codes. Since people buying a home lack the expertise and equipment to assess the energy performance of a building, many governments believe standards are necessary to assure home buyers they will not later be confronted with bankrupting fuel bills. Among the countries with new building energy standards are France, which adopted them in 1974, and Sweden and West Germany, which followed in 1977. Typical of the new codes is the German ordinance, which includes requirements for insulation and also specifies an acceptable level of heat loss through leaks in the building. In the United States, building codes have traditionally been the responsibility of state governments, and nearly all state codes now include energy-related criteria.[74]

The new standards have generally been quite effective. In the United States, the average insulation level in the ceilings of new houses rose 20 percent between 1974 and 1976. During that same period, the proportion of new houses in the cold northeastern states with double- or triple-glazed windows rose from 72 percent to 94 percent. Such measures have helped slow the rate of growth of energy use in buildings from 5 percent down to 1 or 2 percent in many countries. In some ways the building codes are like the fuel-efficiency standards for automobiles enacted by the U.S. Congress in 1975. The new regulations are encouraging builders to gear up for a change in construction practices just as consumers are beginning to press for it themselves. By requiring that certain procedures be made standard practice, building energy codes motivate the various sectors of the industry to work together in the development of appropriate materials and components and in their adaptation for particular buildings.[75]

The most rigorous standards on the books so far are those in Sweden and California; each results in houses with heating requirements that are more than one-third below those of the average American home.[76] (See Table 3.) But even the most demanding of these energy stan-

Table 3: Annual Home Heating Costs According to Different Building Standards*

Structure or Standard	Annual Cost
	(dollars)
U.S. average house, 1978	680
French building code, 1974	500
U.S. building standards, 1978	360
Swedish building code, 1977	230
California building code, 1979	220
Town house with retrofit, Twin Rivers, New Jersey	95
Saskatchewan Conservation House	20
Village House I, passive solar	15

*Assumes similarly sized houses using oil heat in a similar climate.
Source: A. H. Rosenfeld *et al.*

dards does not come close to challenging the efficiency that can be achieved in many passive solar and low-energy buildings. The Saskatchewan Conservation House and Village House I, a passive solar house in New Mexico, exemplify the innovative designs that can shrink heating and cooling requirements to near zero. In fact, many architects and builders consider even the most stringent current standards to be merely a primitive base level that can be exceeded by 50 percent or more.

The U.S. Department of Energy is in the midst of developing new Building Energy Performance Standards (BEPS) that the states will be required to adopt if they are to receive federal housing money. The standards are designed to be even stricter than those in Sweden; they would specify performance only, allowing builders to choose from a range of conservation and passive solar measures to meet a given energy budget. The BEPS have run into strong political opposition from the building and utilities industries, however, and face a long delay before implementation. This is a pity, since even the BEPS would do little more than stop some of the flagrantly wasteful construction practices still in use today. Other types of programs will be needed if the industry is to be really challenged to build more-efficient buildings.[77]

Financial incentives are probably the measures most likely to promote rapid progress in energy-efficient building. As construction costs and interest rates have risen in recent years, the pressure to cut building costs to bare bones levels has been overwhelming. Many of the possible design innovations and technical fixes that can be applied to buildings require a slightly higher initial investment than for a conventional building. Though the changes may be extremely cost-effective, with a payback period of only a few years, many builders are reluctant to do anything that will raise the base price. And both builders and owners sometimes have trouble getting a large enough loan to pay the extra cost. They are not helped by bankers and lending agencies who are unfamiliar with climate-sensitive design and are worried about the soundness of lending money for such a project.

A major effort to educate the financial community about the common sense and cost-effectiveness of energy-saving buildings would be a significant contribution. In calculating a homeowner's ability to meet mortgage payments, loan officers should be aware of the negligible fuel bills of a passive solar building, which leaves more income available to repay a loan. Though very few banks have begun to think seriously about implementing such criteria, there are now a few exceptions. The San Diego Savings and Loan Association in California is one of several U.S. banks that offers slightly reduced interest rates on passive solar houses. This program brings monthly payments below what they would be for a conventional home, adding to the homeowner's savings from reduced fuel costs.[78]

Additional financial inventives will be needed, however, and in the United States a national Solar Energy and Conservation Bank will begin in 1981 to channel low-interest loans to consumers for the purchase of energy-saving homes, solar collectors, and a variety of retrofit measures. Through lump-sum payments to private savings and loan associations, mortgage interest rates that are as much as two points lower than the norm will be available to buyers of climate-sensitive houses. The exact rate will hinge on the efficiency of the building and its ability to do without artificial heating and cooling. The best designs should yield a reduction in mortgage payments of $30,000 over the 25-year life of a loan. According to financial experts, the Solar Bank is likely to give energy-efficient buildings a tremendous boost. Buyers of passive solar houses will be able to realize immediate savings compared with the purchase of a conventional home, and people should soon be lining up at bank doors with their loan applications.[79]

Tax breaks are also becoming available for energy-saving homes and for retrofitting. More than 20 states in the US now offer income tax credits for some solar improvements, and property tax exemptions are available in more than 30. So far, most of these tax incentives are for solar collectors only and don't include passive measures that serve multiple functions and are more difficult to define on tax forms. Conservation improvements such as storm windows and weather stripping are also eligible for tax credits in most

"Serious consideration might be given to requiring the labeling of the fuel requirements of buildings at the time they are sold."

states and at the federal level, but, again, passive solar is generally excluded. This is a serious gap, which places some of the most financially sound solar and conservation measures at a distinct disadvantage.[80]

A number of states, such as New Mexico, have remedied this problem by adding to the tax code detailed standards for what does and does not constitute an energy-saving feature. Another approach, which is being considered by the U.S. Congress, is to provide tax credits directly to builders of climate-sensitive buildings. The credits would be based on performance, and would essentially function as cash grants of up to $2,000 for each energy-efficient building constructed. The resultant savings would be substantial for many developers, and in today's competitive real estate market the tax credits would be a strong incentive to build efficient houses. One interesting aspect of this proposal is that builders of low-cost housing should be particularly attracted to the program, since in percentage terms the $2,000 grant would be much larger. An impressive array of organizations, including the National Association of Home Builders, have joined forces to lobby for the measure, and legislative experts are confident it will pass in the near future.[81]

Educational programs for consumers, builders, real estate agents, and others can also speed up the transition to climate-conscious buildings. The level of awareness concerning energy use in buildings has risen rapidly, but many people still lack the specific information needed to make wise decisions. Trade associations, community groups, and local governments could sponsor seminars and prepare leaflets with the necessary information. Serious consideration might also be given to requiring the labeling of the fuel requirements of buildings at the time they are sold. Expected fuel use and price could be noted as well as the likely life-cycle cost of the building. This would give buyers a chance to compare the efficiency of buildings, an important factor since some of the climate-sensitive structures are hard to distinguish from conventional ones, and the buyer can have a hard time judging competing claims. The fuel bills of solar homes are already an important real estate document in some parts of the US, as they provide evidence of the energy efficiency of houses.

Because the rapid introduction of energy-efficient design will hinge on cooperation between government and industry, the support of builders is crucial. The building industry has traditionally been skeptical of government programs, but bureaucrats are finding that financial incentives and even technical support and demonstration activities are surprisingly popular. If over the next several years such programs can persuade the majority of builders to at least consider seriously the possibility of building climate-sensitive structures, a major milestone will have been passed. The attractiveness of these buildings should ensure that they will sell themselves after that. It may be that the entire package of government programs—including financial incentives and demonstration projects—can be phased out after only a decade, with the job completed.

The politics behind reducing the energy requirements of buildings are convoluted, yet they are the key to giving the world's buildings a needed face-lift. Builders are in favor of receiving passive solar tax credits but are against new building energy standards. Consumer groups approve of standards but are opposed to government decontrol of fuel prices. Slowly some areas of consensus are being found, but a lot of careful politicking—and the development of programs with carrots as well as sticks—will be essential if the process is to continue.

These important political efforts could be usefully complemented by slight changes in the life-styles of millions of individuals who live and work in buildings and who regularly make decisions on energy use that range from whether to add a greenhouse to their home to where to set the thermostat. Recent studies have shown that the fuel requirements of a building can vary by as much as 75 percent depending on the practices of the occupants. A warm sweater is at least as good an investment as storm windows are, and the savings possible through good design can be multiplied by taking sensible steps that do not affect comfort. Simple, unexciting measures such as opening a window on a mildly hot summer day instead of turning on the air conditioner, or switching lights on only when necessary, can yield attractive financial returns. Heightened awareness of seasonal changes and the behavioral shifts that should accompany them could be an important part of the transition to an energy-efficient society.[82]

As support for climate-sensitive design continues to build, it is becoming clear that the new era of more-efficient buildings could have an enormous and beneficial impact on the world energy situation. In the United States, where climate-sensitive buildings will soon be a major factor in the real estate market, programs sponsored by the Department of Energy alone are projected to result in more than 50,000 new passive solar buildings in 1981. This is more than double the number of solar buildings in the country in 1980. The department's goal is to have a half million climate-sensitive buildings standing in the US by 1986, and there is good reason to think that this is a conservative estimate. With the new Solar Energy and Conservation Bank, the promise of passive solar tax credits, and the recent surge in interest by builders and consumers, the United States may reach that target a year or two ahead of schedule.[83]

A not unreasonable goal for the United States would be to have five million climate-sensitive buildings in place by 1990 and to have such structures dominate the building market during the nineties. The result, in the year 2000, would be that 10 percent less energy would be used to heat, cool, and light buildings than if current trends continue. Meanwhile, the fuel requirements of existing buildings could easily be reduced by one-third through successful retrofit programs. These combined efforts would yield the equivalent of five million barrels of oil a day by the end of the century, an amount that comfortably exceeds the quantity of fuel to be produced by the national synthetic fuels program under the most optimistic scenario. Moreover, using buildings as an energy source would "produce" fuel at a lower cost and create more than twice as many jobs.[84]

The global situation is more problematic since there is a greater variety of building types, and individual countries differ substantially in the amount of attention they have devoted to these issues. The United States is now leading the way with innovative government programs as well as technical expertise, but other nations will begin to catch up by the late eighties. In most countries it should be possible to bring energy-conscious design into the mainstream in 1990, and to reduce the fuel requirements of existing buildings by more than 30 percent. Even assuming substantial growth in housing, the world's buildings may be using 25 percent less fuel and electricity in the year 2000 than they do today—an important step toward achieving a sustainable world energy economy.

The potential clearly exists to cure most of the energy ills of the world's buildings by the end of the century. Economically and ethically, the decision to begin moving down that path should be one of the easiest energy choices we have to make. Virtually everyone will benefit from a new era of more rational design and construction. And buildings themselves would in a sense be better off. Climate-sensitive structures work with nature rather than against it. As one solar designer recently observed, "our buildings would be more beautiful if they responded to energy concerns and had a more natural configuration." A more varied and more humane environment could be the result.[85]

Notes

1. Energy use figures are author's estimates based on data from Organisation for Economic Co-operation and Development (OECD), *Energy Balances of OECD Countries* (Paris: 1978), Joy Dunkerley, ed., *International Comparisons of Energy Consumption* (Washington, D.C.: Resources for the Future, 1978), U.S. Department of Energy, *Annual Report to Congress 1979* (Washington D.C.: 1980), and Office of Technology Assessment, *Residential Energy Conservation* (Washington, D.C.: 1979).

2. Department of Energy, *Annual Report to Congress 1979;* U.S. Department of Labor, "Consumer Prices: Energy," May 1980.

3. Architect quoted is Belinda Reeder, talk presented to the U.S. Department of Energy Passive and Hybrid Solar Energy Program Update Meeting, Washington, D.C., September 21-24, 1980 (referred to in following notes as DOE Passive Solar Update Meeting).

4. Figure on current number of passive solar buildings in US is estimate by U.S. Department of Energy representative at DOE Passive Solar Update Meeting; estimates vary widely and the figure would be much higher if all buildings with an attached greenhouse or with solar orientation were included.

5. Socrates quote from Ken Butti and John Perlin, *A Golden Thread: 2000 Years of Solar Architecture and Technology* (New York: Van Nostrand Reinhold and Company, 1980).

6. The historical material in this section draws heavily on Butti and Perlin, *A Golden Thread,* Amos Rapaport, *House Form and Culture* (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1969), and Victor Olgyay, *Design with Climate: A Bioclimatic Approach to Architectural Regionalism* (Princeton, N.J.: Princeton University Press, 1963).

7. Butti and Perlin, *A Golden Thread;* information on Justinian Code from Borimir Jordan and John Perlin, "Solar Energy Use and Litigation in Ancient Times," *Solar Law Reporter,* September/October 1979.

8. Butti and Perlin, *A Golden Thread.*

9. Rapaport, *House Form and Culture;* Selma A. Newburgh, "Rediscovering Energy-Conscious Architecture," *Technology Review,* August/September 1980; Mehedi N. Bahadori, "Passive Cooling Systems in Iranian Architecture," *Scientific American,* February 1978.

10. Richard G. Stein, *Architecture and Energy* (Garden City, N.Y.: Anchor Press/Doubleday, 1978).

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11. These points are well treated in Stein, *Architecture and Energy*.

12. European figure based on Building Research Establishment, "Energy Conservation: A Study of Energy Consumption in Buildings and Possible Means of Saving Energy in Housing," A B.R.E. Working Party Report, Watford, England, date unknown, Patrick J. Minogue, *Energy Conservation Potential in Buildings* (Dublin: An Foras Forbartha, 1976), and Stig Hammarsten, "A Survey of Swedish Buildings from the Energy Aspect," *Energy and Buildings*, April 1979; U.S. figure from Office of Technology Assessment, *Residential Energy Conservation*.

13. OECD, *Energy Balances of OECD Countries;* William W. Hogan, "Dimensions of Energy Demand," in Hans H. Landsberg, ed., *Selected Studies on Energy, Background Papers for Energy: The Next Twenty Years* (Cambridge, Mass: Ballinger Publishing Co., 1980); Dunkerley, *International Comparisons of Energy Consumption*.

14. Dunkerley, *International Comparisons of Energy Consumption;* OECD, *Energy Balances of OECD Countries*.

15. Leslie Dienes and Theodore Shabad, *The Soviet Energy System: Resource Use and Policies* (New York: John Wiley & Sons, 1979); Marshall I. Goldman, "Energy Policy in the Soviet Union and China," in Landsberg, *Selected Studies on Energy*.

16. Hassan Fathy, *Architecture for the Poor* (Chicago: University of Chicago Press, 1973); Alan Jacobs, Energy Office, U.S. Agency for International Development, private communication, July 9, 1980.

17. Department of Energy, *Annual Report to Congress 1979;* Chris Peterson, "Report on Energy Conservation Trend Indicators," U.S. Department of Energy, Washington, D.C., August 21, 1980; West European data in figure are for France, Italy, the Netherlands, United Kingdom, and West Germany, from Hogan, "Dimensions of Energy Demand"; Swedish figure from "Energy Conservation: Results and Prospects," *OECD Observer*, November 1979.

18. Hogan, "Dimensions of Energy Demand"; Office of Technology Assessment, *Residential Energy Conservation*; TVA customer quote from Joanne Omang, "TVA's Electrifying Change: Cheap Power Yields to 'Quality Growth'," *Washington Post*, June 1, 1980; Consumer Energy Council of America, "An Analysis of the Economics of Fuel Switching Versus Conservation for the Residential Heating Oil Consumer," Washington, D.C., October 5, 1980. The figures in Table 2 are somewhat misleading because oil is more frequently used as a heating fuel in cold regions than natural gas or electricity are. Therefore, for buildings in any one area, actual electricity and natural gas bills would be higher relative to oil bills than the table makes it appear.

19. For a good general discussion of energy use trends and conservation potential in the residential and commercial sectors, see Eric Hirst and Jerry Jackson, "Historical Patterns of Residential and Commercial Energy Uses," *Energy*, 1977, Vol. 2, pages 131-140, Eric Hirst and Bruce Hannon, "Effects of Energy Conservation in Residential and Commercial Buildings," *Science*, August 17, 1979, "Energy Conservation," *OECD Observer*, and Fred Roberts, "The Scope for Energy Conservation in the EEC," *Energy Policy*, June 1979.

20. The fundamentals of solar architecture are discussed in detail in Bruce Anderson, *The Solar Home Book: Heating, Cooling, and Designing with the Sun* (Andover, Mass.: Brick House Publishing Co., Inc., 1976), Bruce Anderson, *Solar Energy: Fundamentals in Building Design* (New York: McGraw Hill Book Company, 1977), Edward Mazria, *The Passive Solar Energy Book* (Emmaus, Pa.: Rodale Press, 1979), and Los Alamos Scientific Laboratory, *Passive Solar Buildings* (Springfield, Va: National Technical Information Service, July 1979).

21. Anderson, *Solar Home Book; Business Week* quote from Butti and Perlin, *A Golden Thread*.

22. Wade Green, "A Conversation with the New Alchemists," *Environment*, December 1978.

23. For a general discussion of passive cooling technology, see the "Cooling" section in *Proceedings of the 4th National Passive Solar Conference*, American Section of the International Solar Energy Society, Kansas City, Mo., October 3-5, 1979, and Herbert Naumann, Fred Quivik, and Tom Riley, "Natural Cooling for Homes," National Center for Appropriate Technology, Butte, Mont., 1979.

24. Anderson, *Solar Home Book.*

25. The Trombe wall is discussed in Anderson, *Solar Home Book,* J. D Walton, Jr., "Space Heating with Solar Energy at the CNRS Laboratory Odeillo, France," in *Proceedings of the Solar Heating and Cooling fo Buildings Workshop,* National Science Foundation, 1973, and Ian Hogan "Solar Building in the Pyrenees," *Architectural Design,* January 1975.

26. Anderson, *Solar Home Book;* for another example of heat storage ir water-filled barrels, see "The Sun Earth House," *Solar Age,* February 1980.

27. Mazria, *Passive Solar Energy Book.*

28. The Underground Space Center, University of Minnesota, *Earth Sheltered Housing* (New York: Van Nostrand Reinhold and Company, 1979).

29. Harold R. Hay, "Roof Mass and Comfort" and "Skytherm Natural Ai Conditioning for a Texas Factory," in *Proceedings of the 2nd Nationa Passive Solar Conference,* American Section of the International Solar Energy Society, Philadelphia, Pa., March 16-18, 1978; "Roof Ponds Can Work Anywhere," *Solar Energy Intelligence Report,* June 9, 1980; William A. Shurcliff, *Superinsulated Houses and Double-Envelope Houses* (Cambridge, Mass.: William A. Shurcliff, 1980).

30. Darian Diachok and Dianne Shanks, *International Passive Architectural Survey* (preliminary) (Springfield, Va.: National Technical Information Service, forthcoming); Darian Diachok, Solar Energy Research Institute, private communication, September 18, 1980.

31. Shurcliff, *Superinsulated and Double-Envelope Houses;* Karl E. Munther, "Three Experimental Energy Houses in Östersund," in *Swedish Building Research Summaries* (Stockholm: Swedish Council for Building Research, 1978); Per Madsen and Kathy Goss, "Low-Energy Houses in Denmark," *Solar Age,* February 1980.

32. Robert W. Besant, Robert S. Dumont, and Greg Schoenau, "Saskatchewan House: 100 Percent Solar in a Severe Climate," *Solar Age,* May 1979; "Operational Saskatchewan Solar-Conservation House Yields Further Data on Energy Efficient Building Designs," *Soft Energy Notes,* May 1979.

33. Diachok and Shanks, *International Passive Architectural Survey,* and Darian Diachok, Solar Energy Research Institute, private communication, September 18, 1980.

34. General information on architectural situation in developing countries from Alan Jacobs, Energy Office, U.S. Agency for International Development, private communication, July 9, 1980; Malcolm Lillywhite, Domestic Technology Institute, private communication, July 8, 1980.

35. Fathy, *Architecture for the Poor;* Malcolm Lillywhite, Domestic Technology Institute, private communication, July 8, 1980; information on Indian research program included in Diachok and Shanks, *International Passive Architectural Survey.*

36. Recent reports that discuss the economics of alternative building designs include Rosalie T. Ruegg *et al., Life-Cycle Costing: A Guide for Selecting Energy Conservation Projects for Public Buildings* (Washington, D.C.: Government Printing Office, 1978), James W. Taul, Jr., Carol F. Moncrief, and Marcia L. Bohannon, "The Economic Feasibility of Passive Solar Space Heating Systems" and Mark A. Thayer and Scott A. Noll, "Solar Economic Analysis: An Alternative Approach," in *Proceedings of the 3rd National Passive Solar Conference,* American Section of the International Solar Energy Society, San Jose, Calif., January 11-13, 1979, and Peter F. Chapman, "The Economics of UK Solar Energy Schemes," *Energy Policy,* December 1977.

37. The Saskatchewan Conservation House is one recent building that needs auxiliary heating on only a few days a year, making a furnace an unnecessary investment; see Besant, Dumont, and Schoenau, "Saskatchewan House."

38. Ted Kurkowski, "The Design of Passive Commercial Buildings: Background and Major Lessons Learned," presented to DOE Passive Solar Update Meeting.

39. J. Douglas Balcomb, "Energy Conservation and Passive Solar: Working Together," Los Alamos Scientific Laboratory, 1978.

40. Larry Sherwood, "Passive Solar Systems . . . The Economic Advantages," in *Proceedings of the Solar Energy Symposia,* Denver, Col., August 1978; Harrison Fraker, Jr. and William L. Glennie, "A Computer Simulated Performance and Capital, Cost Comparison of 'Active vs. Passive' Solar Heating Systems," in *Proceedings of the Passive Solar Heating and Cooling Conference,* American Section of the International Solar Energy Society, Albuquerque, N.M., May 18-19, 1976.

41. "Statement of Alan Hirshberg," U.S. House of Representatives, Subcommittee on Oversight and Investigations of the Interstate and Foreign Commerce Committee, *Passive Solar Energy*, Hearings, August 11, 1978.

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