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POTENTIAL ENERGY SAVINGS IN THE RESIDENTIAL SECTOR OF THE UNITED STATES

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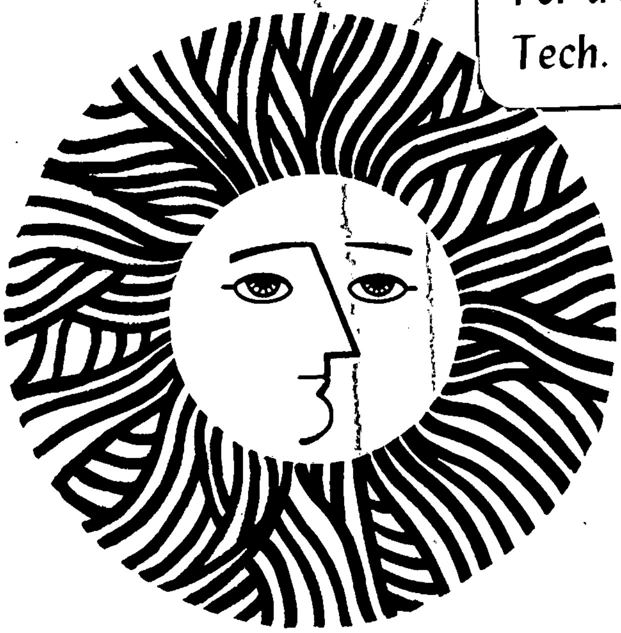

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DISCLAIMER

POTENTIAL ENERGY SAVINGS IN THE RESIDENTIAL SECTOR OF THE UNITED STATES

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ABSTRACT

Using the state-of-the art computer program, DOE 2.1, to simulate the hour-by-hour thermal performance of residential buildings in the four major climate zones of the United States, and applying a life-cycle cost analysis to determine the optimal energy requirement of a typical house, we have demonstrated that present levels of energy consumption can be reduced by a factor of two without compromising health and comfort standards. Within our present technology, additional energy savings can be achieved but not yet in a cost-effective way.

KEYWORDS

residential energy consumption; space conditioning; water heating; lighting; appliances; life-cycle cost minimum; computer simulation; energy-efficient designs.

INTRODUCTION

The residential sector in the United States encompasses some 80 million dwellings and accounts for almost 25% of the total energy consumption in the country. Of that percentage, by far the greatest proportion is for space conditioning (51% heating, 7% cooling). Domestic water heating accounts for 13%, lighting for 7%, and all other appliances for the remaining 22% (OTA 1979). It is apparent that reducing space-conditioning and water-heating requirements in the United States housing stock could result in substantial energy savings to homeowners as well as to the nation. Furthermore, development of more energy-efficient lighting devices as well as other appliances (mainly electric) could have an important impact on the remaining one-third of our residential energy usage.

This report presents the energy savings that are realizable in the residential sector through more efficient design of the building shell and its equipment and appliances. The analysis used for this determination is based on existing technology and know-how. Various options designed to achieve energy-efficient space conditioning are presented along with the one determined to be the most cost-effective to the consumer, (also based on current technology and fuel prices).

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For purposes of this report, we will consider the heating and cooling components of space conditioning as one entity. Domestic water heating, lighting, and appliances will be considered separately. At a later point in time, our cost-optimization procedure will be extended to regard all of these components as an integral system.

METHODOLOGY

Computer Model

The analytical tool used to determine energy requirements for space conditioning is DOE 2.1, a public-domain, state-of-the-art computer program capable of simulating hour-by-hour energy performance of a building in any given climate. This program was chosen because of its relative flexibility in handling variations in building design, even though its ability to model certain parameters remains limited. In our analysis, we consider technical conservation measures only -- that is, we ignore such occupant behavior as lowering thermostats. By "technical measures," we refer to increased wall, ceiling, and foundation insulation; multiple glazing on windows as well as movable insulation and shading; reasonable reductions in air infiltration; inclusion of thermal mass, whenever appropriate; and improved efficiency of equipment and appliances.

Assumptions

Climate zones. Four climate zones were selected as representing the major climates of the United States: (1) cool, (2) temperate, (3) hot-humid, and (4) hot-arid. The geographical boundaries of these climate zones are shown in Fig. 1 (Olgyay, 1973). For the purposes of this analysis, these four divisions are adequate; for specific applications, however, a more detailed study of a particular climate region would be necessary.

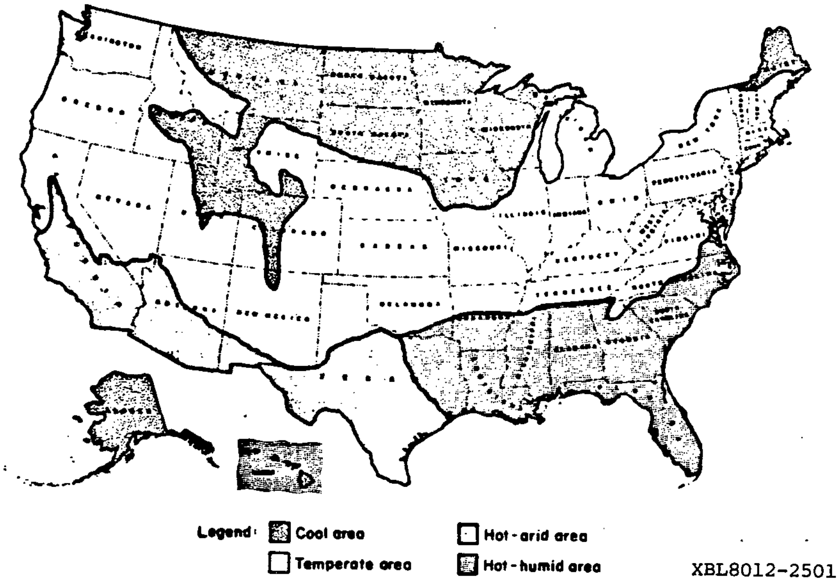

Fig. 1. Major climate zones of the United States.

House Characteristics. The prototype house modelled represents a composite of present design practices for an average newly constructed residential building in the United States, i.e., a one-story wood-frame house with a floor area of 1540 ft^2. The window area was assumed to be 10% of the floor area and equally distributed on all four sides of the building. Two options were used for the foundation of the building based on the foundation types most commonly used in this country -- basement or slab-on-grade.

Comfort conditions in the building were assumed to be 70 °F during the heating season and 78 °F during the cooling season; relative humidity between 30 and 60%; infiltration rate 0.6 to 0.9 air changes per hour (ach) (depending on the climate but adequate to preserve indoor air quality). Space-conditioning equipment is assumed to be a gas furnace with an air conditioner, and a heat pump. The respective efficiencies of this equipment were taken to be: gas furnace, 77% with 10% air-duct loss for a net efficiency of 70%; air-conditioner, EER 9.2; heat pump COP 3.0 at 47 °F and 2.3 at 17 °F (heating) and EER 9.2 (cooling). Under actual operating conditions, the seasonal performance of the air conditioner and the heat pump is much lower than the values given. Electric-resistance heating was not considered in this analysis because, generally, it requires more energy (primary resource) than gas heating or electric heat-pump heating. (Methodology and assumptions for modelling this prototype are presented in detail in Goldstein, Levine, and Mass, 1980.)

Additional advanced-design equipment also modelled are pulse-combustion gas heaters with an efficiency of 95% (to be made commercially available in the near future), air conditioners with an EER of 13, and water-to-air heat pumps (using ground water or solar-heated ground water) with a COP range of 3.2 to 3.9 and an EER range of 12.7 to 15.6 depending on the water temperature. The hot water heater, whether gas, electric-resistance, or electric heat-pump, is assumed to have a 40-50 gallon capacity (typical of latest models) and R-12 blanket or foam insulation.

In general, advanced-design equipment and appliances tend to be expensive and/or not widely available at the present time and, depending on the energy requirements specific to the climate, they may not be cost-effective. In the case of water-to-air heat pumps, for instance, an additional cost ($2,000 - $3,000) may be incurred simply to provide access to ground water.

Economic Analysis

The determination of cost-effective options for space conditioning is based on a life-cycle cost analysis, which involves assumptions related to conservation costs and fuel prices as well as projected discount rates and fuel escalation rates (See Levine and co-workers, 1979.). As in any economic analysis, the assumptions used introduce uncertainties, which can be crucial to the outcome -- in the present case, the minimum life-cycle costs derived.

Fuel and conservation costs were based on 1980 prices, and the fuel escalation rates for the next 30 years were obtained from forecasts compiled by the Energy Information Administration branch of the U.S. Department of Energy. The net discount rate (real discount rate minus inflation rate) was set at 5% based partially on historical trends observed in the United States. "Optimal conservation levels" are those reflecting the total life-cycle cost minimum achievable for a given house (initial conservation costs plus fuel costs over a typical mortgage period of 30 years). In all cases, there is more than one set of conservation measures whose life-cycle costs are nearly equal (less than 1% difference) to the absolute minimum. In such cases, we generally opt for the more stringent conservation measures, for even though such a selection entails higher initial investment in conservation, it also results in higher fuel savings over the life of the building. This decision also assures that the measures selected are uniform over large regions of the country.

Energy savings tend to be highest when the most cost-effective conservation measures are implemented; further improvements show a proportionally descending rate of savings, as illustrated in Table 1 for insulation of the building envelope. In an already well insulated building, any significant reduction of energy requirements involves improvements in equipment or in their efficiency.

TABLE 1 Energy Budgets for Varying Levels of Envelope Insulation in a Single-family One-story House in Washington, D.C.

Insulation Level			Energy Budget (per annum)[a] (in kBtu/ft²)	
Ceiling(R)	Wall(R)	Window Glazing(#)	Heating	Cooling
0	0	1	87.76	11.22
19	11	1	38.24	8.08
19	11	2	27.11	7.64
19	19	2	23.80	7.47
30	19	2	21.22	7.28
30	19	3	18.04	7.04
38	19	3	17.16	6.97
49	19	3	16.39	6.91
49	27	3	15.03	6.83
60	27	3	14.56	6.80

[a] Heating budget assumes a gas heater at 70% net efficiency and cooling budget assumes an electric air conditioner with an EER of 9.2.

RESULTS OF THE ANALYSIS

The estimated present distribution of households and their respective energy consumption for the four major climate zones in the United States is given in Table 2. It is assumed that the electricity conversion efficiency is 10,200 Btu of fuel (primary resource) for every kWh of electricity delivered.

For each of the four zones listed, the potential energy savings for space conditioning are examined separately. Comparable savings in hot-water heating, lighting, and the use of appliances are examined in detail although lighting and appliances, not being sensitive to weather, do not require a breakdown by climate zone.

TABLE 2 Residential Energy Consumption in the United States by Climate Zone (1980)[a]

Climate Zone	No. of Households (10^6)	Annual Energy Consumption[b] (primary resource) (10^{15} Btu)
Cool	5.2	1.3
Temperate	52.3	12.0
Hot-Humid	14.2	3.2
Hot-Arid	8.3	1.5
Total	80.0	18.0

[a] Data extracted from ORNL (1979), AGA (1978), and DOE (1979)

[b] Actual energy consumption is 5% lower because 5% of the total number of U.S. residences, on the average, is vacant in any given year.

Space Conditioning (Heating and Cooling)

The base-case house employed in this comparison is assumed to use gas for heating and electricity for cooling, reflecting common practice in the United States today (AGA 1978; DOE 1979).

Cool climate. The present energy consumption in the cool climate zone is 140 MBtu/yr for heating and 2165 kWh/yr for cooling. The saturation level of air conditioners is 60% in this zone; thus the actual energy consumed for cooling is 1300 kWh/yr. Our energy analysis for houses in this climate zone indicates that the life-cycle cost minimum would be obtained with R-49 ceiling insulation; R-27 wall insulation (R-19 batt plus R-8 sheathing); R-10 exterior perimeter insulation (eight feet down to basement floor level or, if freezing of the basement is not a problem, R-19 batt underfloor insulation); and triple glazing for windows and glass doors. The energy requirements for the prototype house of this level of conservation would be 90 MBtu/yr for gas heating and 1300 kWh/yr for electric cooling. In this climate, neither fixed window overhangs nor the color of roof and walls has any net effect on the total load of the building. Similarly, the inclusion of thermal mass in the building, in the form of exposed concrete floor or walls, has no effect on heating loads and a slight effect on cooling loads. Increasing the area of the south windows would result in a net increase in energy consumption unless movable night insulation (R-5) is used from 5 P.M. to 8 A.M., October through May, and movable day shading is used in the remaining months to achieve a 50% reduction in solar gain, a net savings on the order of 10% can be gained even with a 10 to 15% increase in south window area.

Additional savings can be achieved by installing more efficient gas heaters (e.g., pulse-combustion gas heaters) in which case a net reduction of about 1 MBtu/yr can be realized for every percent increase in net efficiency above 70%. The effect of increasing the efficiency of the air conditioners is not as dramatic because the energy requirement for cooling is relatively low. The use of air-to-air heat pumps is ruled out in this climate zone because the severe winter conditions cause their performance to deteriorate to the level of an electric-resistance heater; however, a water-to-air heat pump operating in a 40 °F to 50 °F underground water temperature in the winter and 60 °F to 70 °F in the summer does have energy-saving potential for this climate. The results of our analysis are summarized in Table 3.

TABLE 3 Effect of Energy-saving Measures on Annual Space-conditioning Energy Requirements: Cool Climates

	Present Base House[a]	Life-Cycle Cost Minimum House[b]	Increased South Window Area[c]	Water-to-Air Heat-Pump[d]	Pulse Combustion Gas Heater[e]
Heating	140 MBtu	91 MBtu	80.1 MBtu	6150 kWh	69.7 MBtu
Cooling[f]	1300 kWh	780 kWh	820 kWh	310 kWh	550 kWh
Total primary resource	153.3 MBtu	99 MBtu	88.4 MBtu	65.9 MBtu	75.3 MBtu

[a] Energy presently consumed.

[b] Energy consumed in prototype: 1540 ft^2 floor area, 10% glass, gas-heated.

[c] Same as b but with 20% window glass (south glass 12.5%, R-5 night insulation, movable shading).

[d] Same as b but with a water-to-air heat pump.

[e] Same as b but with a pulse-combustion gas heater and advanced-design air conditioner.

[f] Assumes 60% saturation level of air conditioners.

Temperate climate. The present energy consumption in the temperate zone is 125 MBtu/yr for gas heating and 2165 kWh/yr for cooling. The saturation level of air conditioners is 60% in this zone; thus the actual energy consumed for cooling is 1300 kWh/yr. Our analysis indicates that the life-cycle cost minimum for houses in this climate zone can be obtained with R-38 ceiling insulation; R-19 wall insulation; R-10 exterior perimeter insulation (eight feet down to the floor of the basement or, if freezing of the basement is not a problem, R-19 underfloor batt insulation or, for slab on grade, R-10 exterior perimeter insulation down two feet from top surface of the slab); and triple glazing for windows and glass doors. The energy requirements for the prototype house at this level of conservation are 47 MBtu for heating and 780 kWh for cooling. It was found that substantial energy savings could be achieved (on the order of 20%) by increasing the area of the south glazing from 10 to 15%, including thermal mass in the form of exposed concrete slab (direct solar gain), and installing R-5 movable insulation for the winter and movable shading for the summer months. Fixed shading over the windows and color variability of walls and roof have generally a negligible effect on the net energy consumption of the building. The use of an air-to-air heat pump in most locations in the temperate zone has an overall energy resource requirement equal to that of a gas-heated building. Pulse-combustion gas heaters have the potential of reducing the energy resource requirement by about 20%, whereas water-to-air heat pumps can reduce this energy resource requirement by about 35%. The results of our analysis are summarized in Table 4.

TABLE 4 Effect of Energy-saving Measures on Annual Space-conditioning Energy Requirements: Temperate Climate

	Present Base House[a]	Life-Cycle Cost Minimum House[b]	Direct Solar Gain[c]	Air-to-Air Heat Pump[d]	Water-to-Air Heat Pump[e]	Pulse-Combustion Gas Heater[f]
Heating	125 MBtu	47.0 MBtu	37.5 MBtu	4600 kWh	3200 kWh	36.6 MBtu
Cooling[g]	1300 kWh	780 kWh	860 kWh	780 kWh	330 kWh	550 kWh
Total primary resource	138.3 MBtu	55.0 MBtu	46.3 MBtu	54.9 MBtu	36 MBtu	42.2 MBtu

[a] Energy presently consumed.

[b] Energy consumed in prototype: 1540 ft^2 floor area, 10% glass, gas heated.

[c] Same as b but with 20% window glass and thermal mass (south glass 12.5%, exposed concrete slab, R-5 night insulation, movable shading).

[d] Same as b but with an air-to-air heat pump.

[e] Same as b but with a water-to-air heat pump.

[f] Same as b but with a pulse-combustion gas heater and advanced-design air conditioner.

[g] Assumes 60% saturation level of air conditioners.

Hot-humid climate. At present, the average energy consumed for space conditioning in hot-humid climates is 74.2 MBtu/yr for gas heating and 7500 kWh/yr for cooling. The saturation level of air conditioners is 90% in this zone; thus the actual energy consumed for cooling is 6750 kWh/yr. According to our analysis, the life-cycle cost minimum for houses in this zone could be achieved with R-30 ceiling insulation; R-19 wall insulation; R-5 exterior perimeter insulation for slab-on-grade two feet down from top surface; and double glazing. These measures would reduce the heating budget to 12.5 MMBtu/yr and the energy used for cooling to 4850 kWh/yr. Although of lesser effect, additional measures for reducing energy requirements include the installation of fixed shading, 3-ft overhang, on south-facing windows and 5-ft overhang on west-facing windows for a gain of about 4%; light roof color for a gain of 3%, and light wall color for a gain of 2%. If the concrete slab is exposed to provide thermal mass, and movable shading is used in the summer to reduce solar gain, the south window area can be increased to as much as 5% of the floor area without causing any net loss in resource energy requirements. A net decrease cooling energy of 25% can be gained by using a whole-house fan for ventilation when the outdoor temperature is below 82 °F and using the air-conditioner only when temperatures exceed 82 °F.

Use of more efficient air conditioners can further reduce the cooling load at the rate of 4.5 MBtu/yr of primary energy resource for every 10% improvement of the EER above the base case of 9.2 used in our analysis. Air-to-air heat pumps can be used anywhere in this region, and water-to-air heat pumps are cost-effective as long as wells used for irrigation and drinking are already present. The energy-saving measures and gains for this zone are summarized in Table 5.

TABLE 5 Effect of Energy-saving Measures on Annual Space-conditioning Energy Requirements: Hot-humid Climate

	Present Base House[a]	Life-Cycle Cost Minimum House[b]	Direct Solar Gain[c]	Direct Solar Gain Masonary Construction[d]	Whole-House Fan[e]	Air-to-Air Heat Pump[f]	Water-to-Air Heat Pump[g]	Advanced Air-conditioner[h]
Heating	74.2 MBtu	12.5 MBtu	12.0 MBtu	11.6 MBtu	12.5 MBtu	1500 kWh	710 kWh	9.6 MBtu
Cooling[i]	6750 kWh	4365 kWh	4185 kWh	4055 kWh	3185 kWh	4365 kWh	2880 kWh	3090 kWh
Total primary resource	143.1 MBtu	57 MBtu	54.7 MBtu	53.0 MBtu	45.0 MBtu	59.8 MBtu	36.7 MBtu	41.2 MBtu

TABLE 6 Effect of Energy-saving Measures on Annual Space-conditioning Energy Requirements: Hot-arid Climate

	Present Base House[a]	Life-Cycle Cost Minimum House[b]	Direct Solar Gain[c]	Direct Solar Gain Masonary Construction[d]	Evaporative Cooler[e]	Air-to-Air Heat Pump[f]	Water-to-Air Heat Pump[g]	Advanced-design Air-Conditioner[h]
Heating	30.0 MBtu	7.0 MBtu	6.5 MBtu	6.5 MBtu	7.0 MBtu	840 kWh	410 kWh	5.4 MBtu
Cooling[i]	7000 kWh	5095 kWh	4870 kWh	4660 kWh	4076 kWh	5095 kWh	3125 kWh	3605 kWh
Total primary resource	101.4 MBtu	59.0 MBtu	56.2 MBtu	54.0 MBtu	48.6 MBtu	60.5 MBtu	36.1 MBtu	42.2 MBtu

[a] Energy presently consumed.

[b] Energy consumed in prototype: 1540 ft^2 floor area, 10% glass with movable shading, gas heated.

[c] Same as b but thermal mass (exposed concrete slab) and movable shading.

[d] Same as b but with masonry construction (heavy thermal mass) and movable shading.

[e] Same as b but with air-conditioning set-temperature 82°F outdoor dry-bulb.

[f] Same as b but with an air-to-air heat pump.

[g] Same as b but with a water-to-air heat pump.

[h] Same as b but with a pulse-combustion gas heater and advanced-design air conditioner.

[i] Assumes 90% saturation level of air conditioners.

Hot-arid climate. The present energy consumption in this zone is 30 MBtu/yr for heating and 7775 kWh/yr for cooling (excluding the coastal areas of southern California where cooling requirements are very small). The saturation level of air conditioners is 90% in this zone; thus the actual energy consumed for cooling is 7000 kWh/yr. The life-cycle cost minimum for houses in this climate zone can be obtained with R-30 ceiling insulation; R-19 wall insulation; R-5 exterior perimeter insulation for slab-on-grade two feet down from top surface; and double-glazed windows and glass doors. The energy required for the prototype house at this level of conservation would be 7 MBtu/yr for heating and 5660 kWh/yr for cooling. Other measures that could further reduce the energy requirements include installation of 3-ft overhangs on south windows and 5-ft overhangs on west windows for a gain of 4%, light roof color for a gain of 3%, and light wall color for a gain of 2%. As with houses in the hot-humid zone, the presence of thermal mass in the form of exposed concrete floor-slab and movable shading in the summer to reduce solar gain, allows the south window area to be increased up to 5% of floor area without incurring any net loss in resource energy requirements. If heavy masonry construction is used, assuming the same levels of insulation on the exterior of the building, the south glass area could be increased to as much as 12.5% before any net loss would be incurred.

Air-to-air heat pumps and water-to-air heat pumps can be used anywhere within this climate zone and, as in hot-humid climates, the latter is cost-effective when wells used for other purposes already exist. Using evaporative coolers when the outdoor temperature is at 82 °F or below, and air conditioners only when temperature is above 82° could result in an energy resource savings of roughly 20%. More efficient air-conditioners can further reduce the cooling energy requirements at the rate of 5 MBtu/yr primary resource for every 10% improvement of the EER above the base case EER of 9.2 used in our analysis. The energy savings and gains for this climate zone are summarized in Table 6.

Domestic Hot-Water

Energy consumption of domestic hot water for the four climate zones is given in Table 7. In the same table, the potential energy consumption when water heaters are insulated with R-12 batt or foam is also given for gas and electric (electric resistance and heat-pump) heating. It is obvious from the table that in terms of their consumption of primary energy resources, gas water heaters are the most efficient in all climates, and heat-pump water heaters compare favorably in the warm climates.

TABLE 7 Effect of Energy-efficient Domestic Water Heaters on their Annual Energy Requirements, by Climate Zone

Zone	Average Gas Energy Consumption[a]	Efficient Water Heaters[b]		
		Gas	Electric-Resistance	Heat-Pump
Cool	35.0 MBtu	22.0 MBtu	40.8 MBtu (4000 kWh)	N/A
Temperate	32.9 MBtu	21.0 MBtu	39.3 MBtu (3850 kWh)	24.6 MBtu (2400 kWh)
Hot-Humid	25.2 MBtu	20.0 MBtu	37.8 MBtu (3700 kWh)	21.0 MBtu (2055 kWh)
Hot-Arid	29.9 MBtu	20.0 MBtu	37.8 MBtu (3700 kWh)	21.0 MBtu (2055 kWh)

[a] In all climate zones, 90 to 100% of water heaters use gas.

[b] Capacity assumed to be 40-50 gal; insulated with R-12 batt (fiberglass) or foam (polyurethane or polystyrene).

Lighting and Appliances

The present levels of energy consumed for lighting and appliances are about the same for all four climate zones and are given in Table 8, together with the performance of state-of-the-art lighting devices and other appliances. The greatest gains have occurred in the area of lighting: the new compact fluorescent and halarc lamps (40 to 50 lumens/watt) can improve the average light output to 25 lumens/watt from the present average output of incandescent lights of about 12 lumens/watt or, alternatively, from about 1 watt/ft^2 to 0.5 watts/ft^2.

TABLE 8 Effect of Energy-efficient Lighting and Appliances on their Annual Energy Requirements (All Climate Zones)

Device/ Appliance	Present Saturation Level[a] (percent)	Average Energy Consumption per Unit[a]	State-of-the-Art Energy Consumption per Unit	Present Energy Use	Present Potential Energy Use
Lighting	100	1267 kWh	650 kWh	1267 kWh	650 kWh
Refrigerator	100	1400 kWh	1125 kWh	1400 kWh	1125 kWh
Freezer	45	1345 kWh	950 kWh	630 kWh	428 kWh
Range-Oven (elec.)	55	1246 kWh	1200 kWh	685 kWh	660 kWh
Dryer (elec.)	43	1115 kWh	950 kWh	479 kWh	408 kWh
Miscellaneous	30	2355 kWh	1650 kWh	706 kWh	495 kWh
Range-Oven (gas)	45	10.0 MBtu	6.0 MBtu	4.5 MBtu	2.7 MBtu
Dryer (gas)	20	7.5 MBtu	6.5 MBtu	1.5 MBtu	1.3 MBtu
Total Electric				5167 kWh	3766 kWh
Total Gas				6.0 MBtu	4.0 MBtu
Total primary resource				58.7 MBtu	42.4 MBtu

[a] Based on unpublished data from J. McMahon, Lawrence Berkeley Laboratory.

SUMMARY OF RESULTS

Using the results of the analysis, we can now estimate the potential energy resource consumption in the residential sector assuming that all existing households in the various climate zones are properly insulated and equipped with energy-efficient devices and appliances. For the space-conditioning systems, we chose the life-cycle minimum over other energy-saving options because it is presently the most cost-effective for the consumer. Table 9 summarizes these results.

TABLE 9 Potential Annual Energy Consumption in U.S. Residences by Climate Zone[a]

Climate Zone	No. Households (10^6)	Primary Energy Consumption (10^{15} Btu)
Cool	5.2	0.85
Temperate	52.3	6.29
Hot-Humid	14.2	1.69
Hot-Arid	8.3	1.01
Total	80.0	9.84

[a] Potential is based on current life-cycle cost minimums for space-conditioning and state-of-the-art water heaters, lighting devices, and appliances.

Comparing the energy-consumption figures in Tables 2 and 9, we conclude that, under present technology and consistent with the criterion of cost-effectiveness, residential energy consumption in the United States could be reduced from 18 quads to 9.84 quads per year, or by 45 percent, without affecting our standard of living. Under present technology, energy consumption could be even further reduced to 8 quads per annum or 55 percent from the present level but not, as yet, in a cost-effective way. These additional savings could be achieved with the combined simultaneous use of advanced designs for the building envelope (passive solar) and more efficient gas-heating devices (pulse-combustion furnaces) and electric heating and cooling devices (water-to-air heat pumps, ultra-efficient air conditioners). Furthermore, integrated systems that use the waste heat of one device as the source heat of another (such as water heater/air conditioner, furnace/water heater, refrigerator/water heater and drain-water heat recovery) can produce even greater savings. As stated in the introduction, we plan to evaluate the performance and cost-benefits of integrated systems in the near future.

CONCLUSIONS

From the preceding analysis, it becomes apparent that the present energy consumption in the residential sector, even with presently available technology and know-how, can be reduced, cost-effectively, by a factor of almost two. A further reduction is also possible if more advanced systems are used, even though such usage does not appear to be cost-effective at present fuel prices.

Two questions arise with regard to implementing the results of our analysis (1) Can this energy reduction actually be accomplished on a national scale? (2) How long would it take for that to happen? The first question is difficult to answer because it involves human behavior, an entity that cannot be modelled with any accuracy. Conflicting statements have appeared with regard to consumer response to fuel prices and energy conservation (Levine and Graig 1980; OTA 1979). Assuming that consumers can be encouraged to think seriously about using energy more efficiently, the answer to the second question involves a rather simple calculation. If 2 to 3% of the housing stock is replaced every year, and if all houses built after 1981, for example, were built and equipped according to the standards given in our analysis, then it would take 30 to 50 years to reduce energy consumption by a factor of two. Since the equipment used in houses is normally replaced two or three times during the lifetime of the building, and the envelope of existing buildings is also periodically upgraded, the lag time could be brought down to 20 to 30 years. From a technical standpoint, the outlook is optimistic. If the physical and social scientist assume joint responsibility for facilitating the shift to an energy-efficient economy, the homeowner and the nation as a whole will reap the benefits.

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