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Blueprint for efficiency: Maximizing the economic benefit of California's building energy conservation standards

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San Jose State University, 1991

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BLUEPRINT FOR EFFICIENCY:
MAXIMIZING THE ECONOMIC BENEFIT OF CALIFORNIA'S BUILDING ENERGY CONSERVATION STANDARDS

A Thesis
Presented to
The Faculty of the Department of Geography
and Environmental Studies
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By
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May, 1991

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ABSTRACT

BLUEPRINT FOR EFFICIENCY: MAXIMIZING THE ECONOMIC BENEFIT OF CALIFORNIA'S BUILDING ENERGY CONSERVATION STANDARDS

by Mark David Walsh

This thesis evaluates the economic effectiveness of building envelope energy conservation measures and standards in California homes. The purpose of this study is to reveal and document the favorable relationships and results of appropriate strategies for residential energy efficiency. The heart of this project involves the computer simulation and economic evaluation of various home-envelope configurations for energy conservation.

The California building efficiency standards have captured a significant share of the potential energy savings in new residential construction, but they fall short of maximizing the full economic benefit of the conservation investment. Life cycle economic analysis must guide the application of cost-effective building designs and equipment. The synthesis of engineering and economics approaches offers a "blueprint" for energy efficiency and economy--to increase the productive application of valuable energy resources and to bolster the economic adaptability of households, communities, and regions to changing energy costs and supplies.

Dedicated to Myle and Makena--
whose patience and understanding made this
endeavor possible.

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PROGRESS AND POTENTIAL

Focus

The aim of this thesis is to reveal and document the favorable relationships and results of appropriate strategies for residential building-envelope energy efficiency. The synthesis of technical improvements provided by engineering and the practical "bottom line" evaluation provided by economics may define important parameters of our built environment and offer a "blueprint" for energy efficiency and economy.

The purpose of this project is 1) to appraise the effectiveness and limitations of the California residential building efficiency standards as a policy tool for energy conservation; 2) to determine and compare the optimal home envelope design for energy <u>and</u> economic efficiency with the current state-mandated design in four climate zones; 3) to examine the costs of the optimal and state-required designs' effect on housing affordability (purchase and operation); and 4) to assess the macroeconomic effects of the mandated investment in building energy conservation on regional economic activity and employment.

This study begins with an examination of the state's current energy situation, the progress made to date in implementing effective energy conservation strategies, and the potential for improving building energy efficiency. Subsequently, the various approaches that may contribute to the development of energy-efficient architecture are addressed, including engineering, regulatory, and market-based methods. Chapter three details the history of the California building energy conservation standards and is followed by an appraisal of the role that economics plays in the evaluation of appropriate building energy conservation measures and materials.

The heart of this project involves the computer simulation and economic evaluation of various home-envelope configurations for energy conservation in different climates. Life cycle economic analyses are applied to determine and compare the most cost-effective investment in envelope energy conservation measures with the requirements of the state building efficiency standards. Then, a review of relevant macroeconomic studies evaluates the regional impacts of conservation expenditures substituting for energy purchases. Finally, a summary assesses the related impacts of effective building energy conservation strategies on energy consumption, personal and regional economies, employment, and environmental quality.

The state building energy conservation standards have captured a significant share of the potential energy savings in new residential construction, but they fall short of maximizing the full economic benefit of the conservation investment. Life cycle economic analysis must guide the application of cost-effective building designs and equipment. Appropriate building efficiency standards, as part of a concerted effort to reduce the wasteful and inefficient use of energy resources, bolster California's adaptability to changing conditions of energy supplies and costs and stem the flow of dollars out of the state. These regulations also improve the economic returns of investments in valuable energy resources by redirecting energy consumption to more productive uses. For these reasons, the California "climate-specific" building energy standards are a valuable policy innovation for energy conservation and economic development, with applicability beyond the state's borders.

Background

The energy shortages and rapid energy price escalations of the early 1970's prompted the first significant energy conservation efforts in California and the United States. The Arab oil embargo of late 1973 proved to be a relatively short-lived distortion of the world energy markets, but one that served to highlight the potential for great inconvenience, vulnerability, and volatility arising from the uneven distribution of vital energy resources around the globe. Regional natural gas shortages later in the decade augmented the widespread public perception of an "energy crisis" and concern over dwindling fossil fuel reserves.

The disruptions stemming from the embargo presaged the peaking and subsequent decline of the fossil fuel reserves and discoveries on which we are so dependent. For 100 years after the first oil strike in Pennsylvania, the United States remained the leading producer and consumer of petroleum products in the world. As recently as 1954, domestic production exceeded 50% of the world's annual supply. But, U.S. oil production peaked in 1970. At present, we pump less than 15% of the world total. Annual world-wide discoveries of new petroleum reserves have declined to less than 1% of known supplies, despite vigorous exploratory efforts (Pirog and Stamos 1987).

Imported oil and natural gas have continued to supply a growing share of domestic energy needs. For the first time ever, imports comprised more than half of U.S. oil consumption in January, 1990. The vulnerability and implications for national security resulting from this position of dependence have once again been realized by the 1991 events in the Middle East and contributed to an American administration's willingness to wage war in "defense" of foreign oil interests.

With the exception of the volatile petroleum markets, most energy prices have kept pace with inflation and maintained fairly steady "real" (inflation-adjusted) prices. Still, these prices do not reflect the full social cost of energy consumption due to continuing government subsidies and policies _and_ non-monetary impacts. One example of this influence is from 1985, long before the military buildup around the Persian Gulf, when U.S. defense costs in the Mideast amounted to approximately $47 billion--an amount equivalent to a hidden subsidy of $26 per barrel of oil shipped here through the Straits of Hormuz (Flavin 1988).

Aside from the strategic importance of maintaining adequate energy supplies, between 25-50% of the U.S. annual trade deficit in recent years has been generated by this growing share of energy imports, resulting in the flow of $25-42 billion out of the country every year (Sagan 1990). Such high levels of energy imports undermine the competitiveness of domestic products in world markets, reduce American employment levels, and curtail the cascading interactions of interindustry sales and purchases resulting from domestic expenditures. Readily available energy conservation strategies and technologies can reduce this dependence in a cost-effective manner and redirect energy consumption to more efficient and economically productive uses.

California's Situation

Total energy use in California doubled between 1950-1977. This rate of increase paralleled the national rate of energy growth during this period, which increased at an average annual rate of 3.8% (much more quickly than population growth). The demand for electricity, in particular, grew at twice the rate of all other energy uses, stimulated by the stable or declining real prices of all energy sources (Williams, Dutt, and Geller 1978).

But, in response to the oil shocks of 1973 and 1979, between 1973-1986 total energy consumption stayed virtually unchanged in-state and throughout the nation, despite continuing population growth. This abrupt about-face was achieved through great gains in productivity in all sectors provided by the aggressive pursuit of energy efficiency improvements in machines and processes, and structural shifts in the state and national economy away from heavy manufacturing to the service sectors.

California has witnessed firsthand the crucial importance of energy efficiency in maintaining a competitive stance within the dynamic Pacific Rim economic community. The California Energy Comission has aggressively stalked the energy potential in the more efficient use of resources by incorporating rigorous building, appliance, and utility management programs into its resource planning into the next century.

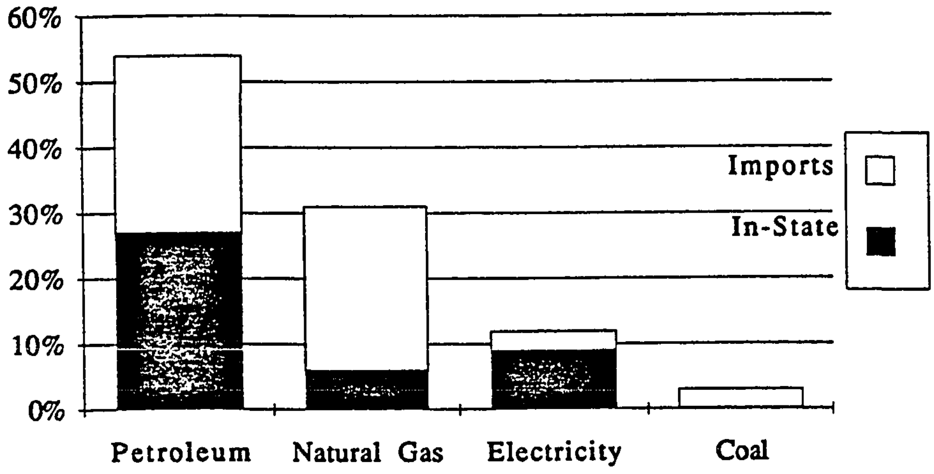
In California between 1973 and 1986, 35% less energy was required to produce a dollar of economic output, as measured by the Gross State Product (GSP). Population grew 33%, yet per capita energy use declined 15%; vehicle miles driven were up by a full 74%, but transportation fuel use increased only 22% over the same period (CEC 1990)! Numerous utilities and government agencies instituted aggressive research and development efforts for effective energy conservation strategies in transportation, industrial, manufacturing, residential and commercial uses. Stringent statewide minimum efficiency standards were developed for new buildings and appliances. After more than a decade of increasing price incentives, a 1985 League of California Cities survey of members found that a full 60% had some form of organized energy management program in operation (California Energy Commission 1988).

The quantity of energy used within California's borders every year (6.9 quadrillion Btu in 1989) makes it the fourth largest consumer of energy in the world, surpassed only by the United States, the USSR, and the state of Texas. The value of annual economic activity occurring within the state, as measured by the Gross State Product ($590 billion in 1987), makes its economy the sixth largest in the world, and a significant contributor to the U.S. Gross National Product (13% of the total GNP in 1990). The benefit of the state's favorable location in generally milder climatic zones plays a large part in its reduced per capita energy use compared to the U.S. average. Still, a full 7% of its GSP is spent directly on energy purchases (Tooker 1989).

Californians' energy consumption in 1987 was just under 10% of the national total. This energy use cost state residents $37.7 billion--averaging $1,363 per capita (Energy Information Administration 1990). Motor fuels for transportation were responsible for the greatest part of this consumption, representing 41% of the state total. Industrial uses and the residential/commercial sectors each accounted for about 30% of the remainder. This is somewhat different from the national picture of energy consumption, where there is an approximately equal division between transportation, industry, residential and commercial uses.

The state is a net energy importer, requiring substantial amounts of natural gas, petroleum and electricity from other western states and Canada. In 1988, California produced 74% of the electricity, 50% of the petroleum, and less than 20% of the natural gas consumed within the state (Borg 1990). (See Figure 1). California boasts a fairly low energy requirement due to its predominantly mild heating seasons, but the fastest-growing central valley and desert regions may match or even exceed this energy use by an extended "cooling" season requiring air conditioning.

Figure 1. California's Energy Sources(1987).



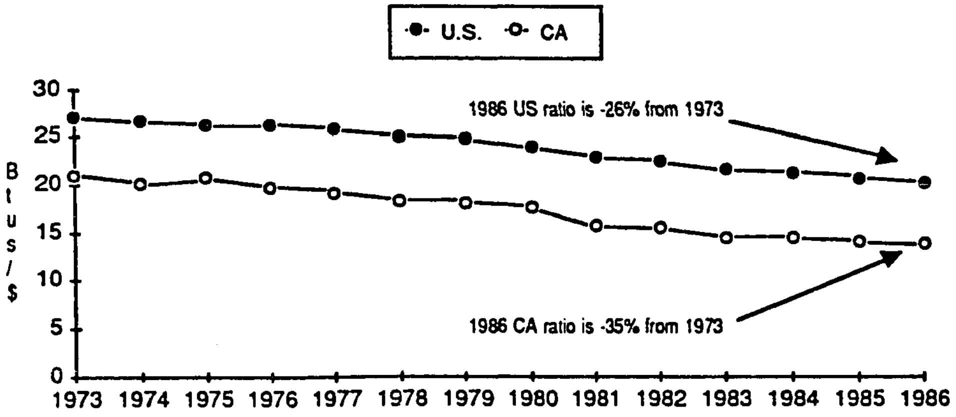
Data from Tooker 1989

The consequences of the state's high level of energy imports increases its vulnerability to supply disruptions and escalating prices. Large portions of state revenues flow out of California to the producers and distributors of the requisite interstate flows of natural gas, petroleum, and electricity. The state's hydroelectric potential has been fully exploited, considering the great environmental costs of additional damming. The nuclear power industry has stalled because of skyrocketing construction costs, and unresolved safety and waste disposal issues. The construction of coal-fired power plants in California has been all but precluded by stringent state air quality regulations. Because of these conditions, it is unlikely that further use of in-state resources or new plant production will substantially curtail this level of imports. The most dependable, and suitable, energy resource for California lies in the application of strategies to enhance energy efficiency and promote cost-effective energy conservation.

Progress in Energy Conservation

Until the early 1970's, many analysts believed that there was a direct relationship between energy consumption and economic growth in the United States. During the 1960's, domestic energy use grew at nearly 4% per year, leading many observers to issue dire predictions about the impending exhaustion of conventional fossil fuel reserves. Since that time, though, there has been a dramatic decoupling of economic growth and energy use: the nation as a whole cut energy use 26% per dollar of Gross National Product (GNP) between 1973-1986, during a period with an average 3% annual rate of economic expansion. By 1988, this reduction in energy consumption was saving Americans the equivalent of $150 billion a year in energy costs compared to projected trends just 15 years earlier (Akbari and Rosenfeld 1990). California did even better during this period of time, producing a 35% gain in Gross State Product (GSP) per unit of energy consumed over the same period, with virtually unchanged total energy use. Because of these gains, Californians are now saving an estimated $12 billion a year in avoided energy costs. (See Figure 2).

Figure 2. Trends in California and U.S. Energy Use per Dollar of GSP and GNP.



Reprinted from California Energy Commission, <u>1988 Conservation Report</u>, State of California (Sacramento, CA 1988), p. 25.

Analysts have concluded that half of these gains in productivity were derived from efficiency improvements (getting more work out of each unit of energy input) due largely to the stimulus provided by rising prices and sporadic energy shortages, and half to structural changes in the state and national economies. These changes are the result of a significant decline in the most energy intensive, domestic heavy manufacturing industries, offset by extensive gains in the service sectors (Chandler, Geller, and Ledbetter 1988).

One of the more well known examples of this shift toward increased energy efficiency is provided by the Corporate Average Fuel Economy (CAFE) standards promulgated by the U.S. Department of Transportation. Between 1975 and 1986, the doubling of new car fuel economy has held nationwide transportation fuel use steady, despite an expanding population and greater miles travelled. The average fuel economy of all cars on the road has also increased nearly 60%, averaging more than 20 miles per gallon by 1990. By one estimate, these improvements have cut U.S. gasoline consumption 20 billion gallons per year and lowered oil imports by 1.3 million barrels per day (Flavin 1988).

Government funded research and development has advanced the development of a number of more efficient products and processes, including windows, lights, refrigerators, and heat pumps. The results of two of these programs are particularly notable because of their impact on advancing technology. A $2 million federal contribution to glazing research speeded the commercial development of radiant barrier window coatings by an estimated 3-5 years. These new, low emissivity ("Low-E") coatings boost the thermal performance of a double pane window to a level close to that of a triple glazed unit, at a much lower cost. These "Low-E" windows are expected to constitute 50% of the market by 1995, and save the equivalent of $120 million worth of energy per year--worth a total of over $3.6 billion in energy cost savings over the next 25 years.

A $2.7 million investment in research on solid state ballasts for fluorescent lights was instrumental in developing a product that has penetrated the lighting market even more rapidly. These improvements are even now producing energy savings of $50 million per year, and are expected to generate $25 billion in savings over the next 30 years (Geller et al. 1987), (Flavin and Durning 1988). These technical improvements, implemented at costs ranging from 2-10 times cheaper than the cost of energy supplies, suggest the significant potential for enhanced energy productivity that is, as yet, untapped.

The building industry has modified some of its practices to adjust to the demand for greater energy efficiency. Many new and existing structures have been insulated or weatherized since the first energy "shocks" of the early 1970's. Most new construction practice now regularly incorporates a number of energy conservation measures due to expanded building code requirements and growing consumer demand. In polls of new homebuyers, energy efficiency is regularly mentioned in the top three most desirable features considered in the home purchase decision, after location and home cost (California Energy Commission 1988).

At this time, 33 states have adopted some form of mandatory energy efficiency standards for residential buildings, and most of the others have endorsed provisions of one of the model energy codes for voluntary local enforcement. Nine states have taken the initiative to develop their own codes or standards (Marsh et al. 1989). California has become a leader in the development of energy-efficient architecture since the adoption of the first insulation requirements for homes in 1975 and the subsequent development of the statewide energy performance standards for residential and commercial construction. Buildings constructed with no consideration for their energy performance are now the exception, rather than the rule. There is general recognition that the use of energy conservation materials and more efficient heating, ventilation, and air conditioning (HVAC) equipment in buildings can reduce energy consumption by 50% or more, in all climates.

Rationale for Energy Conservation

Much progress has been made in the implementation of effective energy conservation measures and strategies, but analysts have determined that a large portion of the current national energy budget is still wasted by inefficient and inappropriate uses. Although many communities and states have made headway in developing explicit energy management goals and programs, there still exists, by one conservative estimate, the potential to provide the same level of services with a further 30-50% reduction in energy consumption with commercially available, cost-effective conservation strategies and technologies (Gibbons, Blair, and Gwin 1989).

The energy derived from conservation measures is, in most instances, less costly, more reliable, and less polluting than that available from any conventional source. Pacific Gas and Electric, one of California's three investor-owned utilities, has itself estimated the costs of new electrical generation capacity as requiring up to 7 times the cost of conserving an equivalent amount of energy. More energy has been "supplied" in the last 15 years through the use of more efficient processes, with redesigned machines and by changing behavior than has been added by all other sources combined (Rosenfeld and Hafemeister 1988), (Hollander 1987). Many energy utilities now routinely consider and compare demand-side management programs to reduce energy growth, and the costs of "conserved energy," with the more traditional means and costs of increasing supplies or generation capacity.

The focus of most public concern with energy may wax and wane with the price of gasoline at the pumps, but steady, incremental efficiency changes are assimilated into everyday life. A comparable level of services can be provided, often with little effect on personal behavior or convenience, from a fraction of the original energy input. For example, under similar conditions, an insulated home can be heated to the same comfortable temperature as an uninsulated home with only a fraction of the energy requirement. More efficient automobiles travel further on a gallon of gasoline; fluorescent lamps provide the same lighting intensity as incandescent fixtures with one-quarter the energy consumption.

The uses and misuses of energy resources have far-reaching effects on personal convenience, land-use, and air and water quality. Inexpensive vehicle fuels promote reliance on automobile transportation, which contributes to urban sprawl and longer commuting distances, which in turn aggravates air pollution and roadway congestion, and which then leads full circle back to increased fuel consumption. Citizens and government officials alike decry the deterioration of air quality and worsening traffic congestion, but are reluctant to relinquish the convenience of their automobiles.

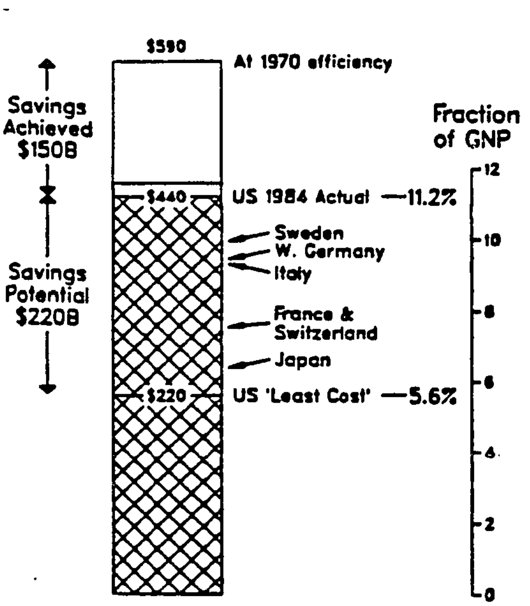
Energy is integral to every aspect of the process of supplying goods and services throughout the economy. An energy shortage, or rapidly escalating energy prices, will have repercussions on every process, in every sector requiring an energy input. Prudent energy management is inextricably linked with all aspects of sound economic development, including: employment, the competitiveness of domestic industry, interest rates, and economic growth.

The U.S. has made great strides in improving efficiency since the early 1970's, but the examples of other industrial nations show the practical potential of even greater efforts. Japan and the industrialized western European nations use an average of only 60% of the per capita energy consumed by the United States, while maintaining comparable standards of living. Japan spends 6% of its GNP on energy purchases, compared to the United States' 11% ratio. This, combined with a low level of energy used per dollar of value added to manufacturing, has been determined to give Japan an automatic

5% price advantage in manufactured goods sold in international markets (Akbari and Rosenfeld 1990). (See Figure 3). When differences in home size and climatic severity are normalized, Swedish homes use an average of one half the energy used in the U.S. to heat and cool residences. The on-road average fuel economy of French automobiles is more than 50% greater than the American automobile fleet. West German manufacturing uses 15% less energy per dollar of value added compared to the American manufacturing sector (Energy Information Administration 1990).

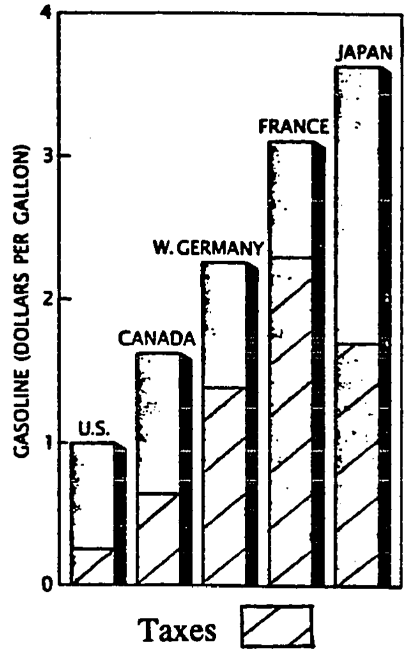
Of course, not all of these comparisons can be taken at face value: there are mitigating factors involved. The U.S. still maintains extensive and energy-intensive chemical, primary metals, and petrochemical industries. The Swedish government has made affordable housing a national priority for all its working citizens and the additional costs of meeting the stringent national building energy efficiency standards there are generously subsidized. Many of the European nations levy large taxes on gasoline. (See Figure 4). These surcharges, on the order of $1-$3 per gallon, provide a substantial incentive for the purchase of fuel-efficient vehicles and reduced driving. The smaller sizes and greater population densities of these countries (compared to the United States) may provide more favorable conditions for the coordinated design of mass transportation infrastructure.

Figure 3. U.S. Annual Energy Costs and GNP Comparisons



Reprinted from CEC, <u>1988 Conservation Report</u>, State of California, (Sacramento, CA 1988), p.9.

Figure 4. International Gasoline Prices and Taxes



Data from Gibbons, Blair, and Gwin 1989

The quantity and quality of natural resource endowments may be a significant component of attitudes toward resource uses, and provide powerful incentives for their frugal use. Domestic energy resources are considerable in the United States. Much of the reason for the delayed pursuit of energy efficiency in this country can be traced to our nation's abundant natural endowment. The ratio of energy production to consumption in the United States is one of the highest in the world, at approximately 87%. Japan produces only

18% of its energy requirement (Energy Information Administration 1990).

Energy reductions through efficiency improvements can have favorable effects on disposable household incomes <u>and</u> reduce overall levels of emissions related to energy use. Recycling and re-use illustrate this synergy between efficiency, economy, and environmental impacts. Many communities now regularly recycle aluminum, glass, and newspaper; the remanufactured products can often be produced at a fraction of their original energy cost with substantial related reductions in resource use, landfill space requirements, and cost. As an example, aluminum is one of <u>the</u> most energy-intensive materials to produce, yet new beverage cans are created from recycled stock with only 5% of the original energy cost of manufacture (Long 1989).

The quantities, qualities, and location of the energy resources we harness are linked to environmental impacts on terrestrial and aquatic ecosystems. Proposed oil exploration on the coastal plain of the Arctic National Wildlife Refuge may disrupt the calving range of the largest elk herd in North America; marine life is threatened by oil tanker spills and the operations of offshore drilling platforms; alpine forests and lakes are damaged by airborne nitrogen and sulfur emissions hundreds of miles downwind of large coal-fired electric plants.

The residents of large metropolitan areas are regularly exposed to unhealthy air quality, due largely to the concentrated effects of motor vehicle exhausts. In California, an estimated 80% of all air quality problems are the result of fossil fuel use. And the greatest share of the global warming effect in the earth's atmosphere is now believed to be derived from the combined effect of fossil fuel production and combustion, which add 5.4 billion tons of carbon to the atmosphere annually--close to one ton generated per person alive on the earth (Raloff 1988), (Flavin and Durning 1988).

American coal reserves are sufficient for a several hundred year supply, yet even with the best available pollution control technology, coal combustion remains the dirtiest form of power generation and one of the most significant contributors to acid rain and carbon dioxide emissions. Nuclear power is a "clean" alternative in this regard, but suffers from essential safety questions (highlighted by the Three Mile Island and Chernobyl incidents) and the as yet unresolved issue of long-term waste disposal. Advances in energy efficiency and cost-effective conservation strategies offer, on the other hand, the opportunity to harness an energy "supply" with few long-term or unmanageable impacts--an opportunity that we cannot afford to ignore.

Architectural Potential

Building energy use for space heating, cooling, lighting and water heating currently commands one quarter of the U.S. annual energy budget, at a cost of close to $110 billion (Gibbons, Blair, and Gwin 1989). When the costs of construction, material production, and maintenance are included, buildings are responsible for the consumption of more than one third of the nation's annual energy requirement. At present, the source of more than 90% of this energy requirement is met by fossil fuels in the form of oil, natural gas, and coal (Durning 1988).

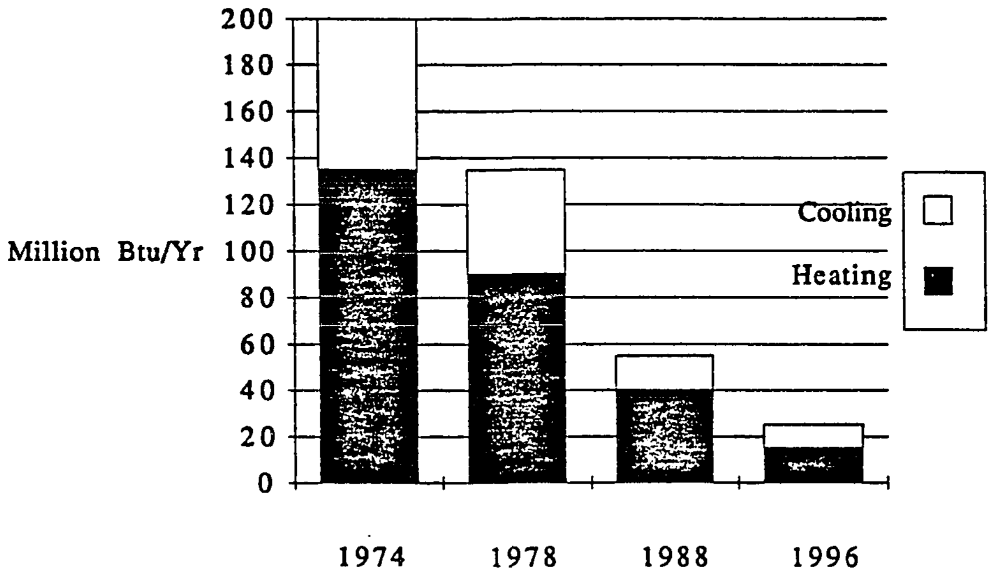
The successful regional building styles of the past reflected their link to climate and resource limitations. The vernacular architectural styles of many areas exhibit an intuitive understanding of the ways in which shelter can be adapted to best temper the extremes of the local microclimate. Some examples of this innate design sense include the compact, heat-conserving configuration of the New England saltbox house with its central fireplace and long sloping back (north) side, the shading wrap-around verandas of the southern plantation home, and the massive heat-absorbing adobe construction of the high southwest that buffers the great fluctuations in daily air temperatures (Fitch 1972).

More recently, though, the availability of abundant and inexpensive fossil fuels has led to the predominant modern reliance on mechanical solutions for heating and cooling needs, to the exclusion of considerations of improving the thermal integrity of building shells and making beneficial use of their siting and shading. Many homes built before the 1970's had little or no insulation, were equipped with single glazed windows, and featured infiltration rates of 1.0 or more air changes per hour in uncontrolled ventilation.

Much progress has been made in the development of energy efficient architecture in the recent past. The construction industry is now capable of producing homes that require a fraction of the operating energy budgets of homes built in the early 1970's through cost-effective enhancements of insulation, better siting, improved infiltration control, and increased appliance efficiency. Because the useful lifetimes of homes can reach 50 years or more, today's architectural designs will contribute to patterns of energy use well into the next century. The state of the art in today's carefully constructed home designs provide a comparable level of comfort with less than one half the space-conditioning energy input of the typical home built just 15 years ago. (See Figure 5).

These advanced designs are marked by careful attention to all the components of building shells, the use of greater quantities of thermal insulation, high performance-low emissivity glazings that incorporate coatings to limit radiant heat loss, and the installation of continuous air and vapor barriers around all exterior surfaces of building shells. These membranes seal the joints between components of a structure and can limit air infiltration to such low levels that mechanical ventilation may be required to remove the buildup of potentially harmful indoor pollution. The performance of passive solar and superinsulated home designs may achieve an even greater level of energy efficiency by admitting and storing solar radiation in the thermal storage materials within a structure, or by incorporating significantly greater levels of insulation in exterior building components.

Figure 5. Annual Source Energy Consumption for a Typical California Home by Year of Construction.



Data from Phillips 1990

The synthesis of engineering and economics can define the boundaries of the cost-effective application of energy conservation measures and standards in new homes. Building technology is capable of virtually eliminating the space conditioning energy requirement in homes, but only with a substantially increased investment in design, materials, and installation. Economics provides a gauge of the relative cost-effectiveness of a conservation investment in light of the continuing energy costs required to supply heat, light, and power for household needs over time. One economic approach, life cycle cost analysis, can be used to determine an optimum building design by comparing the total sum of expenditures over a building's useful economic life, including: initial purchase price, financing, operation, maintenance, taxes, and salvage value. Using this approach, the most economically efficient design may have a greater <u>initial</u> cost to purchase and install energy conservation measures and materials, but a lower <u>lifetime</u> cost due to the reduced total of energy expenses.

The higher initial construction cost is perhaps the greatest barrier that has hindered the diffusion of energy-efficient building techniques in the United States, but it is by no means the only one. Homeowners and buyers have resisted making investments in home energy efficiency for a number of reasons, including: a lack of information about effective energy conservation measures, misconceptions about the effect on personal comfort or convenience, and the lack of understanding about the life cycle cost-effectiveness of conservation strategies. A fragmented government policy has not synthesized a cohesive program to increase the development of energy-efficient housing, despite the potential to increase the productive use of valuable energy resources. And, despite the demonstrated cost-effectiveness of many building energy conservation measures compared to conventional energy sources, long-standing habits and practices are difficult to change. It is also obvious that without an energy "crisis," most people and government bodies will face an uphill struggle in attempting to reform wasteful energy practices.

California has become a leader in the development of energy-efficient architecture since the enforcement of the first insulation requirements for new construction in 1975. The first energy performance requirements for commercial construction were enacted in 1978 to mandate a stringent energy budget for buildings according to their location in a specified "climate zone." The residential building energy performance standards, recorded in Title 24 of the California Administrative Code in 1983, followed this example to set limits on the annual new home energy use for space heating, cooling and hot water use at a level less than one half the national average (Wilson 1985). California's "Title 24" standards were enacted to establish new patterns in building energy consumption, recognizing that the greatest opportunity for securing building energy efficiency is presented at the time of initial design and construction. Most energy conservation measures are more readily performed, at lower cost, on the exposed structure of new homes under construction than on existing homes.

The state's building efficiency standards have been responsible for significant energy savings since their implementation, yet they suffer from some essential limitations. Only 1-2% of the total building stock is constructed new every year; the standards do not address the weatherization of the much larger pool of existing buildings, unless they are remodelled. By 1988, 76% of California's 9.5 million residences were still estimated to have been built before <u>any</u> requirements for energy efficiency (Miller and Griffin 1988). The last economic evaluation of the state building standards was performed in 1980. The costs of energy and conservation in 1991 and forecasts of these costs in the future have changed the economic parameters for determining the cost-effective investment in building energy efficiency.

PRACTICAL APPROACHES TO ENERGY-EFFICIENT HOUSING

Engineering and Behavior

The development of energy-efficient residences can contribute to a strategy to increase the productivity of our energy use. The repercussions of inefficient and inappropriate energy uses create a persistent drain on personal and regional economies and on ecological systems. The question is clear: what steps should be taken to assure that the proper level of conservation investment can and will be made in architecture?

The interaction of natural forces and demands, physical constraints and behavior, defines the need for space conditioning in our homes. It is important to understand how energy is used in homes: what services require energy use, and what factors determine the level of energy consumption required to meet these needs. Residential energy consumption is dependent upon a number of physical and behavioral characteristics based on a building's construction, location, and equipment, and the behavior and attitudes of its occupants. The greatest share of residential energy use is dedicated to space conditioning (heating and cooling), followed by hot water heating, refrigeration, and lighting. The heating and cooling loads are typically responsible for 50% or more of total home energy consumption, and compensate for two kinds of energy demands--through conduction gains and losses, and infiltration loads.

The physical laws of thermodynamics govern the flow of heat through the components of a building's envelope. These laws dictate the spontaneous movement of heat (transfer of energy) from warmer to cooler areas through three basic processes of heat transfer: conduction, convection, and radiation. Any adjacent areas, surfaces, or materials of differing temperature will seek to establish an equilibrium by the transfer of heat through one or more of these processes. Conductive flows express the amount of heat energy transferred through the materials of a building's exterior envelope, and include the energy flow resulting from convection (air movement on building surfaces) and radiation (electromagnetic transmission).

The "conductivity" and surface area of building components and assemblies, and the difference between indoor and outdoor temperatures, determine the rate of heat flow through those materials, which is expressed by a "U-value." This value is a measurement of the rate of heat flow in Btu/Hour-Square foot-Difference in Temperature (in Degrees Fahrenheit), and includes the heat lost by conduction, convection at surfaces in contact with moving air, and the thermal radiation of warm objects and materials. The rate of heat flow is inversely related to the thermal resistance ("R-value") of a building component or assembly. For a constant temperature differential, a doubling of the thermal resistance of an assembly will halve the rate of heat flow through that assembly. The conductive (skin) losses comprise, on average, two thirds of the total heat transfers out of homes. (See Figure 6). Since conductive energy flows comprise the greatest share of envelope heat transfers, increasing the thermal resistance of the exterior surfaces of a building (by insulating walls, ceilings, and floors) is often one of the first and most effective energy conservation strategies.

Figure 6. Distribution of Home Heat Loss.

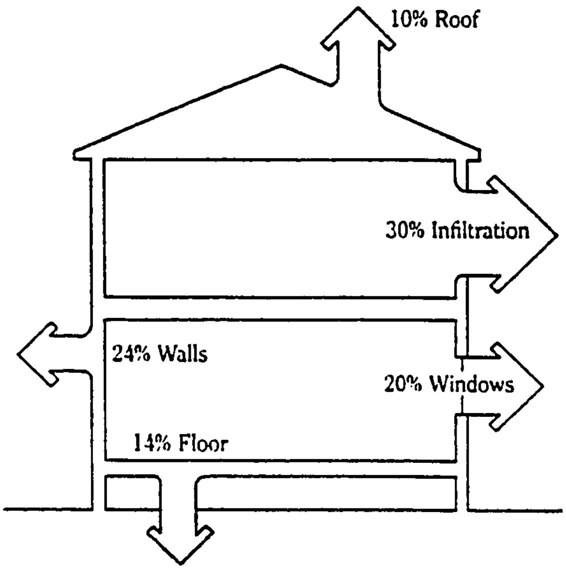
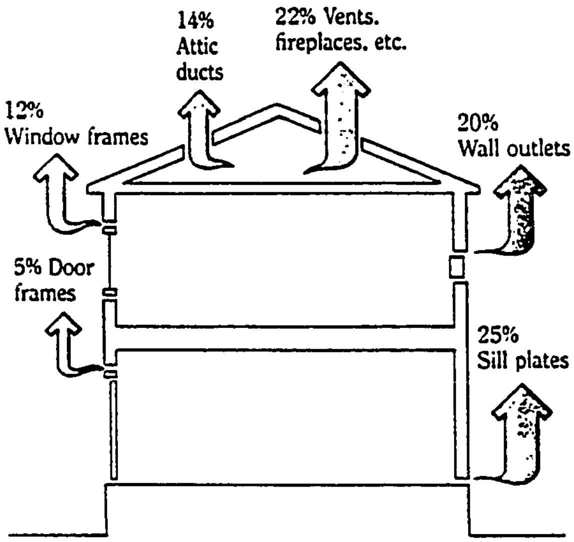


Figure 7. Home Air Leakage.



Data from Lenchek, Mattock, and Raabe 1987

Infiltration is the second primary process of heat transfer in homes, expressing the leakage of conditioned air through the seams and joints between the many components of house construction. This method comprises, on average, the other third of envelope heat losses, depending on the "tightness" of construction and on wind conditions at the site. Even in well-built, insulated homes, the many invisible air leaks around door and window jambs, electrical outlets on exterior walls, and plumbing penetrations through roofs and walls, can make infiltration a significant contributor to heat loss. (See Figure 7). The extremely low energy requirements of "super-insulated" designs are due in part to the careful wrapping of all exterior building surfaces with continuous air and vapor barriers to seal these seams and leaks and curtail the free movement of air through the building envelope.

These advances may not be achieved without cost; the synergy between elements of home designs generate unexpected impacts. As construction practices reduce uncontrolled ventilation through building shells, the build-up of moisture from human activities, and indoor pollutants from stoves, household cleaners, and the out-gassing of building materials may require mechanical ventilation to introduce adequate supplies of "fresh" air. Also, recent research has uncovered a latent relationship between infiltration levels and the design of forced-air heating systems. In tests performed on North-west U.S. homes, infiltration levels increased several fold due to pressure differentials generated by the cycling of forced-air heating systems. The effects of these internal pressure changes was found to be equivalent to the effects of 20-60 mile per hour winds outside, and responsible for an increased heating load to condition interior air volumes (Burt et al. 1990).

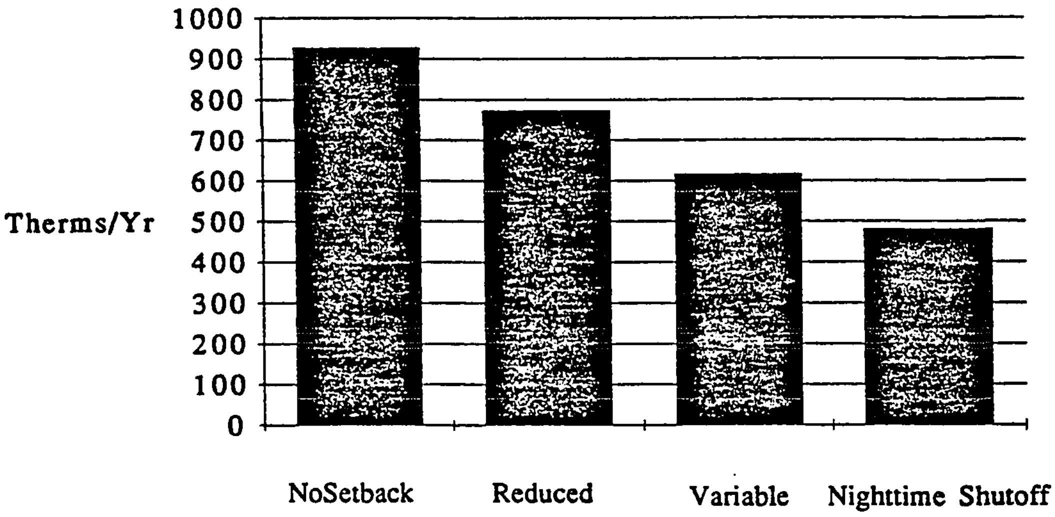
While engineering addresses the improvement of the technical performance of building components and equipment, the importance of residents' values, attitudes, and habits regarding the operation of their homes and its equipment is of equal importance and should not be discounted. In estimating the performance of energy conservation materials or techniques, variations in occupant behavior introduce a constant source of uncertainty. One study of adjacent, identical townhouses found a variance of up to 100% in metered energy use due solely to differences in household behaviors, perceived comfort levels, and hot water and appliance use (Stern and Aronson 1984). No thorough consideration of improving residential energy efficiency should fail to consider both the structural and behavioral elements that define the parameters of energy use.

All other things being equal, there is a linear relationship between the severity of a climate, measured in "degree days" above or below a temperature range of 65-78 degrees, and a building's requirement for cooling or heating (Hutchins 1978). The most direct method available to manage building energy use is, therefore, through the control of thermostat settings to minimize the difference between indoor and outdoor temperatures, subject (of course) to limitations imposed by human requirements for comfort. There is some variation in practical indoor temperature settings due to individual sensations of a "comfortable" range, the level of activity, the humidity level, and the amount of clothing worn. But, in general, most people feel most comfortable within a fairly narrow temperature range of 68-78 degrees Fahrenheit during their waking hours.

The example provided by the use of setback thermostats illustrates some of the variation in energy use and conservation potential that may arise from differences in personal comfort, attitudes, and knowledge. This device can be programmed to reduce central furnace and air conditioner use automatically by allowing indoor temperatures to "float" at night, or when no one is home, or to allow a greater "deadband" comfort range. It is a fairly inexpensive energy conservation measure which can save as much as 20% of annual space-conditioning costs, depending on the severity of the climate and the selected household temperature settings. (See Figure 8). The value of the energy savings generated is dependent on how residents' awareness and values are translated into action--in this case accommodating a wider range of indoor temperatures.

Significant reductions in residential energy consumption may be made possible by an understanding of the weaknesses of traditional building envelope construction. The careful treatment of conduction and infiltration energy transfers by insulating and sealing can conserve 50-80% of home space conditioning energy loads, and serve as an important component of a strategy to enhance the productivity of energy use.

Figure 8. Effects of Thermostat Setback on a Northern California Home's Space Heating Energy Use.



Data from Schultz 1983

Vernacular Designs

The context of building has always been defined by climate and material limitations; the best examples of indigenous and vernacular architecture express their adaptability to these constraints. Elements of architectural design defined regional vernacular styles and tempered the extremes of climate before the advent of central space conditioning systems. The function of many of these design elements has been forgotten with the adoption of mechanical systems to provide comfortable indoor environments. But now, considering the mounting economic and environmental repercussions of this dependence, it may be worthwhile to reexamine the lessons provided by unknown builders in considering building siting, orientation, and the mass of building materials as the foundation of energy-efficient design.

The architecture of the low latitude desert regions must temper the extreme daily temperature swings, and provide shelter from the intense solar radiation common to these areas. Many indigenous designs in these climates make use of thick masonry or adobe walls and roofs to absorb the great daytime solar gain (heat), and reradiate it during the night. The use of massive materials with a great capacity for heat storage in these climates tends to have a "flywheel" effect in buffering the fluctuations in diurnal temperatures above and below comfortable levels. Light-colored walls on interior and exterior building surfaces tend to reflect more of this intense solar radiation. Small apertures (windows and doors) shield interior spaces from the direct sun, and restrict convective heat transfers during the hottest part of the day. The combined effect of these design elements can transform a daily exterior temperature range of 55-105 degrees into a much more amenable interior range of 70-85 degrees (Dumas 1976). For these same reasons, it is believed that the Anasazi Indians of the American Southwest built their dwellings into the south-facing, undercut sandstone walls of Utah and Arizona, to take advantage of the tremendous thermal mass of the rock itself. The overarching cliff walls would provide shade in the summer and protection from storms, but would not hinder the penetration of the lower angle rays of the winter sun, which could warm the adobe walls of their clustered alcoves.

In the arctic regions of North America, the Eskimos built sturdy shelters out of the most prevalent material available--hard-packed snow cut in blocks 18" thick, 36" long, and 6" high. These blocks would be laid in an inward sloping spiral to form the dome-shaped "igloo", which has the lowest ratio of surface area to enclosed volume of any shape, and a very low profile to winter winds. In contrast to high mass materials (which would serve as a reservoir of cold in this frigid climate), this structure's use of the low thermal mass of dry snow allowed the enclosed air to be warmed rapidly by a single heat source, usually an oil lamp. Raised sitting and sleeping platforms were built above a floor pit, which acted as a cold "sink". Furs draped the interior of the dome, and covered the sleeping platforms to insulate against the cold interior walls. The interior surfaces of the igloo would melt and refreeze, providing a wind-resistant glaze against penetrating winds. This enclosure could provide basic shelter from the harshest sub-zero weather, and provide a livable space where interior temperatures could be kept as much as 65 degrees above ambient exterior conditions (Fitch 1972).

In tropical climates, dwellings must accommodate high heat with little daily or seasonal temperature variation. Many examples of primitive architecture in these areas also make use of low mass materials (indigenous fibers and woods) in their construction, since high mass materials would exacerbate the accumulation of heat, and restrict the movement of air currents. Large, overhanging, woven fiber roofs deflected the direct solar gain, and shaded the air and ground directly around the house, reducing the convective and radiative heat gain to the interior spaces. These large overhangs would shade the interior rooms from even fairly low angle sunshine, and also protect them from windblown precipitation. The use of stilted floors raised houses off the ground to more effectively catch prevailing breezes, and also replaced the high-mass heat storage capacity of earthen floors with low mass fiber platforms. This permitted cooling around another surface of the building and reduced ground-level drainage problems.

These examples of vernacular design illustrate how indigenous materials can contribute to tempering the climatic extremes of heat and cold. Today's builders and architects can benefit from these time-tested examples of functional design by taking advantage of natural energy flows through the use of proper orientation and materials. Even in severe climates, the application of these design principles in combination with proper insulation and infiltration control can significantly reduce the supplemental space-conditioning energy requirement of homes, demonstrating the benefit of seeking an accommodation between the building design, its site, and climate.

Regulation and Information

The implementation of effective building energy conservation strategies requires the reform of old habits and practices. There are two primary approaches that can contribute to the reduction of energy inefficiency and waste in our homes, based on regulations and market-based policies. Engineering establishes the technical potential for energy efficiency, but it cannot, by itself, direct the application of these improvements. The incorporation of these changes may be motivated by "hard" or "soft" approaches involving overt or indirect penalties or incentives. Both methods have their benefits and limitations which present significant differences in implementation, enforcement, effectiveness, and political popularity. However the signals are relayed, though, it is clear that new values and practices must be engendered to redirect energy use to more productive uses, to provide a greater economic return on the use of energy resources, and to reduce the external costs resulting from excessive energy production and use.

Regulation is the most familiar form of social persuasion, and is often thought of as the most effective means of securing public cooperation. At this time, most states have adopted some form of building energy efficiency regulations in recognition of the long-lived effect that the building stock has on energy consumption patterns. The popularity of this approach has been enhanced by the availability of existing administrative structures, with experience in building construction. Generally, building efficiency regulations have been appended to building codes under the jurisdiction of city and county building departments, in an extension of their traditional responsibilities regarding health and safety issues in the built environment. The primary strength of regulation in this campaign comes from the universal coverage it provides, subject to the enforcement capabilities of building departments and the substantial incentive for compliance supplied by the force of official sanction.

Building standards can serve a valuable role in overcoming the market barriers that have hindered the voluntary adoption of cost-effective building energy conservation measures, and in disseminating information about appropriate energy conservation strategies to the building industry and housing consumers. The penalties for noncompliance generate pressure for correct information as to how "accepted practice" in the construction industry must be modified to achieve compliance, which encourages the interaction of builders, designers, and regulators.

Sweden has had a long and successful history of regulating elements of building energy efficiency since the onset of firewood shortages over 100 years ago. The latest generation of building standards there are a contributing factor to the record of significantly lower residential energy use in Sweden compared to the United States. Yet, some observers have professed the belief that the most important effect of the Swedish building standards has been through the generation of greater public awareness about the interrelation of quality construction, comfort, energy efficiency, and economy (Schipper, Meyers, and Kelly 1985).

Regulation seems to work well where there are a limited number of similar products that can be tested under static conditions, as in the appliance or automobile industries. Relatively simple tests, like the dynamometer tests for automotive fuel efficiency, while not perfectly representative of actual on-road performance, can provide a benchmark for a general comparison of different vehicles' economy. A similar measurement of a home's "energy performance" resists such a ready representation, complicated by factors related to the building's size, design, equipment, and location. The implementation of the federal automobile fuel efficiency standards benefitted from their applicability to a small, relatively homogeneous group of manufacturers. In contrast, the domestic building industry, comprised of several hundred thousand practitioners, is characterized by the disparate interests and motivations of many specialized crafts and professions.

Utility and state energy planners in utilities and state agencies have a particular appreciation for the ways that uniform efficiency standards compress the variation in home energy use and help to focus long-range demand forecasts. Building energy standards, and appliance efficiency standards, can help to weed out the most obsolete and wasteful designs and products and motivate industries to advance the state of their technology. Cost-effective enhancements to energy efficiency allow equivalent building services to be supplied with substantial reductions in energy use, and contribute to restraining the growth in an expanding population's energy demand. The need to develop marginal energy resources and higher cost production or generating capacity is deferred, as is the incremental upward pressure on average energy utility rates (Weberg 1982).

There are limitations to the imposition of uniform building regulations. The blanket coverage afforded by statewide requirements can only approximate the optimum balance of conservation and energy supply because of variations in climates, energy prices and supplies, and the costs of energy conservation materials and installation. The codification of approved measures and materials may stifle innovation and hinder the flexibility of builders and designers to explore alternative approaches to energy efficiency not subsumed under official practice. A fraction of the population bears the costs of new building efficiency standards, yet a much larger group benefits from the regulations' influence on restraining energy growth. Builders are motivated to meet the minimum requirements of energy regulations, but are not rewarded for exceeding those minimums.

Building energy regulations, unless they are simply prescriptive requirements, may not be readily assimilated into building department operations. Building energy performance requirements, in particular, may require a certain technical expertise to translate policy goals by calculation or simulation methodologies into explicit conservation measures or materials. Traditionally, these standards have been incorporated into existing building codes and requirements, and placed under the authority of city or county building departments. Most elements of conventional building codes in effect today have been developed to provide safe and sanitary conditions in the built environment. The incorporation of energy efficiency requirements is a new and unfamiliar departure from the norm. Budget and staffing limitations may hinder the adoption of the additional enforcement responsibilities. Building department staff members without a technical background may not be prepared to support or implement the complex technical requirements of energy performance standards.

Incentives and Markets

The other primary approach to the establishment of energy-efficient architecture relies, instead, on indirect means to encourage the investment in building energy efficiency. Proponents of the "market" approach are opposed to the coercive effect of regulation, and believe that consumers themselves will make the most economically efficient choices to balance energy conservation and consumption in a properly functioning free market. This approach may include government subsidies or taxes--either of which may be imposed to encourage energy conservation investments or to reduce energy consumption and induce a revaluation of established energy-using habits and practices. These methods may be readily incorporated into existing administrative structures. Or, the reliance on a laissez-faire market policy may do without an overt structure to encourage the implementation of measures to enhance energy efficiency; the price incentives to motivate energy conserving behavior are already built into established, automatic, and self-regulating market interactions. The great appeal of the market approach to energy efficiency is linked to concepts of freedom and personal autonomy, expressing the individual's right to choose his own course (or, to maximize the personal benefit from an economic transaction).

Theoretically, the market approach has much to recommend it, yet practical results have been erratic due to the volatility of the energy markets and distortions in the free operation of those markets. The energy markets are dominated by a small number of multinational corporations and resource-rich states and countries. Government policies have subsidized the exploration and production costs of domestic energy resources, and controlled energy prices in interstate commerce. Consumers have not been well informed of the economic benefits of appropriate energy conservation measures, are unaware of the energy waste inherent in their everyday practices, and have not been motivated to become informed because of under-valued energy resources.

In contrast to the results of compulsory efficiency standards, the market approach is more likely to produce uneven results due to the variety of individual values and attitudes regarding energy use and the investment in efficiency. Lower income households, who already spend a greater share of their incomes for energy services and would therefore benefit most from effective energy conservation, are the least able to afford the "luxury" of energy conservation investments (Cose 1979).

The so-called "free" market is a misnomer in regards to the supply, distribution, and pricing of energy. The conventional energy resource suppliers and producers enjoy near-monopoly status and substantial subsidies from all levels of government, including reduced lease fees on public lands, guaranteed returns on productivity, income tax deductions for exploration and development, and a captive market for their services. For example, in 1979 the U.S. oil industry enjoyed $5.4 billion in federal tax credits for depletion allowances, exploration and development costs, and foreign tax deductions. Residential energy conservation tax credits for this same year totalled only $.4 billion (Williams, Dutt, and Geller 1983). There is some doubt that a voluntary, market-based approach to advance energy efficiency can overcome these distortions in the operation of energy markets without some form of regulatory intervention.

Proponents of the rational economic approach suggest that market incentives themselves will stimulate the demand for more complete information, and motivate the investment (of dollars and commitment) to increase the level of home energy efficiency. This approach is related to education in that, it is thought, if energy consumers can be convinced of the advantages (in monetary terms) accruing from the more efficient use of energy, the purchase of "cost-effective" energy conservation will be justified. But, even when consumers are made aware of effective energy conservation strategies, their unrealistic expectations of the return on their conservation investments may preclude the application of some of the most effective, but higher cost, energy conservation measures.

Consumers are not directly concerned with energy per se; they are primarily interested in the services supplied by energy use -- transportation, heat, light, and power. This commodity is essential to many activities, yet it remains hidden and intangible inside the gas tanks of our cars or running through the electrical wiring inside the walls of our homes. Most consumers are not well informed about energy issues, and are not readily motivated to become knowledgeable.

Government Policy

There is a strong correlation between many elements of our built environments, the availability of energy resources, and government policies regarding those supplies. The United States' abundant endowment of natural resources is linked to the land use patterns of the nation. Longstanding government policies to ensure the availability and affordability of motor fuels, and to provide for the generous subsidization of road construction and maintenance, have contributed to urban sprawl. Energy prices and taxes in the United States are extremely low in comparison to many other industrialized countries. Government agencies, until fairly recently, controlled domestic oil and natural gas prices in interstate markets below their world market values, and sometimes below their nominal replacement value. This has led to occasional regional energy shortages due to the conflicting price signals sent to consumers and producers, and encouraged greater consumption and continuing inefficient uses in all sectors, vehicles, manufacturing, and homes.

The nuclear power industry provides another example of the government's continuing influence on the energy markets. Federal research programs were first charged with developing peaceful uses for nuclear fission, as an offshoot of the weapons research done in World War II. Ever since that time, federal agencies have held a close guard on all applications of the technology, have shepherded its development as a civilian power source, and even set liability limits for nuclear power plant operators in case of accident. Yet, even with continued government support, no new nuclear plants have been proposed in the last 10 years, none have been ordered since 1978, and no new plants are expected due to the soaring costs of construction, recurring questions of operating safety, and the unresolved issue of providing a secure disposal method for the hazardous wastes produced. These problems have become so pervasive that some critics have questioned the viability of the nuclear power industry without continuing federal government support and funding (Iglesias 1987).

Many other operations of the energy industries have benefited from government subsidies to augment energy resource exploration, development, power generation and transmission. Unfortunately, the influence of this hidden hand has contributed to the distortion of energy markets, and confounded the proper social valuation of energy resource uses according to their effects on regional economics, health, safety, and environmental quality.

Synthesis

Although much progress has been made in reducing the wasteful and inappropriate use of energy resources in the residential sector over the last 15 years, what has been accomplished is only a fraction of what can be justified on a technical or economic basis. Many energy conservation technologies have established their cost-effectiveness in comparison to conventional sources of energy supply, yet their adoption has been hindered by ingrained habits, barriers that have distorted the costs of conventional energy resources in the markets, government policies that have subsidized the exploration, production, and distribution of those resources, and the lack of a concerted effort to advance the development of effective building energy conservation strategies.

A synthesis of the approaches discussed here may contribute to this endeavor by drawing upon their respective strengths and recognizing their particular limitations. Careful building design and engineering can advance the technical capability of materials and construction. Economics can provide the criteria and the incentives to compare and motivate the implementation of effective conservation measures and strategies and regulation can counteract the barriers of information, policy, and pricing that have hindered the voluntary deployment of appropriate advances in conservation and energy efficiency.

Inefficient energy practices are not likely to be reformed without a programmed revaluation of energy resources and consumption on the individual and social levels. The physical and behavioral components that define energy use cannot be considered in isolation; for while the characteristics of a building and its location dictate important factors bearing on its "energy performance," behavioral constraints and practices determine just how a building and its equipment is operated and what potential exists for improving its energy uses.

Many energy utilities have been enlisted in this cause by utility regulators' requirements for the consideration of broader social concerns, and of the costs and benefits resulting from energy production and supply. Utility commissions have taken a more pro-active role in exacting energy utility concessions to assume more responsibility as energy service providers--responsible for research, development, information, and outreach activities specifically targeted toward the careful management of future energy growth. Utility regulatory boards have become increasingly wary of approving new electric capacity in the face of uncertain forecasts of energy demand in their service areas. This has led 23 state regulatory commissions to adopt or study the use of "least cost" planning for energy supplies, as a means of examining all alternative methods of meeting energy demand (Flavin and Durning 1988). Using this planning tool, a fair comparison may be made of the "supply" potential embodied in energy conservation and efficiency advancements through demand-side management programs with that of more traditional "supply-side" assessments.

Today, many "demand-side" energy conservation applications are competitive with conventional energy supply options. Innovative regulatory programs require the dedication of utility expenditures to conservation strategies to reduce overall energy consumption, and allow these expenses to be included in utilities' cost of business and rolled into energy rates. In these cases, the energy utilities may find themselves the unlikely purveyors of information and materials dedicated to reducing energy use (and sales), as the agents of regulatory boards intent on containing energy growth and prices, avoiding shortages, and limiting the social costs of energy uses.

Because domestic energy resources are not sufficient to meet the aggregate demand, it would be prudent to consider any and all means to effectively reduce energy consumption or to make better use of the available resources. A laissez-faire energy policy has not formed an adequate response to the growing share of energy imports and the market distortions propounded by existing energy source subsidies and price-controlled markets. Regulations and incentives can affect attitudes about the greater social value of energy resources, and translate these values into practices and processes that increase the productive application of those resources. Building energy regulation, among many energy conservation and efficiency strategies, offers an opportunity to extend the availability and affordability of the valuable energy resources we require.

CALIFORNIA'S EXPERIENCE

Setting the Stage

California is the most populous state in the union, with a 1990 census total of just under 30 million citizens (Goldstein 1990). Close to one in eight Americans resides within the state's borders. This population is predominantly urban, with more than 75% of the state's residents concentrated in the three extended metropolitan areas of the Los Angeles basin, the greater San Francisco Bay area, and San Diego. California is the third largest state, encompassing an area of over 158,000 square miles. The state borders 850 miles of Pacific coastline, and its moderate coastal climates have been an important factor in the concentration of settlement along this coast (most of the state experiences less than 4,000 heating and cooling degree days per year).

California's diverse physiography is made up of four main regions: the coastal mountain ranges, the Central Valley, the Sierra Nevada, and the Basin and Range provinces which encompass the southeastern deserts. Its topography includes the lowest and highest points in the "lower 48" states, from 280 feet below sea level in Death Valley to an elevation of 14,494 feet at the top of Mount Whitney.

The value of California's annual economic output constitutes a full 13% of the United States' Gross National Product, and is surpassed in global terms only by the U.S. as a whole, the USSR, West Germany, France, and Japan (California Energy Commission 1988). The state has the largest number of employed in the nation, representing 47% of the state's population--13.3 million people in 1988. California boasts a diversified economy with large manufacturing, aerospace and defense, electronics, and agricultural industries. Manufacturing output and employment is second in the nation while the state agricultural output is the greatest in the nation, generating an average of $14 billion of income per year. Petroleum and natural gas are the leading mineral resources, but production is not sufficient to meet the aggregate in-state demand. The state must import a full 59% of its annual energy requirement (Tooker 1989).

Early Building Energy Regulation

California was one of the first states in the early 1970's to recognize the important role that buildings play in regional energy consumption patterns. It would become a leading proponent of the development of energy efficient architecture, with the systematic adoption of regulations and standards regarding minimum performance requirements for building insulation, glazing, heating and air conditioning systems, hot water heaters, and major appliances.

The first legislative initiative dealing with these issues was adopted in November, 1972, even before the outpouring of concern generated by the first energy "crisis." At that time, Governor Reagan signed a bill requiring all California communities to adopt minimum energy conservation standards for all new residential structures with mechanical space conditioning. This bill also directed the California Commission on Housing and Community Development (HCD) to develop and adopt rules and regulations for minimum insulation standards for homes, apartments, hotels, and motels. With help from an advisory committee made up of architects, builders, and state and local building officials, the HCD adopted the first insulation standards for buildings in February, 1974, for implementation one year later. These regulations were the first to require, as a minimum, the installation of R-11 insulation in walls and R-19 insulation in the ceilings of all new homes.

Before those rules would become effective, an important law was enacted that would set the agenda for California's pursuit of greater productivity in all building energy uses. The Warren-Alquist State Energy Resources Conservation and Development Act of 1974 created a state level agency with responsibility for all energy management activities, for forecasting energy demand and evaluating supply options, and for providing a central repository for energy research, information, and training. The Energy Resources Conservation and Development Commission (ERCDC) was given responsibility for the implementation of the insulation standards developed by the HCD, and charged with five other tasks, including: 1) the development of lighting, insulation, space conditioning, building design and construction standards for all new residential buildings, 2) the establishment of energy performance standards for new residential buildings, 3) the setting of minimum appliance efficiency standards, 4) the development of a public domain computer program for use by architects and builders as a design and compliance tool to model building energy performance, and 5) responsibility for the coordination of informational manuals, training and technical assistance for the building industry and officials responsible for enforcing the efficiency standards. A companion bill was passed in 1974, extending the energy agency's mandate to include the development of energy performance standards for all new nonresidential buildings.

In 1978, the legislature reorganized the state energy agency, shortened its name to the California Energy Commission (CEC), and extended its administrative responsibilities to include electric utility rate-regulation, power plant siting, and the development of new, more stringent building and appliance energy efficiency standards. This commission would be overseen by a five-member directorate comprised of one engineer/scientist, an environmentalist, an economist, an attorney, and one public citizen.

By 1977, Energy Commission staff had completed development work on the first nonresidential building standards, and had also expanded the residential building efficiency requirements, for implementation in 1978. A series of workshops were held around the state to familiarize builders, designers, and building officials with the imminent changes to the building codes and to introduce the use of the newly-developed building design manual for compliance. Twenty two-day seminars, and a number of shorter workshops, were conducted before mid-1978, attended by more than 7,000 interested people.

The new standards, to be subsumed under Title 24 of the California Administrative Code, were expected to reduce residential energy use to half the level of homes built before the insulation requirements were enacted. They mandated the installation of higher levels of insulation and double-glazed windows for homes built in the colder climates of the state (more than 3000 degree days), set limitations on the total area of single glazing allowed (a ratio of no more than 16% glass-to-enclosed-floor-space), and required all new homes to install low flow showerheads, water heater insulation, appliances meeting the new minimum efficiency standards, and caulking and weatherstripping for all windows and doors. The use of electric resistance heating was restricted to supplying only 10% of residential heating loads, unless justified by an economic analysis, to motivate builders to take advantage of the plentiful and inexpensive supplies of natural gas for heating. Any home undergoing remodelling of more than 30% of its total floor area was also required to have its ceiling insulated to standard levels (Feinbaum and Ruby 1983).

Implementation and Enforcement

Despite the Energy Commission's scheduling of workshops, the publication of an informational newsletter, and the establishment of a "hot-line" to respond to questions about the building standards' requirements, there was initially a great deal of confusion about how the new regulations would affect the state building industry. A number of building officials and building industry members alike found parts of the new building requirements too complex, the state training sessions inadequate, and the accompanying design manual confusing. In contrast to the earlier home insulation requirements, which had been developed with input from an advisory committee made up of builders, designers, and building officials, the new standards were developed largely "in-house" by Energy Commission staff. Most of the 15-member staff of the Conservation Division responsible for building standards development and administration had little construction industry experience: most staff members held engineering degrees, while only two held architecture degrees.

Building departments were charged with the responsibility for the verification and enforcement of compliance with the energy standards by plan checks, energy calculations, and inspections to verify construction according to specifications. The CEC expected the local building departments to incorporate the management of the energy standards into their workloads, and granted them the power to increase permitting fees to cover any additional expenses. Yet, because of the indirect municipal budgeting process (most California building departments are operated on allocations from municipal General Funds and do not receive revenues from permit applications), only one third of the building departments in the state increased their fees to cover the increased enforcement costs.

There was some resistance within the building industry to the new building energy efficiency requirements, which some viewed as confusing, unnecessary, and expensive. An industry-supported nonprofit corporation, Building Code Action, filed suit to prevent enforcement of the new standards for nonresidential construction and to overturn the more stringent insulation requirements for residential construction in colder climates. Although this suit was withdrawn when the organization appealed to federal authorities for relief, implementation of the new building efficiency standards was delayed for six months, until July, 1978 (National Institute of Building Sciences 1978).

The enactment of the first building efficiency standards precipitated a period of adjustment within the state building industry. A flurry of building permit applications, submitted just before the official enforcement deadline to avoid the increased building and design costs, made 1978 a record construction year. Some building departments were not adequately prepared to administer the requirements of the state building standards, and this led to delays in building permit processing and plan-checking. Certain building departments with limited budget, staffing, and technical expertise were compelled to pass on the responsibility (and liability) for certifying compliance with the new efficiency regulations to the designers and builders of projects, through a loophole allowed by the law. Even in jurisdictions where building officials enforced the energy code, insulation inspections were not a regularly required component of building inspections, and installer certification of work completed to plan specifications was generally accepted as adequate proof of a properly completed job. Initially, spot shortages of mineral fiber insulation were also reported in various areas due to the increased demand.

The expanded requirements of the new building standards created a great demand among certain professions and trades, primarily architects, designers, heating/ventilation/ and air conditioning contractors, and building officials, for information and training. These groups were the most affected by the new building energy efficiency standards because of the requirements necessitating calculations of building heating loads under varying circumstances, the proper sizing of heating and cooling systems, and the ability to cross-check energy calculations for compliance. One study, conducted to measure the statewide employment effects of the building energy standards, found that the induced labor changes were essentially qualitative rather than quantitative in nature-requiring new knowledge and techniques, but not necessarily new skills or additional manpower (Wilms, McCarthy, and Moore 1982). Larger architectural design firms were found to devote the resources to develop an in-house "expert" on the standards, while smaller firms and building departments, at least initially, often relied on hired consultants to provide technical assistance and support to guide them through compliance procedures.

Building industry groups had differing interpretations on the effect the building efficiency standards had on the practice of their professions. Some architects felt that the new standards reduced their flexibility and freedom to design. A number of builders felt that the higher construction costs resulting from the building requirements would reduce new housing demand, and that although the regulations saved energy, the required additional expense was not cost-effective. Due to budgetary constraints imposed on all levels of government in California (Proposition 13), many smaller building departments with limited funding, staff, and expertise gave the enforcement of the new energy regulations less attention than their established priorities regarding health and safety issues in new construction.

These concerns and perceptions made it clear that the initial implementation of California's building efficiency standards would not be automatic, and that verification and enforcement issues would be critical to the success of the regulations. The legislation establishing the CEC program for the development of building efficiency standards also charged building departments with responsibility for enforcing those standards. Energy Commission actions regarding enforcement of the building energy standards demonstrated a reluctance to interfere in building departments' jurisdictional responsibilities, and were focused, instead, on providing informational and training support. There were initial expectations that building departments would readily assume the additional enforcement responsibilities into their normal scope of operations, with minimal additional expense or time. But, the fairly complex requirements of the performance standards necessitated a significant amount of staff attention, both to plan checking and to answering builder inquiries about acceptable means of compliance. Pre-existing funding and staffing limitations in building departments, arising from the constraints of the post-Proposition 13 era of restricted government budgets, were exacerbated by these additional requirements. Some jurisdictions were unable to properly administer the new code, and ceded certification responsibility (and liability) for compliance with the building efficiency codes to the architects and contractors heading up local building projects (Feinbaum and Ruby 1983).

These problems slowed the dissemination and application of the new building efficiency standards. After a few years of experience with the standards, building departments and Energy Commission staff came to realize the importance of universal enforcement in speeding the acceptance of policy changes. Ensuring that all building plans and projects are subjected to the same scrutiny creates the incentive for all designers and builders to become aware of the efficiency requirements, generates pressure for building industry members to become familiar with the processes and procedures required for compliance, and speeds the implementation of the new requirements. In the absence of uniform enforcement of the building efficiency standards, unscrupulous contractors who successfully circumvented the intent of the regulations were rewarded with reduced construction costs, while compliant builders were penalized by losing a share of their cost-competitiveness.

A 1980 investigation conducted by the state licensing boards, to promote an understanding of how licensing requirements could be used to promote compliance with the energy standards, found that the lax and uneven enforcement of the building efficiency regulations hindered their effectiveness. Similar suspicions led the Energy Commission to prepare a report on compliance with the building efficiency standards, based on a sample of 140 plan checks and 90 inspections in 29 cities around the state. This study found lower-than-expected compliance levels of 55-72%, which would lead to revised expectations of the results of "hard" paths to enforcement (Wilson 1985).

Appliance Standards

Another important component of the Energy Commission's mandate involved the development and implementation of minimum appliance efficiency standards. In 1976, California adopted the first three of twelve planned appliance minimum efficiency standards (the first in the nation) for all refrigerators, room and central air conditioners, and electric heat pumps sold in the state. The

Association of Home Appliance Manufacturers filed suit to block the standards, but later withdrew their case and appealed for federal intervention to overturn the state law. The legislature recognized appliance manufacturers' concerns and amended the provisions of the new efficiency standards to grant retailers and manufacturers an extension until November, 1978 to clear their inventories. In the interim, the Energy Commission set minimum efficiency requirements for gas furnaces, hot water heaters, and kitchen ranges, also to take effect in late 1978.

The responsibility for appliance testing and certification of compliance with these minimum appliance standards was left to the manufacturers, subject to commission review. Building officials would check for compliance by comparing the appliances installed in new construction with directories of approved products before granting occupancy permits. If consumer complaints warranted investigation of any appliance's claimed performance, the Energy Commission was vested with the authority to conduct its own testing and to decertify substandard products. Six more appliance standards were planned for televisions, gas fireplace logs, washers, dryers, dishwashers, and cooking stoves, but staffing and time limitations prevented their development.

These standards have weeded out the most inefficient of the regulated appliances, and brought pressure to bear on manufacturers to advance the technical performance of their products. One example of this progress is illustrated by the improved performance of refrigerators: the California minimum efficiency standards have stimulated the technical development of refrigerator design and reduced the energy consumption for a 16-18 cubic foot automatic defrosting refrigerator from 1,900 kilowatt hours (Kwh) per year in 1977, to 1,500 Kwh/year in 1979, down to an average of 1,000 Kwh/year in 1987. Although commission consultants expected to cut refrigerator energy use to 700 Kwh in 1993, further advances may be constrained by the ceiling set by new, preemptive federal appliance efficiency standards. Still, experts estimate that if all 125 million refrigerators in the nation were built to the present California minimum efficiency level, the output of 20 large electric-power plants presently in operation would be superfluous (Akbari and Rosenfeld 1990).

By the early 1980's, a number of other states were following California's lead in developing their own appliance standards, and the major appliance manufacturers were prompted to advocate the development of national standards to foreclose the fragmentation of their markets by a patchwork of separate state requirements. The National Appliance Energy Conservation Act was passed by Congress in 1986, to provide a uniform basis for appliance efficiency requirements, with preemptive authority over individual state laws. The first appliance efficiency levels set in California would serve as the model for the development of national appliance efficiency standards with the enactment of this legislation (Messenger 1987).

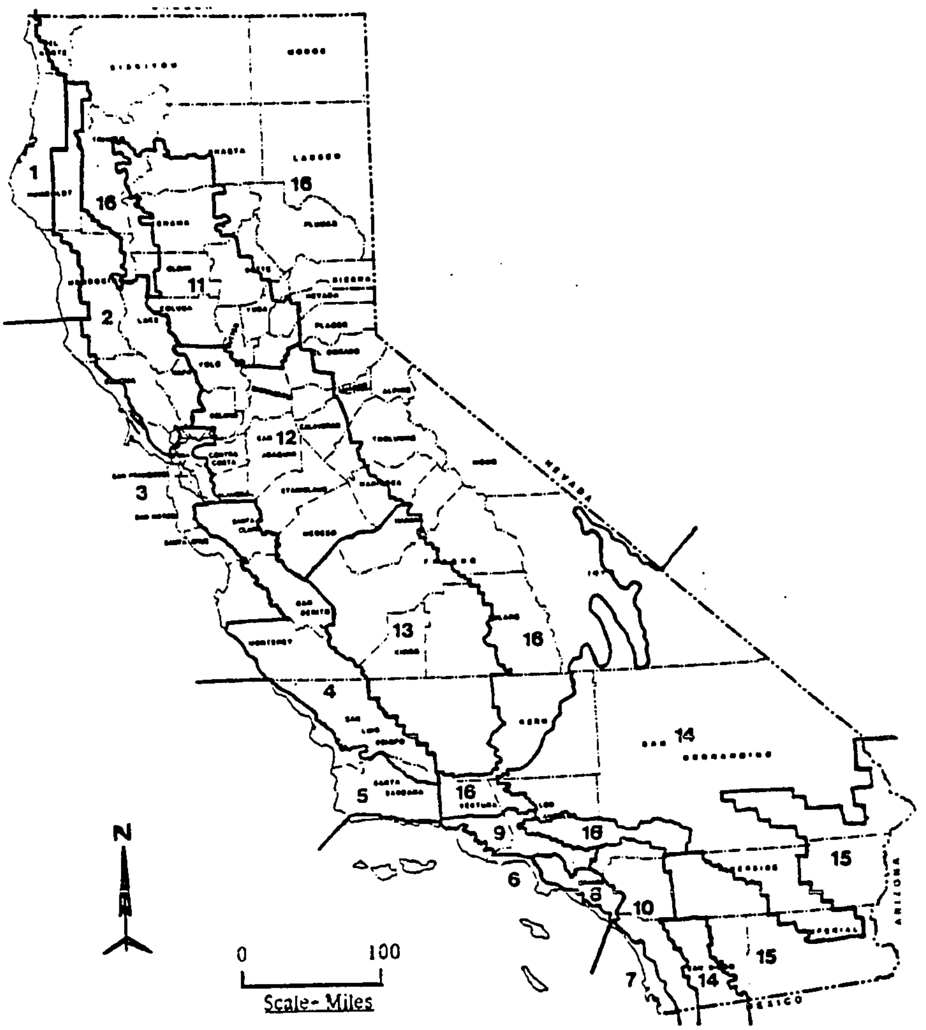
Energy Performance Standards

In mid-1981, the requirements for residential energy efficiency were amended again and incorporated in a new, more comprehensive set of building energy regulations. Commission staff collaborated with meteorologists, physicists, architects, and engineers to draft the first performance-oriented residential building standards in the nation, for enactment in mid-1983. In contrast to the previous requirements mandating the incorporation of specific building materials and components, the new standards enabled an alternate approach to the achievement of building energy efficiency by setting an overall energy "budget" and allowing tradeoffs between the efficiency levels of different building components, provided that the overall budget was not exceeded. For example, the installation of a higher efficiency furnace could reduce the requirements for ceiling insulation. The adopted standards specified a maximum permissible energy budget according to a home's location within one of 16 state climatic zones. (See Figure 9).

A home design was required to prove compliance with the requirements of these "Title 24" building efficiency standards by one of three approved methods: 1) by incorporating all the energy conservation measures and materials of one of three state-specified "packages", 2) by a demonstration of the design's energy efficiency using a "point system" calculation technique, or 3) by showing that a home design's performance met the state-set "energy budget" using an approved computer simulation of the home's operation over a full year. A home design would need to fulfill two basic requirements before a building permit could be issued: 1) the inclusion of a set of mandatory conservation measures regarding minimum wall, ceiling, and duct insulation levels, HVAC and water heating efficiency levels and 2) a demonstration, by application of one of the three compliance approaches mentioned above, that the building's predicted annual energy use would not exceed the designated energy budget for that location.

The choice of a compliance approach had ramifications on the degree of flexibility permitted in the design process (Wilson 1985). The "package" approach to compliance is inherently the simplest, and least flexible approach. A builder or designer could choose between three prescriptive packages--formulated around alternatives based on the incorporation of passive solar design features, extra insulation, or an active solar water-heating system. A builder could simply incorporate the "recipe" of conservation measures specified by a particular package, along with the mandatory measures required of every home design, to achieve compliance with the state energy standards. However, the simplicity of following this "package" approach to compliance is achieved at the cost of design flexibility: every particular requirement for energy conservation measures, materials, and equipment must be met--no substitutions are permitted.

Figure 9. Climate Zones for California's Building Energy Conservation Standards.



Reprinted from California Energy Commission, Building Energy Efficiency Standards, State of California (Sacramento, CA 1988), p. 160.

Use of the point system compliance technique entails assigning point values to all the components of a prospective house design--wall/ceiling/and floor insulation levels, glazing, shading, thermal mass, HVAC systems and water heating equipment--to represent their performance in the selected climate zone. Positive points are assigned to components that reduce energy use compared to the standard package component construction (e.g., greater ceiling insulation); negative points are assigned to measures that increase annual energy use. Compliance with the building energy standards is demonstrated by summing the assigned point values for all design components and achieving a point total of zero or greater--proving an equivalent level of energy efficiency with the approved package design totals for that particular climate zone. Using this technique, designers can "trade-off" the efficiency levels of individual elements of a building design as long as the total design exhibits an overall acceptable level of energy efficiency by maintaining a point total of zero or better.

The use of computer design simulation is the most demanding, detailed, and complex compliance technique, but it enables the greatest freedom to consider the interaction of building components' effect on energy performance. Once a house plan is converted into computer-readable form (mathematical parameters), these programs calculate a building's requirement for heating, cooling, and hot water energy use over the course of a year in response to simulated hourly weather conditions for a particular area. These results are compared to the energy budget established by the performance of the standard design (equipped with all required prescriptive package features) to determine whether the proposed plan achieves an adequate level of energy efficiency. Although this technique requires a greater initial investment in time and effort to translate the elements of building plans into workable software files, the results of this effort provide the greatest flexibility to model and compare the effects of design changes on energy consumption and to achieve compliance with the building standards.

Over the years, a cottage industry has developed various building energy simulation programs to test and document design compliance with the requirements of the Title 24 building efficiency standards. At present, four different computer software packages are certified for this use by the Energy Commission (Phillips 1990).

The residential building efficiency standards are subject to periodic revisions to accommodate changing economic conditions, energy and conservation costs, and technical advancements. The standards were amended in 1988 to make the glazing performance requirements more stringent, to incorporate different insulation requirements for exterior "mass" walls to account for their heat storage capacity, and to adjust the boundaries of the state climate zones. As the result of lobbying by powerful building industry and appliance manufacturing groups, the state legislature adopted two new energy conservation "packages" for the building efficiency standards, and eased the building requirements for the southern California climate zones. The 1988 amendments introduced these two new prescriptive packages, for raised and slab floor building designs with exposed thermal mass. The definitions, rules, and regulations regarding the 1988 California building energy efficiency standards fill 200 pages of printed text, not including the directory of approved appliances.

At the present time, the standards are being revised once again, for enforcement in 1992. The proposed changes to the existing building energy regulations include: the establishment of minimum insulation levels for floors (which did not previously require any insulation), the establishment of maximum allowable infiltration rates for manufactured windows and doors, increased minimum efficiency levels for heating and cooling systems, and adjustments to the minimum insulation requirements for walls, ceilings, and floors in the approved prescriptive packages (California Energy Commission 1990).

Cost Effectiveness

The program established to advance the energy efficiency of California's buildings has come a long way from its uncomplicated beginnings involving the setting of basic insulation levels for the walls and ceilings of new homes. A full understanding of the fairly complex, current building energy regulations can now be achieved only with some serious study. The standards have helped offset most of the expected growth in residential energy needs over the last 15 years, at a moderate cost premium to new-home buyers, and with some constraints on building design (Tooker 1989). There is no argument that the building standards have reduced energy consumption; there is, however, some question about whether the costs imposed to achieve the state-specified level of energy efficiency maximize the economic investment in building energy conservation measures and materials.

Ever since the implementation of the first building efficiency standards in 1978, the energy commission's requirements for energy conservation measures and materials have been guided by interpretations of economic efficiency. The Warren-Alquist Act directs the commission to:

> Prescribe, by regulation,...building design and construction standards which increase the efficiency in the use of energy for new residential and new nonresidential buildings. The standards shall be cost effective, when taken in their entirety, and when amortized over the economic life of the structure when compared with historical practice (Wilson, 1985, 162).

The imprecise language of this directive leaves substantial room for the interpretation of what constitutes the "cost effective" level for building energy efficiency standards. A literal reading of this mandate would justify the investment in building energy conservation up to the point where conservation costs would no longer be recouped by energy savings.

The determination of cost-effective energy conservation measures and materials in the California building standards has historically been based on a more rigorous test, based on the lowest net life cycle costs. The Energy Commission chose to use marginal energy costs in its initial economic evaluation of the standards in

1980, to encourage more productive energy uses. From the viewpoint of social policy, the alternative to an energy conservation program is likely to be increased energy consumption, with costs more accurately represented by the higher, "marginal" costs of new energy production and generation facilities. The use of marginal energy costs in the analysis would lead to results justifying a greater investment in residential energy conservation.

The development team for the 1983 building energy performance standards made several important assumptions to conduct the evaluation of economically-effective building energy conservation strategies. Their analysis set the discount rate at 4%, to represent the inflation-adjusted consumer "cost of money" at that time (based on 14% mortgage rates and 10% inflation). The assumptions for energy escalation rates were based on 30-year utility forecasts, which estimated average "real" cost increases of 2% per year for electricity and 4% per year for natural gas (Wilson 1981). A 10-year "moving average" inflationary rate of 8% was used to convert 1980 costs to future values.

Despite their proven cost-effectiveness, the original, staff-proposed energy efficiency requirements were relaxed during review when they were estimated to add as much as $6,000 to the construction costs of a new California home (Najarian 1981). The adopted building standards were projected to increase the construction costs of a representative home design by $500-$3900 ($1500 average). These costs were estimated to require an additional $240-

$1900 in household annual income to qualify for conventional mortgage financing. The building efficiency requirements were expected to add $4-$34 to the monthly mortgage cost of the test design, depending on the location of the building site (Wilson 1981).

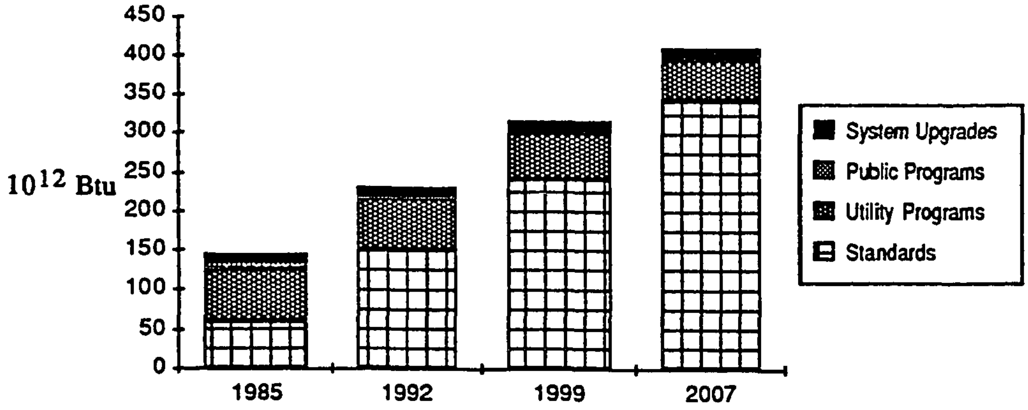
The staff members in charge of the 1992 building energy code revisions have adjusted these assumptions and taken a somewhat different tack by applying an incremental life cycle cost-analysis of alternative energy conservation measures. According to this methodology, any energy conservation measure or material used in residences is determined to be cost-effective if the application of that measure reduces the net life cycle costs of homes built to the current requirements of the state building efficiency standards. The latest revisions' appraisal of the effectiveness of energy conservation investments uses "average" rather than "marginal" energy prices. The use of the lower, "market" price of energy is more representative of the housing consumer's perspective and will lead, in comparison, to a lower cost-effective conservation expenditure.

The stated assumptions of this evaluation include a 3% "real" discount rate, which translates to an 11.9% "nominal" rate with moderate (5%) inflation and average tax liability (28% federal income tax, 9% state income tax). Other important assumptions of this analysis include stable energy prices (increases in electricity and natural gas prices of less than 1% per year), a modest rate of inflation (averaging 5.25%), and a 30 year useful economic life for homes and their structural components (Leber 1990).

One of the California Energy Commission's responsibilities includes the preparation of a biennial report of the progress the state has made toward increasing its productive use of energy. The Conservation Report details the long-term trends in energy supply and demand within the state, and serves as a commission report card and planning document, rating the effectiveness of existing programs, as well as suggesting appropriate directions for future policy initiatives. The most recent reports carry on what is now an Energy Commission tradition--to advocate the continuing pursuit of advances in energy efficiency and conservation to bolster the state's economic competitiveness, to reduce California's dependence on imported energy sources, and to restrain the growth in emissions from fossil fuel combustion. The Conservation Report compiles a running total of the energy savings resulting from all state and utility energy conservation programs, and forecasts the estimated cumulative impact of these programs into the early 21st century.

The CEC has determined that the energy savings generated by the imposition of building and appliance efficiency standards constitute a large share of the total energy conserved by all state, utility, and public agency conservation programs implemented in California to date. These regulations are expected to have a pervasive and growing influence in the future, as more new buildings are constructed and appliances are replaced. (See Figure 10).

Figure 10. Estimated Energy Savings from California Conservation Programs



Reprinted from California Energy Commission, 1988 Conservation Report, State of California, (Sacramento, CA 1988), p. 24.

Although only 24% of California's buildings have been constructed since the implementation of the first building efficiency standards, the influence of the regulations has been significant. By 1987, the 10-year total of energy savings resulting from the adoption of the building energy standards reached an estimated 4,372 gigawatt hours (one gigawatt hour equals one million Kilowatt hours) of electricity, and 740 million therms (one therm equals one hundred thousand Btu) of natural gas (CEC 1988). The value of those savings at 1987 average energy prices approached a total of $744 million ($359 million for electricity at $.082/ Kwh, and $385 million for natural gas at $.52/therm). The California Energy Commission's twenty-year forecasts of the expected energy savings derived from the imposition of building efficiency standards, compared to the energy performance of pre-standard construction, estimate cumulative electricity savings of 20,164 Gwh (equivalent to the annual output of four large powerplants) and natural gas reductions of 2.4 billion therms (enough to supply the needs of nearly one half of the state's households for one year). In constant 1990 dollars and energy prices, the projected 30 year cumulative value of the energy savings derived from implementation of the state building standards surpasses $3.2 billion: $1.94 billion in electricity and $1.28 billion in natural gas (Phillips 1990).

ECONOMICS AND EFFICIENCY

Economic Approaches and Theory

The value of the energy savings generated by the imposition of the California building efficiency standards is noteworthy, yet it constitutes only part of the overall economic "picture" shaped by those requirements. The additional material and construction costs resulting from the standards pressure home prices higher and place an added financial burden on home buyers. It is fair to question whether this has affected housing demand, and how these increased costs affect home affordability, both initially and over the course of the years. This section will examine these issues quantitatively by conducting an economic analysis of the state building standards' requirements for home envelope energy conservation measures.

The concerns of housing consumers and energy policy makers are complementary; a balance must be established between the regulated level of building energy efficiency and economic efficiency (Horowitz and Haeri 1990). The Energy Commission's definition of what constitutes the cost-effective investment in energy conservation guides the design and construction of all California homes. We have an idea of the significant energy cost savings that have been generated by the implementation of the state building efficiency standards. It is important to determine what the costs of compliance with these standards are in 1991, and whether this investment maximizes the investment in building energy conservation.

The technical potential for improved energy efficiency in residential architecture is now well understood. Economic analysis provides a methodology to assess the application of these advances and the appropriate balancing of expenditures for energy supply and energy conservation in the built environment. Although there are a number of related advantages derived from any strategy to reduce energy use, economics is limited to evaluations of the resulting monetary impacts. Other impacts, such as reduced emissions from fossil fuel combustion, increased resilience to energy shortages or price hikes, and a reduced dependence on energy imports, are not as readily quantified and are beyond the purview of this science.

The parameters of an economic analysis can determine what investment in energy conservation measures and materials is cost-effective, and will reduce the costs of home ownership and operation by achieving a savings in energy costs that outweigh the cost of the conservation measures. The different techniques of economic analysis may be used to quantify the benefits of an investment in building energy conservation in several ways: to secure the greatest energy cost savings for a given budget; to achieve a targeted reduction in energy use at the least cost; or to determine the home design that achieves the lowest total of lifetime costs for purchase and operation. Each approach is applied to maximize the net benefits of an investment in energy conservation within certain constraints, and to guide the selection of the strategy that best balances economy and efficiency.

The challenge for the home builder or designer interested in optimizing energy efficiency and economic efficiency is in determining how a static design can best accommodate dynamic economic conditions. The determination of the optimal home design, its materials and equipment, by economic analysis is based on conditions and assumptions regarding the costs of energy, money, and conservation, now and in the future. Although the long-term, "real" (inflation-adjusted) price of most conventional energy sources has held steady or declined slightly, there is evidence to suggest that increases in these prices will soon begin to outpace the rate of inflation. The Department of Commerce has projected the long-term rate of energy price escalation at 1-3% per year (Pirog and Stamos 1987). Forecasts of future fuel prices play an important part in the economic evaluation of cost-effective building energy conservation today. Because of the great variability and uncertainty inherent in these forecasts 20 or 30 years into the future, some observers have advocated the over-investment in conservation measures in the present to insure against the possibility of even higher than expected future energy prices (Anderson 1987).

Economic analysis is complicated by the consideration of costs and benefits occurring at different times, amidst changing economic conditions. The comparison of the value of costs and benefits, which occurr at different times, requires their conversion to a time-equivalent basis to compensate for the changing value of money over time.

The value of money is time-dependent for two reasons: first, the effects of inflation can change the purchasing power of the dollar, and second, money can be invested to earn a yield above the rate of inflation. For example, a person who is willing to place $100 in a savings account at 5% simple interest will see his investment grow to $105 in one year's time. This person could be expected to be indifferent to receiving $100 now or $105 in a year, since they are equivalent values according to this "time-value" for money. For this particular investor, the 5% interest rate expresses a measurement of his/her willingness to defer monetary gain, and is an appropriate rate to convert present values to future equivalent dollar values, or, conversely, to discount future monetary values to present equivalent values. This measure of the time-preference for money is known as a "discount rate"; a person with a stronger desire for money in the present rather than in the future has a greater time-preference for money, which is represented by a higher discount rate.

The installation of most building energy conservation measures requires an initial investment to secure a stream of future energy savings: a capital expenditure substitutes for energy costs by the purchase of materials or more efficient equipment that reduce energy use. The economic evaluation of this investment requires the conversion of costs and benefits occurring at different times into comparable "time-equivalent" values by the use of the discount rate, as an expression of the time-value of money (Kreith and West 1980).

The assumptions used to define the parameters of an economic analysis are <u>crucial</u> to the results of the study. In the case of building energy conservation, the choice of a study period, discount rate, and estimated changes to the values of energy, conservation, and inflation are integral to the determination of the cost-effective conservation investment over time. The care taken in the selection of appropriate values for these factors guides the application of the economic assessment and the correlation of results with changing "real world" conditions.

The choice of a study period (the time horizon) is a particularly influential factor in the evaluation of energy conservation measures and materials, because of the growing cumulative effect of energy savings over longer time periods. The determination of the proper time horizon to be used in an economic analysis must be based on factors relating to the perspective and objectives of the investor and the economically useful life of the conservation investment. The selection of a short study period may lead to the underestimation of the total value of benefit streams and the under-investment in energy conservation. The 30 year mortgage lending period is more indicative of the useful economic lifetime of homes and their durable conservation components (such as insulation), and provides, in this case, a more suitable and representative time horizon for economic study (Stern 1986).

One of the reasons for the delayed development of energy efficient housing has been as a direct result of builders' inappropriate short-term perspective on conservation investments. Many home-builders' primary motivation has been to secure the quick turnover of completed properties. Because housing markets are very price-sensitive, the building industry has been hesitant to incorporate energy conservation measures which add to construction costs. Uncertainty about whether conservation investments are capitalized in home sales prices or have increased their marketability has inhibited the development of energy-efficient architecture. In contrast to more common housing amenities, such as a master bedroom suite or a jacuzzi tub, the benefits of most energy conservation investments may only be experienced indirectly.

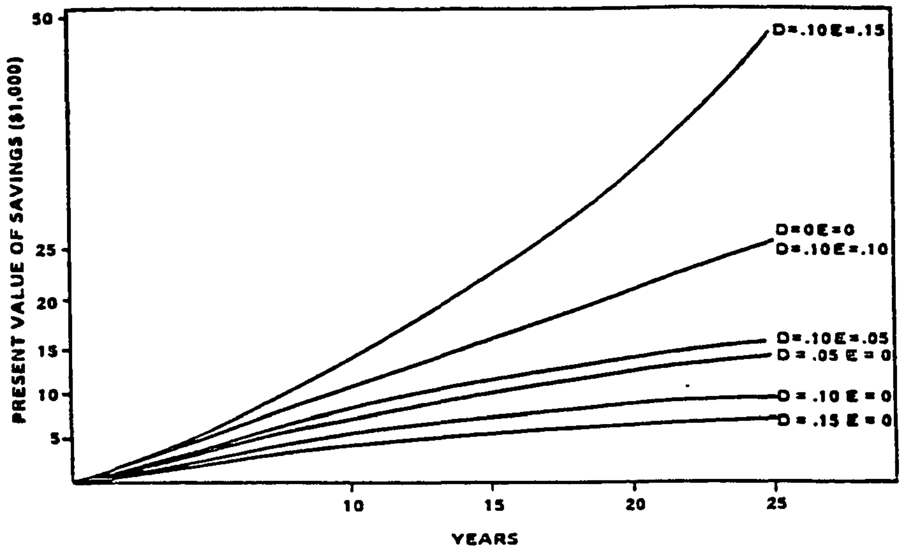
The discount rate is another important factor in an economic evaluation, and is essential to the conversion of costs and benefits occurring at different times to an equivalent basis. The selection of an appropriate discount rate may be guided by the rates of return available on alternative investments, or by the cost of borrowing capital, after the effects of taxes are subtracted. This rate may be expressed in either "real" or "nominal" terms. A real discount rate expresses only the increased earning power of money over time; the nominal rate, with which we are more familiar, includes the effects of inflation. A tax-free money-market fund paying an 8% "nominal" rate of return is actually earning only 3% "real" interest in a year when inflation averages 5% (8% nominal interest minus 5% inflation equals a 3% real interest rate). Therefore, under conditions of rising consumer prices, nominal interest or discount rates are always higher than "real" rates. Higher discount rates reduce the present value of future costs <u>or</u> benefits, and work to favor investments with quick payoffs.

There are several approaches that may be used to select an appropriate rate which can be illustrated as follows; 1) an investor may be able to borrow money on a home equity loan at an 11% interest rate, less 37% of that rate (assuming the deductibility of finance charges for a 28% federal tax rate and a 9% state tax rate) for a net rate of 6.9%, minus a 4% inflation rate yields a <u>2.9%</u> "real" after-tax cost of money (discount rate), or 2) an alternative investment is available in tax-free municipal bonds paying 7.25% interest, minus a 4% rate of inflation, to produce a <u>3.25%</u> real return on investment (discount rate). Both of these examples present optimistic results, considering that inflation rates have averaged 4.5% for the last several years, and have been calculated at 5.5% for 1990, which would reduce the inflation-adjusted discount rate accordingly (Leber 1990). The "real" rate of return on riskless investments over the long run is estimated to average between 3-4% (Brown 1985).

The effects of inflation and energy price changes are two other factors that are integral to the economic analysis of energy conservation. Because the analysis of costs and benefits over time is based on their conversion to a time-equivalent basis, it is important to remove the distorting effects of inflation on monetary values, so the use of "real" rates is preferred. The estimation of energy price escalation rates, and their value compared to the chosen discount rate, is critical to the determination of the compounded value of an energy conservation investment over time. The choice of an energy escalation rate less than the chosen discount rate limits the total value of energy savings over time; the use of an energy escalation rate greater than the discount rate will produce a significantly greater value of energy savings over longer study periods. Since future inflation rates and energy prices cannot be predicted with certainty, it is prudent to consider a range of values for these factors in an economic evaluation to compare their influence on study results. This comparison of alternative study parameters is performed in a "sensitivity" analysis. (See Figure 11). In this chart, "D" is the chosen discount rate; "E" is the annual increase in energy costs.

Concepts of economic efficiency must govern the investment in building energy efficiency. The tradeoff between the costs of energy conservation and energy consumption, and the functioning of the law of diminishing returns, is best illustrated graphically. (See Figure 12). At first, the costs of energy conservation (the upward sloping curve) are more than offset by the reductions in energy costs (the downward sloping curve), and the total of energy and conservation costs combined (upper U-shaped curve) declines. But, eventually, as more conservation measures are adopted, a smaller share of energy reductions are secured, the rise in conservation costs becomes greater than the fall in energy costs, and total costs increase.

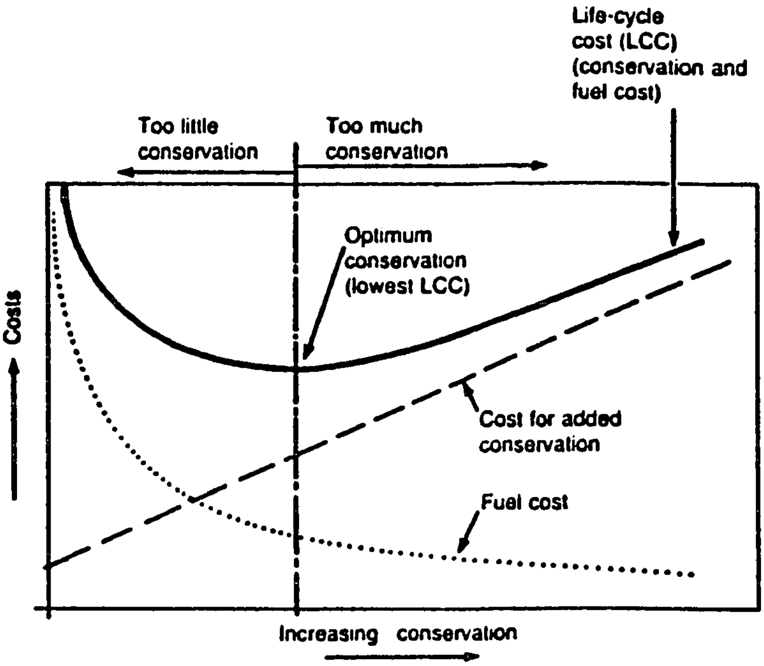
Figure 11. Sensitivity of Energy Savings to Time Horizons, Discount Rates, and Energy Escalation Rates.



Data from Kreith and West 1980

The most economically efficient level of investment in building energy conservation is the point where the net benefits are maximized. On the graph, this level is represented by the lowest point of the total cost curve. More or less investment in conservation may save energy and reduce costs, but not as effectively as the optimal investment, leading to higher combined costs for conservation and energy consumption (Carroll 1987).

Figure 12. Optimum Life-Cycle Cost Energy Conservation Investment.



Derived from Lenchek, Mattock, and Raabe 1987

Economic Analysis Techniques

There are five approaches that are commonly used to assess different aspects of the economic value of an investment in building energy conservation: 1) life cycle cost analysis, 2) net benefits analysis, 3) benefit/cost (or savings to investment) ratio, 4) internal rate of return, and 5) discounted payback period. All of these techniques address differences in the timing of cash flows, and all except payback analysis can be used to evaluate life cycle costs and benefits.

The application of the benefit/cost analysis and internal rate of return approaches are useful in providing comparative rankings of energy conservation investments under budgetary constraints, or to achieve a targeted reduction in energy costs. Using these techniques, the more effective energy conservation measures or investments will secure higher benefit/cost ratios or rates of return on investment than alternative measures, expressing the greater value of energy savings generated per dollar spent. However, these techniques are not very effective in determining an optimal energy conservation investment without budgetary limits. Referring back to Figure 12, it is clear that the first expenditures for conservation produce the greatest energy savings (energy costs decline sharply), and also the highest ratio of benefits to costs or rate of return per dollar. Because the rate of change in total energy costs is less dramatic after these first savings are secured, these ratios decline before the optimal investment size for lowest life cycle cost is reached, and the use of either of these approaches will lead to undersizing the expenditure for energy conservation.

Payback analysis offers a similar comparative technique with results expressed in terms of the time required to recoup energy conservation expenditures in accumulated energy savings. For many people, the payback period provides the most vivid and understandable gauge of the cost-effectiveness of an investment, particularly for those investors with a limited investment horizon. Because payback analysis may overemphasize the turnover in value of short-term investments over ultimately more efficient, long-term investments, its use is not recommended as the sole evaluative technique. Also, because costs and benefits occurring after the breakeven point are not considered, the picture this evaluation provides of an investment's profitability is incomplete (Meyer 1983).

The two remaining economic analysis techniques, net benefits analysis and life cycle costing, are interchangeable approaches that provide a larger perspective of the economics of all aspects of building purchase and operation. These techniques may be used to assess the effectiveness of building energy conservation investments by determining their influence on cumulative life cycle housing costs.

Net benefits analysis can be applied to comparisons of various conservation investments by converting the lifetime costs of conservation and the benefits of energy savings into "present" values by discounting procedures. The level of energy conservation that is determined to generate the largest net present value maximizes the economic benefits of the conservation investment, and is the most economically efficient choice. Life cycle cost analysis works in essentially the same manner as net benefits analysis, except that it treats these net savings as reductions in the lifetime costs of building ownership. The building design with the smallest total combined costs for energy conservation and energy consumption secures the lowest "net" life cycle cost, and also derives the maximum economic benefit from the conservation investment.

These techniques are best applied to the appraisal of optimal "packages" of conservation measures, and are not as well-suited to the ranking of the relative economic efficiency of any particular conservation investment. With these two economic analysis approaches, large or small investments that generate the same net life cycle value for conservation and energy costs are regarded as equally effective, despite differences in the return per dollar invested.

It is apparent that life cycle economic analysis can play a valuable role in guiding the application of the most effective building energy conservation strategies, and inform designers and builders of the optimal building configuration for energy efficiency and economy. Life cycle cost analysis may be applied to evaluate the effectiveness of the single family home-envelope energy conservation measures required by the California building efficiency standards. The results of this comparison for four climate zones will be used to assess the "fit" between the level of building energy conservation that maximizes economic efficiency and the level that is mandated by the state energy standards.

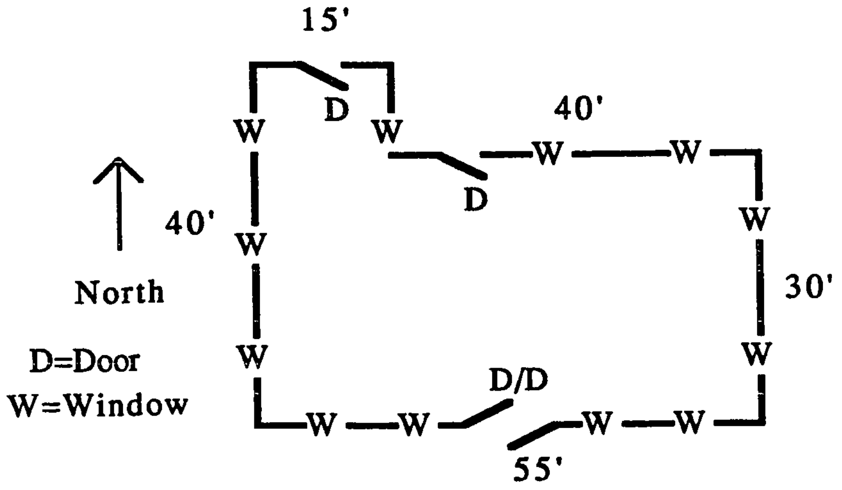
Applied Life Cycle Analyses

The procedure chosen for the evaluation of home-envelope energy conservation measures entails the development of a single family home design that is representative of current construction practices in California, the consideration of variations in building envelope component construction, and computer simulation of these changes' influence on annual energy consumption. The economic analysis of the various building envelope conservation measures requires the compilation of current energy and conservation costs, the setting of an appropriate discount rate and study period, and estimates of the effects of inflation and escalating energy prices over this period of time. These values will be used to convert the costs and benefits of energy-conserving design modifications to a time-equivalent basis, to facilitate a comparative analysis.

The prototype home design developed for testing the effects of the various envelope energy conservation measures is a 1,800 square foot, L-shaped single level home. The CEC used a 1,384 square foot home design to appraise the effects of the first state building energy performance standards in 1980. The greater size of the chosen prototype design represents the trend in the housing market toward the construction of larger homes since that time. The state median size for existing homes reached 1,720 square feet in 1985, and 1,925 square feet for new construction (Anderson 1987). The selected design is wood-framed with a raised wooden floor, 8 foot high ceilings, a pitched roof with an unheated attic, 240 square feet of windows distributed evenly on all sides, two exterior doors, and one sliding glass door. (See Figure 13).

This design is tested with two space conditioning systems: 1) a natural gas forced-air heating system with electric air conditioning, and 2) a central, electric heat pump. The gas furnace efficiency is set at a 78% AFUE (annual fuel utilization efficiency) rating with an 82% duct efficiency rating (based on duct insulation of R-4).

Figure 13. Prototype Home Plan.



The air conditioner has a SEER (seasonal energy efficiency rating) of 10.0. The electric heat pump operates with an ACOP (adjusted coefficient of performance) of 2.5. These efficiency levels have been set higher than the present California minimum standards to reflect the new baseline performance levels required by the National Appliance Energy Conservation Act, which will take effect in 1992.

The basic house design is uninsulated and single-glazed. Numerous computer simulations have been conducted to systematically assess the effects of various wall, ceiling, floor, and window constructions on the prototype design's annual energy consumption.

Seven different levels of wall and ceiling insulation, four levels of floor insulation and four window types have been analysed and compared to determine the lowest life cycle cost building envelope assemblies for energy conservation in California's single family homes.

These variations to the prototype design have been simulated by the use of "CALRES," the public domain computer program specifically developed for the California Energy Commission to test and document the compliance of home designs with the state building efficiency standards. The evaluation of home envelope component characteristics on energy consumption has been based on values for "energy analysis coefficients" determined through research performed by the Berkeley Solar Group and Charles Ely Associates as part of the building standards revision for 1992. Their work involved the completion and analysis of several hundred computer simulations of prototype building designs to determine the change in energy consumption resulting from changes to building component (walls, ceilings, floors, windows) construction. Each component was tested at low, medium, and high performance levels to represent uninsulated construction, current building standards, and the maximum feasible construction practice in each state climate zone.

Statistical regression analysis was then applied to the results of these simulations to determine an energy analysis coefficient for each building component in each climate zone, representing the unit change in heating and cooling loads per unit change in a building component's thermal performance, usually expressed as a "U-Value." This process does not account for interactions between measures, since these effects are believed to be small and simulation of all the possible combinations of measures would require an enormous number of computer runs. These coefficients were then applied to the evaluation of various component constructions on the prototype design's energy consumption in a representative range of four California climates, including: southern marine-influenced; south-eastern desert; northern Central valley inland; and Sierra foothill environments.

The present costs of energy and energy conservation measures and materials, and future energy costs, are integral to the life cycle economic analysis. It is the intent of this study to conduct an economic evaluation of envelope energy conservation measures using the California Energy Commission's own assumed values for discount rates, energy escalation rates, and inflationary effects. The net cost of the conservation measures considered in this report is assumed to be their initial cost, since they are durable materials with no required maintenance. The costs of the various building component constructions for energy conservation have been derived from a variety of sources, including: the National Association of Home-builders (1986), Mahoney (1990), the University of Washington (1988), Charles Eley Associates (1990), and the U.S. Department of Energy (Vine 1986). These costs have been adjusted to represent the incremental construction costs of conservation measures compared to the basic uninsulated design, and to reflect the actual area of walls, windows, floor and ceiling of the chosen prototype design for use in the life cycle cost analysis. (See Figure 14)

Figure 14. Incremental Costs of Envelope Energy Conservation Measures in the Prototype Design.

Component	Area sq.ft.	Unit Cost	Total Cost		Component	Area sq.ft.	Unit Cost	Total Cost
Ceiling-R"0"	1800	$0.00	$0		Wall-2x4, R"0"	1240	$0.00	$0
Add R11	1800	$0.27	$486		Add R11	1240	$0.28	$347
Add R19	1800	$0.40	$720		Add R13	1240	$0.34	$422
Add R30	1800	$0.61	$1,098		Wall-2x6, R19	1240	$0.71	$880
Add R38	1800	$0.73	$1,314		Add R21	1240	$0.81	$1,004
Add R49	1800	$0.87	$1,566		Add R11, R14	1240	$1.29	$1,600
Add R60	1800	$0.98	$1,764		Add R21, R14	1240	$1.82	$2,257
Floor-R "0"	1800	$0.00	$0		Single Glazed	280	$0.00	$0
Add R11	1800	$0.33	$594		Alum. Double	280	$2.56	$717
Add R19	1800	$0.46	$828		ATB Double	280	$4.24	$1,187
Add R30	1800	$0.67	$1,206		Vinyl Double	280	$7.53	$2,108

The unit costs of the conservation measures in this chart express the additional installed costs per square foot of insulation or glazing. The example for walls is an exception and requires explanation. The basic house design uses 2x4 wood frame construction which allows the installation of only 3.5 inches of insulation in the wall cavity. Higher wall insulation levels require the use of a wider 2x6 wood frame with a 5.5 inch cavity and/or the use of rigid insulating sheathing on one side of the wall. The incremental costs of these higher levels of insulation include a premium for the additional labor and materials costs required to construct the heavier wood framing. For wall components with two numbers for insulation, the first figure represents the cavity insulation and the second number represents the insulating sheathing.

Calculation of the value of energy costs and savings over time requires their conversion to a time-equivalent basis. California's average residential energy prices are presently $.096 per kilowatt-hour of electricity, and $.535 per therm (100,000 Btu) of natural gas. Energy costs and forecasted escalation rates for the next 30 years have been compiled and weighted according to the projected growth in the five state utility areas. These estimates project a conservative average annual increase in residential electricity prices of just 1/10 of one percent (.12%), and increases in natural gas prices of just under 1% (.99%), in constant dollars (adjusted for inflation). Under these assumptions, and applying a 3% "real" discount rate, the Energy Commission has determined that the net present worth of one kilowatt hour of electricity per year over the next 30 years is $1.95; and the net present worth of one therm of natural gas per year over this same period is $14.08 (Leber 1990).

The evaluation of the effects of the various envelope energy conservation measures on the prototype design's annual energy consumption has been performed for four climate zones, with two different space conditioning systems. An economic analysis was then conducted to evaluate the effect of the various conservation measures on the prototype design's combined life cycle costs for energy consumption and energy conservation. This report evaluates seven levels of ceiling insulation to R-60, seven levels of wall insulation to R-35, four levels of floor insulation to R-30, and four types of windows (single-glazed, double glazed, aluminum thermal-break frames, and vinyl frames) in the gas and electrically-heated homes. (The worksheets documenting the costs of conservation, the effects on energy consumption, life cycle costs and savings are attached in the appendix to this report.)

The results of this analysis, summarized in Figure 15, reveal the lowest life cycle component construction for single family homes in each California climate zone, and the level of investment in envelope energy conservation that maximizes both energy efficiency and economic efficiency. In this chart, "Total Costs" are the costs of incorporating the specified conservation measures in the prototype design. "Total LCC Savings" is the net present value of the life cycle cost savings generated by adopting the most economically favorable package of conservation measures, compared to an uninsulated design.

The most effective investment in envelope energy conservation measures studied here ranges from $1100 to almost $6700, depending on the building's location and space-conditioning energy source. This initial expenditure generates 30 year constant-dollar energy savings of $6,200 to over $52,000 compared to the same home design, if left uninsulated. The lifetime benefits of the most appropriate envelope energy conservation packages outweigh the costs of implementation in all cases by a range of greater than 3:1 to almost 8:1, again depending on the conditions set by the particular case study.

Figure 15. Lowest Life Cycle Cost Home-Envelope Construction.

Climate Zone	City	Energy Source	Ceilings R-Value	Walls R-Value	Floors R-Value	Window Type	Total Costs	Total LCC Savings
8	Anaheim	Nat. Gas	19	13	0	Single	$1,142	$6,175
8	Anaheim	Electric	19	13	19	Double	$2,687	$11,187
12	Sacramento	Nat. Gas	38	21	19	ATB Dbl	$4,333	$16,023
12	Sacramento	Electric	49	21	30	ATB Dbl	$4,963	$29,066
15	PalmSprings	Nat. Gas	49	21	19	ATB Dbl	$4,585	$23,717
15	PalmSprings	Electric	60	21	19	ATB Dbl	$4,783	$32,077
16	Susanville	Nat. Gas	38	21	19	Vinyl Dbl	$5,254	$25,370
16	Susanville	Electric	60	11,14	30	Vinyl Dbl	$6,678	$52,626

The results of this analysis present the not-unexpected correlation between the increasing severity of a location's heating and cooling seasons and the increase in the amount of the cost-effective investment in additional building energy conservation measures. The mildest of the climates studied here, represented by Zone 8 in southern California, requires the least conservation investment to secure the lowest combined construction and operation costs over a 30 year period. The more severe climate of the Sierra foothills, in Zone 16, necessitates a significantly greater energy conservation expenditure to secure the lowest life cycle costs and to maximize the economic benefits of that investment. The levels of cost-effective conservation in both heating load-dominated climates (Zone 16) and cooling-dominated climates (Zone 15) are surprisingly comparable.

The effects of higher energy costs on the economic analysis are reflected in the cost-effective application of additional conservation measures in electrically-heated homes compared to gas-heated houses in every climate. In the more severe climate zones, this difference in energy costs leads to the economically efficient application of ceiling insulation to R-60 (equivalent to a 20 inch thick blanket of fiberglass)!

There are some interesting differences between the optimal home envelope design, as determined by this analysis and summarized in Figure 16, and the current building efficiency levels mandated by the state energy standards (as defined by the requirements of Prescriptive Package E for buildings with raised floors). Figure 16 reveals that for homes in the mild southern California climate, Zone 8, the state building standards require a greater investment in ceiling and floor insulation and windows than is justified by the life cycle economic analysis. These more stringent requirements impose initial additional construction costs of $1850 in gas-heated homes compared to the optimal prototype design for this area, and accumulate life cycle costs more than $500 higher.

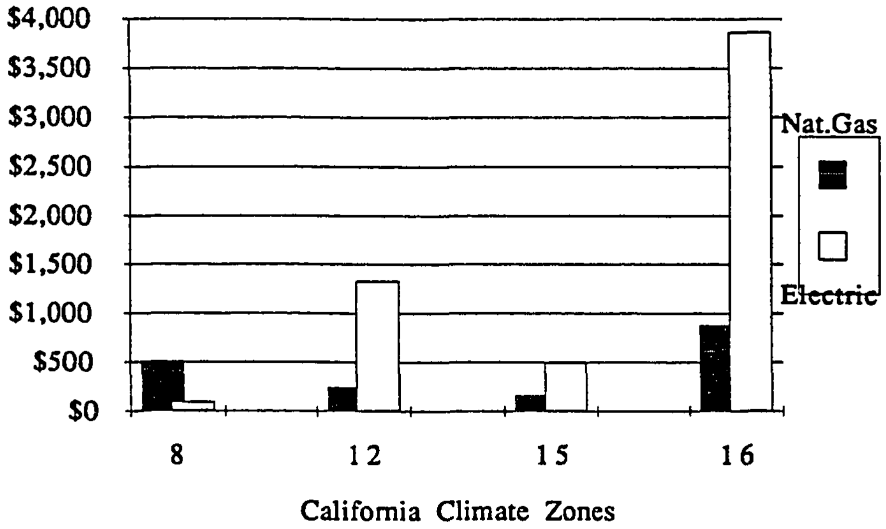
Figure 16. Comparisons of Design Configurations' Life Cycle Energy and Conservation Costs and Savings.

Zone			Ceilings	Walls	Floors	Window	Total	LCC Cons.	Total LCC
	City		R-Value	R-Value	R-Value	Type	Costs	& Energy	Savings
	Uninsulated	Gas				Single		$11,448	
8	Std.Package	Gas	30	11	19	Double	$2,990	$5,789	$5,659
	Anaheim	Gas	19	13	0	Single	$1,142	$5,273	$6,175
	Uninsulated	El				Single		$18,339	
8	Std.Package	El	30	11	19	Double	$2,990	$7,248	$11,091
	Anaheim	El	19	13	19	Double	$2,687	$7,152	$11,187
	Uninsulated	Gas				Single		$25,601	
12	Std.Package	Gas	38	11	19	Double	$3,206	$9,821	$15,780
	Sacramento	Gas	38	21	19	ATB Dbl	$4,333	$9,578	$16,023
	Uninsulated	El				Single		$41,297	
12	Std.Package	El	38	11	19	Double	$3,206	$13,559	$27,738
	Sacramento	El	49	21	30	ATB Dbl	$4,963	$12,231	$29,066
	Uninsulated	Gas				Single		$36,515	
15	Std.Package	Gas	38	19	19	Double	$3,739	$12,959	$23,556
	PalmSprings	Gas	49	21	19	ATB Dbl	$4,585	$12,798	$23,717
	Uninsulated	El				Single		$46,798	
15	Std.Package	El	38	19	19	Double	$3,739	$15,220	$31,578
	PalmSprings	El	60	21	19	ATB Dbl	$4,783	$14,721	$32,077
	Uninsulated	Gas				Single		$36,331	
16	Std.Package	Gas	38	19	19	Double	$3,739	$11,840	$24,491
	Susanville	Gas	38	21	19	Vinyl Db	$5,254	$10,961	$25,370
	Uninsulated	El				Single		$67,330	
16	Std.Package	El	38	19	19	Double	$3,739	$18,567	$48,763
	Susanville	El	60	11,14	30	Vinyl Db	$6,678	$14,704	$52,626

In contrast, Figure 16 also reveals that the results of the evaluation for the remaining state climate zones, representing the central valley, desert, and foothill climates, establish the cost-effectiveness of significantly higher levels of ceiling, wall, and floor insulation, and better quality windows, compared to the requirements of the state building efficiency standards. The differences between the state requirements and the optimal designs are especially noticeable in the more severe desert and mountain climates, Zones 15 and 16. In these areas, once again, the influence of higher energy costs on the economic analysis justifies a significantly greater expenditure for energy conservation components and construction in electrically-heated homes--a difference that is <u>not</u> even addressed by the current state building standards. The additional costs of the optimal energy conserving home designs for these climates compared to the present state requirements ranges from $800 to almost $3000, yet these initial costs are more than offset by the energy savings they secure, resulting in combined life cycle savings of $160-$3900. (See Figure 17).

From these results, it is apparent that there is still room for improvement in the level of conservation specified by California's "Title 24" building efficiency standards for single family homes. The present state standards do not promote the most cost-effective building energy designs and fall short of maximizing the life cycle investment in building energy conservation according to the economic conditions and forecasts and the state of conservation technologies in 1991.

Figure 17. Life Cycle Savings: Optimum Building Envelope Design vs. Current California Building Standards.



Critical flaws in the application of these standards have led to over-investment in home envelope energy conservation measures in the milder climate zones, and under-investment in building efficiency in the more severe climatic regions of the state. The current building standards have also not adequately compensated for the energy performance of homes incorporating electric heat pumps, which, because of their much higher space conditioning energy costs, should be subjected to even more stringent efficiency requirements.

These limitations have resulted in the wasteful allocation of investment dollars and the inefficient use of energy resources, considering the significant benefits that may be accessed by building the least life cycle cost home designs. The Energy Commission should take advantage of the opportunity presented by the standards revision process to adjust the building efficiency requirements accordingly and secure the remaining potential for energy and economic savings, that has been revealed by economic analysis.

The results of this evaluation need to be qualified. The energy cost savings are not "absolute" values; they represent only an estimate of the expected savings based on the assumptions about discount rates, increases in energy costs, and the length of the study period used in the economic analysis. This study has been founded on CEC economic forecasts and assumptions, to facilitate an equitable comparison between the economically-efficient investment in envelope energy conservation measures and the requirements of the state building efficiency standards.

The selection of an appropriate discount rate is crucial to the results of the analysis and must be based on the general economic conditions extant at the time of evaluation. The application of higher discount rates diminishes the net present value of future energy savings and leads to the justification of smaller cost-effective investments in building energy conservation measures. The application of a 3% "real" discount rate in this analysis translates to a "nominal" tax-free rate of return of 8% (which includes a 5% annual rate of inflation) or the equivalent of an 11.9% taxable rate of return (assuming a 28% federal and a 9% state income tax liability). These are very favorable rates, considering the current economic conditions. In contrast, the use of a higher 5% real discount rate presupposes the availability of alternative investments paying an annual (tax-free) nominal return of 10%, or a 14.9% taxable annual rate of return--both of which are unrealistic expectations in the 1991 investment climate.

Energy escalation rates are equally important to the determination of the compounded value of future energy savings. The use of projections of higher future energy costs in the economic analysis increases the net present value of conservation expenditures because of the compounding of energy cost savings. This evaluation has been based on very conservative estimates of energy price escalations (less than 1% annual increases in electricity and natural gas prices). Use of higher energy cost escalation rates would justify a greater cost-effective investment in building energy conservation in the present to forestall the effects of significantly higher future energy costs. There is a good probability that "real" energy costs will increase more rapidly than the values chosen for this appraisal. In that case, the optimum investment in envelope energy conservation measures and materials is larger than what has been determined by this economic analysis.

These different assumptions for the elements of the economic evaluation affect the determination of the cost-effective building energy conservation investment and the compounding of energy cost savings. But, even if the discount and energy escalation rates selected for this analysis are inaccurate, they are likely to have offsetting effects. If the 3% discount rate is low, the likelihood of future energy costs increasing by more than 1% will have compensating effects on the determination of the cost-effective investment in home envelope energy conservation.

Effects on Housing Affordability

There is a clear, long-term economic advantage to the determination of the lowest life cycle cost building envelope construction, but it is also fair to question how the additional construction costs affect home buyers in the short run, in terms of the initial increased costs of a home purchase and its continuing operation expenses. The impact of these costs on the homeowner is dependent on a number of factors related to how the home purchase is financed: the required downpayment percentage; loan and closing costs; the interest rate and term of the loan.

Conventional mortgage financing offers a convenient way for the financed costs of conservation investments to be compared with the reductions in energy costs--on the same monthly basis. Qualifying for conventional housing financing usually requires a downpayment of 10-20% of the home purchase price, payment of loan fees and closing costs, and proof of adequate income to cover the continuing responsibility of regular mortgage payments. After the initial costs are paid and a mortgage loan is secured, the net combined energy and conservation costs of the energy efficient home design may be compared with the basic uninsulated design.

This appraisal of the effect of increased building envelope energy conservation costs on home purchase prices, on the requirements for additional income to qualify for financing, and on monthly cash flows for combined energy and mortgage costs, is based upon the results of the life cycle economic analysis and on common housing financing practices. This evaluation will also be based on the incremental effects of additional conservation investments compared to the uninsulated prototype design. Although the California residential building efficiency standards are not limited to envelope energy conservation measures and materials, the remaining requirements are inexpensive and are not particularly relevant to residential space-conditioning energy loads. These mandatory measures include a setback thermostat, fluorescent general lighting in kitchens and bathrooms, and hot water heater insulation, and cost less than $200 in the studied design. The assumed conditions for mortgage financing of the additional conservation expenditures include an 11% mortgage interest rate, a 20% downpayment requirement, 2% loan and closing costs, and a 28% ceiling on the ratio of housing costs (including insurance and taxes) to gross household income.

The initial incremental costs of complying with the envelope performance requirements of the present state building energy conservation standards in the prototype design range from $660-$820 for downpayment, loan and closing costs. In contrast, the optimum home energy design for lowest life cycle cost requires the commitment of $250-$1470 in additional financing costs, according to the particular climate zone under consideration. The study of the net costs of energy consumption and energy conservation for each design permit a comparison of cash flows with and without the investment in building energy efficiency.

In every case, in every state climate studied, the combined monthly cost of energy and conservation (rolled into the mortgage financing) of the home built to lowest life cycle cost envelope design is less than that of the uninsulated basic design. The investment in cost-effective building energy conservation produces continuing operational energy cost savings ranging from $17-$195 per month. Although the total costs of mortgage payments must be increased to cover the initial conservation expenditure, the resulting increase in energy efficiency generates an even greater value of monthly energy savings that outweigh these costs. For the lowest life cycle cost envelope design, these savings provide a return on the initially higher downpayment costs of energy conservation, and recoup those expenses in straight-line payback periods of just 8-24 months, according to the location. Figure 18 reveals that, from first occupancy, the investment in an appropriate level of envelope energy conservation measures provides a continuing, guaranteed, tax-free return to a home's residents, regardless of economic conditions.

Figure 18. Financed Costs of Envelope Energy Conservation Measures.

Zone	City	Energy Source	Total Costs	Initial Costs	Annual EnergyCost	Avg.Cost Energy/ Month	Cons. Cost/ Month	Net Cost Cons.and Energy
	Uninsulated	Nat. Gas			$495.08	$41.26	$0.00	$41.26
8	Std.Package	Nat. Gas	$2,990	$657.80	$124.17	$10.35	$22.93	
	Anaheim	Nat. Gas	$1,142	$251.24	$178.29	$14.86	$8.76	$23.61
	Uninsulated	Electric		$0.00	$1,121.75	$93.48	$0.00	$93.48
8	Std.Package	Electric	$2,990	$657.80	$211.14	$17.60	$22.93	
	Anaheim	Electric	$2,687	$591.14	$318.18	$26.52	$20.60	$47.12
	Uninsulated	Nat. Gas		$0.00	$1,103.25	$91.94	$0.00	$91.94
12	Std.Package	Nat. Gas	$3,206	$705.32	$289.47	$24.12	$24.58	
	Sacramento	Nat. Gas	$4,333	$953.26	$233.59	$19.47	$33.23	$52.69
	Uninsulated	Electric		$0.00	$2,050.99	$170.92	$0.00	$170.92
12	Std.Package	Electric	$3,206	$705.32	$521.90	$43.49	$24.58	
	Sacramento	Electric	$4,963	$1,091.86	$360.32	$30.03	$38.06	$68.08
	Uninsulated	Nat. Gas		$0.00	$1,741.92	$145.16	$0.00	$145.16
15	Std.Package	Nat. Gas	$3,739	$822.58	$444.54	$37.05	$28.67	
	PalmSprings	Nat. Gas	$4,585	$1,008.70	$397.17	$33.10	$35.16	$68.26
	Uninsulated	Electric		$0.00	$2,310.46	$192.54	$0.00	$192.54
15	Std.Package	Electric	$3,739	$822.58	$566.36	$47.20	$28.67	
	PalmSprings	Electric	$4,783	$1,052.26	$490.08	$40.84	$36.68	$77.52
	Uninsulated	Nat. Gas		$0.00	$1,444.23	$120.35	$0.00	$120.35
16	Std.Package	Nat. Gas	$3,739	$822.58	$324.44	$27.04	$28.67	
	Susanville	Nat. Gas	$5,254	$1,155.88	$232.10	$19.34	$40.29	$59.63
	Uninsulated	Electric		$0.00	$3,353.61	$279.47	$0.00	$279.47
16	Std.Package	Electric	$3,739	$822.58	$738.32	$61.53	$28.67	
	Susanville	Electric	$6,678	$1,469.16	$399.43	$33.29	$51.21	$84.49

The monthly incremental financed costs for these envelope energy conservation measures runs from $23-$29 for the prototype design constructed to the specifications of the present building standards, and from $9-$51 for the optimal life cycle cost home configurations.

Conventional mortgage lending policies call for additional annual household income levels of $983-$1229 to qualify for the higher incremental costs of homes built to the present state building energy standards compared to uninsulated homes. The same guidelines would require income levels of $375-$2195 to qualify for the lowest life cycle cost home design.

The "nominal" values (including the effects of inflation) of these conservation investments (Figure 19) illustrate the mounting dollar values of energy savings over time, even with very conservative annual energy escalation rates and inflationary effects. And, the true value of the monthly financed costs of conservation investments actually declines over time because inflation reduces the buying power of money (the value of a dollar). These combined influences result in even greater life cycle savings from effective envelope energy conservation measures and materials, producing $18,000-$182,000 in 30-year nominal savings for the prototype home design --compared to an uninsulated home. The optimal energy-conserving design for minimum life cycle cost also generates $1,100 to more than $17,500 in net energy savings compared to the requirements of the current state building efficiency standards (depending on the climate zone under consideration).

The costs of the current state building efficiency standards are remarkably comparable for the climate zones under consideration, despite the recognized climatic-dependence of effective building energy conservation levels and investments.

Figure 19. Nominal Life Cycle Values of Energy Conservation Measures.

Zone	City	En.	Initial Costs	Annual Energy Cost	Cons. Cost/ Month	Net LCCost Cons.and Energy	Life Cycle Savings	Savings Opt./Std.
	Uninsulated	Gas		$495.08	$0.00	$32,397		
8	Std.Package	Gas	$657.80	$124.17	$22.93	$14,519	$17,878	
	Anaheim	Gas	$251.24	$178.29	$8.76	$13,382	$19,015	$1,137
	Uninsulated	El.	$0.00	$1,121.75	$0.00	$72,611		
8	Std.Package	El.	$657.80	$211.14	$22.93	$27,351	$45,260	
	Anaheim	El.	$591.14	$318.18	$20.60	$24,629	$47,982	$2,722
	Uninsulated	Gas	$0.00	$1,103.25	$0.00	$72,195		
12	Std.Package	Gas	$705.32	$289.47	$24.58	$23,755	$48,440	
	Sacramento	Gas	$953.26	$233.59	$33.23	$21,792	$50,404	$1,963
	Uninsulated	El.	$0.00	$2,050.99	$0.00	$132,760		
12	Std.Package	El.	$705.32	$521.90	$24.58	$38,595	$94,165	
	Sacramento	El.	$1,091.86	$360.32	$38.06	$30,775	$101,985	$7,820
	Uninsulated	Gas	$0.00	$1,741.92	$0.00	$113,989		
15	Std.Package	Gas	$822.58	$444.54	$28.67	$34,703	$79,286	
	PalmSprings	Gas	$1,008.70	$397.17	$35.16	$32,874	$81,115	$1,829
	Uninsulated	El.	$0.00	$2,310.46	$0.00	$149,556		
15	Std.Package	El.	$822.58	$566.36	$28.67	$42,274	$107,282	
	PalmSprings	El.	$1,052.26	$490.08	$36.68	$38,904	$110,652	$3,369
	Uninsulated	Gas	$0.00	$1,444.23	$0.00	$94,509		
16	Std.Package	Gas	$822.58	$324.44	$28.67	$26,844	$67,665	
	Susanville	Gas	$1,155.88	$232.10	$40.29	$23,077	$71,432	$3,768
	Uninsulated	El.	$0.00	$3,353.61	$0.00	$217,079		
16	Std.Package	El.	$822.58	$738.32	$28.67	$53,405	$163,674	
	Susanville	El.	$1,469.16	$399.43	$51.21	$35,881	$181,197	$17,523

One reason for this pattern may lie in the potential political liability of requiring significantly different conservation levels and costs by area, which, despite their demonstrated long-term economic efficiency, might be perceived as geographically inequitable. This may explain why the economic analysis of envelope energy conservation measures reveals that the current building standards mandate the over-investment in conservation in the mildest southern California climate, and the under-investment in more severe state climate zones.

Even though the expenditure for the optimal level of envelope energy conservation generates significant favorable life cycle economic benefits, any additional income qualifying requirements to obtain mortgage financing for this expense can only be expected to exacerbate the state's general housing affordability problem. California has a lower proportion of homeowners than the national average: 55% in-state vs. 64% of households nationwide. The rate of increase in state median home sales prices has outpaced income growth for the last three decades. State median home prices reached $200,000 in 1990--a level 6 times the state median income and 55% above the national average (Earle 1990)! Home prices in California are already the highest in the continental United States. Only 19% of state households can afford the average priced home compared to 47% throughout the U.S., despite state median incomes $3,000 higher than the national level (Goldstein 1990).

In general, direct construction costs have declined as a percentage of home prices and now comprise, on average, only 45-60% of total building costs. Land costs and site development fees have increased significantly. The added costs of building energy-efficient residences, whether to state standards or lowest life cycle configurations, are only a small fraction of median home values (one half to three and one half percent of median prices). The greatest effect of these additional conservation costs may be felt in areas removed from the major metropolitan centers and coastlines, especially inland and in northern California. In a number of these areas, new homes are available at purchase prices below $150,000. At these values, the expense of incorporating the appropriate conservation measures may add as much as 5% to new home purchase prices, depending on the severity of the climate zone and the type of space-conditioning system.

Summary

Several informational barriers have hindered the development of energy conserving home designs in the past. Home buyers and builders have been unsure of the housing market's treatment of the built-in, largely invisible enhancements of home energy efficiency. Recent statistical and sales-price comparisons, however, have documented the capitalization of durable energy conservation measures in home resale prices (Levy 1987), (Heinly 1989). Also, information on the favorable influence that effective energy conservation packages have on homeowners' cash flows, despite higher mortgage costs, has been unavailable.

The remaining barriers for housing consumers lie in 1) meeting mortgage lenders' additional income requirements for the increased home prices of energy efficient housing, and 2) paying the incremental downpayment costs. In light of the favorable cash flows generated by optimal energy conservation strategies, it would be sensible for lenders to take a more flexible approach to the income-qualification of marginal buyers seeking mortgages on energy-efficient homes. If California lenders evaluated the net costs of energy-efficient housing, they would find that the reduced combined costs of energy and financed conservation expenditures essentially eliminate any additional income requirement for the lowest life cycle cost home designs, despite their greater initial cost!

The remaining obstacle for the marginal home buyer--that of the greater required downpayment for higher-cost, energy-efficient homes--may well provide an appropriate avenue for government or utility intervention. Since the optimal building envelope designs are documented to recoup their initial finance costs (downpayments) in fairly short order, "energy conservation" loans could be made available, with conservation finance charges included in monthly utility bills and essentially repaid with monthly energy cost savings. The Bonneville Power Administration in the Pacific Northwest has experimented with this kind of utility-financed conservation incentive, in "energy mortgage valuations," to maintain electricity demand within their system's capacity. At this time, both the California Energy Commission and Pacific Gas and Electric are studying the feasibility of adopting this approach in California. Without concessions of this kind, it is evident that the marginal home buyer may continue to be precluded from higher quality housing. Or, that purchaser may find other, more tangible, amenities (such as an extra bathroom or a hardwood floor) more appealing--and settle for an older and most likely, less energy-efficient home.

The California building efficiency requirements have established a fairly rigorous standard for residential building energy conservation, which, however, does not promote the most cost-effective investment in building energy efficiency. The optimal home-envelope configurations secure the lowest net life cycle costs by balancing energy efficiency with economic efficiency. As one step toward the development of new, more productive patterns of energy resource use, there is a compelling rationale for the application of life cycle cost-effective building energy conservation measures and strategies.

REGIONAL IMPLICATIONS OF CONSERVATION INVESTMENTS

Introduction

The influence of optimal building envelope energy conservation on individual homeowner economy is clear and favorable. It is fair to question what, if any, larger-scale repercussions may result from the diversion of expenditures from energy consumption to energy conservation in a regional economy. It is evident that the incorporation of the appropriate level of envelope energy conservation measures in California homes provides substantial benefits to the housing consumer, provided that he/she is not excluded from the new home market by the greater downpayment and income qualifying requirements. The resulting reductions in energy consumption favorably affect monthly cash flows by generating monthly energy cost savings greater than the financed costs of conservation. The implementation of the cost-effective level of energy conservation in home design produces significant life cycle savings for the homeowner, despite the initially higher costs, compared to uninsulated designs.

The costs and benefits of building energy efficiency are not confined to the individual homeowner, however. Consumer expenditures for conservation materials and installation affect the distribution of dollars and employment within a number of affected industries involving construction, energy production, and energy conservation materials suppliers. This shift in expenditures affects, in turn, the economic interactions between the numerous other businesses and industries which supply services and materials to the directly-affected industries. In this case, the substitution of energy conservation expenditures for energy purchases creates repercussions and provides favorable advantages beyond the immediate impact on homeowners' utility bills, across many linked segments of the economy.

The availability and cost of energy supplies is a crucial component of the vitality of economic systems--witness the surge in inflation rates caused by the volatility of oil markets in the fall of 1990. Shortages of energy supplies, or rapidly escalating energy prices, affect every process, in every sector requiring an energy input, which explains why prudent energy management is linked with many facets of sound economic development, including security, employment, the competitiveness of domestic industry, interest rates, and economic growth (Nordlund and Robson 1980). California and many other states have experienced periods of dampened economic productivity over the last 20 years, exacerbated by fluctuations in energy costs. For this reason, many states <u>and</u> major industries have taken steps to increase their productive use of energy resources and enhance the economic returns of energy expenditures.

Econometric Theory

There are several econometric approaches which have been developed to model the behavior of economic systems. One of these methods, Input-Output analysis (I-O), was developed specifically to illustrate and interpret the interactions between production and consumption, and to document the interindustry flow of goods and services, within an economic system. The foundation of this economic theory is based on the tenet that the behavior of the components of an economic system cannot be understood in isolation, that they are instead interactive and interdependent elements of a greater order. The first I-O model of the United States economy was compiled by Leontief in 1951, based on Quesnay's "Tableau Economique" of 1758.

For input-output analysis, expenditures to purchase commodities define the "input"; the production of industry is the "output." An Input-Output model constructs a detailed matrix of all the industries of a selected region (at a community, state, or national scale) to measure and interpret the transactions between industries as a single system. With I-O, the relative impact of a shift in expenditures between sectors in an economy, within a specified geographical region, can be measured. Changes in demand, production, or distribution of any one commodity have a ripple effect on the supply and cost of other goods and services (Lawrence Berkeley Laboratory 1982).

An input-output model is based on the construction of a detailed transactions table which traces the purchases and sales of all industries in the economy. This table illustrates and quantifies how the output of any industry is distributed to other industries and finally to consumers, government purchases, and exports. An input-output analysis reduces industry outputs (products) to their basic component costs and materials, so that changes in demand for a finished product may be converted to the fractional impacts on supporting industries.

This technique uses the concept of "economic multipliers" as indicators of how demand for the output of one industry affects the production and employment of other industries. The economic multiplier describes the cumulative effect of a change in the demand for any one product on the flow and production of other goods and services within the economic system under consideration. The multiplier also represents the compounding of the value of expenditures for products caused by the cascading interactions between primary industries and their supporting businesses and suppliers.

Any expenditure has direct <u>and</u> indirect effects on economic activity and employment. For example, the sales levels of new cars has a direct effect on the profitability and employment levels of the auto industry. Auto sales also indirectly affect production and employment in the many supporting industries that provide materials, services, machining, and component manufacturing for the auto manufacturers, such as the producers of steel, rubber, and tempered glass (among many others).

The locations of industries and suppliers, and the flow of products and services within (and beyond) the boundaries of a study area, are essential to input-output analysis. The determination of an economic multiplier for a particular industry takes into account the geographic distribution of all the elements of production to determine what share of expenditures actually remain within the region under consideration. For example, a state may import 50% of the gasoline it needs for transportation purposes. The money spent to obtain that portion of total gasoline requirements "leaks" out of the state economy and cannot be respent there, resulting in a reduced petroleum multiplier for that region. As a rule, there is a general correlation between the increasing size of the region or system under consideration and the completeness of its economy, and the reduced dependence on imports (Laitner 1985).

There are some characteristics of Input-Output analysis that limit its ready application as an economic modeling tool. The construction of an appropriately detailed matrix of the industries and interactions comprising an economic system, particularly on a state-wide or national basis, requires an enormous amount of data and a significant effort to compile and convert that information into useable form. Because this process may require several years, by the time a transactions table is formulated, changes in the industry interactions and the relative values of materials and services may have rendered parts of the study obsolete.

Since the construction of the transaction tables used for I-O analysis is so demanding, several methods have been developed to translate dated input-output coefficients to current values, and to renovate existing transactions tables for an updated analysis. The fixed input-output coefficients cannot reflect changes due to advances in technology that affect industrial processes. Also, some economists have criticized the use of input-output analysis being used to model the marginal economic effects of changes in demand, when its coefficients are based on average expenditures for production, materials, and labor.

Input-output analysis is basically a complex accounting system that can be useful for examining general relationships between sectors of the economy. It is not an appropriate tool to model major shocks to systems (such as an oil embargo), because coefficients are fixed, not flexible. In effect, the detailed preparation of an I-O matrix provides a snapshot of the economic activity of a region in a particular year, which, it is hoped, is representative of the general operation of that area's economy. Finally, because of the great number of variables being considered, input-output analysis, as other economic models, may still be considered more "art" than science. It does, however, provide a valuable look into the general operation of economic systems, and may be considered a particularly useful tool for evaluating the implications of policies that would encourage the redirecting of public or private expenditures, such as requiring an investment in energy conservation to curb energy consumption (Donnelly 1987).

Case Studies

Input-Output analysis seems particularly well-suited to the evaluation of the economic repercussions of substituting expenditures for building energy efficiency for continuing energy costs. Although it is beyond the scope of this work to conduct a separate I-O analysis, the results of relevant studies will be reviewed. Several input-output evaluations have been conducted to measure the effects of weatherization programs on economic activity at the community, state, and national scale. Three studies have focused on the economic and employment impacts of energy conservation expenditures in California in particular, and although dated, provide some insight into the macroeconomic repercussions of those investments.

Lerner and Posey (1979) conducted a study of the comparative effects of energy technologies on employment by compiling the first detailed input-output transactions table of the California economy. This work examined the employment impacts of substituting capital investments in retrofit home insulation and solar hot water heating systems for conventional fossil-fuel energy expenditures. Their analysis found that conservation expenditures provided significantly greater direct employment effects than comparable outlays for energy supplies. Weatherization and solar water heating produced twice as many jobs per million dollars of expenditures as fossil-fuel energy consumption.

These results reflect the significantly higher level of capital investment per employee in the energy production industries and the state's high levels of energy imports--resulting in the "leakage" of revenues out of the state economy. In contrast, the in-state production capacity for conservation materials was much more closely matched to demand. A full 83% of the state fiberglass insulation requirement was supplied by California manufacturers in 1972, even before the industry geared up to service the expanded market stimulated by the first statewide minimum insulation requirements in new housing in 1975.

This study estimated a substantial potential market for retrofit ceiling insulation in 90% of all California homes, comprising the 60% that were uninsulated and the 30% that were under-insulated. The average payback period for California insulation expenditures was estimated to be just five years for the representative 1,600 square foot, gas-heated single family home. And, once the initial insulation investment was recouped, real increases in disposable household incomes were expected to generate <u>four</u> times the employment per dollar compared to average expenditures in induced "respending" effects. These results led to the conclusion that:

> ...investment in the least cost technology counters inflation and, because of reduced capital needs and the additional income made available to the ratepayer, creates employment opportunities in the general economy (Lerner and Posey 1979, 3).

Another study (Carlson 1979) was initiated to consider the economic repercussions caused by substituting energy conservation and renewable energy sources for conventional energy supplies in California. This report revealed that short term changes in state employment and income are influenced by changes in total expenditures, involving consumption, investment, government, and net exports. For California, which imported 59% of its total energy requirements in 1987, the rising costs of those imports diminish the net value of state exports and reduce aggregate expenditures, output, and employment (Tooker 1989).

Any energy technology that could substitute for energy imports, all other things being equal, would lead to increased state employment in the short run and real income in the long run. The magnitude of these effects would be dependent on the relative costs of energy supplies. If conservation or renewable energy sources could supply energy requirements at lower unit costs than conventional energy supplies, even more favorable income and employment impacts would be produced. Under the general conditions and costs extant in 1979, energy conservation and renewable energy sources were found to produce 3 times the employment per dollar of sales compared to the conventional energy supply industries.

This evaluation found California well-suited to energy source substitution, considering its below average energy costs, the small amount of energy consumed per dollar of value added in manufacturing, and the increasing level of imports. The analysis of a proposed program to supply one third of the state's energy needs by conservation and renewable energy sources, at costs equal to conventional sources, estimated the generation of some 600,000 new jobs (+ 7.6%) resulting from the substitution of imported energy alone. However, considering the dominance of petroleum products in state energy consumption and the lack of suitable alternative transportation fuels at equivalent costs, this scenario may have been overly optimistic.

Schultz (1983) conducted another input-output analysis of the California economy as part of a study to measure and analyse the energy conservation potential in the state's residential sector. This thorough evaluation considered a wide range of cost-effective conservation measures and techniques for reducing space conditioning and hot water heating energy consumption. The estimated $12 billion investment required to implement the proposed residential energy conservation program was evaluated for net economic effect by the fabrication of a detailed interindustry transactions table. The conservation expenditures were found to generate favorable overall effects on total personal income and employment levels, despite reduced sales, investment, and employment in the energy sector.

The conservation investment's greatest economic effect was through reduced utility bills, which were projected to accumulate dollar savings at a rate 2.5 times the conservation costs. The total economic effect of the proposed substitution of conservation expenditures for energy expenses was expected to result in a net increase of 571,000 person-years of employment, and $15.6 billion in personal income. Although these figures are impressive at first glance, they must be placed in perspective. For comparison, in 1983, the number of employed California residents was close to 12 million, and annual personal income exceeded $400 billion. Assuming the most optimistic conditions, if the residential conservation potential could be tapped through an aggressive 5-year program, the conservation investment would create less than a 1% average annual increase in both statewide employment and personal income. (See Figure 20).

The results of several other input-output analyses concerning the substitution effects of energy conservation programs bear consideration, even though they do not address California's situation in particular.

Laitner (1986) documents the regional economic study conducted by a four-state consortium (Nebraska, Iowa, Missouri and Kansas) in 1985 to quantify the effects of energy and conservation expenditures on economic development within their area. Nebraska's energy consumption alone had grown by almost 80% between 1960-1982, yet the portion of that energy produced in-state had slipped from 50% to just 10%. During that period, the relative value of the state's major product (its agricultural exports) had declined, while energy costs continued to climb. The study group constructed a regional input-output matrix to analyse the impact of a federally-supported home weatherization program in Nebraska.

Figure 20. Net Benefits to California from Conservation Investments.

Effect	Expenditure (Billion 1983 $)	Employment (Person-Yrs)	Personal Income (Billion 1983 $)
Conservation Investment	12	468	10.9
"Average" Expenditure Displaced (from investment)	-12	-336200	-9.6
"Average" Expenditure Gained (reduced energy utility bills)	39.9	1117200	31.9
Utility Expenditure Reduced (reduced energy use)	-39.9	-678300	-17.6
Total Net Indirect Benefits		570900	15.6

Data from Schultz 1983

The results of their evaluation illustrate the favorable economic repercussions created by energy conservation expenditures. In 1983, the federal program had invested $2.6 million to weatherize 2,200 units of low-income housing. The study determined that this initial investment had resulted in a total of $6.9 million in statewide economic activity by the compounding of interindustry transactions for materials and services, and the respending of utility bill savings. Another government-subsidized program in 1985-1986 allocated $3.85 million to weatherize an additional 2,242 homes in Nebraska. This investment was estimated to be responsible for the generation of $9.6 million in economic activity, and the preservation or creation of 212 jobs (NEO 1986).

The Nebraska study determined that, on average, every dollar spent on energy purchases generated about $1.00 less in economic benefits to the regional economy compared to a dollar spent on energy conservation measures. The economic multiplier for energy purchases in Nebraska was determined to be in the range of 1.32-1.45; that is, $1.00 spent to purchase electricity or natural gas was found to generate a total of about $1.40 in economic activity within the state. By comparison, the same $1.00 expenditure on energy conservation retrofit measures generated $2.37 in direct and indirect economic activity. The Nebraska weatherization retrofits reduced average energy consumption by 21% per household, resulting in two direct impacts from the investment in energy conservation: 1) lower utility bills, leading to an increase in disposable household incomes, and 2) enhanced statewide economic activity, and employment opportunities. It was evident that, dollar for dollar, the investment in energy conservation measures in Nebraska could be expected to provide a greater economic "punch" than any energy purchase.

The analysis of other weatherization programs in Iowa and Missouri produced similar results and values for the economic multipliers for energy and conservation expenditures, but analysis in Kansas did not. Kansas achieved an energy multiplier of 2.33, comparable to the figure for conservation expenditures, because the state produced almost all of the oil necessary to meet in-state demand. This multiplier may tend to overstate the true in-state value of oil production in this instance, however, due to the influence of the outside venture-capital interests that finance the costs of production and refining, and that collect the greatest share of any resulting profits. In general, though, the results of this study highlight the value of dedicated energy conservation investment as a valuable component of economic development.

Another, earlier study (Schwartz 1979) was conducted to compare the economic impact of a proposed nuclear power plant with an alternative "energy conservation" scenario for the New York state region near Long Island. This study found little difference in the calculated economic multipliers for energy conservation (2.77) and energy expenditures (2.84), which were both much lower than the figure for personal consumption expenditures (3.89) in general. It did, however, find evidence to suggest that the conservation alternative would favorably affect disposable household income levels in the long run. The alternative program would require an initial $4 billion investment in residential conservation measures, which were expected to generate two to three times their value ($7-$11 billion) in lifetime household energy savings.

Although the calculated multipliers for energy conservation and energy purchases were similar, the observed difference in employment impacts was substantial. The aggressive energy conservation strategy was determined to generate 45.4 jobs per million dollars of investment--<u>three times</u> the expected level sustained by a similar investment in the energy industry (15.2 jobs), representing the different allocations of expenditures for labor, materials, and energy between industries (Schwartz 1979). In New York, an estimated 41% of all the conservation expenditures were expected to be dedicated to wages for local workers and contractors. This figure is in agreement with government studies of the national employment impact of weatherization services, which suggest a range of 30-50% of all expenses being committed to labor (Nordlund 1980). In general, a much smaller proportion of energy industry sales are dedicated to labor costs. The acquisition of energy resources comprise the greatest share of utility operating expenses. Taking the case of one California energy utility, in 1988, only 9% of every dollar of Pacific Gas and Electric (PG&E) sales was paid out in wages to employees (Phillips 1990).

The results of three other relevant government sponsored input-output analyses also bear mentioning. Two of these studies were performed to model the impacts of federal building efficiency standards, under development in the early 1980's for both new and retrofit construction (Department of Energy 1980), (National Institute of Building Sciences 1980). Both of these economic analyses found that these regulations were likely to generate a small drop in energy utility sales and employment (1-2%), which was more than offset by modest gains in other sectors. The implementation of the proposed energy conservation requirements was expected to boost construction and service employment levels by 80,000 to 246,000 jobs nationally. This increase would comprise only a fraction of a percent (.1-.3%) of total employment, but would be responsible, nevertheless, for a significant number of new jobs.

The most recent econometric analysis involving an input-output methodology was based on a 537 component industry/commodity transactions table for 130 national sectors (Marsh et al. 1989). This study, conducted to evaluate the effects of a voluntary building efficiency standard for new housing, found significant long-term benefits from the implementation of cost-effective residential energy conservation strategies. This study's input-output analysis found equilibrating economic effects between the gains in output and employment from increased expenditures for new residential construction and the output "losses" resulting from reductions in energy sales (less than .1% change in total national output and employment). Once again, the substitution of conservation for energy expenditures was expected to have its greatest effect on household incomes and the respending of energy savings. The net present value of combined energy savings and conservation costs was estimated to reach $1 billion per year within four years after full adoption of the building standards, correlated with the number of new housing starts in the nation.

Macroeconomic Impacts

The results of these economic analyses highlight the favorable, if modest, macroeconomic impacts secured by the application of effective energy conservation measures. In all cases, cost-effective energy conservation investments are responsible for more related economic activity and employment opportunities than energy purchases alone. In California's case, the displacement of energy imports by conservation strategies making use of available in-state resources and labor has a particularly favorable influence on disposable household incomes and employment. The magnitude of these impacts is dependent on the relative unit cost of the alternative energy "supplies" compared to conventional energy sources. If energy requirements can be reduced by energy conservation or more efficient products or processes at lower unit costs, even greater benefits may accrue in terms of the personal <u>and</u> regional economic effects.

Certain capital-intensive industries, such as energy production and supply, support fewer jobs per dollar of sales than other, more labor-intensive industries. Nationally, the petroleum industry supports 10.7 jobs per million dollars in sales, the natural gas suppliers maintain 10.9 jobs/ million dollars, and the electric utilities support a spartan 5.5 jobs/ million dollars. By comparison, the service industry sustains 22 jobs per million dollars in sales, the construction industry supports 23 jobs/ million dollars, and the manufacturing field provides 18 jobs per million dollars in total sales (Laitner 1985). Expenditures in the energy industries provide employment opportunities of less than one half that of other, more labor-intensive sectors.

Input-output analysis documents the way that investments in energy conservation measures can enhance regional economic interactions by advancing the productivity of energy resource use. The shift of expenditures from the capital-intensive energy production and supply industries to more labor-intensive sectors also favorably affects the creation of expanded employment opportunities.

The argument is persuasive: cost-effective investment in energy conservation reinforces profitability, efficiency, competitiveness, employment, _and_ economic growth. The investment in cost-effective energy conservation measures also promotes the economic resilience of individuals, businesses, regions, and nations to energy supply and price disruptions. Expenditures for energy purchases (especially imported energy) are diverted from more productive sectors of the economy, resulting in reduced overall economic activity. Input-output analysis provides a methodology to quantify the beneficial effects of energy conservation on a larger scale, and a rationale for taking advantage of the opportunity to secure the more effective use of energy resources _and_ dollars.

SYNTHESIS

Optimizing the Potential

The physical characteristics of homes designed and built today, because of their useful lifespans of 30-50 years or more, will affect patterns of energy use well into the next century. It is apparent that there is still room for improvement in advancing the efficient use of energy in California homes, as one component of a strategy to secure the enhanced productivity of all energy uses. The state building energy conservation standards have captured a significant share of the potential energy savings in new residential construction, but they fall short of maximizing the full economic benefit of the conservation investment. Also, because three quarters of the state's 9.5 million residences were built before any requirements for energy efficiency were in effect, there is still a substantial retrofit potential that has not been addressed.

Significant reductions in residential energy consumption have been achieved by the study and correction of the thermal weaknesses of conventional building envelope construction. The building industry is now capable of producing homes that require only a fraction of the energy budgets of homes built 20 years ago through cost-effective enhancements of building envelope thermal performance, reduced infiltration, and more efficient heating and cooling equipment and appliances. And, the careful treatment of conduction and infiltration energy transfers by insulating and sealing building shells has been demonstrated to conserve 50-80% of home space conditioning energy loads, in <u>all</u> climates. But, while engineering provides the technical capability for the improved performance of building components and equipment, it cannot, by itself, direct the application of those advances.

Traditional building designs, by necessity, reflected their adaptability to climatic and resource limitations. Modern architecture can benefit from an examination of the design principles exhibited by these approaches: regarding the value of accommodating the natural energy flows at the building site, proper orientation, and the use of design elements to temper climatic extremes.

The interactions of natural forces (weather), building characteristics, and personal demands (comfort) define the parameters of space-conditioning energy requirements. The level of residential energy consumption is dependent upon both physical <u>and</u> behavioral characteristics concerning a home's construction, its location and equipment, and the attitudes and habits of its occupants. Long-standing values and practices have hindered the ready development of new, more efficient architectural approaches. The building industry has been hesitant to incorporate energy conservation measures and materials in new construction because of uncertainty about the marketability of the additional investment in price-sensitive housing markets. Consumers have been most concerned with initial home purchase prices, and have been unaware of the significant long-term advantages of energy-efficient designs. Government policies have distorted the operation of energy markets and contributed to the continued undervaluation of energy resources. Much of the attention paid to advancing building energy efficiency has focused on the technical aspects of the problem, but policy, economic, and behavioral issues are equally as important.

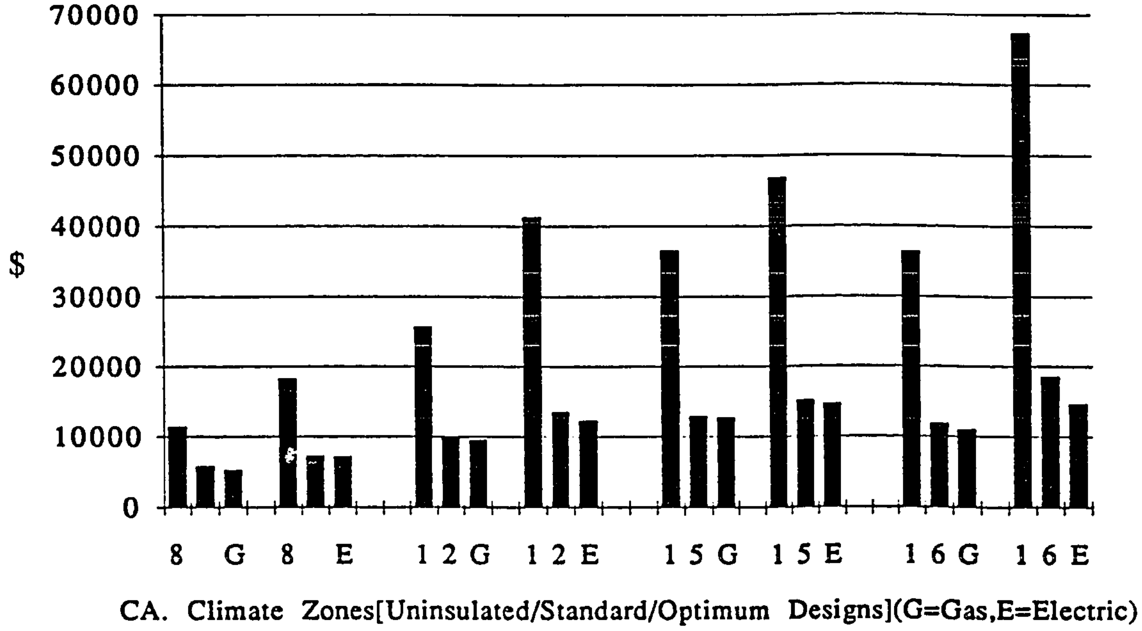
The two primary approaches to reforming wasteful energy practices involve regulatory or market-oriented strategies, so-called "hard" or "soft" policies to encourage the application of effective building energy conservation measures and materials. The greatest strength of building efficiency regulations is derived from the universal coverage they provide, backed by the administrative structure and authority of building departments. Regulation plays an appropriate role in counteracting the barriers that have hindered the voluntary deployment of appropriate advances in energy conservation and building energy efficiency. Market-based approaches rely on less-direct means to achieve the same goal, depending on the motivation provided by monetary incentives (or penalties, such as taxes) to affect behavior. These methods differ in effectiveness, flexibility, and political appeal, but have as a common aim the initiation of new patterns of building energy use and new values for limited energy resources.

Economic Effectiveness

Economics provides a framework that can guide and motivate the implementation of the most cost-effective energy conservation measures and materials in buildings based on budget limitations, investor time-horizons, or minimum life cycle costs. While housing consumers and builders remain preoccupied with the initial costs of home purchases, the failure to consider the long-term, continuing operation costs of home designs leads to significantly higher housing expenditures than are necessary. The level of housing investment that maximizes "economic efficiency" is determined by the design "package" that minimizes the combined costs of home ownership over its economically useful lifetime. In all of the California climates studied, the optimal building design (according to prototype specifications) requires an additional investment of $1,100-$6,700 in envelope energy conservation measures which, over the years, is responsible for generating from $6,200-$52,600 in net savings (4-8 times the first cost in constant dollars). (See Figure 21).

The impressive results of lowest life cycle cost building envelope configurations highlight just one of the ways that cost-effective energy conservation strategies can be applied to supply an equivalent level of services with less energy at lower cost. In this case, life cycle economic analysis may help to dispel lingering misconceptions about the link between energy conservation and personal sacrifice, and facilitate a more farsighted perspective on the value of investments, energy, and efficient building design over time.

Figure 21. Net Life Cycle Cost Comparisons for Energy and Conservation in the Prototype Design.



The repercussions of inefficient energy uses create a persistent drain on personal and regional economies, leaving individuals, states, and nations more vulnerable to energy price hikes and supply disruptions. The capital-intensive energy production industries produce fewer jobs per million dollars of sales than most other industries, and fewer interindustry transactions. The investment in energy conservation measures and materials is likely to generate more economic activity and employment than a comparable expenditure on energy supplies. And, where the relative unit costs of energy "supplied" by conservation are less than conventional sources, real household incomes are increased.

The regulation of building energy efficiency, when it is based on principles of economic cost-effectiveness, can affect personal values by translating increasing social values for energy resources into individual terms. Housing consumers may find that the economic benefits available from the implementation of cost-effective energy conservation measures provide an incentive to modify longstanding apathetic attitudes and habits regarding energy use.

The best use of life cycle economics in evaluating building energy efficiency is early in the design process, where it can facilitate the comparison of alternative designs, materials, and equipment in light of changing economic conditions, energy and conservation costs, and advancing conservation technologies. This synthesis of engineering "potential" and economic "practicality" provides a foundation for the application of the most effective energy conservation measures and strategies in housing, and access to the more productive use of energy resources in the residential sector.

Social Benefits

Regulatory programs, such as the California building energy efficiency standards, have been instituted primarily to limit the increasing external costs of energy resource production and consumption. Although the market prices of most energy sources have not changed much in real economic terms, there is evidence to suggest that the social costs of expanding energy use are increasing. The combustion of fossil fuels is linked to acid rain formation and is suspected to constitute the greatest share of global warming effects. The future of the nuclear power industry has been clouded by several serious accidents and the as-yet unresolved dilemma of providing a secure long-term disposal method for its hazardous waste by-products. The geological concentration of petroleum reserves has affected the United States' international balance of trade and domestic security, and contributed to the willingness of an American administration to wage war in the Mideast.

The livability of our towns and cities is directly affected by the capability of natural systems to absorb or dissipate the concentrated emissions resulting from energy production and consumption. These impacts are not confined to the well-publicized oil tanker or nuclear plant disasters: everyday, terrestrial and marine habitats are damaged by energy resource exploration and production, and urban environments are clogged with the concentrated emissions of motor vehicle exhausts. The annual energy requirement of the average American home is met by the combustion of 6,400 pounds of coal, 52,000 cubic feet of natural gas, and 2 barrels of oil--which generates 14,000 pounds of carbon emissions. United States homes' energy consumption is responsible for 14% of all domestic fossil fuel emissions and the production of 770 million tons of carbon emissions per year, one quarter of the sulfur oxides, and one eighth of all nitrogen oxide emissions (Flavin and Durning 1988).

The longstanding availability of inexpensive energy sources has contributed to the perpetuation of wasteful and inappropriate building designs, which have resulted in increasing energy consumption, higher utility bills, greater pressure to expand energy resource development and production, and increased polluting emissions. Regulations establishing minimum building efficiency standards impose additional construction costs on new home buyers, who benefit from reduced energy costs. But, as we have seen, the required energy conservation expenditures generate favorable economic impacts on interindustry transactions, and also benefit other ratepayers by curtailing the necessity for utility development of new, higher cost energy resources or production capacity.

State utility regulators, charged with accommodating increasing electrical demand, are finding cost-effective alternatives (conservation, efficiency, time-of-day pricing) to lengthy and expensive construction programs increasingly palatable. And, wherever in-state conservation services or materials can be applied to substitute for any share of the 59% of California's annual energy requirement that is imported, the state reaps a double benefit in expanded employment opportunities and increased real income. Because energy is integral to so many services and all economic sectors, the interactions of energy use and misuse reverberate across many seemingly disparate areas, including (to name just a few) land use patterns, air quality, the cost of living, and domestic security.

Productivity and Sustainability

Although the building industry has made great strides in reducing the wasteful and inappropriate use of energy resources in the built environment, what has been accomplished has not maximized the technical capability or the economic efficiency of energy conservation investments. The adoption of many energy conservation measures and techniques, which have established their cost-effectiveness in comparison to conventional sources of energy supply, has been hindered by barriers that have distorted the costs of conventional energy resources in the markets, government policies that have subsidized the exploration, production, and distribution of those resources, and limited research and development funding for energy conservation and efficiency programs. The synthesis of engineering and economics approaches in building design defines what energy conservation measures and strategies are appropriate and cost-effective in light of current and projected economic conditions, the costs of conservation and energy, and technological advances in building materials and equipment.

California's increasingly stringent building and appliance energy efficiency standards have helped offset much of the state's energy growth for the last 15 years. The state expects these standards to displace 9,200 Megawatts of electrical capacity (the equivalent of nine large power plants) by 1999, compared to extrapolated 1977 energy consumption trends. The state building energy efficiency program has evolved from a relatively uncomplicated beginning, mandating minimum insulation levels in new home walls and ceilings, to the fairly complex regulation of many aspects of home design and equipment. Homes complying with the state building standards can be expected to consume 50-75% less energy for space heating compared to previous construction practice, with only moderate additional construction costs and some constraints on home design. Still, in light of current and projected economic conditions and energy and conservation costs, the state-mandated levels of building energy efficiency do not maximize the energy conservation investment.

Life cycle economic analysis must guide the application of cost-effective building envelope conservation measures. The most effective approach to the development of energy efficient architecture should be adaptable to changing conditions. In that regard, the implementation of life cycle economic analyses of home designs may prove to be a valuable policy innovation for energy conservation <u>and</u> economic productivity. The challenge of reforming ingrained design and construction practices is great, but so is the opportunity.

APPENDIX

Climate Zones Energy Conservation/Economy Worksheets

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone 8	City:	Anaheim			Nat. Gas			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.0741	0.807	133.38	$1,878	1452.78	$2,833	$1,878	$4,711	
6	Add R11	$486	0.0183	0.199	32.94	$464	358.20	$698	$950	$1,648	
7	Add R19	$720	0.0127	0.138	22.86	$322	248.76	$485	$1,042	$1,527	***
8	Add R30	$1,098	0.0091	0.1	16.38	$231	179.10	$349	$1,329	$1,678	
9	Add R38	$1,314	0.0074	0.08	13.32	$188	144.36	$282	$1,502	$1,783	
10	Add R49	$1,566	0.0061	0.066	10.98	$155	119.34	$233	$1,721	$1,953	
11	Add R60	$1,764	0.0053	0.058	9.54	$134	104.40	$204	$1,898	$2,102	
12											
13	Wall-2x4, R "0"	$0	0.1624	0.56	201.38	$2,835	694.03	$1,353	$2,835	$4,189	
14	Add R11	$347	0.0331	0.114	41.04	$578	141.36	$276	$925	$1,201	
15	Add R13	$422	0.0301	0.104	37.32	$526	128.46	$251	$948	$1,198	***
16	Wall-2x6, R19	$880	0.0213	0.073	26.41	$372	90.89	$177	$1,252	$1,429	
17	Add R21	$1,004	0.0189	0.065	23.44	$330	80.85	$158	$1,334	$1,492	
18	Add R11, R14	$1,600	0.0138	0.048	17.11	$241	59.15	$115	$1,841	$1,956	
19	Add R21, R14	$2,257	0.0101	0.035	12.52	$176	43.28	$84	$2,433	$2,518	
20											
21	Floor-R "0"	$0	0.0383	0.02	68.94	$971	35.64	$69	$971	$1,040	***
22	Add R11	$594	0.0186	0.01	33.48	$471	17.28	$34	$1,065	$1,099	
23	Add R19	$828	0.0134	0.007	24.12	$340	12.42	$24	$1,168	$1,192	
24	Add R30	$1,206	0.01	0.005	18.00	$253	9.36	$18	$1,459	$1,478	
25											
26	Single Glazing	$0	0.1048	2.006	29.34	$413	561.60	$1,095	$413	$1,508	***
27	Alum. Double	$717	0.0159	1.719	4.45	$63	481.32	$939	$780	$1,718	
28	ATB Double	$1,187	0	1.675	0.00	$0	468.89	$914	$1,187	$2,101	
29	Vinyl Double	$2,108	0	1.636	0.00	$0	458.00	$893	$2,108	$3,001	

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone 8	City:	Anaheim			Electric			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.0741	0.807	133.38	$3,717	1452.78	$3,320	$3,717	$7,037	
6	Add R11	$486	0.0183	0.199	32.94	$918	358.20	$818	$1,404	$2,223	
7	Add R19	$720	0.0127	0.138	22.86	$637	248.76	$568	$1,357	$1,926	***
8	Add R30	$1,098	0.0091	0.1	16.38	$457	179.10	$409	$1,555	$1,964	
9	Add R38	$1,314	0.0074	0.08	13.32	$371	144.36	$330	$1,685	$2,015	
10	Add R49	$1,566	0.0061	0.066	10.98	$306	119.34	$273	$1,872	$2,145	
11	Add R60	$1,764	0.0053	0.058	9.54	$266	104.40	$239	$2,030	$2,268	
12											
13	Wall-2x4, R "0"	$0	0.1624	0.56	201.38	$5,612	694.03	$1,586	$5,612	$7,198	
14	Add R11	$347	0.0331	0.114	41.04	$1,144	141.36	$323	$1,491	$1,814	
15	Add R13	$422	0.0301	0.104	37.32	$1,040	128.46	$294	$1,462	$1,756	***
16	Wall-2x6, R19	$880	0.0213	0.073	26.41	$736	90.89	$208	$1,616	$1,824	
17	Add R21	$1,004	0.0189	0.065	23.44	$653	80.85	$185	$1,657	$1,842	
18	Add R11, R14	$1,600	0.0138	0.048	17.11	$477	59.15	$135	$2,077	$2,212	
19	Add R21, R14	$2,257	0.0101	0.035	12.52	$349	43.28	$99	$2,606	$2,705	
20											
21	Floor-R "0"	$0	0.0383	0.02	68.94	$1,921	35.64	$81	$1,921	$2,003	
22	Add R11	$594	0.0186	0.01	33.48	$933	17.28	$39	$1,527	$1,567	
23	Add R19	$828	0.0134	0.007	24.12	$672	12.42	$28	$1,500	$1,529	***
24	Add R30	$1,206	0.01	0.005	18.00	$502	9.36	$21	$1,708	$1,729	
25											
26	Single Glazing	$0	0.1048	2.006	29.34	$818	561.60	$1,283	$818	$2,101	
27	Alum. Double	$717	0.0159	1.719	4.45	$124	481.32	$1,100	$841	$1,941	***
28	ATB Double	$1,187	0	1.675	0.00	$0	468.89	$1,071	$1,187	$2,258	
29	Vinyl Double	$2,108	0	1.636	0.00	$0	458.00	$1,047	$2,108	$3,155	

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone12	City:	Sacrame	nto		Nat.Gas			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.181	1.662	325.80	$4,587	2991.06	$5,833	$4,587	$10,420	
6	Add R11	$486	0.0446	0.41	80.28	$1,130	737.46	$1,438	$1,616	$3,054	
7	Add R19	$720	0.031	0.285	55.80	$786	512.10	$999	$1,506	$2,504	
8	Add R30	$1,098	0.0223	0.205	40.14	$565	368.82	$719	$1,663	$2,382	
9	Add R38	$1,314	0.018	0.165	32.40	$456	297.00	$579	$1,770	$2,349	***
10	Add R49	$1,566	0.0149	0.137	26.82	$378	245.88	$479	$1,944	$2,423	
11	Add R60	$1,764	0.013	0.12	23.40	$329	215.10	$419	$2,093	$2,513	
12											
13	Wall-2x4, R "0"	$0	0.3286	1.238	407.46	$5,737	1534.50	$2,992	$5,737	$8,729	
14	Add R11	$347	0.0669	0.252	82.96	$1,168	312.60	$610	$1,515	$2,125	
15	Add R13	$422	0.0608	0.229	75.39	$1,062	283.96	$554	$1,484	$2,037	
16	Wall-2x6, R19	$880	0.043	0.162	53.32	$751	201.00	$392	$1,631	$2,023	
17	Add R21	$1,004	0.0383	0.144	47.49	$669	178.68	$348	$1,673	$2,021	***
18	Add R11, R14	$1,600	0.028	0.106	34.72	$489	130.82	$255	$2,089	$2,344	
19	Add R21, R14	$2,257	0.0205	0.077	25.42	$358	95.73	$187	$2,615	$2,802	
20											
21	Floor-R "0"	$0	0.0762	0.086	137.16	$1,931	154.26	$301	$1,931	$2,232	
22	Add R11	$594	0.037	0.042	66.60	$938	75.06	$146	$1,532	$1,678	
23	Add R19	$828	0.0268	0.03	48.24	$679	54.18	$106	$1,507	$1,613	***
24	Add R30	$1,206	0.0199	0.022	35.82	$504	40.32	$79	$1,710	$1,789	
25											
26	Single Glazing	$0	0.4398	4.554	123.14	$1,734	1274.98	$2,486	$1,734	$4,220	
27	Alum. Double	$717	0.2327	3.846	65.16	$917	1076.96	$2,100	$1,634	$3,734	
28	ATB Double	$1,187	0.0989	3.697	27.69	$390	1035.10	$2,018	$1,577	$3,595	***
29	Vinyl Double	$2,108	0	3.566	0.00	$0	998.42	$1,947	$2,108	$4,055	

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone12	City:	Sacrame	nto		Electric			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.181	1.662	325.80	$9,080	2991.06	$6,835	$9,080	$15,915	
6	Add R11	$486	0.0446	0.41	80.28	$2,237	737.46	$1,685	$2,723	$4,408	
7	Add R19	$720	0.031	0.285	55.80	$1,555	512.10	$1,170	$2,275	$3,445	
8	Add R30	$1,098	0.0223	0.205	40.14	$1,119	368.82	$843	$2,217	$3,059	
9	Add R38	$1,314	0.018	0.165	32.40	$903	297.00	$679	$2,217	$2,896	
10	Add R49	$1,566	0.0149	0.137	26.82	$747	245.88	$562	$2,313	$2,875	***
11	Add R60	$1,764	0.013	0.12	23.40	$652	215.10	$492	$2,416	$2,908	
12											
13	Wall-2x4, R "0"	$0	0.3286	1.238	407.46	$11,356	1534.50	$3,506	$11,356	$14,862	
14	Add R11	$347	0.0669	0.252	82.96	$2,312	312.60	$714	$2,659	$3,373	
15	Add R13	$422	0.0608	0.229	75.39	$2,101	283.96	$649	$2,523	$3,172	
16	Wall-2x6, R19	$880	0.043	0.162	53.32	$1,486	201.00	$459	$2,366	$2,825	
17	Add R21	$1,004	0.0383	0.144	47.49	$1,324	178.68	$408	$2,328	$2,736	***
18	Add R11, R14	$1,600	0.028	0.106	34.72	$968	130.82	$299	$2,568	$2,867	
19	Add R21, R14	$2,257	0.0205	0.077	25.42	$708	95.73	$219	$2,965	$3,184	
20											
21	Floor-R "0"	$0	0.0762	0.086	137.16	$3,823	154.26	$352	$3,823	$4,175	
22	Add R11	$594	0.037	0.042	66.60	$1,856	75.06	$172	$2,450	$2,622	
23	Add R19	$828	0.0268	0.03	48.24	$1,344	54.18	$124	$2,172	$2,296	***
24	Add R30	$1,206	0.0199	0.022	35.82	$998	40.32	$92	$2,204	$2,296	***
25											
26	Single Glazing	$0	0.4398	4.554	123.14	$3,432	1274.98	$2,913	$3,432	$6,345	
27	Alum. Double	$717	0.2327	3.846	65.16	$1,816	1076.96	$2,461	$2,533	$4,994	
28	ATB Double	$1,187	0.0989	3.697	27.69	$772	1035.10	$2,365	$1,959	$4,324	***
29	Vinyl Double	$2,108	0	3.566	0.00	$0	998.42	$2,281	$2,108	$4,389	

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone15	City:	PalmSpri	ngs		Nat. Gas			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.0677	4.08	121.86	$1,716	7344.18	$14,321	$1,716	$16,037	
6	Add R11	$486	0.0167	1.006	30.06	$423	1810.98	$3,531	$909	$4,441	
7	Add R19	$720	0.0116	0.699	20.88	$294	1257.48	$2,452	$1,014	$3,466	
8	Add R30	$1,098	0.0083	0.503	14.94	$210	905.40	$1,766	$1,308	$3,074	
9	Add R38	$1,314	0.0067	0.405	12.06	$170	729.36	$1,422	$1,484	$2,906	
10	Add R49	$1,566	0.0056	0.335	10.08	$142	603.72	$1,177	$1,708	$2,885	***
11	Add R60	$1,764	0.0049	0.293	8.82	$124	528.12	$1,030	$1,888	$2,918	
12											
13	Wall-2x4, R "0"	$0	0.121	3.908	150.04	$2,113	4846.04	$9,450	$2,113	$11,562	
14	Add R11	$347	0.0247	0.796	30.63	$431	987.29	$1,925	$778	$2,703	
15	Add R13	$422	0.0224	0.723	27.78	$391	896.64	$1,748	$813	$2,562	
16	Wall-2x6, R19	$880	0.0158	0.512	19.59	$276	634.76	$1,238	$1,156	$2,394	
17	Add R21	$1,004	0.0141	0.455	17.48	$246	564.20	$1,100	$1,250	$2,350	***
18	Add R11, R14	$1,600	0.0103	0.333	12.77	$180	413.04	$805	$1,780	$2,585	
19	Add R21, R14	$2,257	0.0075	0.244	9.30	$131	302.19	$589	$2,388	$2,977	
20											
21	Floor-R "0"	$0	0.0287	0.443	51.66	$727	797.04	$1,554	$727	$2,282	
22	Add R11	$594	0.014	0.215	25.20	$355	387.72	$756	$949	$1,705	
23	Add R19	$828	0.0101	0.156	18.18	$256	280.08	$546	$1,084	$1,630	***
24	Add R30	$1,206	0.0075	0.116	13.50	$190	208.26	$406	$1,396	$1,802	
25											
26	Single Glazing	$0	0.1038	11.4	29.06	$409	3192.28	$6,225	$409	$6,634	
27	Alum. Double	$717	0.0344	9.481	9.63	$136	2654.76	$5,177	$853	$6,029	
28	ATB Double	$1,187	0	8.693	0.00	$0	2434.04	$4,746	$1,187	$5,933	***
29	Vinyl Double	$2,108	0	8.001	0.00	$0	2240.22	$4,368	$2,108	$6,476	

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone15	City:	PalmSpri	ngs		Electric			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.0677	4.08	121.86	$3,396	7344.18	$16,781	$3,396	$20,178	
6	Add R11	$486	0.0167	1.006	30.06	$838	1810.98	$4,138	$1,324	$5,462	
7	Add R19	$720	0.0116	0.699	20.88	$582	1257.48	$2,873	$1,302	$4,175	
8	Add R30	$1,098	0.0083	0.503	14.94	$416	905.40	$2,069	$1,514	$3,583	
9	Add R38	$1,314	0.0067	0.405	12.06	$336	729.36	$1,667	$1,650	$3,317	
10	Add R49	$1,566	0.0056	0.335	10.08	$281	603.72	$1,380	$1,847	$3,226	
11	Add R60	$1,764	0.0049	0.293	8.82	$246	528.12	$1,207	$2,010	$3,217	***
12											
13	Wall-2x4, R "0"	$0	0.121	3.908	150.04	$4,182	4846.04	$11,073	$4,182	$15,255	
14	Add R11	$347	0.0247	0.796	30.63	$854	987.29	$2,256	$1,201	$3,457	
15	Add R13	$422	0.0224	0.723	27.78	$774	896.64	$2,049	$1,196	$3,245	
16	Wall-2x6, R19	$880	0.0158	0.512	19.59	$546	634.76	$1,450	$1,426	$2,876	
17	Add R21	$1,004	0.0141	0.455	17.48	$487	564.20	$1,289	$1,491	$2,780	***
18	Add R11, R14	$1,600	0.0103	0.333	12.77	$356	413.04	$944	$1,956	$2,900	
19	Add R21, R14	$2,257	0.0075	0.244	9.30	$259	302.19	$690	$2,516	$3,207	
20											
21	Floor-R "0"	$0	0.0287	0.443	51.66	$1,440	797.04	$1,821	$1,440	$3,261	
22	Add R11	$594	0.014	0.215	25.20	$702	387.72	$886	$1,296	$2,182	
23	Add R19	$828	0.0101	0.156	18.18	$507	280.08	$640	$1,335	$1,975	***
24	Add R30	$1,206	0.0075	0.116	13.50	$376	208.26	$476	$1,582	$2,058	
25											
26	Single Glazing	$0	0.1038	11.4	29.06	$810	3192.28	$7,294	$810	$8,104	
27	Alum. Double	$717	0.0344	9.481	9.63	$268	2654.76	$6,066	$985	$7,052	
28	ATB Double	$1,187	0	8.693	0.00	$0	2434.04	$5,562	$1,187	$6,749	***
29	Vinyl Double	$2,108	0	8.001	0.00	$0	2240.22	$5,119	$2,108	$7,227	

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone16	City:	Susanvill	e		Nat. Gas			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.4005	0.774	720.90	$10,150	1392.66	$2,716	$10,150	$12,866	
6	Add R11	$486	0.0987	0.191	177.66	$2,501	343.44	$670	$2,987	$3,657	
7	Add R19	$720	0.0686	0.133	123.48	$1,739	238.50	$465	$2,459	$2,924	
8	Add R30	$1,098	0.0494	0.095	88.92	$1,252	171.72	$335	$2,350	$2,685	
9	Add R38	$1,314	0.0398	0.077	71.64	$1,009	138.24	$270	$2,323	$2,592	***
10	Add R49	$1,566	0.0329	0.064	59.22	$834	114.48	$223	$2,400	$2,623	
11	Add R60	$1,764	0.0288	0.056	51.84	$730	100.08	$195	$2,494	$2,689	
12											
13	Wall-2x4, R "0"	$0	0.6943	0.657	860.93	$12,122	815.05	$1,589	$12,122	$13,711	
14	Add R11	$347	0.1415	0.134	175.46	$2,470	166.04	$324	$2,817	$3,141	
15	Add R13	$422	0.1285	0.122	159.34	$2,244	150.78	$294	$2,666	$2,960	
16	Wall-2x6, R19	$880	0.0909	0.086	112.72	$1,587	106.76	$208	$2,467	$2,675	
17	Add R21	$1,004	0.0808	0.077	100.19	$1,411	94.86	$185	$2,415	$2,600	***
18	Add R11, R14	$1,600	0.0592	0.056	73.41	$1,034	69.44	$135	$2,634	$2,769	
19	Add R21, R14	$2,257	0.0433	0.041	53.69	$756	50.84	$99	$3,013	$3,112	
20											
21	Floor-R "0"	$0	0.1563	0.064	281.34	$3,961	115.38	$225	$3,961	$4,186	
22	Add R11	$594	0.076	0.031	136.80	$1,926	56.16	$110	$2,520	$2,630	
23	Add R19	$828	0.0549	0.023	98.82	$1,391	40.50	$79	$2,219	$2,298	***
24	Add R30	$1,206	0.0408	0.017	73.44	$1,034	30.06	$59	$2,240	$2,299	
25											
26	Single Glazing	$0	1.1212	2.102	313.94	$4,420	588.64	$1,148	$4,420	$5,568	
27	Alum. Double	$717	0.6639	1.724	185.89	$2,617	482.58	$941	$3,334	$4,275	
28	ATB Double	$1,187	0.3835	1.609	107.38	$1,512	450.63	$879	$2,699	$3,578	
29	Vinyl Double	$2,108	0.1368	1.509	38.30	$539	422.60	$824	$2,647	$3,471	***

	A	B	C	D	E	F	G	H	I	J	K
1	Climate Zone16	City:	Susanvill	e		Electric			LCC	LCC	
2			Therm/	Kwh/	Heat	PV	Cooling	PV	PV Heat &	PV Heat,Cool	Lowest
3	Component	Cost	sq.ft.	sq.ft.	therms	Heating	(Kwh)	Cooling	Cons.Cost	& Cons.Cost	LCC
4											
5	Ceiling-R "0"	$0	0.4005	0.774	720.90	$20,091	1392.66	$3,182	$20,091	$23,274	
6	Add R11	$486	0.0987	0.191	177.66	$4,951	343.44	$785	$5,437	$6,222	
7	Add R19	$720	0.0686	0.133	123.48	$3,441	238.50	$545	$4,161	$4,706	
8	Add R30	$1,098	0.0494	0.095	88.92	$2,478	171.72	$392	$3,576	$3,969	
9	Add R38	$1,314	0.0398	0.077	71.64	$1,997	138.24	$316	$3,311	$3,626	
10	Add R49	$1,566	0.0329	0.064	59.22	$1,650	114.48	$262	$3,216	$3,478	
11	Add R60	$1,764	0.0288	0.056	51.84	$1,445	100.08	$229	$3,209	$3,437	***
12											
13	Wall-2x4, R "0"	$0	0.6943	0.657	860.93	$23,994	815.05	$1,862	$23,994	$25,857	
14	Add R11	$347	0.1415	0.134	175.46	$4,890	166.04	$379	$5,237	$5,616	
15	Add R13	$422	0.1285	0.122	159.34	$4,441	150.78	$345	$4,863	$5,207	
16	Wall-2x6, R19	$880	0.0909	0.086	112.72	$3,141	106.76	$244	$4,021	$4,265	
17	Add R21	$1,004	0.0808	0.077	100.19	$2,792	94.86	$217	$3,796	$4,013	
18	Add R11, R14	$1,600	0.0592	0.056	73.41	$2,046	69.44	$159	$3,646	$3,805	***
19	Add R21, R14	$2,257	0.0433	0.041	53.69	$1,496	50.84	$116	$3,753	$3,870	
20											
21	Floor-R "0"	$0	0.1563	0.064	281.34	$7,841	115.38	$264	$7,841	$8,105	
22	Add R11	$594	0.076	0.031	136.80	$3,813	56.16	$128	$4,407	$4,535	
23	Add R19	$828	0.0549	0.023	98.82	$2,754	40.50	$93	$3,582	$3,675	
24	Add R30	$1,206	0.0408	0.017	73.44	$2,047	30.06	$69	$3,253	$3,321	***
25											
26	Single Glazing	$0	1.1212	2.102	313.94	$8,749	588.64	$1,345	$8,749	$10,094	
27	Alum. Double	$717	0.6639	1.724	185.89	$5,181	482.58	$1,103	$5,898	$7,001	
28	ATB Double	$1,187	0.3835	1.609	107.38	$2,993	450.63	$1,030	$4,180	$5,209	
29	Vinyl Double	$2,108	0.1368	1.509	38.30	$1,068	422.60	$966	$3,176	$4,141	***

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