ENERGY UTILIZATION BY HOUSEHOLDS AND TECHNOLOGY ASSESSMENT AS A WAY TO INCREASE ITS EFFECTIVENESS

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ABSTRACT

ENERGY UTILIZATION BY HOUSEHOLDS
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by

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Energy shortages on the one hand, consequences of energy use on the other hand, are threatening our way of life. Shortages are manifest in the difference between availability and expectancy, largely a societal phenomenon. Market, public policy, and technology in combination -- governed by the level of knowledge -- will continue to change the relationship between availability and expectancy. Several options will be pursued: find new as yet unkown sources, increase and improve production and distribution of known energy resources, or, reduce consumption by means of social measures; but the outcome is difficult to predict. More predictable appear to be the consequences of the intensive management of end-uses, that is, maximizing utilization effectiveness. This approach is the subject of this study.

The work is presented in two parts. The first, set against a general background of the energy situation in the United States, is a description of the great multitude of energy uses, practices, and potentials for improving utilization efficiency. An attempt is made to clarify the meaning of "conservation" which relates to the issue. This part then

constitutes a data base essential for the development of a management method aimed at reducing the differential between availability and expectancy, in tune with "a Btu saved is a Btu earned."

The second part of the study points to the critical role of the decisions made within family units which control energy consumption, either directly, or indirectly in the form of products and services. Seen in this light, the residential or household sector is responsible for an exceedingly large, but still indistinctly dimensioned share of the overall demand for energy resources. It is in this sector that energy consumption is assumed as least amenable to management-rationalized practices. Yet, major benefits could accrue from such practices to consumer, the environment and society as a whole.

The management method that is proposed and illustrated is an outgrowth of the concept of technology assessment. The application of the concept to analysing and evaluating the great multitude of components comprising the final aggregation of energy consumption in a micro-approach is new, and differs to some extent from the macro-projects for which technology assessment was originally introduced. New also is the use of a "satisfaction index" which depends on four interrelated "human-wants categories," a scheme by which environmental, social, and individual human factors are added to the familiar provision of goods and services. The index is an attempt to create a scale for measuring well-being, i.e., quality of life, which in industrial society critically depends on adequate supplies of energy (and materials and information).

The proposed scheme goes beyond conventional management methods which normally operate in an almost exclusively economic and technical context. Evaluation of alternatives is illustrated by means of crude trial assessments done by four different groups of "assessors" guided by varied sets of instructional information. The assessments identify and thereby permit the ordering of respective advantages and disadvantages in terms of their impact on the categories which determine the quality of life.

The findings justify further exploration and development of the scheme. It elicits remarkably few difficulties in the mechanics of its use. However, it does exhibit shortcomings whith respect to uniformity and consistency among the individual assessments. Initial investigation of the problem discloses, among other points, need for: (1) judicious peparation of the assessor, (2) careful selection and description of alternatives, (3) greater specificity with respect to categories, (4) weighting of categories, (5) time horizons, and (6) further trials giving effect to the preliminary findings. It appears that at the very least the scheme has merit as a heuristic device useful in educating decision-makers. It promises to improve capability in socially-effective decision-making, particularly at the level of the family unit where most of the critical decisions with respect to energy utilization are made.

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PART A

I. INTRODUCTION: Energy, the Environment, and Energy Consumers

The use of tools and the utilization of energy have traveled a parallel path through man's recorded history. The story of industrialization is interwoven with the development of tools to extend man's dependence on energy, first to make the tools, and then to power them. The energy output of primitive man's own body was supplemented by energy stores of the animal and plant world, plus natural energy existing in the earth environment, fire, wind, water, which in turn are derived primarily from the most basic energy resource of all, the sun. In addition, through uses of energy, man has sought comfort and amenities, mobility and communication through the employment of energy forms, such as artifically lengthening the natural daylight hours. Higher-order civilizations depend on and can only function through power derived from non-human energy, indeed, fantastic quantities of it. Man himself is good for only about .05 horsepower of external work on the average (1 kWh/day), whereas the U.S. per capita daily energy consumption is about 800 kWh/day equivalent.[(1)]

Through man's earlier ages he has resorted to the use of energy resources that were mostly renewable on the scale of man's lifetime. The

(1) M. Jack Snyder and Cecil Chilton, PLANNING FOR UNCERTAINTIES: Energy In The Years 1975-2000, in Battelle Research Outlook, Vol. 4, No. 1, 1972, Battelle Memorial Institute, Columbus, pp. 4 and 5.

industrial era, by its increasing demands for energy, ushered in the large-scale use of non-renewable fossil fuels, apparently starting with coal and peat, then later on, oil, gas, and nuclear fuels. Application of power, extracted and converted from these fuels, has grown at compound rates, especially in the United States.

It is difficult to assess, or even comprehend, the magnitude of what energy means to modern society. Attempts are frequently made to characterize it by quoting the fact that the highly industrialized United States with merely 6% of the world's population uses 35% or more of the world's energy.[(2)] It is not clear what this statement is supposed to imply. To some persons high energy consumption is a good thing, to others it is a sin. The citing of data that had been intended to bring the issue into better focus, for example, that energy consumption in the United States represents about 4% of GNP,[(3)] does not help much. It only goes to show the need for great care in interpreting available information when assessing the impact of energy uses.

An energy resource by the usual definition is not a resource until it is available for use. It is the problem of availability which is of highest concern in any discussion of energy problems. Technology, functioning in accord with natural laws, has the capability to increase availability, which in turn encourages the development of energy technology. The process has been closely linked to economic growth and development, although by no means are all of the relationships well understood.

(2) President Richard M. Nixon, in an Energy Message to the United States Congress, June 29, 1973 (as reported in the Detroit Free Press, June 30, 1973).

(3) , TIME Magazine, May 7, 1973, p. 41.

Abundance and availability of fossil fuels made them cheap--so cheap in fact, that the freest use was taken for granted. Expanding demand, and the resulting scale of production, reduced costs. Technology helped to make these reduced costs possible. The promise of atomic power bolstered the notion of the availability of cheap energy. The energy enterprises did their best to promote consumption and new uses of energy, as did the suppliers of energy-consuming devices.

The fantastic economic growth in the United States, supported by available energy resources, eventually made these resources into a strategic necessity. During more recent years, voices of doubt and concern over effects on man and his environment were being heard with increasing frequency. "Environmental pollution" and "ecological damage" became key phrases. It was pointed out that human health and the future of mankind were being endangered, that the cheap energy costs ignored significant externalities. Questions centered on the waste-assimilation capacity of the environment--which society has to live with and live in--to absorb the massive and often potentially dangerous wastes generated in energy production and consumption.

The "great ecology movement" was symbolically born when President Johnson pronounced his "great-society" policy. "...the water we drink, the food we eat, the very air we breathe, are threatened with pollution..."(4) At the same time the late President stated that "the great society rests on abundance." It did not take very long to recognize, however, that such abundance has absolute limits. Many writers and scholars became preoccupied with the environmental issues, and only much more recently with the

(4) Lyndon B. Johnson, speech at Commencement Exercises, Ann Arbor, Michigan, May 22, 1964.

availability of natural resources, especially energy resources.[5] Complaints were voiced that the energy industries, supported by regulatory policy, had aimed investments solely at increasing productive capacity, with only token allocation to R & D, and that little consideration had been given to environmental impacts and their social costs.[6] The ecological concerns so expressed took concrete form in a series of federal and state legislative acts to protect the environment. That energy use is to various degrees in conflict with the environment found slow acceptance, as is the case with the finiteness of availability of non-renewable energy resources.

Viewing these developments with hindsight, one can see that the preoccupation with the environmental issues was one of the factors that delayed our coming to grips with how we use our earth resources, particularly energy resources. It took until the early 1970's for the energy problem to become recognized in its own right. At some not very ascertainable point in time, the energy issue surfaced to stand side by side with the environment issue, the causes of which are to a large extent to be found in the various forms of energy utilization. To put it differently, a fair question might be: why did society look at environmental degradation and engage in efforts to halt it, rather than face the energy problem itself, making energy utilization more efficient in economic, technical and environmental terms,

(5) A comprehensive collection may be found in:
SELECTED READINGS ON ECONOMIC GROWTH IN RELATION TO POPULATION INCREASE, NATURAL RESOURCES AVAILABILITY, ENVIRONMENTAL CONTROL AND ENERGY NEEDS, Committee on Interior and Insular Affairs, U.S. Senate, SR 45, Series 92-3, USGPO, Washington, 1971.

(6) CONSIDERATIONS IN THE FORMULATION OF A NATIONAL ENERGY POLICY, Committee on Interior and Insular Affairs, U.S. Senate, SR 45, Series 92-4, USGPO, Washington, 1971, particularly p. 24.

conserving energy, and thereby solving both energy and environment problems simultaneously?

In retrospect, it almost seems that for some period of time the illusion persisted that environmental problems had to be and could be solved independent of, and without interfering with, patterns of growth in energy consumption. That additional amounts of energy were to be used for "environmental protection" seems to have escaped notice. Depletion of non-renewable energy resources was given small weight in the debate over what was happening to the ecology.

Now that the problem is being recognized for what it is, courses of action are being set into motion. Fortunately, there are several policy alternatives. One such alternative is for government, business operators, families, and individuals to put into effect a program of improving on energy-utilization technologies and practices directed toward using available energy resources more wisely. The assumption is that there are almost unlimited opportunities to do so, that benefits in terms of economic and enviromental cost reduction could indeed be substantial, and that extension of available fuel resources so achieved would allow more time for the development of, and transition to, new or improved energy resources and technologies, knowledge and skills.

All of this is being said mindful of the constraints imposed by natural laws, for example thermodynamics, which tell us that energy once utilized cannot be recycled. Energy availability imposes a limit on man's activities, and this study accordingly argues the case for energy utilization efficiencies to be carefully optimized in the best interest of society.[7]

The objective of the present study is to develop a methodology, or rather a framework for a methodology, which can identify and order the alternatives leading to the deliberate adoption of best-possible strategies. The importance of energy resources to the quality of human life mandates that considerations other than market distribution of energy be a part of the strategies, that is, the physical environment, the individual self, and the social environment along with social justice. In a wider framework, however, the concept of quality of life might be extended to encompass and weight values beyond the ones commonly considered. In this case the arguement would require reexamination as suggested in the second part (Part B) of this work.

The first and obvious step is to assemble a data base. It would indeed be a large task to scrutinize all energy uses. In order to limit the study to one specific area of interest and need, the "residential sector" was chosen. According to available statistical information this sector accounts for about one-fifth of the energy consumed in the United States.[8] The other major sectors are industry, transportation, and commercial (often lumped together with residential).

Sectoral division in this manner for purposes of rationalizing energy consumption, that is by industry, transportation, commercial and residential, or, by industry, transportation, electric power, commercial and residential, as it has come into use by policy-makers and students of the

(7) For an overview of how energy use to develop physical resources in the production chain of goods and services is limited by thermodynamic principles beyond purely economic constraints, see: Peter Chapman, NO OVERDRAFTS IN THE ENERGY ECONOMY, in New Scientist, May 17, 1973.

(8) ________, PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES, Office of Science and Technology, Executive Office of the President, done by Stanford Research Institute, USGPO, Washington, 1972, Table 1, p. 6.

energy problem, is unfortunate and misleading. The point is made that the primary locus of the demand for energy is centered in the decisions made within family units, either directly or indirectly, an argument to be dealt with in more detail. When seen in this light, the "residential sector" has a much larger dimension than is implied by the "one-fifth" generally referred to.

The probability of inefficient utilization of energy resources in household and peripheral uses, perhaps even waste, is assumed to be substantial. This assumption, and the further assumption that utilization efficiencies can be materially improved, forms the basis of the present study. Business and industry have the inherent capability to rationalize energy use to a high degree by following management principles. Unfortunately, household activities are less amenable to effective management practices, practices which influence the other sectors as is argued in the above. Few would contend that the consumption of energy resources need not be rationalized at all levels, but it appears to be most critical at family level, with respect to the various impacts on the family unit.

The energy problem is a complex one. Solutions will be sought in many ways. Categorized, there are these five options:

(1) Develop basic energy resources not now being used.

(2) Enlarge upon present sources of supply.

(3) Increase efficiency of conversion and distribution.

(4) Reduce consumption by means of social measures (meaning to reduce the standard of living).

(5) Improve the efficiency of "end-use."

As already indicated, the present study will concentrate on option (5), limited to residential or household end-uses.

To set the stage for an examination of energy uses by family units, and to create a data base, it is necessary to review several aspects of the energy situation in the United States. One is the nature of the demand, to be followed by a look at the price of energy. Then there are social forces which in turn are created by energy availability and energy technology, and which in turn are a part of social structure and have a role in social change. The price and supply outlook is related to evolving social change. And finally, the meaning of conservation needs to be clarified. Chapters II through VI are intended to provide this review. Chapter VII deals with energy utilization by family units and households. The second part of this study (Part B) proposes and describes a scheme for improving the decision-making processes in order to effect better utilization of energy resources.

II. DEMAND FOR ENERGY

There is no indication that any of the developments mentioned in the foregoing have had a slowing effect on demand. The term "demand" is used in a sense of "consumption over a period of time." What has happened, is, that there has been a shift from "dirtier" to "cleaner" fuels, accelerating demand for and more rapid depletion of the latter. Nuclear energy has been held back because of cost, safety, and environmental-impact questions. More recent demand studies and projections fail to raise hopes that demand trends will change of their own accord. Generally, the more recent projections show increases over earlier forecasts.(9)(10) Some of the underlying reasons which tend to accelerate growth and demand may be the additional energy needed to clean up past pollution effects and to lower existing pollution levels, the growth in numbers of women in the work force resorting to time-and effort-saving gadgets at home, and the possibility that leisure-time activities are relatively energy-intensive. Examples of the last are: week-ending and vacationing away from home, off-the-road vehicles, power-boating, or simply more travel over greater distances. Modern society extensively uses energy to overcome distance,

(9) SURVEY OF ENERGY CONSUMPTION PROJECTIONS, Committee on Interior and Insular Affairs, U.S. Senate, S.R. 45, Ser. 92-19, USGPO, Washington, 1972.

(10) Also see: ENERGY "DEMAND" STUDIES, An Analysis and Appraisal, Committee on Interior and Insular Affairs, U.S. House of Representatives, USGPO, Washington, Sept. 1972.

and to save time and reduce manual work. When the time so freed is taken up with other activities, as it most often is, the addition to demand has a multiplier effect not yet quantified. The rate at which human effort and time have been replaced with non-human-energy operated equipment may have been excessively rapid, the consequences being manifest in some of the contemporary social problems, resource depletion, and ecological upset.

What has been happening over the last 50 years is illustrated by Table 1. Of note is the acceleration in energy consumption during the 1960 decade, the fantastic increase in electricity consumption over the period, and finally, the trend reversal in energy consumption per dollar of GNP. For many years up to the mid-1960's, the energy required to produce a dollar's worth of GNP had been declining. Since then it takes relatively more energy to produce the same dollar's worth of GNP. Future economic expansion and growth policies will need to take this trend into account.

Over the period there have been remarkable shifts among the basic sources for energy and that part of the resources which has been end-used in the form of electricity. This shift is illustrated in Table 2.

TABLE [illegible]. TOTAL USE AND PER CAPITA U.S. ENERGY AND ELECTRICITY CONSUMPTION, GNP AND POPULATION 1950-1970.

TABLE 1. TOTAL USE AND PER CAPITA U.S. ENERGY AND ELECTRICITY CONSUMPTION, GNP AND POPULATION 1920-1970.

	Total Energy Consumption (trillion Btu)	Electricity Consumption (billion kWh)	GNP (billion 1958 dollars)	Population (million)	Energy Consumption (million Btu)	Electricity Consumption (kWh)	GNP (1958 dollars)	Energy Consumption (1000 Btu)	Electricity Consumption (kWh)
1920	19,782	57.5	140.0	106.5	185.8	540	1,315	141.3	.41
30	22,288	116.2	183.5	123.1	181.1	944	1,490	121.5	.63
40	23,908	182.0	227.2	132.6	180.3	1,376	1,720	105.2	.80
50	34.154	390.5	355.3	152.3	224.3	2,564	2,342	96.1	1.10
60	44,960	848.7	487.7	180.7	248.8	4,967	2,699	92.2	1.74
65	53,785	1,157.4	617.8	194.6	276.4	5,948	3,175	87.1	1.87
70	68,810	1,648.3	724.1	205.4	335.0	8.025	3,525	95.0	2.28

Source: ENERGY RESEARCH NEEDS, Consumption, Production, Technology, Environmental Effects, Policy Issues. A Report to the National Science Foundation by Resources For The Future, Inc. and MIT Environmental Laboratories, Oct. 1971, NITS PB-207 516, Table 1, p. I 7.

TABLE 2. TOTAL U.S. ENERGY CONSUMPTION, BY SOURCE AND FORM OF USE 1920-1970.

	By source					By form used			
						Fuel and power			
	Coal	Natural Gas	Petroleum	Hydro and nuclear	Total	Total	Electricity	Other	As raw material
	Trillion Btu								
1920	15,504	827	2,676	775	19,782	n.a.	1,663	n.a.	n.a.
30	13,639	1,969	5,898	785	22,288	n.a.	1,965	n.a.	n.a.
40	12,535	2,726	7,781	917	23,908	n.a.	2,458	n.a.	n.a.
50	12,914	6,150	13,489	1,601	34,154	32,712	5,142	27,570	1,442
60	10,414	12,699	20,067	1,780	44,960	42,715	8,387	34,328	2,245
65	12,358	16,098	23,241	2,088	53,785	51,140	11,104	40,036	2,645
70	13,792	22,546	29,617	2,855	68,810	64,910	16,967	47,943	3,900
	Percent								
1920	78.4%	4.2%	13.5%	3.9%	100.0%	n.a.	8.4%	n.a.	n.a.
30	61.2	8.8	26.5	3.5	100.0	n.a.	8.8	n.a.	n.a.
40	52.4	11.4	32.4	3.8	100.0	n.a.	10.3	n.a.	n.a.
50	37.8	18.0	39.5	4.7	100.0	95.8%	15.1	80.7%	4.2%
60	23.2	28.2	44.6	4.0	100.0	95.0	18.7	76.3	5.0
65	23.0	29.9	43.2	3.9	100.0	95.1	20.6	74.4	4.9
70	20.0	32.8	43.0	4.1	100.0	94.3	24.7	69.7	5.7

Source: ENERGY RESEARCH NEEDS, Consumption, Production, Technology, Environmental Effects, Policy Issues. A Report to the National Science Foundation by Resources For The Future, Inc. and MIT Environmental Laboratories, Oct. 1971, NITS PB-207 516 Table 2, p. I 8.

The data presented in Tables 1 and 2 do not clearly show the remarkable increase in the per kWh electricity yield per unit of primary energy resources. This trend is shown in Table 3.

TABLE 3. ELECTRICITY, PER KILOWATT-HOUR (kWh) YIELD DERIVED FROM BASIC FUELS 1920-1970.

	COAL	OIL	NATURAL GAS
		Requirements per kWh	
1920	3.05 lb.	.254 gal.	36.9 cu.ft.
30	1.60	.132	19.0
40	1.34	.112	16.5
50	1.19	.094	14.1
60	.88	.078	10.9
65	.86	.075	10.5
70	.91	.077	10.5

Source: U.S. Historical Statistics, Colonial Times to 1957, Series S 36-43
1972 Statistical Abstract of the United States, Table No. 829, p. 510.

Of note is that the continuing gain in yield ended about 1965. Since then, for coal and oil, there has been an unfavorable turn-around in trend, whereas for gas there has been no further gain. There appears to be a similarity with the trend noted earlier with respect to GNP and the energy required for a unit of growth in GNP. These developments are discussed further in Chapter V.

Also of note for the purposes of this study is the 1970 percent distribution of fossil fuel consumption in terms of eventual end-use as shown in Table 4.

TABLE 4. TOTAL U.S. CONSUMPTION OF ENERGY, BY SOURCE AND TWO CONSUMING SECTORS, 1970.

	Coal	Natural Gas	Petroleum	Utility Electricity	Total
Household & Commercial	2.3%	43.2%	37.3%	17.1%	100%
Industrial	23.8	44.9	21.7	9.7	100

56% of all electricity is consumed by residential and commercial uses.[11] The residential share alone of electricity consumption increased from 23.8% in 1950 to 32.3% in 1960.[12]

These data underline the growth of energy-resource consumption together with the environmental-impact problems attributable to household operation and peripheral residential energy-use activities. It is often assumed that population-increase factors account for the growth in energy consumption. This is only partially so, because the doubling time for population is 50-100 years, whereas the doubling time for energy consumption is about 10 years. Considering the thermodynamic inefficiencies associated with utilizing electric energy, it is not too difficult to see the major problem, namely, the multiplication of impact effect on the

(11) R. D. Doctor, THE GROWING DEMAND FOR ENERGY, Rand Corp., P-4759, Santa Monica, Cal., Jan. 1972, Figure 5, p. 16.

(12) From 1972 Statistical Abstract of the United States, Table No. 831 p. 512.

environment together with the accelerating depletion of fossil-fuel resources.

Upon switching an electric heating load of 1 kW-electrical to the network, energy resource demand will be increased by more than the equivalent of 3 kW-thermal. Going to the extreme, additional demand for 1 W-luminous useful incandescent-light output creates a demand on the order of 50 W-thermal energy-resource input at the generating plant.

The respective shares of electricity consumption in 1970 by the various sectors are shown in Table 5 below:

TABLE 5. DISTRIBUTION OF ELECTRICITY CONSUMPTION, BY SECTORS, 1970.

Residential	Commercial	Industrial	Other
33.4%	22.8%	42.8%	1%

Source: 1972 Statistical Abstract of The United States, Table No. 832, p. 512.

Two points can be made at this time. The first one is that the acceleration of growth in demand for electricity in the residential and commercial sector is also accelerating the demand for basic energy resources, but by multiple amounts. The second point is that any betterment in utilization efficiencies at the point of actual use would pay relatively high benefits in reducing pressure on basic energy resources and the environment.

To recap, energy consumption and growth rates, as more recently experienced in the United States, are shown in Table 6. The sectoral breakdown follows the method adopted by policy makers and others, but is not necessarily most effective toward reducing the energy problem.

TABLE 6. TOTAL AND SECTORAL ENERGY CONSUMPTION IN THE UNITED STATES, 1960 and 1968.

	Consumption (quadrillion Btu)		Growth Rate (percent)	Percent of Total	
	1960	1968		1960	1968
Residential	8.0	11.6	4.8%	18.6%	19.2%
Commercial	5.7	8.8	5.4	13.2	14.4
Industrial	18.3	25.0	3.9	42.7	41.2
Transportation	11.0	15.2	4.1	25.5	25.2
Total	43.0	60.6	4.3%	100.0%	100.0%

Source: PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES, Office Of Science And Technology, Executive Office Of The President, (Stanford Research Institute), USGPO, Washington, 1972, p. 5.

The structure of the so-called "residential demand" for energy is made up of factors such as those shown in Figure 1 which follows.

FIGURE 1. STRUCTURE OF RESIDENTIAL DEMAND FOR ENERGY

RESIDENTIAL DEMAND	=	CONSUMPTION PER HOUSEHOLD	x	NUMBER OF HOUSEHOLDS
		Personal transportation		Fertility rates
		Residential structure and setting		Rate of household formation
		Numbers and characteristics of household equipment, gas, electric or oil		Migration and other demographic factors
		Urban or rural household		
		Income per household		
		Fuel prices and electric rates		
		Prices of household appliances and other house equipment		
		Life styles, leisure and recreation activities and resulting wants		

III. PRICE

To look at demand without at the same time considering price would appear to be a wide departure from classic economics principles. The evidence suggests, however, that price has been a factor only for the energy companies and the regulating agencies. Though there are some few exceptions, price has had only a small role in consumer-sector behavior, i.e., residential and commercial. If anything, the price structure has simply encouraged consumption. Users, over the last 25 years at least, have hiked demand as if energy resources were forever abundant in supply, and price elasticity nearly zero. Most often, the first cost of the energy-using apparatus or building structure has been the primary criterion -- never mind life-cycle costs, which would include the energy to be consumed. This statement may be trite, but the supplier or builder does not have to pay the operating costs.

The demand-growth projections referred to earlier considered prices not at all, or only marginally.(13)(14). These projections were based on studies by some 30-plus different organizations, and were assembled for use by congressional committees and other government agencies. McCracken, before one of the committees, stressed past failure to use price for purposes of developing a national energy policy:

(13) _op. cit._, ENERGY "DEMAND" STUDIES.

(14) _op. cit._, SURVEY OF ENERGY CONSUMPTION PROJECTIONS.

" . . . There are critical substantive questions of energy economics that are unresolved but could be better answered if a more extensive effort were made . . . I would therefore like to take this opportunity to say what I believe is one important area of further research. A key unknown in the energy future is the price structure that will be required to equate future supply and demand. Meaningful judgments about the volume of energy required in the future and the pattern of prospective sources cannot be made without recognizing the role of price. Sometimes estimates of supply and demand are made without mentioning price, and potential supply/demand gaps are estimated that are then assumed to be a measure of the problem. In practice, so long as most energy markets are open and reasonably free, these gaps will not actually occur. Any potential gap would tend to be eliminated by changes in prices that would bring the various sources of supply and the different demands into equilibrium. Indeed, the change in the average level of real prices required to equate supply and demand in 1980 would be a better measure of the energy problem than a so-called energy gap which leaves unspecified its assumptions about prices."(15)

There is only meager information on the economic behavior of the energy-consuming public. We know by reading the meters how much energy is consumed; there is a dearth of information beyond this point.

Whether price under prevailing conditions is elastic, and to what degree, is unclear. There is insufficient evidence at present to make a case one way or the other. Additionally, there is not only the question of price elasticity between various forms of energy, but also the more complicated question bearing on consumer-expenditures for energy in any form, versus expenditures for other goods or services in the total of personal consumption. Available data are poor or inadequate for an evaluation of the price role.

It is not the purpose of this study to refute conclusions drawn by other studies which attempt to make a case for the price elasticity of

(15) Paul McCracken, former Chairman of the President's Council of Economic Advisors, in SURVEY OF ENERGY CONSUMPTION PROJECTIONS, op. cit., p. 61.

residential electricity as being 1.0.[16] It could be shown that there have been many more factors operating which tend to point toward inelasticity. For example, most uses of electricity save work and/or time. Many such uses of electricity have become a necessity rather than a matter of choice.

Stated in a different way, experience with energy price increases in the United States and their effects on demand has been too limited to draw any meaningful conclusions regarding price elasticity. We know, that the consumer response to a decrease in price can be significant as was demonstrated when natural gas became available in large quantities via long-distance pipelines. Its cost was much lower than the manufactured gas which had been used heretofore, and at the same time the cost of natural gas was much lower than other fuels when measured on a heat-content basis. Of course, there were other factors which made the lower cost gas more attractive. It is relatively "clean," and lends itself to nearly carefree automatic heating of homes. The question of utilization efficiency was not given much attention. One of the industry's goals was "load-building" to rationalize the large investments in production and distribution facilities. Table 7 is to illustrate the historical trend.

(16) John W. Wilson, RESIDENTIAL DEMAND FOR ELECTRICITY in Quarterly Review of Economics and Business, Vol. 2, No. 1, Spring 1971, University of Illinois, Champaign, pp. 7 and 8.

TABLE 7. RESIDENTIAL GAS CUSTOMERS, PERCENT HEATING WITH GAS, TOTAL, AND AVERAGE USE 1950-1970.

	House Heating percent of Gas Customers	Total Gas Customers (in 1,000)	Average Gas Use by Residential Customers (millions of Btu)	Population (in millions)
1950	40.7	24,001	62.5	152.3
55	56.0	28,479	85.2	
60	68.2	33,054	104.8	180.7
65	76.1	37,338	116.5	
70	81.0	41,482	129.2	205.4

Source: Gas Facts 1971, RESIDENTIAL CUSTOMERS, American Gas Association, New York, Table 61, p. 71.

1973 Statistical Abstract of the United States, POPULATION Table No. 2, p. 5.

Known energy resources, not necessarily available, are:

(1) Fossil fuels, oil, gas, coal, shale, and tar sands

(2) Materials suitable for nuclear fusion or fission

(3) Solar, including wind, water, tidal, and ocean thermal

(4) Geothermal

(5) Plant and animate.

The physical quantities of energy resources consumed in the United States are indeed large. Few people are capable of visualizing the enormous volumes involved, for others some highlights of 1970 consumption(17) may be helpful: 530 million tons of coal, 5 billion barrels of petroleum,

(17) From a Talk by Reginald H. Jones, Chairman and Chief Executive Officer, General Electric Co., Cincinnati, Jan. 17, 1973.

150 cubicmiles (at atmospheric pressure) of natural gas, and 75 cubic-miles of water falling from a height of 1000 feet. As yet only insignificant amounts of nuclear energy resources have a part. Energy represents roughly 7% of the U.S. GNP.

Unit prices for gas and electricity have not moved upward on a par with the general price level. In other words, over time the price of these fuels became a bargain. This is illustrated by Table 8.

TABLE 8. RETAIL PRICE INDEXES FOR FUELS AND ELECTRICITY, CONSUMER PRICE INDEXES 1940-1970 (1967 = 100).

	1940	1950	1960	1970
Electricity and Gas	82.1	81.2	98.6	107.3
All Items	42.0	72.1	88.7	116.3

Source: 1972 Statistical Abstract of the United States, Retail Price Indexes for Fuels and Electricity, Table No. 5674, p. 354, and Consumer Price Indexes, Table No. 565, p. 348. See footnotes with these tables for qualification of data which can be taken only as indicators.

Consumer-expenditures information, regularly and irregularly collected by the United States Department of Labor, Bureau of Labor Statistics, does not go into the details of energy expenditures. These are lumped into cost of shelter, or cost of household operation. The Bureau has not made any special studies concerning energy.[18] No

(18) , letter dated Feb. 23, 1973 from Joel Popkin, Assistant Commissioner, PRICES AND LIVING CONDITIONS, U.S. Dept. of Labor, Bureau of Labor Statistics.

evidence could be found to indicate that such data were assembled by any other agency or organization.

From some older, very limited survey data, we can see that energy, i.e., heat, light, and miscellaneous uses, has taken about 4 1/2 percent of the expenditures of one type of family. This 4 1/2 percent is a part of some 24 percent for shelter costs. There was a time when the energy share appears to have been higher as illustrated by Table 9.

TABLE 9. FUEL AND RELATED COSTS AS A PART OF THE FAMILY BUDGET, FROM SURVEYS 1917/19, 1934/36, 1950, 1960/61.

Survey Dates	1917-19	1934-36	1950	1960-61
Fuel, Light, Water and Refrigeration (ice) (percent of current consumption)	5.8	6.2	3.8	4.5
For comparison:				
Auto Purchase, plus operation plus other transportation (percent of current consumption)		7.8	13.2	14.9

Source: CITY WORKERS FAMILY BUDGET FOR A MODERATE LIVING STANDARD, Autumn 1966, Bulletin 1570-1, U.S. Dept. of Labor, Bureau of Statistics, p. 9.

Also, HANDBOOK OF LABOR STATISTICS 1971, U.S. Dept. of Labor, Bureau of Labor Statistics, Table 125, AVERAGE ANNUAL INCOME AND EXPENDITURES, FAMILIES (two persons or more), City Wage Earners and Clerical Workers.

These findings show how it has become possible for individual consumer units to buy more energy for a constant equivalent share of the consumer budget. Many factors have contributed to the absolute consumption increases. One factor is promotional activities by the energy firms and related industries. Another factor is the price trend of energy-fueled home equipment as illustrated by Table 10 which follows:

TABLE 10. PRICE INDEX OF APPLIANCES Vs. INDEX OF ALL ITEMS 1950-1970 (1967 = 100)

	1950	1960	1970
Appliances	138.3	117.9	104.1
All Items	72.1	88.7	116.3

Sources: 1971 HANDBOOK OF LABOR STATISTICS, U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Index, Urban Wage Earner and Clerical Workers, Table 117, p. 266.

1972 Statistical Abstract of the United States, Consumer Price Indexes, Table No. 5674, p. 354.

Obviously, trends such as these have favored the market for energy-consuming products, unleashing forces and consequences manifested in the increasing demand for energy. Relatively low energy prices, technology which made energy-consuming devices abundantly available, promotion of energy and product, coupled with social forces, have helped to create the so-called "energy gap."

IV. SOCIAL FORCES

Facts on the displacement of human effort by energy-powered machinery in agriculture, industry, transportation, and commerce are well known. Data on labor productivity are the comprehensive indicators of the shift from manual labor to work accomplished through use of tools which require energy to manufacture and use.

A parallel development has occurred in the American home, its activities and environment. Unfortunately, no paralleling data, e.g. productivity indicators, are available. To illustrate what has happened one must resort to inference. The basis for one such process is contained in the time-series statistics on women in the labor force. These statistics project an image of vast social change which has been made possible by energy and technology, both closely related. See Tables 11 and 12.

TABLE 11. WOMEN IN THE LABOR FORCE 1900-1972.

	Percent of Total Workforce	Percent of Women of Working Age
1900	18.1	20.4
10	20.9	25.2
20	20.4	23.3
30	22.0	24.3
40	24.3	25.4
50	28.8	33.9
60	32.3	37.8
70	36.7	43.4
72	37.4	43.8

Source: Economic Report to the President, January 1973, USGPO, Washington, Table 21, p. 91.

TABLE 12. MARITAL STATUS OF WOMEN IN THE CIVILIAN LABOR FORCE 1940-1970.

	Single	Married	Widowed or Divorced
1940	48.5%	36.4	15.1
50	31.6	52.1	16.3
60	24.0	59.9	16.1
70	22.3	63.4	14.3
Median Ages in 1971	22.3	40.7	52.6

Source: 1972 Statistical Abstract of the United States, Table 346, p. 219.

Additional emphasis can be placed on these data if one takes into account that availability and use of hired domestic help nearly disappeared in the process. In 1900, 29% of all female workers were classified as "household workers"; in 1970, it was 6%.[19] The source of such workers has also dried up. During the year 1900 there were 448,000 immigrants, of whom 9% are reported to have gone into domestic household work; during 1970 there were 373,000 immigrants, but fewer than 3% appeared to have entered into domestic household work.[20] In the interim, the number of United States households has grown from 16,000,000 in 1900 to 63,000,000 in 1970.[21]

(19) percent calculated from data in Historical Statistics of the U.S., colonial Times to 1957, A Statistical Abstract, Supplement, MAJOR OCCUPATION GROUPS, etc., Series D-72-122, p. 24; and 1972 Statistical Abstract of the U.S., LABOR FORCE etc., Table No. 341, p. 217.

(20) Historical Statistics of the U.S., Colonial Times to 1957, A Statistical Abstract Supplement, IMMIGRANTS BY MAJOR OCCUPATIONAL GROUPS etc., Series C-115-132, p. 60.

(21) Historical Statistics of the U.S., Colonial Times to 1957, A Statistical Abstract Supplement, HOUSEHOLDS etc., Series A-242-244, p. 15.
1972 Statistical Abstract of the U.S., HOUSEHOLDS etc., Table No. 50, p. 39.

Clearly energy-utilizing and time-saving devices in the home have made it possible for women to gain income in the employment-market place, while increasing the family unit's purchasing power to invest in such capital equipment. Efficiency of energy utilization has mattered little in proportion to gains derived from wages. True, there were related elements, such as the dramatic increase in life expectancy for women, completion of child-bearing at lower ages, to help produce a longer uninterrupted span of years in the labor force.[22]

Suburban living has been made possible through use of energy in various ways, and the new life-styles which have in turn increased energy demand. The trend to larger-per-person residential spaces is another manifestation of energy use, making home management of larger units possible. Automatic heating, air conditioning, and mechanical devices play a role here. It should be noted that these devices take up some of the larger residential spaces.

Time freed from the older traditional home tasks provided for leisure time, which constitutes the basis for growth in demand for home-entertainment apparatus, another factor adding to the demand for energy. Home workshops are another example. Acceleration in energy demand due to all these use-opportunities, happened almost as an unselfconscious development accompanied

(22) , ECONOMIC REPORT TO THE PRESIDENT, January 1973, USGPO, Washington, p. 93.

by, or a part of, social change.

During the period of unparalleled expansion in the multitudes of domestic energy uses and the resulting increases in consumption during the 20th century, notably of electricity, one finds a declining interest in utilization efficiency in the residential, and also commercial, sector. This trend was interrupted during World War II, when fuel shortages were experienced. Rationing was resorted to, primarily for purposes of assuring equitable supply for domestic consumption after the needs of the military and the war industries were provided for. The shortages were not then in energy resources as such, but in transportation, industrial capacity, and manpower. Public information efforts were urging "conservation". . . . there are still many simple changes in adjustments you can make in your present heating system. Many of these without spending a single penny . . ., no matter what kind of a system you use or what fuel you burn, . . . cut down on fuel consumption, you benefit in two ways: you make a definite contribution to the war effort, and you reduce your fuel bills substantially." (23) The publication cited gave an extensive checklist and made a plea for pampering the heating equipment and appliances for better utilization of available fuel and extending life of the equipment itself. During World War II gasoline was also rationed and highway speeds were severly restricted to reduce fuel consumption. The heating-fuel conservation idea carried over into the immediate post-World War II period, aided by inflation

(23) From a booklet: FUEL CONSERVATION MADE EASY, How To Save Fuel And Keep Warm, distributed by General Electric Co., Consumer Institute, Bridgeport, Conn., no date given.

pressures on the consumer.[24]

From the very beginning of home economics at about the turn of the century, home economists were concerned with taking drudgery out of housework by making it more efficient. Technology served this purpose very well in providing tools and methods to attain this objective. Energy availability and use made it possible.

Continuing efforts of home economists together with those of the home-equipment industries brought improvements, or new equipment, often requiring higher energy input. As home economists matured they found employment in the industries' sales, research and engineering departments. Many turned to teaching in the secondary school systems. Home-economics colleges, agricultural and engineering colleges, as a part of their education programs, had laboratories where the products were tested, improved, and demonstrated for convenience of use, time-saving characteristics, service, and performance. Energy-use cost and efficiency were important until mid-century. After that, the relative cheapness and abundance of energy availability -- supported by industry promotion -- killed interest in amounts of energy consumed by the equipment or process. From an economics point of view, first cost has become the key element of the mass-marketing strategy, with markets to be expanded on the basis of lowest possible first-cost product-prices.

The ever-greater variety of models and their growing technical complexity, along with vanishing faculty and student interest, were behind

(24) See booklet: HOME HEATING, Better Buymanship - Use And Care, published by Household Finance Corp., Chicago, 1947, 40 pages. Note: This booklet gives a comprehensive overview of domestic heating practices and equipment of that era. It also has an extensive bibliography on the subject, going back to the 1920's.

decisions to drop or drastically curtail home-equipment programs in most of the home-economics colleges. The USDA and the Extension Service had sponsored many of these activities for years, and their support was also coming to an end. The USDA Laboratories, which at one time had worked extensively in this area, have also severely cut down research activities. The cost of doing this work had become too high in terms of interest and return. Compounding the issue has been the inadequacy of natural-science background of the representative college student. The home-economics graduate of today has little knowledge and skill related to the energy technology.(25)

Engineering colleges have never played a significant role in the realm of home equipment, other than perhaps in refrigeration, air conditioning, and a few civil-engineering matters. As electric power dissappeared from the electrical engineering curriculum, along with it went whatever home-equipment engineering there was.

Energy economics has not been accepted as a legitimate discipline, other than practiced by the specialists of the large energy companies. Consumer economics has made scant mention of energy costs. Growth and demand have occurred without public awareness of the consequences encouraged by the general neglect of utilization efficiency.

The experience-history of the organizations that test consumer products has followed similar lines. Here we find that energy-consuming products were indeed initially evaluated for cost of operation. As illustration, a refrigerator test program in 1936 looked first at the

(25) From conversation with Jeanette Lee, retired Dean, College of Human Ecology, Formerly College of Home Economics, Michigan State University, East Lansing, Jan. 19, 1973.

cost-of-operation factor, then durability, and finally "other important factors."[26] Also evaluated were different compressors and refrigerants in terms of their energy-utilization performance. Reports listed monthly operating-cost data in cents and kWh. Similar data were given for washing machines.[27] Another test gave extensive information on various types of heating equipment which was comparatively rated. "Saving fuel in heating a house" is referred to.[28] Another consumer testing organization magazine during the latter 1940's stressed operating costs, reporting on various appliances and water heaters.[29] From this point in time on, less and less attention is given the matter of energy-utilization efficiency or operating cost. The substance of the testing reports was made up of other criteria--convenience, cleanability, service, durability, safety, facility of use, style, and the like. That interest was lost in fuel or energy consumption costs--and associated pollution effects and their own costs--must have been for reasons of the prevailing consumer attitudes and values. Aware of these attitudes, manufacturers of equipment cannot be blamed for directing their efforts towards features having higher market appeal.

There were many examples illustrating that at one time energy-saving

(26) ________, Consumers Union Reports, REFRIGERATORS, Vol. 1, No. 3 July 1936, pp. 6-8.

(27) ________, Consumers Union Reports, WASHERS, Vol. 2, No. 4, May 1937.

(28) ________, Consumers Union Reports, HEATING EQUIPMENT, Vol. 2, No. 8, October 1937, pp. 19-25, quoting from SAVING FUEL AND HEATING A HOUSE, Technical Paper No. 97, U.S. Bureau of Mines and from Tests of Household Fuel Savers and the Economical Use of Coal, Penn. State College of Engineering, Experiment Station Bulletin No. 34.

(29) Consumer Reports, April 1946, p. 98 is on freezers, Oct. 1947, p. 379 is on washing machines, May 1948 p. 214 is on water heaters and June 1949 p. 248 is another report on refrigerators.

features were successful in the market place. The Frigidaire "Meter-Miser" compressor, the General Electric "Monitor-Top," both on refrigerators of the 1930's, and somewhat later the Kenmore-Whirlpool "Suds-Saver" (saving hot water) come to mind. Granted, there were other factors besides energy saving. In the case of the "Suds-Saver," it provided for the convenience of not having to wait for the then smaller water heaters to recover.

Except for the FHA specifications which were changed during 1971 to call for better building insulation materials for houses that the Agency insures, the only people who actively promoted better insulation were the manufactureres of insulating materials. The energy companies by nature have not been interested, nor have been the builders and equipment manufacturers. The builder of a house obviously does not have to pay the fuel bill; he sells houses. It was not until 1973, with a crisis at hand, that energy companies started to promote home insulation.(30)

Trends in lighting, which have materially contributed to the growth in energy demand, will be covered later in a separate section.

The foregoing represent only a broad-brush illustration of the forces which have been at work to create the energy demand/supply situation of 1973. "Loadbuilding" efforts on the parts of the energy companies, the utilities and others have had their part. Public policy generally followed or encouraged these trends. The regulating agencies built rate structures, which made it imperative for the utilities to continuously push consumption so as to assure satisfactory return on the investments. Availability of

(30) Michigan Consolidated Gas and Consumers Power in Michigan.

cheap energy and related technology propelled these mighty forces into massive social change and a social structure which depends on abundant supply of energy.

V. "THE ENERGY GAP"

History is likely to look upon the late 1960's and the early 1970's as an important turning point in the energy-price trend, as demand continued to rise with a concurrent decrease in the relative and absolute availability of energy resources. Whereas in the long range the impact of these developments is unknown, in the short range it is clear that there are bound to occur adjustments tending to bring demand into line with available supply, and conversely, to bring the supply into line with demand.

Demand is related to how well people live and want to live and how they feel about reducing the demand by means of social choice. On one hand, any downward change which materially affects the experienced or expected quality of life is likely to be resisted. On the other hand, mitigation of the demand by means of eliminating waste or increasing the efficiency of utilization is perhaps a good possibility, with rising price providing the incentive. Only experience will clarify this dimension.

On the supply side, the principal sources of energy that we can look to for now are: coal, petroleum, natural gas, hydro-and nuclear-power. All of these are naturally limited in supply, but a rise in price may for some time add to availability, as may the potential exploitation of two other known fossil-fuel resources, oil shale and tar sands. Higher energy prices can be expected to accelerate exploration and development of extraction technology and so increase availability. It must be borne in mind, however, that any shift in technology to accommodate a change in the demand/availability/price situation can only occur over relatively long periods of time. The fact of the matter is that the United States economy is pretty well tied to what we now have, and probably will be so for many years to come.

Wholly new sources, solar energy in the forms of direct sunlight utilization (other than daylighting), wind, tidal, and ocean-thermal souces depend on the development of appropriate technology as do geothermal energy, breeder reactors, and nuclear fusion. Plant and animate sources may also play more of a role as the price advances, and thereby make utilization economically more feasible.

Not only are there economic constraints, there are also environmental constraints, as well as ones concerned with the safety risks associated with most higher-level technologies. Added to these constraints must be the time required to develop these technologies, to bring them to market in sufficient magnitude for them to have a worthwhile impact on overall patterns of energy consumption. Technology assessment, a method suggested as a management aid to rationalize the broader aspects of the decisions to be made, is discussed later on in this study. In the following, major energy resources currently being relied upon are examined in more detail, especially as they relate to price and supply.

Coal deposits appear to be adequate for a long time to come. Its share of the basic energy resources consumed has declined through the years because of environmental impact, cost, and restricted availability. To minimize pollution arising from coal is technologically difficult and costly. Less-polluting coal deposits are located far from where they are needed (Montana, Wyoming and Utah), imposing transportation costs which have to include the energy consumed in transport (oil at present). The basic difficulty with coal is its sulfur content, particularly as organic sulfur. There is no commercially proved process for the removal of sulfur from raw coal, or during combustion, or from the products of combustion, to an extent that can meet current air-quality standards. Another problem imposed by these standards is emission of particulates whose dispersal requires very tall stacks, on the order of 800 ft. high. The mining of coal has a more important drawback: it is not an attractive occupation. Years ago, when immigrant labor was available, staffing coal mines was no problem. It will likely be a severe problem when greatly increased mining output is needed.

Coal mining is now heavily mechanized. Output/man/year rose from 1239 tons in 1950 to 4497 tons in 1969, but has since declined to 3784 tons in 1971.(31) Yet, this increase in productivity did not keep the wholesale price of coal from rising much more rapidly than the general price level, i.e., 1950: coal - 83.3, all items = 81.8, 1972: coal = 193.8, all times = 119.1.(32) This trend can be expected to continue because of a number of factors: availability of labor as mentioned above, increased demand to off-set deficiencies in the oil and gas supply, costs associated with environmental-protection regulations, and costs imposed by new federal and state laws, notably the Federal Mine Safety Act of 1969, PL 91-173.

Petroleum. The United States, once an exporter of petroleum products, now must rely heavily on imports, in 1972 about 26% of the

(31) 1973 Statistical Abstract of the United States, Table No. 1103, p. 656.

(32) ibid., Table No. 574, p. 350.

total.[33] These imports are relatively low cost, but only so because a large share of domestic easily-accessible crudes are exhausted. No matter what the costs of crude imports are, they have to be paid for by exports. Whether the American economy has the capability to produce the goods and services in sufficient magnitude to pay for the projected oil- and gas-imports is a question beyond the scope of this study, but nevertheless a serious one.

Some of the major oil-exporting countries are bound together in a form which resembles a cartel. In effect, they are owners of the resources and for all practical purposes, they are the producers. The international oil companies merely act as sales agents. The arrangement raises questions of supply dependability and future price stability.[34] The indications are that the foreign producers will effect more control than they have in the past over the availability of oil in world markets through price and cotnrol of production. Whether domestic supplies can be brought in soon enough and in sufficient quantities to materially lessen import dependency is another question. In the least, it gives rise to doubts about the availability of petroleum in adequate volume to meet expectancies.

Aside from economic considerations, it is known that petroleum products can be manufactured from the large domestic deposits of coal, oil shale or the Canadian tar sands. However, to do this on a large scale would subject the approach to constraints very similar to those already mentioned with respect to coal.

(33) John G. McLean, Continental Oil Co. in a newspaper advertisement ENERGY AND AMERICA, Wall Street Journal, Nov. 30, 1972.

(34) M. A. Adelman, HOW REAL IS THE WORLD OIL SHORTAGE? Wall Street Journal, February 9, 1973, p. 6.

Gas. United States consumption now exceeds the rate of development of reserves.[35] Gas is the "cleanest" of the fossil fuels, a virtue which of course has accelerated the demand for it. Well-head prices are rising however, owing to recent public-policy decisions to encourage exploration. Here again new laws, like the Natural Gas Pipeline Safety Act of 1968, PL 80-481, as well as environmentalist objections, are raising the cost of building and operating transmission facilities.

Petroleum and gas exploration usually go hand in hand. Drilling goes deeper and deeper, and delivery distances become greater and greater. Off-shore drilling and production require larger capital investments and entail higher production costs than do traditional land-based operations. Consideration is now being given to exploration of the North American Continental Shelf in the Atlantic Ocean, with still higher anticipated costs, and with many political and environmental impact questions.

A number of energy firms have plans at various stages to import gas in liquefied form from overseas. The handling of natural gas in this manner is not without increased safety and environmental risks. It requires special tankers, harbor facilities, liquefying and re-gasifying plants, technologies and processes which consume energy. Cost is estimated at 3 to 4 times that of present domestic supplies. Again, as is the case with foreign crude, there is the problem of price stability and supply dependability along with paying for such supplies. By the rules of economics, the cost of imported liquefied gas will eventually set the price level for all gas.

(35) , NATURAL GAS POLICY ISSUES AND OPTIONS, A STAFF ANALYSIS, Committee on Interior and Insular Affairs, U.S. Senate, S.R. 45, Serial 93 - 20, USGPO, Washington 1973, p. 7 and others.

Another known option which can augment the supply of gas is the gasification of coal. It is more of an economic problem than it is a technical one. The price-point at which the process becomes economically feasible on a large scale is yet to be determined. Experimentation to gain such experience is under way. Some of the factors associated with the mining and processing of coal already mentioned are likely to affect this development, particularly the price.

The fact is that a large share of the cheapest and most accessible energy materials in the United States has been exhausted. It is this rapid exhaustion which has in part kept energy prices so low. This exhaustion in itself is an obvious stimulus for rapidly advancing prices. Growing demand that exceeds available supplies, extra costs associated with imports, the question of availability of imported supply, can be translated into higher prices associated with scarcity conditions. In 1972 reserves of domestic crude oil (-4.5%), natural gas (-4.6%) and natural gas liquids (-7.0%) fell by the percent indicated in parentheses. Experience in Canada is similar.(36)

Nuclear Power was presented at one time as the low-cost electric energy source of the future. The experience with nuclear plants to date has been that it takes much longer to get them into operation than conventional plants, and that costs are markedly higher, which in turn means rates higher than anticipated. Questions of plant location, safety,

(36) , Wall Street Journal, March 20, 1972, p. 14 citing reports from AGA, the API and the Canadian Petroleum Association.

and particularly the question of nuclear-waste disposal persist. Still, nuclear power as an alternative clearly has an important role in an electric economy, as careful assessment and evaluation of alternatives would probably disclose.

Hydroelectric Power. Before discussing electric energy as an intermediate energy source, a word needs to be said about water power, a form of solar energy. High capital requirements, time needed for construction, land- and water-rights issues limit development, and then mostly to agencies of government. When financing is handled by the government so that advantage of inherent capital cost factors can be taken, hydro energy is relatively low-cost and, most importantly, derived from a renewable resource. The TVA System (Tennessee Valley Authority) has become the model of "yard stick" for low cost, against which the performance of the electric utilities has been measured in the past. It has to be remembered however, that this type of hydropower development serves other purposes, such as flood control, irrigation, and economic area development. Low-cost electric power is only a part of the cost/benefit equation.

In absolute terms, hydro-power generation of electricity has grown steadily over the years and has helped in part to keep the lid on electric rates. How hydro-power has been expanded is shown in Table 13 .

TABLE 13. ELECTRICITY FROM HYDRO-POWER 1950-1970.

	1950	1960	1970
Hydro-electricity Production (Billion kWh)	96	146	242

Source: 1972 Statistical Abstract of the United States, Electric Energy, Sources of Energy, Table No. 622, p. 507.

As a source of electric energy, however, hydro-power has declined in relative terms as illustrated by Table 14.

TABLE 14. SOURCES OF ELECTRIC ENERGY - 1950-1970.

	1950	1960	1970
Coal	47.1%	53.6%	46.2%
Oil	10.3	6.1	11.9
Gas	13.5	21.0	24.3
Hydro	29.2	19.3	16.2

Source: 1972 Statistical Abstract of the United States, Electric Energy, Sources of Energy, Table No. 622, p. 507.

Dealing with hydro-power, the FPC says:

> " . . . most economical sites for economic production of hydro electric energy have been developed, some additional hydro-capacity will be provided at new sites, or by addition to existing plants. The movement of hydroelectric power into the peak of the load is bolstering project power benefits, and permitting consideration of many possibilities which formerly were marginal or uneconomical under higher capacity factor standards . . . "
> " . . . associated benefits as recreation, water supply, fish and wild-life enhancement, flood control, and cooling water for thermal and industrial plants. The multi-purpose benefits allow many projects to be developed that would not be economically justified as single-purpose projects."(37)

(37) ________, The 1970 National Power Survey, Part IV, p. IV-1-71, Federal Power Commission, USGPO, Washington, 1971.

The key words in the above are "economical", formerly . . . marginal or uneconomical." The factors recited under coal, petroleum, gas, and nuclear tend to change the cost/price equations for additional hydropower development. Currently 26% of the potential in the United States is reported as developed.(38) Some of the hydroplants included in the 26% could be updated. One example is the current modernization of the 3-dam Salt River project in Arizona. The output at one of the dams, built around 1910, will be tripled from 70,000 kW to 230,000 kW, simply through technological advances.(39)

Whatever hydro-power can contribute toward restraining the advancing energy costs is not likely to be significant enough to negate the argument that energy price will rise rapidly.

Electricity is not a basic energy resource as we know and use it today. It is only an intermediate stage in the energy-conversion process. Since electric energy has such an important part in energy-consumption patterns, and since growth of demand is relatively rapid, especially in the commercial and residential sectors, electricity has a key role in the price outlook.

(38) ________, HYDROELECTRIC POWER RESOURCES OF THE U.S., Developed and Undeveloped, Federal Power Commission, Jan. 1, 1968, pp. x and xi.

(39) ________, BECHTEL BRIEFS, Vol. 28, No. 1, Jan. 1973, Bechtel Corp. San Francisco.

To explain further, electric rates have not generally followed the trend of all consumer prices, at least until very recently when a trend reversal set in and an upward movement is now being experienced. Factors which are working for higher costs and rates for the electric industry are as follows:

(1) Rising fuel costs for both fossil and nuclear fuels, including the cost of finding new fossil and mineral deposits that are deeper, farther, and less accessible.

(3) Rising capital and construction costs of new facilities (labor-intensive, therefore high-impact).

(4) Rising operating costs, including legislation-mandated safety costs.

(5) Increasing taxation.

(6) Environmental costs, which include the cost of intervenor-precipitated delays in getting new facilities under way.

(7) Costs associated with regulation.

It must be remembered that as a result of regulatory lag these costs are not immediately reflected in rate increases, except where fuel-cost escalators have been granted to the utility firms.

Throughout their history, most electric utilities have been models of good management and relationalization of costs on a per-kWh basis. The conversion rate for coal has been improved from 6 lb. of coal per kWh in 1900 to about 0.8 lb. per kWh in 1965. As mentioned in Chapter II, the long-term gain in conversion efficiency (heat-rate expressed in But/kWh) appears to have come to a halt about 1965, when the trend actually reversed.[40] Per-unit (kWh) labor cost has been rationalized effectively[41], and as has the cubic-size/kW of generating plants.[42] The technology of "topping cycles" is helping. Economies of scale have been achieved by ever-larger generating machinery, higher-voltage transmission lines, and other technical features. There were 5,952 generating plants in the United States in 1917, and 3,519 in 1970.[43] Boiler temperatures and pressures have been increased to the limits of available materials-technology and economic demand therefore. Further improvement and conversion efficiency are constrained by thermodynamics. Little further improvement can be expected other than what may come by major technological breakthroughs, such as magnetohydrodynamics (MHD) or fuel cells, where again materials technology is one of several constraints. Related economic questions lend emphasis to the assumption that solutions will be reflected in price, probably more than supply.

Some gains could be achieved by updating older facilities. Often revamping has to be done anyway to comply with air- and water-quality standards. Many of the older facilities are found in smaller municipal plants, which are often sacred cows. The point that environmental costs will have to be more and more internalized into electric rates has not been sufficiently stressed. These costs are likely to be substantial when adding them to direct production and energy-resource conversion costs.

(40) , ENERGY CONSUMPTION AND GNP in the U.S., An Examination Of A Recent Change In Relationships, National Economic Research Associates, Inc., New York/Washington, 1971, Table IV, Output Per Man-Hour And Heat Rate 1947-1970.

(41) Philip Sporn, TECHNOLOGY, ENGINEERING AND ECONOMICS, MIT Press, Cambridge, 1969, p. 78.

(42) ibid., p. 82.

(43) From Statistical Abstracts of the U.S. for various years.

The clearly evident trend to higher electric rates--in fact, higher price for all energy forms--can be expected to spur development efforts of (1) known or still unknown energy resources, and (2) conversion and utilization technology, either to lessen costs, or to increase efficiencies. Such efforts to achieve higher efficiencies via technology will generally involve initial capital costs, which must be reflected in price. As capital costs are amortized over time, however, they will result in economic savings as soon as the capital outlays have been liquidated.

A plea for higher conversion and utilization efficiencies, yet pointing to additional costs, is contained in a proposed policy statement by the Federal Power Commission:

> " . . . demand pressures make unlikely the continued availability of abundant amounts of electric energy to supply the Nation's requirements at historically low costs. Increased energy demand and public concerns for environmental protection necessitate new technological approaches to the electric energy supply problem and possibly new rate designs which more accurately take into account the environmental costs of producing and distributing ever larger quantities of electricity. They also prompt new concerns for efficient utilization of the energy that is produced. Costs (of energy resources), technology (costs) and environmental considerations (costs) are inextricably interrelated . . ."(44) " . . . in many instances, improved energy utilization (or reduction in environmental impact) is obtained only at increased costs, e.g. a greater overall use of materials, higher manufacturing costs or production costs or other expenditures . . ." (45)

Whereas the foregoing is directed to the electric utility firms, indirectly suggesting capital investments to effect higher efficiencies, the Federal

(44) , In a Policy Proposal, CONSERVATION OF NATURAL RESOURCES . . . THE ELECTRIC ENERGY CONVERSION AND PRODUCTION PROCESSES, Docket No. R-454, Federal Power Commission, Washington, Sept. 14, 1972. p. 4. (Order No. 495 issued Nov. 13, 1973 in modified form).

(45) ibid, p. 6.

Note: Parentheses in both references cited above are the author's.

Power Commission is also asking that these firms promote higher end-use efficiencies on the part of their customers. Investments aiming at higher efficiencies are normal for business enterprise and institutions in that such costs are a part of the cost calculus. If an investment pays off inside an appropriate time horizon, it is usually made. For residential customers, this time horizon ordinarily is very short range, if not immediate, creating need for innovation in providing suitable incentives or disincentives through rate structures and otherwise. Aspects of residential energy use will be covered in Chapter VII.

Electric utility firms, private and public, are now demanding rate increases on the order of 5 to 10% per year for 5 years or longer.[46] Under the assumption that the indicated rise in rates has the effect of reducing demand on the one hand, and of increasing utilization efficiency on the other hand, the resulting lesser demand can in turn be expected to put further upward pressures on price because of the high fixed charges associated with electric utility systems. Instead of lagging far behind the general rise of the price level, as has been the experience over the years, electricity costs are likely to be a leading factor in the rate of change in the price level.

The above will be true, of course, for most energy costs. As such it can be foreseen that energy could take an ever-larger share of personal-consumption expenditures. It must be recognized, however, that far too little work has been done with the energy price and consumption relationship to make a better case than is presented here. In fact, as has

(46) , Wall Street Journal, March 22, 1973 quoting William G. Kuhns, President of General Public Utilities Corp.

already been pointed out, direct and definitive data on the energy-share of personal-consumption-expenditures are not available.

To make meaningful projections of the future supply of energy as related to demand -- if indeed it is possible at all -- would transcend the purpose of this study. The more important supply factors and their respective characteristics have been enumerated. There is a question whether classical economics is adequate to explain the behavior of the demand-supply relationships. The present work, it is hoped, will shed light on the deficiencies, and point the way to overcome some of them. The supply of energy is largely governed by the level of technology encumbered by its short-range and long-range impacts, and by its time lag. On the demand side, physical aspects of energy resources become "expectancy" when proper weight is given to social and ethical questions.

What has been happening, and what may happen in the future, may perhaps be more readily understood with the aid of Figure 2.

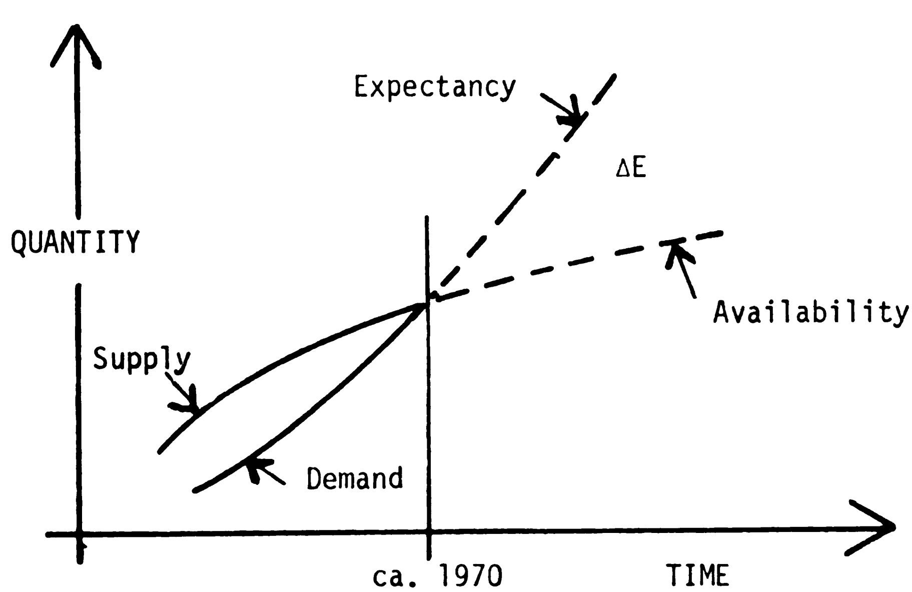

FIGURE 2. THE ENERGY DELTA.

The lines marked "Supply" and "Demand" refer to the past, and hence run through the early 1970's. Reasonably accurate date for "demand," that is, consumption, as listed and explained earlier, are readily available. Likewise, there are also good figures available on productive capacity, which determines "supply." These bits of information tell us that there has existed a positive differential between supply and demand. Good management and operating practices make such a differential desirable on balance, inasmuch as it presumably reflects a reasonable degree of prudence provided the underutilization is not too large. Unfortunately, the differential may have been too large, encouraging inefficient utilization, or even waste.

In more recent years, as has already been shown, consumption has grown faster than productive capacity, i.e. potential supply. The point has been reached where potential demand cannot be satisfied, as illustrated by Figure 2. The region of transition is indicated by the vertical line marked ca. 1970. Since actual consumption cannot exceed actual production -- except for transitory effects of accumulated reserves -- there will be a negative differential between potential demand and potential supply. This negative differential constitutes the well-publicized "energy gap," "shortfall," or "energy delta (ΔE)." The potential demand, or expectancy, because it cannot be met, must adjust to actual consumption which cannot exceed availability. The disparity between desire and fulfillment will surely bring about grave social stress.

The "gap" will be useful as a device to aid resolution over the longer haul. This resolution will come about through the market, public policy, and technology, these three factors in combination serving to reduce the demand, to increase the supply, or most likely both. Several alternatives can effect a reduction in demand. One is to use available, or incipient technologies. Behavioral change to effect lower demand must be considered only as a long-term solution. Similarly, for the short term, as well as the long term, this study argues -- but not exclusively -- for rationalizing end-uses with the help of the scheme described in Part B. The future direction of the trend lines shown in Figure 2, the magnitude of the differential (ΔE), whether negative or positive, depend on the performance of the aforementioned trio: market, public policy, and technology, governed by the level of knowledge, especially technical knowledge. An effective program of rationalizing end-uses would obviously help to make the differential more manageable, with savings and other benefits and/or costs yet to be quantified. Part B of this study attempts to move in this direction.

Limited availability of energy resources under most conditions can only mean distributive and allocation problems. No one should doubt that developments affecting the supply and price structure will bring social upheavals and a reordering of values. As yet, there is no suitable mechanism to order priorities and achieve equitable social choice. Market forces alone have little concern with producing distributive justice. In this sense, there is a question as to whether energy resources are to be viewed as a commodity, available only to whoever can pay the price. In modern society, energy is a life-necessity, which therefore must be distributed equitably, i.e., justly. A just distribution by itself demands that wasteful uses of energy be eliminated, and that all uses and use-practices be optimized in economic, social, environmental, and technological terms. Mechanisms for achieving this goal are yet to be developed. The scheme suggested in Part B is intended as a beginning of one possible means to that end.

VI. "CONSERVATION"

The strong demand for energy resources has not developed all of a sudden. Without lighting a candle in the public mind, the ensuing problem grew at an accelerating rate, nurtured by a social, political, and economic apparatus geared to rapid economic growth and a supportive consumer-oriented social structure. The "economic-growth ethic" has been an underlying philosophy. Aside from recently becoming aware of the environmental impact caused by energy-technology activities, policy-makers and the public did not clearly recognize the energy situation until about the end of the 1960's. Since then, however, public attention has intensified. The subject has been prolifically written about and discussed among legislative committees,[47] institutions, organizations, the energy industry, and the media.

One solution to the problem which is offered in public opinion-and policy-forming rhetoric is "conservation." As a vernacular term it is meant as an exhortation to reduce consumption. The legitimacy of this demand is questioned. Wasteful uses of energy resources are mentioned to strengthen the argument for "conservation." With few exceptions, the purpose is not rationally explained in terms of benefits and costs. In

(47) , A REVIEW OF ENERGY POLICY ACTIVITIES OF THE 92D CONGRESS, Committee on Interior and Insular Affairs, U.S. Senate, SR 45, A National Fuels And Energy Policy Study, Serial 93-1, USGPO, Washington, 1973.

a sense, "conservation" becomes a cosmetic term, intended to get people to accept changed preferences. Merely refraining from using natural resources (consumption) is not likely to "maximize social returns over time" (see Barlowe quotation on page 53). The difficulty is that the exhortation comes from decision-makers who were in part responsible for the shortfall in supply, and therefore raise questions of credibility as skepticism mounts. Any reduction in the use of energy units, without commensurately increasing per unit benefits, i.e., efficiency, will reduce the quality of life.

"Conservation" is frequently mentioned in the records of the congressional hearings and elsewhere. The President's Clean Energy Message was delivered to Congress on June 4, 1971. Among other matters, it referred to the need for "energy conservation."(48) Governor Milliken in a message to the Michigan Legislature on November 26, 1973 referred to " . . . energy conservation measures", " . . . how to conserve energy", and " . . . Statewide ethic of energy thrift."(49)

Current common usage of the terms "conservation" seems not to suggest "save," but suggests "use less," or sometimes "use more efficiently," an exhortation which implies management, economics, or technology, i.e., increased utilization efficiency. This concept is embodied in the subject of this study. Whether to conserve by withholding from use, or to use, or to resort to technology for improving utilization efficiency -- thereby beneficially using less -- , is a legitimate matter for technology

(48) , U.S.C. Congressional and Administrative News, 92nd Congress, First Session, No. 5, p. 931 (June 4, 1971).

(49) Governor William G. Milliken, Special Message to the Michigan Legislature on Energy, Lansing, November 26, 1972.

assessment (which will be dealt with further in Part B).

Until very recently, practically all efforts concerned with energy have been directed toward expanding availability and consumption. Questions which have surfaced are: how might the demand be met; what are the technologies involved, known or unknown; how can the development of such technologies be advanced; what physical and human resources are needed to implement demand realization; and, marginally, what is the possible social and environmental impact. The issue has centered on how to provide the supply necessary for meeting projected demand. Against this campaign, only very minor consideration has been afforded to ideas which might effectively reduce demand, a critically sensitive issue from a socio-economic and public-policy viewpoint. Reduction in demand has an uneasy implication that the standard of living is to be lowered. Some recent studies and reports have considered reduction in demand [50-53]. In a number of cases the stated aim is "conservation," without bothering to define the term. Energy-utilization efficiency as an objective is mentioned less frequently.

(50) ________, CONSERVATION OF ENERGY, Committee on Interior and Insular Affairs, U.S. Senate, A National Fuels and Energy Policy Study, SR 45, Serial 92-18, Committee Print, USGPO, Washington 1972.

(51) ________, THE POTENTIAL OR ENERGY CONSERVATION, A Staff Study by the Executive Office of The President, Office of Emergency Preparadness, USGPO, Washington, 1972.

(52) ________, CALIFORNIA'S ELECTRICITY QUANDARY: III. SLOWING THE GROWTH RATE, prepared for the California State Assembly with Support of the NSF, R-1116-NSF/CSA, Rand Corp., Santa Monica, 1972.

(53) Edgar S. Cheany and James A. Eibling, REDUCING THE CONSUMPTION OF ENERGY, in Battelle Research Outlook, Vol. 4, No. 1, 1972.

The interpretation of energy conservation is obviously in need of clarification, as already indicated. Conservation is a concept of many meanings. In a dictionary sense, it involves the preserving, guarding, protecting, or keeping a thing in an entire or a safe state. In many cases one could also say "non-use." During this century there has been much debate over conservation of land (or earth) resources. One of the older definitions called for "the preservation in unimpaired efficiency of the resources of the earth, or in a condition so nearly unimpaired as the nature of the case or wise exhaustion will permit."(54)

What Barlowe has to say discussing land resources seems to apply very well to energy resources:

> " . . . The idea of preserving land resources intact for future use has never gained much popular acceptance. To be sure, many conservationists stress the need for saving certain resources for future use; and some have probably overemphasized this point. Most people, however, react negatively to policies of non-use. They favor the maintenance and saving of land resources, but only to the extent to which conservation policies are consistent with programs of effective current use. Because of this rationale, much of the emphasis in conservation discussions is on the need for orderly and efficient resource use, the elimination of economic and social waste, and the maximization of social net returns over time.
>
> From an economic and social point of view, conservation may be defined simply as the wise use of resources over time. This definition has the weakness of being both vague and confusing - vague because of differences of opinion concerning what constitutes "wise use," and confusing because conservation practices vary widely with different types of resources. Yet it should be recognized that conservation is basically concerned with choices in the timing of resource use. It deals with public and private decisions concerning the allocation of resources between the present and future, and with policies and actions that are designed to increase the future usable supplies of particular resources. It involves the when of resource use.

(54) Richard T. Ely et al., Foundation of National Prosperity, MacMillan Co., New York, 1917, p. 3.

> As we explore the economic meaning of conservation, it is important that we emphasize the goal of wise or optimum use of resources over time and its interrelationship with the concepts of orderly and efficient resource use, elimination of waste, and maximization of social net returns over time . . ."(55)

Apart from individual residential-land and garden-plot proprietors, with their often parochial interests, the persons directly concerned with land resources and their conservation form a limited segment of society. They fall into two groups. One is made up of people who derive economic benefit from the use, exploitation, or non-use of land resources in various activities. The other group is made up of "idealist" -- environmentalists and conservationists oriented to moral, recreational, political, and perhaps mystical aspects of conservation.

In contrast, every one is concerned with energy resources in an economic, and also social sense, as a life necessity. Ecological issues may be woven into the context. Energy as a means to survival for industrial mass-society is assumed as basic and is taken for granted. Energy is looked upon as a service, whereas land is viewed as a property.

There is one other important corollary in viewing energy resources by making a comparison with land resources. Much of the earth's land area is unavailable for use because of natural limitations of soil, weather, climate, topography, and so on. As ordained by the rules of thermodynamics and/or economics, and by the limitations of technology, a large share of the earth's storehouse of energy is similarly not available for doing work. Whenever heat energy is converted into mechanical energy, i.e., work, only a fraction is available, the remainder being locked into the system. In thermodynamics this effect is described as an increase in

(55) Raleigh Barlowe, LAND RESOURCE ECONOMICS, The Economy of Real Property, Prentice Hall, Englewood Cliffs, N.J., 1972, pp. 220, 221.

entropy. It is not a loss of energy, since the First Law of Thermodynamics, sometimes referred to as the law of conservation of energy, states that energy can be neither created nor destroyed. Availability, the state of low entropy, becomes germane to any discussion of energy-resource conservation.

When energy was readily accessible, abundant, and therefore cheap, little need for conservation was felt. Whatever conservation practices existed were (1) to prevent chaos and glut in the market place; and (2) to maximize economic return over time from owning and operation of a resource. The Interstate Petroleum Compact has had No. (1) as an objective. The compact is operative in the form of cooperative conservation regulations by the oil-producing states to prevent "waste" and to protect the interest of smaller operators.

Now that prices are advancing because of prospects for diminishing availability (growing scarcity), it would appear difficult to gain popular acceptance for deferring use until some other time. In contrast, improving utilization efficiency, by whatever means, should be one of the more attractive alternatives. Effects could be realized quickly, economic and social costs could be relatively small, effects on the environment could be only beneficial, effects on the quality of life need not be detrimental, and finally, delivery is reasonably certain. Improving the utilization would involve choosing among technologies, which because of potentially positive or negative impacts, calls for care in considering the available options. (A proposed scheme for making such selection is described in Part B. The approach is intended to "maximize social net returns over time." What technology can accomplish is well illustrated by the history of the electric power industry and the advances that were made in conversion technology.[56] How the electric utilities have improved conversion efficiency over time has already been described in Chapter V. The improvements come to benefit everyone.

Gains in end-use efficiency, the concern of this study, are possible in at least two ways. The first way is change to more efficient utilization practices, and the second way -- what is probably more promising in economic and quantitative terms -- is higher utilization efficiency engineered and built into products, structures, and human-settlement patterns. Such a built-in bias toward better energy-utilization performance would in turn come in two parts, one at the product level, the other at the consumer level. The first part would be better control over energy consumed in the manufacture and distribution of product and/or structure, thereby achieving an optimum balance between energy content and product life, the second part would be by carefully optimizing in-use-efficiency thereby minimizing energy losses (increase energy availability). Both parts, product and/or structure or system, on the one hand, and life-cycle utilization on the other hand, would have to be correlated and so optimized. A method for doing this is yet to be developed. (See Part B for one suggested method). Unfortunately, as pointed out in a proposed Federal Power Commission Policy Statement concerned with the conservation of natural resources, there may be higher economic costs involved in efforts aimed at increasing

(56) The remarkable history of the electric-utility industry has been ably described in the writings of Philip Sporn and others. The most comprehensive is:
Philip Sporn, VISTAS IN ELECTRIC POWER, 3 Volumes, Pergamon Press, Oxford, 1968.

utilization efficiency.[57] What this means, is that an increase in utilization efficiency for a particular use may not itself be economically justifiable within the time horizon of a consumer, but has societal justification by increasing overall availability of energy at a given cost, or by a decrease in the severity of an environmental impact. The use of heat pumps for electric heating is one example.

There are several tasks in the above. To improve utilization practices raises the level-of-knowledge question. It points to need for education and public enlightenment. Engineering/architecture would have to be linked to education on the one hand, and the search for new knowledge on the other hand. The energy content and product-life-cycle/energy-consumption question is related to energy economics, engineering, the humanities, and users of energy and their various purposes. There are many such relationships. To handle the subject effectively requires development of new methods which can order the salient factors.

(57) FPC Proposed Policy Statement, op. cit.

VII. ENERGY UTILIZATION CONTROLLED BY FAMILY-UNIT DECISIONS

Opportunities for improving residential energy-utilization efficiency are great in number. The preceding chapters have attempted to highlight the critical need for improving end-use or utilization efficiency as a part of any energy policy. We have two options for using less: (1) efforts to maintain at least equivalent-to-the-present, or preferably increased, socio-economic benefits at smaller per unit energy expenditure, or (2) arbitrarily reducing benefit or service levels, i.e. reducing the quality of life. Option (2) would be motivated by non-availability of means; or by wish to conserve for future use, which, as explained earlier, is an ethical question. A suggested means for making comparative assessments between these options in terms of their impact on human welfare and social justice is discussed in Part B. The objective in the present chapter is to delineate parameters within which use or expenditure of available energy could be optimized.

A researcher intent on studying the problem is faced with many difficulties. These range from the dearth of information to a definition of what is meant by utilization efficiency. For the latter, input-output ratio might be an applicable dictionary definition. Unfortunately, the energy-using processes and activities within the residential sector are far from being that simple. Man uses energy in various form not only for avoiding freezing, doing work, or saving time, but also to provide comfort and other amenities. There are also "non-energy" uses which consume energy resources. Mineral energy resources are at the same time chemical resources that go into a large variety of consumer articles and materials for residential uses, construction, and maintenance. Petrochemicals are one example of the non-renewable kind. In other words, the energy input into a machine system with a resulting and measurable output of work may be an inadequate description of the process.

Use of the term "efficiency" needs to be examined. Lighting engineers, for example, have abandoned the term in favor of "efficacy."[58] Some benefits derived from energy utilization may be values hard to measure directly in output terms. In this study, the term efficiency connotes efficacy as well, or rather effective use of energy in terms of society's best interest, combined with the interests of family and individuals, taken together as family units. The qualification terms may be taken from the entire spectrum of the tangible-value and social-value systems.

The principles of thermodynamics prescribe technical limits for what is possible. Under the Second Law, when viewed in the context of the entire earth-energy system, in a certain sense there can be no such thing as efficiency.[59] It is only when working with subsystems that one can express input-output ratios of energies. Such ratios are important

(58) John E. Kaufman, (ed.), IES LIGHTING HANDBOOK, 4th Ed., Illuminating Engineering Society, New York, 1966, pp. 3 - 5 , in text and footnote.

(59) Robert F. Mueller, ENERGY IN THE ENVIRONMENT AND THE SECOND LAW OF THERMODYNAMICS, National Aeronautics and Space Administration, Goddard Space Flight Center, X 644-72-130, Greenbelt, Md., May 1972.

because they are useful indicators for the assessment of energy-utilization practices and technologies. Subsystem outputs, from residential units for example, invariably result in increased entropy, and therefore represent energy no longer available for use. It follows that the objective becomes one of improving sub-system performance so as to reduce input requirements, i.e. increase utilization efficiency, as measured by the input-output ratio. Incremental gains so achieved in a sense could be called conservation, in as much as available energy units are not used. The objective therefore, in part, is to reduce inputs wherever possible, improving or at least maintaining level of output. Small relative amounts help, because the aggregates are so large.

Often, there are stages which frame input and output -- as with electricity -- where appropriate points must be chosen in order to arrive at useful ratios. For example, to say that a 100 W incandescent electric light is only 2% efficient, in terms of visible light output divided by basic energy-resource input, means little toward understanding how to effect better energy utilization. The 98% differential has to be broken down for effective analysis.

A similar situation prevails for the entire United States energy system. The efficiency with which fuels and energy are utilized is basically unknown for the Nation as a whole, or for any single sector, except electric power generation. No data on efficiency are regularly collected by any government agency or other organization, nor does any individual or company maintain such information, so far as can be ascertained.[60] It follows then, that this scarcity of factual information

(60) PATTERNS OF ENERGY CONSUMPTION, _op_. _cit_., p. 149.

calls for intensive effort to develop data and information which can aid the improvement in utilization efficiency performance.

The accelerating consumption of electricity, notably in the residential (and commercial) sector, and the drive for raising the level of living, pushed by the electric utilities and equipment industries, make this consumption practice suspect of inefficiency or even waste. The existing gaps in knowledge reinforce the assumption that the potential for utilization-efficiency improvement may indeed be substantial. Efficient management of any system implies information for effective control. Such control, for reasons already covered, may not have been economically or otherwise justifiable in the past. Now that questions of availability confront the Nation, however, demands for better management and control are a logical development.

The energy consumption in the United States is arbitrarily broken down into a number of very broad categories (one such breakdown is reproduced in Appendix A). The categories do not necessarily identify points of decisions which result in consumption. Without examination in detail, it would be a mistake to use these categories for purposes of assigning priorities for effort. There are many other factors to be considered. Consumption within each category is so large that even the smallest sub-category consumes very large quantities of energy.

To illustrate this point, from 15 to 30 percent of residential electricity consumption is estimated to be for lighting,[61] yet in the

(61) Richard G. Stein, SPOTLIGHT ON ENERGY CRISIS: How Architecture Can Help, in AIA Journal, Vol. 57, No. 6, p. 20.

SRI estimate of energy consumption patterns cited in the foregoing (see Appendix A), lighting is lumped into the item "other."

Moreover, growth-rates vary greatly. It is some of the extraordinary growth in aggregate demands which contributes materially to the overall problem and gives rise to the questions on future availability and conditions of the environment. In the light of emerging changes and outlook in the demand/supply situation, it can be safely assumed, that intensive management of the resources would benefit everyone, and the environment as well.

Other attempts to quantify utilization efficiency have resulted in a series of guesses on what may be the range of possibilities over short-, medium- and long-range terms.[62] Use of this type of information for public and private policy decisions would most certainly be unwise, if not useless or actually dangerous. As to ways out of the dilemma, the most promising source for developing such data appears to be at the point where actual use or consumption is triggered, where individual use-decisions are made, decisions which are ultimately manifested in aggregate demand.

There are, of course, many situations where the decisions take the form of non-decisions on the part of the consumer. In many instances energy use over time was predetermined in the design of the built environment, structure, product, apparatus, and control. This predetermination makes it necessary to look also at the decisions made outside the domain of the consumer demand. These decisions in many ways, however, have their origin in consumer demand. Most of them are conditioned by culture,

(62) PATTERNS OF ENERGY CONSERVATION, op. cit., p. 6.

environment, and institutions, complicating matters no end. The nature of the decisions will be discussed in more detail in Part B.

For purposes of guide-lining decision parameters for the potential of energy-utilization efficiency in the residential sector, the factors appear to fall into three categories (referred to earlier in Chapter VI):

(1) Existing structure and devices

   a. operating-energy cost of stock and the supply infrastructure

   b. maintenance-energy cost

(2) Future, new, or modified structures and devices; energy-costs involved in modification, manufacture and/or construction, and service

(3) Energy cost associated with disposal of wastes created as a result of the activities of above categories.

For any one energy-utilization activity, or a chain of activities, the sum of all energy expenditures associated with (1), (2), and (3) above form an "energy budget." As already pointed out, most of the activities either originated with, or are affected by, consumer decisions. The energy-consuming activities may consist of: (a) manufacture of product; raw and intermediate materials; extraction, refining, marketing, distribution, service, and disposal of wastes (energy "capital" costs); (b) use or consumption of product and/or service; and (c) ultimate disposal of product and/or wastes associated with product use.

It is assumed that some artifact is associated with energy use. And it is the nature, characteristic, and life of the artifact which in a large measure determines the dimension of the energy demand. Since these are technological attributes, they lend themselves to change more so than use-practices occasioned by life-style and other socio-psychological attributes. Parameters for changing the energy-demand dimensions can be assumed to widen with time, as new devices, structures, or environmental designs go into service and create new use-practices, as existing artifacts are replaced, or as existing artifacts, associated uses, and practices are modified as may be dictated by the level of knowledge, energy economics, the state of technology, public policy, wear-out, or obsolescence.

As the parameters widen, as more knowledge becomes available, opportunities for effectively reducing demand can be expected to grow. A relatively small impact can be foreseen from appeals to the public, whereas it may be possible very materially to affect demand through technological approaches as indicated above. It is one thing to tell the people to do a better job of insulating their homes or to reduce thermostat settings, but quite another to use the existing or new knowledge in order to create a livable residential environment that uses less energy to heat or cool. The latter approach appears to merit prime attention when it comes to residential energy use, and an examination of the more important parameters will follow under these groupings:

RESIDENTIAL ENVIRONMENT AND AMENITIES

- Shelter
- Thermal Comfort
- Lighting
- Leisure and Recreation

HOME EQUIPMENT (Life-Support, Work- and Time-Saving)

- Indoor Climate Control
- Water
- Kitchen Appliances
- Home Laundry and Fabrics Care
- Miscellaneous Devices

TRANSPORTATION PERIPHERAL TO THE RESIDENTIAL ENVIRONMENT

As already mentioned, there are many "non-energy uses" of energy resources which are contained in the above. They are not dealt with in detail because of the non-availability of data. Plastics, solvents, refrigerants, detergents, represent only a few of such uses. (All such energy uses, in all consumption factors, appear to be about 5% of the United States total).

An important assumption underlying the following examination is that the entire United States economic and social system, as in other industrialized nations, is built on energy and the way that it is used. Any change in technology or in use patterns will have an impact on the physical and social environment, favorable or adverse, depending on how the change is engineered or arranged through socio-political processes. The scheme outlined in Part B is a suggested method for aiding these processes.

1. RESIDENTIAL ENVIRONMENT AND AMENITIES

a. Shelter, the physical structure or artifact, is one of the key determinants of energy demand. With only minor exceptions, energy, in any form, entering a shelter unit (input), will eventually leave that shelter unit in the form of heat (output). The heat goes into the environment irreversibly and in a practical sense is no longer available (entropy), i.e. without applying work, and therefore using more energy.

Energy has been expended in the production chain which created the shelter unit. More energy is similarly required for the care and maintenance, and perhaps final disposal processes. Only negligible amounts of this energy are recoverable under present technology and economics.

Predominantly, the variables affecting the energy-in and heat-out processes are:

Environmental factors

(1) Geography, climate, and season

(2) Location of the unit with respect to sun, earth, landscape, and other units and structures

(3) Heat-handling characteristics, structure of unit, its bulk, mass, or "heat capacity," characteristics of the barrier between "indoors" and "outdoors," the interface materials, their surfaces, texture, color, finish, emissivity, heat and vapor transmission properties, surface areas of the interface, orientation, cubic size, and arrangement of the interior.

(4) Performance efficiency of household-equipment energy-conversion apparatus used in connection with shelter operation

(5) Household-equipment use practices (man-machine-environment relationships)

(6) Animate and plant metabolisms occurring within the unit

(7) "Indoor climate" and comfort quality level maintained as chosen by occupants. This includes rate of indoor-outdoor-indoor airflow as may be determined by the occupants.

When temperature and accompanying air-vapor-pressure conditions are artifically maintained lower than ambient atmospheric, heat, and vapor flow across the shelter-barrier are reversed. Energy in the form of work has to be supplied to accomplish this reversal. Heat byproducts of this process also go into the environment.

The quantities of heat energy transmitted across the barrier from the interior of the shelter unit to the environment are called "heat loss."

When such transmission is reversed under artificially maintained conditions, there is a "heat gain."

Transmission of heat occurs by the phenomena of radiation, conduction, or convection, the last including all in and out air-movements. These air-movements transport heat energy as usable heat, and as latent heat in the form of water vapor. Such movements may occur through natural forces--wind and drafts--or they may be induced by temperature and atmospheric pressure differentials. Air-movements may also be artificially created by the employment of energy. Radiation is electromagnetic wave transmission. Conduction is based on a mechanism of heat transport by molecular, ionic, or electronic motion within the substance.

These are known natural-science phenomena which are measurable. In one particular instance, they have influenced development of materials and techniques which can reduce heat loss or heat gain, namely the technology of building insulation which has advanced with particular emphasis on materials and their application. The industry that produces such insulation materials has been, until very recently, the only promoter of better insulation.

Insulation tends to increase first cost of a structure. From an economic point of view, this higher cost can be offset by fuel savings, reduction in size, and therefore cost of the heating and cooling installation. This subject is documented in the literature.[63] [64] Figure 3 illustrates the principle.

(63) Tyler Stewart Rogers, DESIGN OF INSULATED BUILDINGS FOR VARIOUS CLIMATES, F.W. Dodge Corp., New York, 1951.

(64) Tyler Stewart Rogers, THERMAL DESIGN OF BUILDINGS, John Wiley & Sons, New York, 1964.

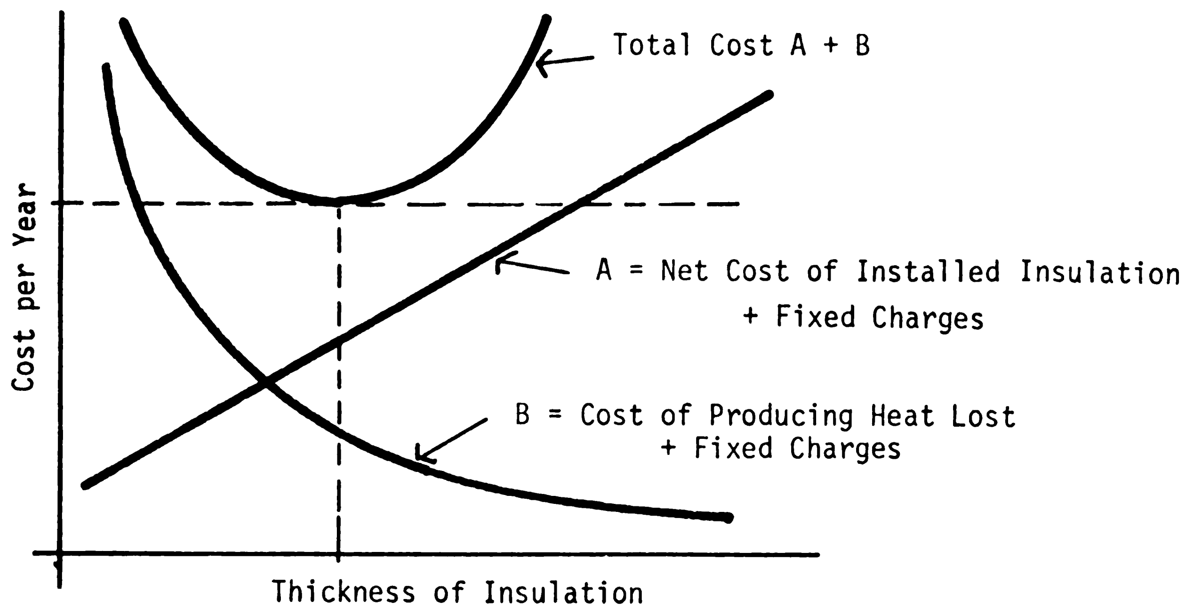

FIGURE 3. ECONOMIC THICKNESS OF INSULATION.

It must be borne in mind that this type of work was actually done during an era when energy was considered relatively cheap and abundant. In the face of the existing knowledge, the "first-cost" principle prevailed, and, except in the case of electric heating, longer-term energy economy was lost. Environmental implications of these higher rates of energy use and the resulting effects caused by the depletion of the resources were not given much thought.

President Nixon in his energy message to Congress in June of 1971 told of having ordered the Federal Housing Agency (FHA) to revise its Minimum Property Standards (MPS) for insulation of construction financed under FHA-insured mortgages. The revision, among other requirements, calls for a maximum heat-loss of 20 Btu/hr/ft^2. This change, which has the stated objective of reducing fuel consumption and air pollution, will result in an appreciable saving to homeowners as well. According to a study by Moyers, however, the change does not reach the level of possible minimum long-term costs to the homeowner.(65) The study shows that for a New York residence the revised MPS's can result in energy savings of 19 to 29%, although the optimum could be 47 to 49%. Correspondingly, these same figures are nationwide given as 42.8% for gas homes and 40.8% for electric homes. In the aggregate, this would mean 4.6% of the United States energy consumption in 1970.(66) There are other benefits not accounted for in this study, as will be discussed later, nor is the future-- and relatively higher--energy price taken into account.

The present organization of the building industry precluded universal adoption of stringent heat loss and heat gain standards. FHA mortgage-insured construction makes up only a part of all construction, a part which has been declining in relative importance. Private mortgage insurance has been gaining, especially since 1971, when regulatory agencies expanded lending limits for private insurers to $36,000 and up to 95% of the appraised value of a housing unit. Mortgage lenders and builders prefer private insurance, since premium costs are 50% under FHA and restrictions are materially less. One firm alone now insures a greater number of mortgages than does FHA.(67)

(65) J. C. Moyers, THE VALUE OF THERMAL INSULATION IN RESIDENTIAL CONSTRUCTION: Economics and the Conservation of Energy, Oak Ridge National Laboratory Report, ORNL-NSF-EP-9, Dec. 1971.

(66) <u>ibid</u>., A summary can be found in ENERGY RESEARCH POLICY ALTERNATIVES, Committee on Interior and Insular Affairs, U.S. Senate, Serial No. 92-30, June 7, 1972, pp. 663-668.

(67) , article concerning MGIC Investment Corp., Wall Street Journal, March 14, 1973, pp. 1 and 20.

The Mobile Home Manufacturers Association (MHMA) has under consideration a change in its standards (NEPA No. 501B of 1972). The proposal is to change from a heatloss of 50 Btu/hr/ft^2 for oil- and gas-heated units to 40 Btu/hr/ft^2, now standard for electrically heated units.[68] The defense of the MHMA position rests on economics, namely, a \$10/ft^2 maximum deemed necessary for Mobile Homes to remain in a viable market.[69] It is maintained, that more insulation would drastically change construction techniques and materials. Clearly, to change existing practices in the building industry would require use of a life-cycle costing approach and an effective set of incentives.[70]

Moreover, it would be helpful toward better control of the problem, if the practice adopted by the MHMA some time ago, i.e., nameplate certification (labeling) of each unit with respect to heat loss and heat gain, were adopted by the entire building industry. Incorporation of this requirement into the building codes could be one solution. Another solution could be for the regulatory agencies to compel the utilities to screen applicants for new service hookups and to make them show evidence that the structure meets certain specified heat loss or heat gain criteria.

Apart from insulation, there are other variables which affect heat loss and heat gain. One research activity, using a standardized and instrumented mobile home as a test vehicle, produced such data for various

(68) See letter from Henry Omson, Director, Standards Division, MHMA, Chantilly, Va., dated April 13, 1973.

(69) See letter from Gerald W. Foster, Home Building Products Division, Owens-Corning Fiberglass Corp., Toledo, March 7, 1973.

(70) Moyers, op. cit.

types of construction, various insulating materials, different types of windowglass, sun-screens, drapes, and awnings. Unfortunately these data were not related to economic values. The research was primarily concerned with alternatives and their effects on heat gain or heat loss of the structure.[71]

Insulation properties and values of most building and construction materials are known. Rarely however, have these values been systematically taken into account for purposes of reducing energy consumption. Building codes generally do not provide for minimum heat loss or maximum heat gain, or similar criteria. Limits on energy consumption as a legal reality are being considered in the new Connecticut State Building Code. " . . . they simply are taking the very reasons for which building codes exist: the general health, welfare of the public, and applying it where most needed, . . . "[72] Actually, this situation is no different from statutory pollution controls which have proliferated in recent years. Statutory limits on how energy is produced, on how, and how much energy is used for what purpose would automatically generate benefits in the form of pollution control.

Defining and assigning values to the variables, based on existing and yet-to-be-developed knowledge, can provide us with guidelines for energy-use control of future construction of buildings and shelter, and the operation of them. As can be easily seen, however, the results of such an approach will not be visible for many years because of the mass of the

(71) Eugene R. Ambrose and J. L. Reynolds, AN INVESTIGATION OF ELECTRIC SPACE CONDITIONING FOR MOBILE HOMES, ASHRAE Journal, Vol. 15, No. 11, Nov. 1972. This article gives comparative data for electric heat pumps, electric resistance heat, gas heat, and air conditioning.

(72) , AVAILABLE NOW: SYSTEMS THAT SAVE ENERGY, Progressive Architecture, Vol. L11, No. 10, Oct. 1971, p. 80, p. 125.

existing building and housing stock. This observation brings up the question of improving on its energy-using attributes and related practices. The problem can best be illustrated by an examination of some housing census data, see Table 15 below.

TABLE 15. AGE OF HOUSING STOCK, 1950 AND 1970.

Age in number of years	1970 Census Million Units	1970 Census Percent		1950 Census Million Units	1950 Census Percent	
30 and older	27.5	41)	54	20.2	44)	63
20 through 29	8.8	13)		8.9	19)	
10 through 19	14.5	22		5.9	13	
Total Units	67.7*	100		46.0	100	

* Includes 2 million Mobile Homes.

Source: 1950 Housing Census, U.S. Summary, HC (1) - B1, Detailed Housing Characteristics, Table 22, p. 1-242.
1970 Housing Census, U.S. Summary, H-A1, General Characteristics, Table 6, p. 1-3.

The above data show that, during the 20-year interval between 1950 and 1970, the 30-year-and-older category gained 7.3 million units. General comparison of the data may not be realistic. The share of older units which declined in absolute terms can be attributed to the Depression, World War II, resultingly pent-up demand, post-World War II demographic factors, and public policy. The "half-life" of a housing unit appears to be in the neighborhood of 24 years.

That this housing stock may be suspect of being inadequately maintained is supported by the figures shown in Table 16, which indicate a decline in effort:

TABLE 16. RESIDENTIAL ALTERATIONS AND REPAIRS (in current dollars).

	Additions, Alterations, Maintenance, Repairs, and Replacements	Major Replacements	Maintenance and Repairs	Combined Expense
	Total	A	B	A + B
1960	$13,120,000 average $298/unit	$2,066,000	$5,553,000	$7,619,000
1965	11,442,000 average $253/unit	1,707,000	4,999,000	7,706,000
1970	14,770,000 average $297/unit	2,629,000	5,895,000	8,524,000

Source: RESIDENTIAL ALTERATIONS AND REPAIRS: Expenditure For Additions, Alterations, Maintenance, Repairs And Replacements, Series C-50, Parts 1 and 2, various issues, U.S. Department of Commerce, Bureau of the Census, Washington, various dates.
Note: Data prior to 1960 are not available.

If one uses the 1960 figure of A + B = $7,619,000 as a basis, and takes into account the rise of building costs for the period,[73] the corresponding 1970 figure should be about $11.5 million. A still higher figure will result if the growth in housing stock for the period is considered.

Assume $20,000 as the average current replacement value of all housing units, and a 2%/year depreciation allowance as a marginal minimum. These assumptions would call for $400 per unit, substantially above what appears to be being spent. "Additions and Alterations" would be additive.

One can further assume that heat loss and heat gain factors will deteriorate with age and sub-par maintenance of a unit. The entire issue gives rise to the pervasive question: would it not be better to place more

(73) , 1973 Statistical Abstract of the United States, PRICE AND COST INDEXES FOR CONSTRUCTION etc., Table No. 1146, p. 678.

emphasis on maintaining, or even upgrading, the existing housing stock, particularly from the point of view of reducing energy consumption? This question becomes ever more important when one thinks of the additions of energy-consuming apparatus to the existing stock.

For example, room airconditioners are being put into service at a rate of roughly 5 million units annually (less the replacement rate, which presumably is relatively small).(74) How effectively these units are being operated is unknown. Room airconditioners are generally sized to the location where they will be used. Few questions are asked on energy consumption, i.e., performance efficiency of the space to be so conditioned.

Two areas appear to be in need of intensive study. One is the economic and energy-demand difference between new structures and existing ones that are suitably upgraded. The other area is ways by which existing structures can be increasingly improved so as to reduce heat loss or heat gain within the known parameters of existing knowledge and the future of energy economics.

An overriding question which evidently has also escaped exploration is: what is the overall energy-economics relationship between the energy content of new residential construction versus comparable requirements adequately to maintain and/or periodically to update existing residential installations. In other words, does one let obsolescence and neglect take their toll, thereby in effect wasting the energy content; or does one conserve what can be conserved, and thereby remain as well off as one would with the new, but with a lesser demand on energy resources?

(74) ________, Current Industrial Reports, U.S. Department of Commerce, AIRCONDITIONING AND REFRIGERATION EQUIPMENT, Series MA-35 M.

b. Thermal Comfort, or environmental comfort, is a basic human need and constitutes an indirect but major factor in energy demand and the growth in such demand. In the U.S., about 20% of energy consumption is for space heating, roughly another 7% is for air conditioning.(75) Additional amounts are consumed for ventilation and other smaller uses originating in the desire for environmental comfort. The sheer magnitude of this consumption justifies inclusion of a survey of the subject in this study concerned with energy utilization. Thermal-comfort phenomena need to be better understood if efforts to improve utilization efficiency are to succeed.

Thermal comfort is an exceedingly complicated and not entirely understood function of body and environment. From the point of view of external control, these variables are controlled by the state of health, by intake of liquid and food, by rate of physical activity, and by the thermal resistance and emissivity of clothing; by dry-bulb temperature (dbt), relative humidity (rh) which is often specified by wet-bulb temperature (wbt) or sometimes dew point temperature (dpt), and velocity of the ambient air (v) (which determine heat transfer by convection and conduction) and mean radiant temperature (mrt) of the human environment (which determines that transfer by radiation). With obvious exceptions localized in time and space, heat transfer by conduction between the body and contacting solids (or liquids or air) is not significant for determining thermal comfort, as the term is commonly understood. The major variables cited point to the available means for achieving thermal comfort.

Schematically illustrated, Figure 4 represents the situation simplified to the degree of approximation suitable for the present discussion.

(75) Roderick R. Kirkwood, President, American Society of Heating, Refrigerating, & Air-conditioning Engineers, in ASHRAE Journal 15, No. 6, June 1973, p. 57.

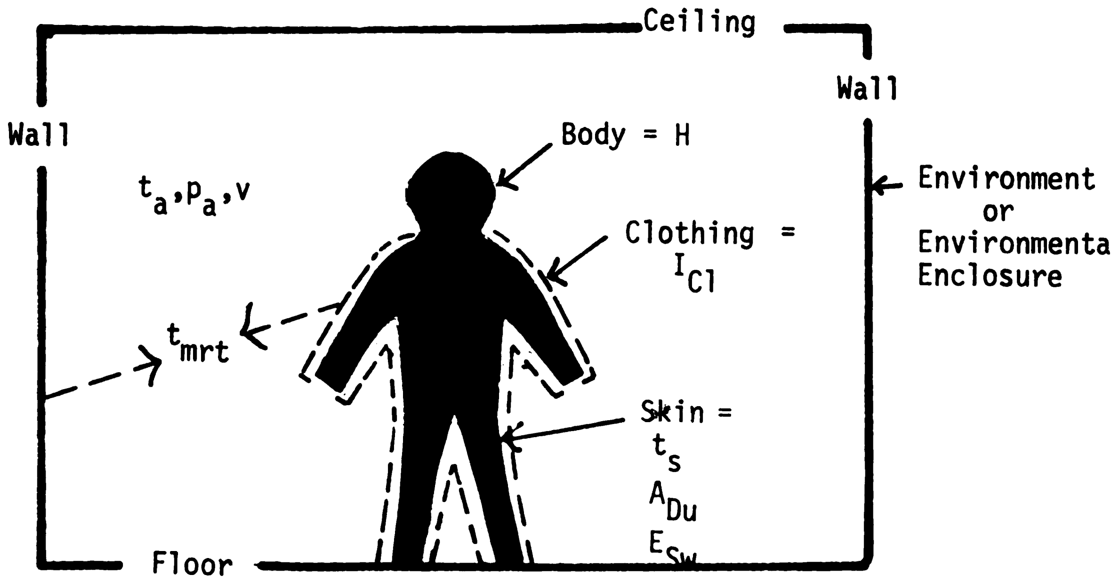

Figure 4. SCHEMATIC OF SIMPLIFIED THERMAL-COMFORT VARIABLES.

The terms appearing in Figure 4, their explanation, and four equations defining the terms are borrowed from THERMAL COMFORT:(76)

> " . . . . . based on the establishment of three basic conditions for optimal thermal comfort.
> The first condition necessary for thermal comfort for a person under long exposure to a given environment is the existence of a heat balance, a condition which is naturally far from sufficient. Man's thermoregulatory system is quite effective and will therefore create heat balance within wide limits of the environmental variables, even if comfort does not exist. With the establishment of a double heat balance an equation of the following form can be obtained (only the main variables have been taken into consideration):

(76) P. O. Fanger, THERMAL COMFORT, Analysis and Applications in Environmental Engineering, Danish Technical Press, Copenhagen, 1970, pp. 21, 22.

$$f(\frac{H}{A/Du}),\ I/cl,\ ta,\ t/mrt,\ p/a,\ v,\ t/s,\ \frac{E/sw}{A/Du} = 0 \qquad (1)$$

where $\frac{H}{A/Du}$ = Internal heat production per unit body surface area (A/Du = DuBois area)

I/cl = thermal resistance of the clothing

t/a = air temperature

t/mrt = mean radiant temperature

p/a = pressure of water vapor in ambient air [not the total pressure]

v = relative air velocity

t/s = mean skin temperature

$\frac{E/sw}{A/Du}$ = heat loss per unit body surface area by evaporation of sweat secretion

" . . . For a given activity level, the skin temperature, t/s, and the sweat secretion, E/sw, are seen to be the only physiological variables influencing the heat balance in eq. (1). The sensation of thermal comfort has been related to the magnitude of these two variables. Experiments involving a group of subjects at different activity levels have been performed to determine mean values of skin temperature and sweat secretion, as functions of the activity level, for persons in thermal comfort. The results have the following form:

$$t/s = f(\frac{H}{A/Du}) \qquad (2)$$

$$E/sw = A/Du\ f(\frac{H}{A/Du}) \qquad (3)$$

"Equations (2) and (3) are presented as the second and third basic conditions for thermal comfort . . ."

". . . The quantitative evaluation of Equations (2) and (3) and the theoretical foundation for relating the sensation of thermal comfort with skin temperature and sweat secretion are set out in the second part of this chapter.

"By substituting conditions (2) and (3) in (1), the desired comfort equation takes the following form:

$$f(\frac{H}{A/Du}, I/cl, t/a, t/mrt, p/a, v) = 0 \qquad (4)$$

"Using the comfort equation (4), it is possible for any activity level (H/A/Du) and any clothing (I/cl) to calculate all combinations of air temperature (t/a), mean radiant temperature (t/mrt), air humidity (p/a) and relative air velocity (v) which will create optimal thermal comfort . . ."

A somewhat different explanation of the thermal-comfort phenomena in physiological terms may be worthy of inclusion at this point:

> " . . . The thermal needs of human beings stem principally from properties of their sensory nervous system. If, for instance, the average temperature of the skin should deviate more than 3°C from the standard figure of 33°C, the nervous system would mildly, but definitely, protest. Another degree or two beyond would result in real discomfort or illness. Within this range of surface temperatures, a person has a capacity for adjusting his heat production by internal regulatory control. The control mechanisms have apparently evolved in order to protect the brain and the internal organs from temperature variations, since they are now so elaborate and complex, that 1° to 2° deviation from the normal deep body temperature results in noticeable loss of mental function." (77)

(77) Richard L. Meier, SCIENCE AND ECONOMIC DEVELOPMENT: New Patterns of Living, MIT Press, Cambridge, Mass., 1956, p. 98.

Unfortunately, the foregoing touches primarily on physical aspects of thermal comfort. Psychological aspects are still more difficult. There is some knowledge which has been developed over time, mostly because of considerations other than the subject of this thesis, i.e. availability and utilization of energy. Whether physical, physiological, or psychological, the underlying principle is one of satisfying human needs and responses to physical arrangements. Stated in another way, the following is taken from another book on the subject:

> " . . . the wellbeing of man depends upon the balance between his energy production and the exchange of energy with the environment. The energy balance must be maintained within the limits of tolerance for heating and cooling the body. This concept is modified by the intervention of clothing . . ."(78)

to which may be added: and/or by the intervention of shelter.

Food is converted by the human body into energy for body-heat and for doing work. The heat must be dissipated into the environment, a physiological requirement which needs to be taken into account.

> " . . . the 2,000 to 4,000 calories which are consumed by a person over a day are in turn emitted by the body. These can be conserved so as to keep human beings comfortable, but to do so efficiently requires a great deal of scientific knowledge about human comfort and the properties of heat."(79)

Research on thermal comfort is rather recent. A handful of papers appeared during the 1920's, more during the latter 1930's. Still more activity came with World War II and military operations all over the world, which prompted intensive investigations. Work done over the

(78) H. L. Newburgh, ed., PHYSIOLOGY OF HEAT REGULATION AND THE SCIENCE OF COMFORT, Saunders, Philadelphia, 1949, p. 1.
Note: This book, in addition to being a basic text, provides us with most detailed and comprehensive bibliography on the subject to the date of its publication. There are 477 references.

(79) Meier, op. cit., p. 97. Also: Mary Ellen Roach, DRESS, ADORNMENT AND THE SOCIAL ORDER, Wiley, New York, 1965, p. 204.

years at the United States Quartermasters' Laboratories at Natick, Mass. is notable in this respect. Also mentioned must be the continuing efforts by ASHRAE, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.(80)

To increase the utilization-efficiency of energy for purposes of achieving environmental comfort, man can--aside from improving energy-conversion methods--change (1) level of physical acitivity, (2) quantity and quality of nutrition, (3) clothing, and (4) buildings. Other options are omitted, because they offer only very long-term possibilities such as change in habitat or acclimatization. All of the four options are related to lifestyles, which of course, are subject to social change.

Heat generated by the body increases with increased activity. Energy-heat values have been empirically determined for various activities under different atmospheric and environmental conditions. Thermodynamic behavior of the physiological system is reasonably well-known. The relationship to energy consumption, however, needs yet to be established.

In the light of energy-utilization economics, the most important option for achieving thermal comfort is clothing. This option has many trade-off advantages. Indeed, one has difficulty understanding why it has not been brought forward more strongly in discussion of the energy problem. Clothing is the most direct means of providing thermal comfort. There is

(80) See the ASHRAE HANDBOOK OF FUNDAMENTALS published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York. 1972, Chapter 7, PHYSIOLOGICAL PRINCIPLES, COMFORT AND HEALTH; pp. 119 through 150 eminently cover present knowledge of the thermal comfort and related phenomena in much more detail than is practical to do here. A two-mode model of man and his environment is included (pp. 124-126). The ASHRAE Technical Committee, 1.4 Physiology and Human Environment, has charge of research and organization of the unfolding knowledge.

a technology available regarding natural and synthetic fibers, textile construction, and garment design. Weight can be light enough for the users to be comfortable in all kinds of activities, even under very cold climatic conditions. Europeans take advantage of clothing rather than fully relying on levels of indoor climate, as is the practice in the United States. Granted, some of the difficulty lies less with physical aspects than with how clothing is perceived and utilized by people, as in matters of fashion, for example. The trade-offs between comfort-control through buildings as against comfort derived from clothing deserves serious study. Whereas a great deal is known about the technology of clothing for more extreme climatic situations, the improvement of clothing to off-set modified indoor-climate levels has been little researched.

In most cultures, sufficient clothing is normally worn indoors and/or outdoors to permit the release of just enough heat that the skin temperature remains within comfort range. The unit of insulation value for clothing in general use is called a "clo." One clo has been determined as necessary to maintain comfort in a normally ventilated room, with air-movement less than 10 ft/minute, at a temperature of 70° F in a relative humidity less than 50%, while the subject is resting in a sitting position. A clo, therefore, is a normalized unit of heat-transfer resistance (insulation).[81] Insulation values of clothing ordinarily worn range from 5 clo

(81) From Fanger, op. cit., p. 30:
Actually, the transfer of dry heat between the skin and the outer surface of the clothed body is quite complicated, involving internal convection and radiation processes in the intervening airspaces, and conduction through the cloth itself. To simplify calculations I/cl (see page 77) was invented as a dimensionless expression for the total thermal resistance from the skin to the outer surface of the clothed body. I/cl is defined by I_{cl}(clo) = R_{cl}/0.18, where R_{cl} = total heat transfer resistance from the skin to the outer surface of the clothed body (m^2-hr-C°/cal). One "tog," especially used in England, = 0.645 clo.

for bitterly cold weather to about 0.5 clo for midsummer. Anything higher than 5 clo is usually too unwieldy for physical movement and comfort. Some researchers classify light clothing 0.5 clo, medium clothing 1.0 clo, and heavy clothing 1.5 clo.[82] Certain differences between individual preferences naturally exist.

The desire for more physical -- and psychological -- freedom has fostered trends to lighter clothing (fashion!). More work done by machinery, and lesser use of human energy, has tended to reduce internal heat production (H) of the human body and thereby changed the heat-balance equation. This development has been accompanied by a change in dietary requirements and diets.

The heating, and more recently the cooling, of spaces rapidly progressed during this century from concentration on limited activity areas to entire interiors of buildings and homes. Climate-controlled shopping malls are an example of how far this trend has been carried. Availability of cheap energy resources, together with development of utilization technology, has encouraged this development. Moreover, " . . . there is substantial evidence that in the United States the temperature criterion for thermal comfort has risen steadily from a range of 65 - 70° F (18 - 21° C) in 1900 to 75 - 78° F (24 - 26° C) in 1960."[83] Larger building- and living-spaces, maintained at higher temperatures, thereby leading to higher energy consumption, are tied to social change.

As already indicated, the environmental variables which have first-order effects on man's thermal comfort are dry-bulb temperature (dbt),

(82) Fanger, op. cit., pp. 44-47.

(83) ASHRAE HANDBOOK OF FUNDAMENTALS, op. cit., p. 138.

relative humidity (rh), mean radiant temperature (mrt), and relative air velocity (v)--plus the change in these variables during the time of exposure in man's activity--and finally the thermal insulation of clothing (I_{cl}). The relationship of these variables to the state of thermal comfort have been investigated by numbers of researchers. Still, there are information gaps. The ASHRAE Comfort Standard 55-66 defines thermal comfort as: " . . . that state of mind which expresses satisfaction with the thermal environment." But, " . . . Unfortunately, very little practical research has been reported to date that specifically answers this ASHRAE definition."(84) Most of the available predictive information is based on the KSU-ASHRAE Comfort Studies started in 1960 at Kansas State University. One outcome of these studies is contained in the ASHRAE Psychrometric Chart, now called the New ASHRAE Comfort Chart, Figure 5.(85) The KSU-ASHRAE "Comfort Envelope" is indicated by the elongated diamond. It is reported to represent a comfortable living environment for 90% of the living conditions of the sedentary individual.(86) The Effective Temperature lines ET representing loci of constant physiological strain are based on a rationally-derived model of physiological thermal

(84) Ralph G. Nevins and A. Pharo Gagge, THE NEW ASHRAE COMFORT CHART, ASHRAE Journal, Vol. 14, No. 5, May 1972, p. 41.

(85) Reproduced by permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers from the ASHRAE HANDBOOK OF FUNDAMENTALS, op. cit., p. 137.

(86) ASHRAE HANDBOOK OF FUNDAMENTALS, ibid., p. 138.

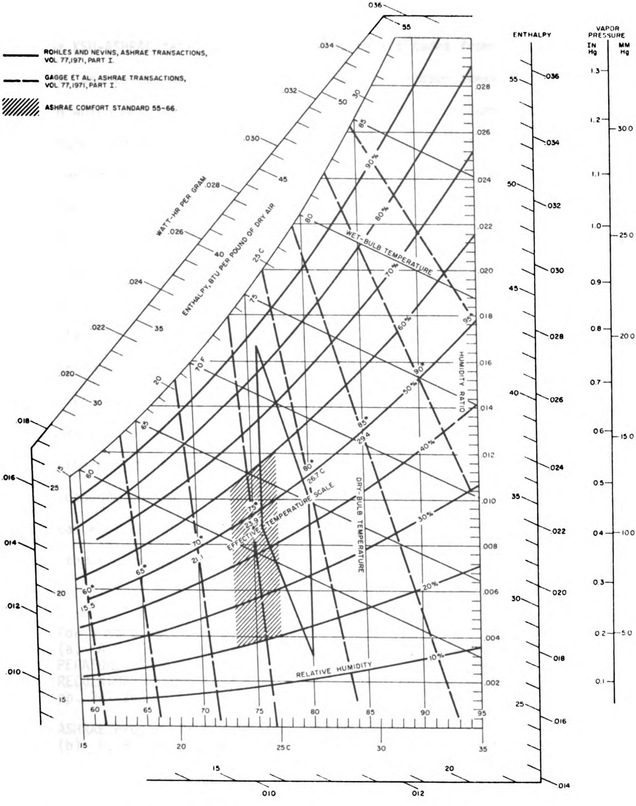

FIG. 5. THE NEW ASHRAE COMFORT CHART.

regulation.[87][88]

The KSU-ASHRAE data "applied generally to altitudes from sea level to 7,000 ft. and to the most common special case for indoor thermal environments in which mean radiant temperature is nearly equal to dry-bulb air temperature, and air velocity is less than 45 fpm. For this case, the thermal environment is well specified by the two variables shown: dry-bulb temperature and the humidity ratio." The data are reported as useful for light clothing (0.5 - 0.7 clo) and for seated or sedentary activities, whereas the ASHRAE Comfort Standard 55-66 applies generally for average clothing (0.7 - 1.0 clo) and medium activity (office work).[89]

Man's metabolism continuously generates heat, which is given off into the environment in five ways: (1) radiation, (2) convection, (3) pure conduction, (4) respiration, and (5) evaporation. Under certain climatic or environmental conditions, net heat-flow may be directed from the environment to the body by means of (1), (2), (3) and (4). Thermal comfort, of course, depends on the detailed characteristics of these phenomena. The significance of radiation markedly rises with increases in the differential in temperature between body and environment. If, on one hand, the

(87) For a more detailed discussion of the subject see:
(a) A.P. Gagge, J. A. J. Stolwigk, and Y. Nishi, AN EFFECTIVE TEMPERATURE SCALE BASED ON A SIMPLE MODEL OF HUMAN PHYSIOLOGICAL REGULATORY RESPONSE, ASHRAE Transactions, Vol. 77, part 1, 1971, pp. 247-262.

(88) ASHRAE Project RP-43, Thermal Comfort:
(b) F. H. Rohles and R. G. Nevins, THE NATURE OF THERMAL COMFORT FOR SEDENTARY MAN, ASHRAE Transactions, Vol. 77, part 1, 1971, pp. 239-246.
(c) T. E. MacNall and R. G. Nevins, A CRITIQUE OF ASHRAE COMFORT STANDARD 55-66, ASHRAE Journal, Vol. 10, No. 6, 1968, pp. 99-102.

(89) ASHRAE HANDBOOK OF FUNDAMENTALS, op. cit., pp. 138-139.

temperature of the environmental mass decreases, there will be increased radiation (heat-flow) from the body, ultimately enough to cause stress and then physiological harm. If, on the other hand, the temperature of environmental and climatic objects goes higher, say beyond the limits of the physiological norm for thermal comfort, then heat radiated to the human body from the environmental mass will rapidly cause stress and worse. Color can modify the intensity of radiation effects, especially short-wave radiation.(90)

The acceptability of an indoor climate permits surprisingly little deviation from an accustomed norm. An air-temperature variation of about 5° F is about all that people will tolerate. Humidity, to which we seem to be less responsive, may vary between 20 and 60% rh without complaint, but higher and lower values become noticable, requiring temperature compensation if they are not to become objectionable. Ambient air velocity must be under 40 ft/min. "Wind-chill" is a well-known sensation outdoors, but unpleasant "drafts" are experienced indoors. Air cleanliness and odors are difficult to define, yet must be controlled for a satisfactory indoor climate.(91)

The role of the relative humidity factor is often misunderstood. To further clarify:

> " . . . it can be seen that the humidity influence for persons in thermal comfort is relatively moderate. A change from absolutely dry air (rh = 0%) to saturated air (rh = 100%) can be compensated for by a temperature decrease of about 1.5-3°C."(92)

(90) Fanger, op. cit., p. 35.

(91) Rogers, THERMAL DESIGN OF BUILDINGS, op. cit., p. 4.

(92) Fanger, op. cit., p. 43.

Under environmental conditions when airconditioning is resorted to, it has long been known that air-dehumidification (at a lesser energy cost) can bring about a state of thermal comfort before air-cooling (at a relatively higher energy cost) is required for comfort. More data are needed in this area, however, such as the data available for heating situations.

No condition can be found which everyone likes, although some discomfort will be tolerated by nearly all people. Temperature ranges of acceptability have been empirically determined between 68° F and 75°F at 50% rh.[93] The reference cited does not mention radiation (presumably, $t_a = t_{mrt}$) which would affect these temperatures. The optimum acceptable effective temperature (ET) varies between men and women, their culture, acclimatization, difference in age (minimal), clothing, winter- and summer-seasons, and even geographic locations. The most popular range is from 66° ET in winter to a high of 73° ET in summer, dry-bulb air temperature 73° to 77° F, air movement about 25 ft/min.[94]

The earlier part of this chapter has touched upon the source of benefits which can be obtained through use of better building insulation, benefits in terms of reducing heat loss or heat gain. Additionally, improved insulation has the effect of raising (lowering) wall-surface-temperatures in the case of heating (cooling), which in turn reduces (increases) radiation from the body to the wall. Lower (higher) ambient air temperatures can be maintained under these conditions with satisfactory thermal comfort. Said differently, improved insulation not only reduces heat-loss (gain),

(93) Frederick H. Rohles, Jr., PSYCHOLOGICAL ASPECTS OF THERMAL COMFORT, ASHRAE Journal, Vol. 13, No. 1, Jan. 1971, pp. 86-90.

(94) Rogers, THERMAL DESIGN OF BUILDINGS, op. cit., p. 4. Author defines "Effective Temperature" (ET) as a set of conditions involving dbt, rh, and v.

but also permits lower (higher) thermostat settings, maintaining acceptable thermal comfort and achieving heat energy savings.

Poor insulation can materially reduce the usefulness of living space. In houses with little or no insulation, at lower outdoor temperatures, say 20° F or below, the space at a distance of less than several feet from exterior walls may be uncomfortable. The same distance in a well-insulated house may be only a few inches.

The principles surrounding insulation of buildings are well known, but useful data are not as readily available as might be. Therefore, energy savings thus possible have probably never been fully taken advantage of. Research in this area could be productive to establish the relationship of human thermal comfort to surface temperatures of environmental objects, walls, and ceilings under varied conditions. Again, the objective of such research would primarily be to achieve higher efficiency of energy utilization.

The most creditable work to date, Rogers' THERMAL DESIGN OF BUILDINGS (1964) refers to the subject of surface temperatures by what he calls "comfort yard-sticks." He points out that with the advent of building insulation, thermally-improved walls became known to be "comfortable":

> " . . . by correlating these U-values with the indoor surface temperatures that resulted from their use, I came to the conclusion that surface temperatures of 10° F or more below indoor air temperature could be considered in the discomfort zone, and that surface temperatures less than 5°F below indoor air temperatures could be classed as the adequate comfort zone. Although insufficient research has been done in this area to establish the actual relationship of human comfort to surface temperatures, this 10-degree yard stick seems to be generally accepted."(95)

A schematic illustration of the problem is provided by Figure 6.

Research should be undertaken in the area of humidity control. As

(95) ibid., p. 6.

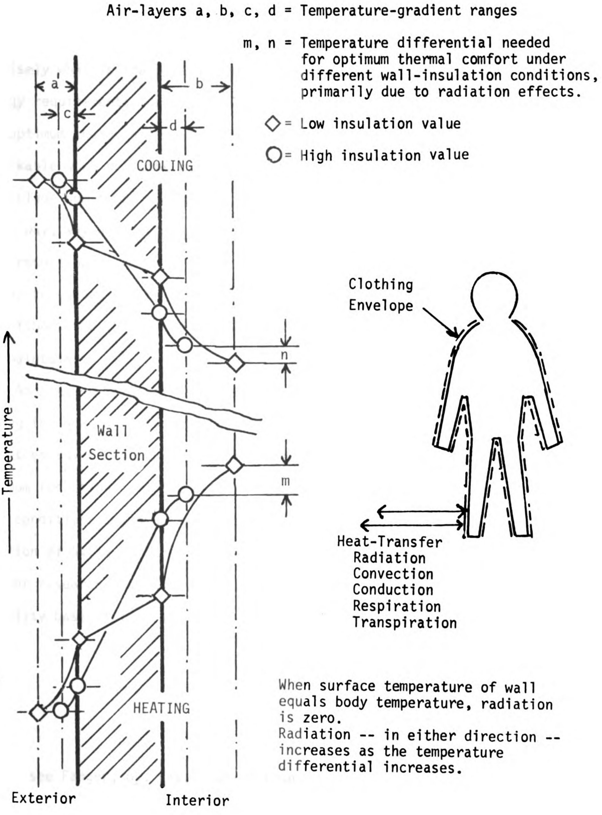

Figure 6. Schematic Diagram of Building-Insulation and Human-Body Heat Transfer.

already mentioned, the sensitivity of the human physiology to air-humidity variations appears to have a wide range of tolerance. Some questions are: precisely what is the relationship between dbt and rh when it comes to energy requirements for heating or cooling, what conditions would provide for optimum energy utilization efficiency, what are the trade-offs? The remarkable work relating clothing to thermal comfort(96) must be expanded to include non-human energy in the comfort equation. Or, stated in another way, why not use clothing first in arranging for thermal comfort before resorting to energy resources for space conditioning, particularly energy resources of the non-renewable variety? It is, of course, understood that fibers, textiles, and clothing require energy to produce, distribute and maintain.

An area which deserves attention is the question of night set-back during the heating season for sleeping under high-comfort conditions at lowest energy expenditure. One analog-computer simulation to determine maximum reduction in space-heating requirements and minimum loss of comfort conditions suggests the possibility of average reduction in fuel consumption of 9% in colder temperature zones, and 15% in milder climates.(97) Further research and testing in living units is needed to expand the reliability base of the data under various real-life conditions.

(96) see Fanger, <u>op</u>. <u>cit</u>., sub-section on Comfort Diagrams in section headed Comfort Equation, pp. 43-55.

(97) Lorne W. Nelson, REDUCING FUEL CONSUMPTION WITH NIGHT SET-BACK IN ASHRAE Journal, Vol. 15 No. 8, August 1973, pp. 41-49.

In many cultures bedding, rather than extensive space heating, serves to achieve sleeping comfort. In the United States, electric-blanket sales are estimated for 1973 at about 5 million units. Growth in demand is 3 - 5% per year. Wattage ranges from 135 - 180 W. It is of note that electric blankets are generally used at off-peak hours. The sales argument is that " . . . they allow a homeowner to lower the thermostat an extra 5 degrees at night and save on fuel."[(98)] If the thermostat is kept at the same setting and light bed-covering is utilized, however, the energy consumption is increased.

Another area which has a shortage of information for American practice has to do with ventilation, either the normal air-in and air-out filtration and/or forced ventilation from the point of view of minimizing heat-energy consumption. Some of the criteria are often arbitrary or rule-of-thumb, such as 120 cfm for kitchen fans or 15 air changes per hour, or 50 cfm for bathroom fans.[(99)] Heated air lost through unnecessary ventilation can incur energy expenditures of .02 Btu/ft^3/°F[(100)], if the replacement air has to be heated. To illustrate, during the heating season, 120 cfm exhausted from a kitchen may represent one-tenth of the heat input into a kitchen. As more and better building insulation comes into use, and air movement between indoors and outdoors is restricted as a part of efforts

(98) Paul Shook, General Manager of Consumer Products, CASCO Division, Sunbeam Corp., and John O'Grady, V.P. Fieldcrest Corp. in Investors Reader, November 1973.

(99) see article in Lansing State Journal, April 4, 1973.

(100) = the specific heat of air, from:
J. J. Barton, ESTIMATING THE HEAT REQUIREMENTS FOR DOMESTIC BUILDINGS, Butterworth & Co., London, 1969, p. 5.

to reduce energy demand, it is obvious that more attention will have to be given to the adequacy of air of healthful air-quality for the indoors. Attention given to clothing and bed-coverings would allow for more flexibility in this connection, but is also subject to further investigation.

In sum, there exists a body of knowledge on thermal comfort, but there is a scarcity of analysis and information which relates thermal comfort to energy consumption, energy-utilization efficiency, and energy conservation. A lack of focus on clothing and bed-coverings in this respect is especially evident.

This chapter up to this point has attempted to cover the more important aspects of the complex phenomena of thermal comfort, an understanding of which is essential for any assessment and evaluation of the related aspects of energy technology. For this purpose, development and use of the scheme suggested in Part B may help.

c. Lighting, like thermal comfort, is labeled as an amenity, even though, some may argue that it is more nearly a life-support necessity. Lighting must produce sufficient radiant energy to be reflected from objects and allow adequate visibility; for " . . . Light is that form of energy which stimulates the eyes to sight."(101)

Man, through time, has engaged in continuous effort to find ways to utilize hours of natural darkness by artificial illumination. The history parallels man's efforts to extend his own energy for performing work through exploitation of non-human energy resources. For centuries

(101) W. R. Stevens, PRINCIPLES OF LIGHTING, Constable & Co., Ltd, London, 1951, p. 1.

lighting methods were primitive. Oil lamps were known as far back as 8000 B.C. Later on came tallow and candles. It was not until the end of the 17th century that lighting with coal-gas became known. It was a hundred years later, when coal-gas began to be piped into houses, before candles and oil lamps acquired competition. Gas-light then was nothing more than flames, yet a revolution in artificial lighting with profound impacts had begun:

> " . . . The social and economic effects of gas can scarcely by exaggerated. Scoffing at those who claimed that sunlight was necessary for growth, Andrew Ure pronounced that children suffered no harm working twelve hours a day in mills lighted by gas. If gas must bear some of the responsibility for the intolerably long hours of labour in the early 19th century, it also gave the workman and his family a new life. For gas encouraged evening classes in the Mechanics' Institutes, and aided the new literacy and education. That people could congregate after their working hours in well-lit halls encouraged the processes of popular government. The social, industrial, and communal life of the 19th century could not have developed as it did without gas-light." (102)

Not long after the commercial introduction of gaslight (ca. 1800) came the beginning of electric lighting, initially by use of the electric arc, suitable for street lighting, but not for residential uses. There were improvements in gas-lighting devices, the atmospheric burner (ca. 1840), for example. Not until the last two decades of the 19th century, however, were there major lighting breakthroughs. These came with the incandescent electric filament-lamp (inventors Swan and Edison) and the incandescent gas mantle (Welsbach). Of note is that the latter came a few years after the former, presumably in response to the threat of competition. Still, with all this progress, even today more than half the world's population

(102) Charles Singer _et al_., eds., A HISTORY OF TECHNOLOGY, Vol. IV, The Industrial Revolution, ca. 1750 to ca. 1850, Clarendon Press, Oxford, 1967 (1958), p. 274.

uses open flames for artificial illumination when natural light is absent.[103]

Artificial illumination under present technology is almost entirely derived from combustion, incandescence of solids, or electrical discharge with or without fluorescence, originating from three sources: (1) vegetable and animal fatty substances, (2) fossil fuels, and (3) electricity. From a physical point of view, illumination through the distribution of radiant energy is derived by conversion from electrical and chemcial forms of energy.

How light is perceived is tied to the physiology of vision. Because of the complexities of this physiology and the primary concern of this present study being energy utilization, details of the processes involved in seeing are omitted. The subject is adequately covered in the literature.[104-106] Precise quantitative information on current energy use for lighting is not available. As previously noted, residential and commercial electricity consumption for lighting is estimated to range from 15 to 30%.[107] Assume it is 25%,[108] then, on the average, one in seven electric power plants could be imagined to exist solely for residential and commercial lighting. But, here again, consumption data are not reliable.

(103) , LIGHTING, Encyclopedia Britannica, 1972, Vol. 14, p. 1.

(104) R. G. Hopkins <u>et al</u>., DAYLIGHTING, Wm. Heinemann Ltd, London 1966.

(105) Yves Le Grand, LIGHT, COLOUR AND VISION, Second Edition, Chapman and Hall, Ltd, London 1968 (1948).

(106) M. D. W. Pritchard, Environmental Physics: LIGHTING, American Elsevier Publishing Co., Inc., 1969.

(107) Stein, SPOTLIGHT ON ENERGY CRISIS, <u>op</u>. <u>cit</u>.

(108) The 25% figure is from: Milton D. Rubin, WASTE NOT, WANT NOT, Article in IEEE Sprectrum, Vol. 10, No. 1, Janauary 1973, p. 68.

A popular assumption is that waste occurs in lighting. The President of the Illuminating Engineering Society (IES), makes this point in a letter to "members of the lighting community", when he says:

> " . . . we have spelled out in our practices what constitutes good current practice, and since so much lighting is not good, do we not stand for elimination of waste in using electric energy? . . . IES accepts the challenge of developing the new technology that will be needed. We also accept the responsibility for the massive education job that has to be done."

This letter reviewed the history of lighting engineering development and progress to the point where: " . . . we are facing a new set of priorities in terms of wise use of resources."(109)

On examination of the subject, questioning overall energy expenditures required in support of contemporary lighting practices, a number of issues are brought to the surface. Some of these are: (1) natural vs. artifical lighting, (2) functional vs. ornamental or decorative lighting (including advertising, merchandise display, etc), (3) present standards for lighting, (4) lighting for safety and security, and (5) thermodynamics and conversion inefficiencies of lighting equipment.

Energy expenditures which can be assessed to natural lighting are probably negligible. These are incurred by heat-loss (-gain) through fenestration, and in the production chain of window-glass, shades, awnings and the like. Artificial lighting obviously consumes energy during all times when such lighting is used. Light sources generally have limited life, and replacement of these sources involves additional energy expenditures.

(109) Robert T. Dorsey, in a letter published in LIGHTING, DESIGN AND APPLICATION, Vol. 3, No. 3, March 1973, p. 52.

As relatively cheap lighting and light sources became available, more and more arguments in favor of displacing natural light by "stable and controllable" artificial lighting were heard. Buildings have been designed and arranged to function in this manner. The lighting business interests have much to gain by this philosophy.(110)

As early as 1930, one author, then connected with the lighting industry, wrote:

> " . . . as civilization advances . . . the construction of the artificial world make man more and more of an indoor being, . . . 'indoorsness' of living and working . . . openings to admit daylight became standard practice." " . . . architecture and indoor world are suffering from the daylighting habit." " . . . congested cities, valuable ground and floor areas are wasted to admit inadequate and uncertain daylight. Wall-space is consumed by windows. Architecture is being handicapped by the window and skylight habit. Set-backs in building ordinances cause losses . . . . age of modern, controllable and relatively inexpensive artificial light." " . . . ordinary glass does not transmit health-maintaining radiant energy . . ."(111)

(110) Artificial lighting has grown into an important industry, as indicated by the following:

Growth of Total Lighting Equipment*

Year	Annual Sales Volume in Millions of Dollars
1947	422
54	634
58	765
63	1,116
67	1,542
70)	1,800
75) **	2,400
80)	3,200

* All types of lighting equipment; manufacturer's selling prices, current dollars, fob plants.

** Estimate based on current economic and construction forecast. Source: Bureau of the Census, Census of Manufactures, MC-36C and Industrial Reports MA-366

(111) M. Luckiesh, ARTIFICIAL SUNLIGHT, Van Nostrand, New York, 1930, pp. 7 and 8.

The author then went on to say that new data are needed to support his arguments.

Data or no data, artificial light has in fact replaced daylight in many uses. A strong argument, apparently based on lack of evidence to the contrary, is that no harm to sight and general well-being could result from working and living with artificial lighting, and hence, natural light is unnecessary.

Looking at the other side of the coin, others recently posed this question:

> " . . . it is not unreasonable to ask that the argument should be put the other way, and to demand evidence to show that any gain in vision or health results from working in a controlled man-made environment, and in particular to show whether there are any advantages in working in a continuous artificial lighting as compared to natural lighting."(112)

Decorative and ornamental lighting as an energy consumer has to be assessed for its justification from several points of view: energy availability, economic impact, alternatives to creating esthetic effects by lighting, effects by lighting, effects on the environment, and social justice (see Part B, explaining the suggested use of technology assessment for this purpose). If in fact such artificial lighting should deprive someone of light for working, as a consequence of energy shortages, a reallocation of resources would surely be called for. Justification of advertising and merchandise display lighting needs to be reviewed in a similar manner.

A good case can perhaps be made for lighting to provide adequately for the safety and security of the people in mass society; but again, the

(112) R. J. Hopkinson and J. D. Kay, THE LIGHTING OF BUILDINGS, Praeger, New York, 1969, p. 68.

resolution of this matter is not obvious and it should be systematically assessed. In another area, the precise relationship between productivity and lighting conditions has never been fully established in the industrial and commercial sectors, much less with regard to the residential sector.

Present American lighting standards are those of the Illuminating Engineering Society (IES), which obviously represents the lighting-equipment industry. These standards specify values of "footcandles on the visual task," and were established as a result of studies by H. R. Blackwell at the University of Michigan during the 1950's. He developed a new quantitative method for determining adequacy of interior illumination levels under varying brightness contrasts and times. Blackwell recognized in his report that it would be necessary to verify his findings to prove its ultimate reliability as a basis for determining illumination levels for actual situations. The IES adopted the Blackwell data as a standard, nevertheless and published his findings in the 3rd Edition of the IES Lighting Handbook (henceforth referred to as the IES Handbook).(113) Although a 4th and a 5th Edition of the Handbook have since appeared, the standards have remained unchanged.

The standards have been subject to critical comment. For example, although favoring architectural lighting and claiming the illumination of buildings to be more the province of the architect rather than the engineer, one architect-author points to the American lighting standards as being too high and not oriented to actual seeing and visual comfort needs.(114)

(113) John E. Kaufman, ed., IES LIGHTING HANDBOOK, The Standard Lighting Guide, 5th Edition, Illuminating Engineering Society, New York, 1972.

(114) Leslie Larson, LIGHTING AND ITS DESIGN, Whitney Library of Design, New York, 1964.

More recently, another architect has been outspoken with respect to what he terms a waste of energy in American lighting practice, and is moreover critical of the entire architects' profession for being contributors to energy waste.(115)

There are a number of conditions for which higher illumination levels might be justified. If these levels were adopted universally, they would result in over-illumination. To illustrate, allowance has to be made for the fact, that older persons need more light:

> " . . . as people grow older their eyes gradually change, and the lens becomes less elastic. At the age of 40 there is a definite change in this direction. Corrective glasses and high-level lighting help older people."(116)

New standards need to take this factor into account.

Standards, specifically for residential lighting, were issued by the IES in 1953 as a result of a study.(117) Lighting levels recommended by these standards were substantially raised in the 3rd Edition of the IES Handbook as a part of the revisions already described. In actual experience, general illumination levels in the United States have risen rapidly through the years and are projected to go even higher by a member of the lighting industry; see Table 17 which follows.

(115) Stein, SPOTLIGHT ON ENERGY CRISIS, op. cit., and unpublished remarks by Mr. Stein under the heading of The Optimization of Lighting Energy, at an IES Symposium in New York, November 28, 1972.

(116) Helen J. Van Zante, HOUSEHOLD EQUIPMENT PRINCIPLES, Prentice Hall, Englewood Cliffs, New Jersey, 1964.

(117) ____________, RECOMMENDED PRACTICE FOR RESIDENCE LIGHTING, prepared by the Committee on Residence Lighting of the IES, in August 1953 issue of Illuminating Engineering.

TABLE 17. LIGHTING LEVEL IN THE UNITED STATES, YEARS 1900 - 2000.

Year	Footcandles	with promotion
1900	3	
10	5	
20	10	
30	20	
40	35	
50	50	
58	85	
65	100	
71	125	
1980) *	175	200
2000)	250	300

* Estimate by Cooper (see below), who believes that there is "economic" justification for the projected values.

Source: Berlon C. Cooper, A STATISTICAL LOOK AT THE FUTURE OF LIGHTING, Article in Lighting Design & Application, Vol. 1, No. 1, July 1971, p. 18.

The question is, how high is enough? European and Australian accepted lighting levels are much lower than those in the United States.(118) These lower levels are usually explained on grounds of economics, cultural, and social differences. Now that the energy-resource problem is recognized as important, the time has come to re-examine lighting in terms of its energy demand. The relatively poor utilization efficiency in the conversion of basic energy resources applied to lighting, given present technology and under the best of conditions, is such that for every additional unit of effective lighting, on the order of 16 to 50 additional basic energy units need to be supplied.

(118) Larson, _op. cit._, p. 22 (gives lighting levels for the U.S., Great Britain, France, Germany, Sweden, Finland, Belguim, Switzerland and Australia).

It is this multiplier effect which deserves serious attention in the management of the problem. A great deal of knowledge is available. The impressive number of available texts and the information on the subject of lighting and vision are witness to the argument that better performance is to be expected, especially in the design and arrangement of residential lighting. Lighting as a subject has only had marginal attention by the education establishment, and even then the real energy costs involved have been passed over.(119)

Aside from the massive trends to artificial lighting already discussed, there has been relatively narrow corresponding technological progress during the more recent decades. Edison's first incandescent 100 W light had an efficacy of 1.4 lumens per watt (Lm/W). By 1900 it had advanced to 4.0 Lm/W. Inventions through about the 1920's (Whitney, Coolidge, Langmuir, Steinmetz and others) raised the efficacy to nearly where it is now, 17 Lm/W. Fluorescent lights in 1940, relatively new then, had an efficacy of 40 Lm/W; now the efficacy is in the 50 - 60 Lm/W range.

Better lighting performance can be obtained up to about 110 Lm/W with commercially-available mercury or sodium high-pressure vapor lamps, but they are unacceptable because of the color of the light. They are moreover economically impractical for residential uses.

The main problem is conversion of electrical or chemical energy into radiant energy. Even after the energy is in radiant form, there is the

(119) In the view of Dr. Robert Summitt, Chairman, Department of Metallurgy, Mechanics and Materials Science, Engineering College, Michigan State University, East Lansing. Dr. Summitt is an expert on light and color, and is currently developing materials for a course in lighting oriented to undergraduate students in Human Ecology and Engineering. Dr. Summitt has had a long-time interest in teaching in the field of his particular expertise.

problem of great differences in lighting effectiveness of the wavelengths (color) in the visible spectrum. That is, efficacy varies with the color of light. Theoretical optimum of lighting efficacy has been established at 675 Lm/W at 595 nm. But this wavelength is that of yellow-green light at a particular wave-length, and is not acceptable for artificial lighting of the human environment and its objects; nor is the technology available for economical application. Inherent in this question is the problem of physiological reaction to radiant energy.

What contributes to the energy-inefficiencies of incandescent lamps is that much of its radiant energy output is outside the visible spectrum. Filament temperature determines the wave-length distribution. The incandescents are strong in red, but deficient in blue, because their temperature is relatively low. To produce more near-white light by increasing the temperature reduces lamp-life -- under present technology. We have therefore a compromise between life time and efficacy -- aside from economic considerations. Operating on 60-Hertz current, a 40-W lamp loses 13% of its lighting efficacy owing to cycle-flicker. This loss decreases as wattage is increased. A 500-W lamp loses only 2% on this account.

As indicated, fluorescent lighting shows better efficacy, on the order of 3 to 1 over incandescents. The life of fluorescents exceeds that of incandescents by a factor of 10. Economic cost of fluorescents is higher. The question of use in residential applications would be a study by itself, and is hereby recommended. It would be a candidate for a technology assessment. Accelerated use of mercury (in fluorescents) would have to be carefully weighed.

Fixtures and fixture arrangements have a great deal to do with efficiency. For example, ceiling-suspended fixtures are more energy-economical than recessed troffers.[120] The latter may require less cleaning and maintenance, however.

The essence of the problem is one of maximizing uses of daylight, improving on the artificial-lighting technology and physical lighting arrangements, including devices. A number of ideas have been suggested for study, such as zone lighting, automatic switching, and most importantly, study of the human factors involved: what is in fact needed, and what is acceptable?

One would normally expect the IES to be aggressively instrumental in establishing policy directed at finding solutions to the problem of energy demand for lighting. In 1972 the IES issued a statement outlining the society's recommendations for better utilization of energy expenditures. The twelve points in the statement are:[121]

" . . .

(1) Design lighting for expected activities (seeing tasks, with less light in surrounding non-working areas)

(2) Design with more effective luminaires and fenestration (use systems analysis based on life cycle)

(3) Use efficient light sources (higher lumen/watt output)

(4) Use more efficient luminaires

(5) Use thermal-control luminaires

(6) Use lighter finish on ceilings, walls, floors, and furnishings

(7) Use efficient incandescent lamps

(120) ______, ENERGY CONSUMPTION AND DESIGN PRACTICES, from the Lighting Design and Application Forum, in Lighting Design and Application, Vol. 2, No. 8, August 1972, p. 26 on.

(121) in L D & A, ENERGY CONSUMPTION AND DESIGN PRACTICES, op. cit.

(8) Turn off lights when not used

(9) Control window brightness

(10) Utilize daylight as practicable

(11) Keep lighting equipment clean and in good working condition

(12) Post instructions covering operation and maintenance."

Examination of these points of recommendation discloses deficiencies, or at least questions. To begin with, it is unfortunate that the recommendations are not quantified in terms of possiblities for reduction in energy consumption. They are directed to industrial, municipal, and institutional users who would normally look for cost/benefit information. Whether the recommendations would have any worthwhile impact upon residential energy consumption for lighting is a question for research. Nor is there mention of R & D, of developing new or better devices, of methods and practices, in general, of the development of the technology.

There are some aspects of lighting which have been ignored by the IES recommendations. One, applicable to residential situations, is decorative or ornamental lighting, indoors and outdoors, already mentioned earlier. Amounts of energy consumed for this purpose are unknown, as are effective alternatives and means for the reduction of such consumption.

The situation is no different from that in other areas of residential energy use, namely, little information is available which can be used directly for a point-by-point evaluation. An assessment of each point of recommendation, along with an evaluation of alternatives and means for attainment appears to be necessary. Such information is required to support more rational decisions leading to improvement in energy-utilization efficiency. One can visualize it as a large task by itself, therefore, in lieu of a detailed specific assessment and evaluation, a brief discussion of the recommendations in the light of the above will have to suffice.

(1) "Design lighting for expected activity . . ."

These recommendations on the part of the IES are nothing new. There is a wide gap between what is recommended and what is practiced. The reason for this disparity should be researched with both energy and economic cost as a basis, i.e. total cost of lighting systems, the sum of owning and operating charges, as related to a set of lighting standards which consider limitations on energy availability as a fact, and also consider environmental costs.

(2) "Design with more effective luminaires and fenestration . . ."

The first objective of any lighting plan should be to maximize utilization of daylight. Careful planning of activities tailored to available daylight would be included (various daylight-saving time schedules). Luminaires, or lighting fixtures as they are referred to in residential uses, should take care of requirements which daylight under the best of conditions cannot fulfill. The effectiveness of lighting fixtures for residential uses is at present ill defined, if not well understood. This subject is in need of inquiry. Efficacy standards for lighting fixtures should be developed.

(3) "Use efficient light sources . . ."

In residential uses, given present technology, this recommendation implies greater use of fluorescent light. Incandescent lights now dominate residential lighting where the stock of existing installations is exceedingly large. Prevailing attitudes and conflicts need to be studied and resolved. Again, there is need for standards.

(4) "Use more efficient luminaires"

If "lighting fixtures" can be included in "luminaires," the use of more efficient lighting apparatus depends on the availability of information regarding efficiency. Standards as suggested under (3) above are required in order to facilitate consumer education. To illustrate, every householder might have access to a light-level meter and so learn how to do a more efficient lighting job.

(5) "Use thermal-control luminaires"

This recommendation would apply almost exclusively to large-scale lighting installations. It is based on the technical fact that fluorescent lights are most efficient at certain temperature levels, and therefore call for thermal control.

(6) "Use lighter finish on ceilings, walls, floors and furnishings."

This recommendation concerns one of the larger factors in residential energy consumption for lighting. It requires knowledge of light, color, vision, and other factors. Mainly, implementation is a task for education. One authority believes that it is possible to reduce energy consumption for lighting by 10% through proper use of environmental materials, colors, and finishes.[122]

(7) "Use efficient incandescent lamps"

Incandescent lamps by their nature are inefficient light sources. What appears as useful light in the form of radiant energy is only about 2% of the basic energy resource which went into the electric generating plant. The life of an incandescent bulb is limited to less than 1000 hours, roughly one-tenth the life of a fluorescent lamp. Given present technology, higher efficiency means higher temperature and hence shorter life. There is little flexibility in this respect. The weight of effort hence has to be directed toward how

(122) from Dr. Summitt, loc. cit.

incandescent lamps are used. Using fluorescent light whenever possible is to be preferred from an energy-consumption point of view, since fluorescents are on the order of three times more efficient than incandescents.

(8) "Turn off lights when not needed"

In the United States, wherever families live, this admonition has a familiar ring. Approach to the problem appears to lie in (a) consumer education, at all levels, formal and informal; (b) incentives and/or disincentives; and (c) technology, timers and automatic switching devices which sense need for light, including proximity switches, dimming devices, and the like.

(9) "Control window brightness"

One of the big problems with daylight illumination is how to use it to illuminate a task or activity adequately and comfortably. Often, glare is a problem, particularly on or near the side of a building facing the sun. Glare or highlighting contrasts can cause discomfort or even stress. A body of knowledge exists on the subject. As daylight is stressed in the interest of reducing energy consumption for lighting, more attention to what is known is called for. Again, this call points to education. Beyond that, more research and experimentation is needed.

(10) "Utilize daylight as practicable"

Since the rapid adoption of fluorescent lighting in buildings in the 1930's, we find that architects, designers, and builders have tended to more and more rely on artificial lighting. Parts of the rationale for this trend were mentioned earlier in this section. Space arrangements have increasingly become dependent upon artificial lighting.

Present space configurations are obviously difficult to change. The entire question needs to be re-studied for better alternatives which must be assessed in terms of their potential impact. If there is a future for solar energy, lighting provides us with an ideal application.

(11) "Keep lighting equipment clean and in good working condition"

The IES Handbook gives six causes for light-loss:[123]

a. Temperature, voltage, and ballast performance;
b. Aging of luminaire finish and material;
c. Accumulation of dirt on room surfaces;
d. Burned-out lamps not replaced;
e. Lamp lumen depreciation; and
f. Luminaire dirt depreciation.

Data on these factors contributing to lighting inefficiencies are available in manufacturers' specifications and the IES Handbook, where one can find information on Lamp Lumen Depreciation,[124] Luminaire Dirt Depreciation,[125] and more. Some of the effects are minor, but persistent.

(12) "Post instructions . . ."

would be more applicable to multi-unit residences and the like. Study for possible effectiveness might well disclose marginal opportunities.

Residential lighting practices are difficult to circumscribe in terms of their energy use, and particularly in terms of utilization efficiency. What may be considered inefficient use or waste by some, may be a peroga-tive for others. Another reason is the great multitude of lighting uses. In themselves the uses are relatively small, and often are so viewed.

(123) IES Handbook _op.cit._, p. 10-12.

(124) _ibid._, p. 9-16.

(125) _ibid._, p. 9-17.

Few people realize the magnitude of the aggregate basic resource requirement to take care of the energy demand for lighting. Adding to the problem is the now heavily built-in bias toward artificial lighting the present-day residential environment. Practices are embedded in culture, lifestyles and personal habits, therefore difficult to change, at least over the short haul.

Few would argue that there are no opportunities or alternatives for improving utilization efficiencies, or, in the terminology of the lighting engineers, efficacies. To assess the alternatives, as well as the means for achieving them, would be a study by itself. There is need for a profile of all energy uses for residential lighting in order to make an assessment and evaluation aimed at the wise use of energy resources allocated to lighting. The continuously increasing demand for artificial lighting on one hand, and the rising lighting levels on the other, make detailed study of the trend imperative. The impact of these trends has never been researched to the point where information is adequate for the development of rational policies.

d. Leisure and Recreation. As explained in earlier chapters, many forces have combined to accelerate the replacement of human effort and time by inanimate forms of energy. At the same time, such energy forms have been increasingly used to provide for amenities, if not pleasure. Manifestation of this development can readily be seen when looking over the data--presented in earlier chapters--which show the accelerating demand over recent decades. One frequently overlooked factor in the demand aggregation is that the personal time made available through the substitution of energy for time is often spent in leisure and recreation activities which add to the energy demand. The very fact of displacement of human toil by energy has built into it opportunities to use more energy. Technology generally provides these opportunities. The sport of hot-air ballooning may serve as an illustration. It uses up leisure time, plus 5 to 10 million Btu of heat energy per hour of flight, plus additional amounts for materials and related transportation.

Unfortunately, no data appear to be available which quantify the above argument. That many recreation-and leisure-time activities are energy intensive can only be presumed. One need to think only of recreation vehicles, snowmobiles, powerboats, autoracing, ski lifts, maintenance of more than one home for week-end purposes, and so on. In the home one finds powered entertainment paraphernalia, workshops, and provision for physical activities such as swimming pools. There are electric organs and music amplifiers. Transportation to a golf course takes energy, and so do the golfcarts.

Energy consumption by home entertainment apparatus is given in Table 18.

TABLE 18. HOME ENTERTAINMENT, ESTIMATED ELECTRICITY CONSUMPTION.

	Average Wattage	Estimated Annual Use in kWh
Television, black and white	237	362
color	332*	502
Radio phonograph	109	109

* Consolidated Edison in New York places this average at 420 Watts.

Source: Estimates by the Edison Electric Institute 1969.

There have been technical advances which have materially reduced energy consumption in home-electronics, for instance, displacement of vacuum tubes by solid-state devices. A TV receiver with vacuum tubes might be rated at 350 watts input, whereas a comparable receiver with transistors, diodes, integrated circuits, and other solid-state devices may be rated 175 watts. The solid-state receiver has the further advantage of increased service life and therefore offers a further reduction in overall energy costs. Hence, technology serves to reduce energy demand through increased utilization efficiency. On the other hand, a recent innovation, the "instant-on" television set, continuously draws electric current, whether the set is on or not. The cost of the electric energy for the feature is $10/year at 3¢/kWh, an estimated total of 333 kWh/year. This reduces the time between switch-on and picture appearance from 1/2 minute to 10 seconds.[126]

Swimming pools are large consumers of energy. There are approximately 3/4 million private pools in the United States, with new installations being added at the rate of 70,000/year. The average size of 16' x 32' consumes an estimated 400 kWh/year electricity, plus 100 million Btu/year, mostly gas, for pool water heating.[127] Shelter-unit heat losses could probably be utilized for this purpose.

Home workshops are equipped with a vast array of powertools and equipment. No information on the energy consumption by these devices appears to have been assembled by anyone. The case is the same with

(126) ______, Color Television, in Consumer Reports, Vol. 38, No. 1, January 1973, p. 8.

(127) ______, SWIMMING POOLS, CHANGING TIMES, Vol. 27, No. 4, April 1973, pp. 45 - 47.

out-door equipment, such as power lawnmowers, sweepers, clippers, and snow-blowers.

What this discussion points up is that single-family suburban living may be much more energy-intensive than higher-density apartment living. Although high-density settlements may rationalize at-home energy consumption, the resulting living patterns may well tend to accelerate away-from-home activities associated with leisure and recreation, activities contributing to energy demand.

These phenomena, to the best of the scantily available information, have never been studied. Such study might also explain the turn-around in the long-term trend of the energy/GNP consumption relationship. As mentioned in Chapter II, starting about with the mid-1960's, increasing amounts of energy seem to be needed to support growth in GNP.[128] One can only suspect that energy is in part used for activities which contribute little to economic growth. It could mean, in effect, disproportionately high social costs when measured against economic benefits to society. The individual activities should be subjected to rigorous technology assessment.

(128) , ENERGY CONSUMPTION AND GNP, op. cit., Figure 1, The Energy/GNP Ratio, 1947 - 1970.

2. HOME EQUIPMENT

Home equipment -- including the facilities for indoor-climate control--lighting, home entertainment, grounds care, and residential peripheral transportation account for almost the entire energy consumption in the residential sector, and much of it in the other sectors. For it is within the structure of the family-unit that many of the consumption decisions are made, decisions which affect the other sectors. By consumption, in this instance, we mean the consumption of goods and services in addition to the direct residential consumption of energy. Two of the most important elements which control direct energy consumption are: (1) the state of technology that is engineered and built into the equipment that uses energy in the various forms, and (2) the level of knowledge and concern with respect to use-practices, care, and maintenance of the equipment.

Non-human energy-powered devices and automatic heating and cooling equipment in the home are essentially a 20th-century development. Technical advances have been rapid, and the now existing stocks are exceedingly large.(129) It is not uncommon for a home to contain over fifty household appliances.

(129) Approximately:

300 x 10^6 major applicances (annual sales 30 x 10^6 units))
32 x 10^6 room airconditioners (annual sales 5 x 10^6 units))
65 x 10^6 water heaters (annual sales 5 x 10^6 units)) *
Unknown stocks of lawnmowers, snowthrowers, garden)
tractors, etc.(annual sales 7 x 10^6 units))

45 x 10^6 central heating installations)
11 x 10^6 individual water systems) **
8 x 10^6 central airconditioners (included in)
heating above))

* from Merchandising Week, February 26, 1973.
** from 1970 Census Data.

The energy-utilization efficiency of the equipment has been a criterion which over time has been afforded scant attention in the development and use of these devices, as mentioned elsewhere in this study. That first cost, rather than energy-operating cost, or life-cycle-cost, has recently been the most significant criterion, has also been touched upon; that social costs, especially environment costs, associated with energy utilization have not normally been a part of the cost calculus; and that prospects, of diminishing availability, of rapidly-rising energy prices, in relative and absolute terms, or even shortages, are changing the priorities, and lending emphasis to need for utilization efficiency and the conservation of energy resources. These concepts can be observed as being on the way of becoming key ingredients of unfolding American energy policy.

Home equipment and energy consuming devices around the home are not a new field of study. Knowledge accumulated over decades of equipment development and use is vast and important. Placed into the context of the United States national energy problem, there is at least one critical shortfall in this knowledge. Energy-availability and energy-use implications have generally been omitted. This observation is not to take away from, or to discredit, the work that has been done.

What must be faced now, however, is that the prevailing assumption of unlimited availability of cheap energy is faulty. Adding on the environmental damage inflicted by and associated with energy use makes a strong argument for massive change. Such change entrains major social impacts affecting and affected by how energy resources are deployed in residential and family-unit activities. "Home economics" as a discipline will be materially altered by the new demands expressing energy-resource availability and implications of energy use as a new dimension.

Past efforts directed toward savings in human effort and time will be cast in a different light. Studies of these phenomena will result in better understanding, if not innovation. In a search for higher efficiency levels, one should view residential activities and home-equipment devices in the context of the residential unit (or system). For example, nearly every indoor residential energy use affects the performance of a climate-control system, not only in technical terms, but also in social or human effect. Analysis may be aided by the assessment scheme suggested in Part B.

One logical outcome of a rigorous assessment of residential energy uses and use-practices is a replacement of home-equipment texts developed and published over the years.[130] The authors were obviously aware of the underlying natural science and engineering principles. Abundant energy availability at relatively cheap costs was taken for granted, however, and environmental-impact costs were not considered. Now that the scarcity threshold for energy resources has been crossed, this fact needs

(130) A partial listing:

(a) Louise J. Peet, with co-authors, HOUSEHOLD EQUIPMENT, 6th Edition, John Wiley & Sons, New York 1970 (first published in 1934).

(b) Betty Jane Johnston, EQUIPMENT FOR MODERN LIVING, MacMillan & Co., New York, 1965.

(c) Helen J. Van Zante, HOUSEHOLD EQUIPMENT PRINCIPLES, op. cit.

(d) Florence Ehrenkranz and Lydia Inman, EQUIPMENT IN THE HOME, Harper Brothers, New York, 1958.

(e) Elizabeth Beveridge, CHOOSING AND USING HOME EQUIPMENT, Iowa State University Press, Ames, Iowa, 1971 (first published in 1952).

to be incorporated as a new dimension into the texts and writings dealing with home equipment. A move in this direction necessitates a broader background in chemistry and physics, engineering, and a number of other disciplines. A joint effort for Home Economics and Engineering appears appropriate.

The growing technical compexities of home equipment make it mandatory that practitioners in the field -- which would naturally include all homemakers -- be somehow supplied with sufficient science and technology information to cope with energy-related problems. Need for such background has been recognized for some time. One author published a text purposely directed toward mitigating the deficiencies. In addition to the subjects already mentioned, the book covers construction and finishes of home appliances, utensils, and so on.[131] But it does not come to grips with the broad aspects of the energy problem. Apparently the only full-sized text with physics as a discipline involved in home equipment was originally published in 1938 and is now outdated.[132]

There have been a number of "equipment guides" for homemakers. The theme woven through these guides is one of "saving energy," that is, the homemakers' energy and her time. What the authors of the writings on home equipment meant by efficiency is significant: ". . .Efficient use of equipment includes the correct selection, arrangement, operation, and care of appliances, so that the homemaker may accomplish the maximum amount of work with the minimum of effort in the shortest possible time"[133], whereas energy costs are marginally referred to in the texts and then only in an

(131) Louise J. Peet, SCIENCE FUNDAMENTALS: A Background In Household Equipment, Iowa State University Press, Ames, Iowa, 1972.

(132) Madalyn Avery, HOUSEHOLD PHYSICS, A Textbook For College Students In Home Economics, MacMillan, New York, 1946 (first published in 1938).

(133) Peet, HOUSEHOLD EQUIPMENT, op. cit., Preface.

economic sense. None of them mention equipment for the care of residential grounds, such equipment in recent times has become a substantial energy consumer.

In what follows, parameters of energy utilization for home equipment will be considered under these headings:

Indoor Climate Control
Water
Kitchen Appliances
Home Laundry and Fabrics Care
Miscellaneous Devices

Parameters fall into four groups, viz., those limited by (1) energy form, (2) the equipment package, (3) the equipment installed and operated, and (4) the comprehensive area of consumer or user, economics, lifestyle, level of knowledge and resulting use practices, including operation, care, and maintenance of the equipment. Groups (1), (2) and (3) are primarily energy-resource and technological in nature, whereas group (4) is the human part of the man-machine relationship. It is these relationships which apply to all home equipment powered by non-human energy.

Choice of energy form (1) is dictated by availability, economics, and market influences. Often the consumer either has no choice or his knowledge is inadequate.

a. Indoor Climate Control is generally achieved by equipment for control of heating and cooling, humidity, dust, and odor. Roughly two-thirds of the residential energy consumption can be so accounted for.[134]

(134) PATTERNS OF ENERGY CONSUMPTION, op. cit., p. 6.

The 1970 Census enumerated heating equipment and heating fuels as shown in Table 19 below.

TABLE 19. RESIDENTIAL HEATING EQUIPMENT AND HEATING FUELS 1970.

Heating Equipment	
Steam or hot water	13.8×10^6 units
Warm air	28.8
Built-in electric	3.5
Floor, wall, or pipeless	5.9
Room heaters with flue	7.9
Room heaters without flue	3.9
Fireplaces, stoves, and portable heaters	3.3
None	0.6
All housing units	67.7
Heating Fuel	
Gas	35.0×10^6 units
Fuel oil etc.	16.5
Coal or coke	1.8
Wood	0.8
Electricity	4.9
Bottled gas	3.8
Other fuel	0.3
None	0.4
Occupied housing units	63.5

Source: Census of 1970, U.S. Summary HC (1) - B1, Detailed Housing Characteristics, Table 23, p. 1-248 and Table 24, p. 1-254.

Airconditioning was reported by the 1970 Census as shown in Table 20 below.

TABLE 20. RESIDENTIAL AIRCONDITIONING 1970.

Room units		
one	12.0×10^6 units	*
two or more	4.9	*
Central	7.3	
Housing units with airconditioning	24.2	

Source: Census of 1970, U.S. Summary, HC (1) - B1, Detailed Housing Characteristics, Table 23, p. 1-248.

* Merchandising Week, Feb. 26, 1973, p. 30 gives the number of room airconditioners in use during 1972 as 31.4 million units.

The above gives an overview of the variety of equipment and fuels utilized. There are no satisfactory data available on energy-utilization performance of the equipment as a part of individual comfort-conditioning systems, primarily because these systems are made up of more than the piece of equipment and the fuel as components.

A gas-or oil-fired furnace, for example, will have a specified name-plate input and output. Optimum values for conversion of fuel into heat are known quantities which do permit evaluation of the equipment by itself. The requirements for "complete combustion" can be found in handbooks and texts, as can be for "stoichiometric combustion" where scientifically precise data is required.(135) The theoretical ultimate is never achieved in actual practice. Standards giving practical design targets as well as theoretical ones do not generally exist.

(135) , ASHRAE GUIDE AND DATA BOOK, American Society of Heating, Refrigeration and Airconditioning Engineers, New York, 1968, p. 206 as an illustration.

To keep first cost of the equipment competitively low in line with mass-production and distribution objectives, many trade-offs are made which compromise utilization efficiency. Compromises are also resorted to in order for the equipment to be made adaptable to many field conditions, rates of use, and variations in fuel characteristics. Safety rules are another factor which tends to lower efficiencies. The state of the art limits any maximum design demand.

Once installed and in operation, moreover, the equipment becomes a component in the comfort-conditioning system of residential units. Numerous factors enter the efficiency equation, some of which need to be separately and individually determined for each installation. To illustrate: size, direction and location of flue-pipe to chimney, type of draft-diverter or hood, practices of the occupants of the unit, affect the utilization efficiency of the energy supply. Maintenance may materially affect it.

There is a wide latitude of choice among commercially available equipment. Any such piece of equipment may be considered a relatively efficient energy-into-heat-converter when tested in the laboratory. Performance of the equipment, once a part of a functioning and operating system, is quite another matter. Information is scarce inasmuch as tests are rarely made which result in comprehensive operational conversion-efficiency data for an installation over time. Some method of certification should be developed which will give information regarding efficiency of actual use. Moreover, instrumentation might be provided which permits monitoring of performance.

Manufacturer's performance specifications, generally available, are verified and certified by institutions which have been organized by the industries to serve that purpose. For example, airconditioning equipment and heatpumps are so certified by the Air-Conditioning and Refrigeration

Institute. Certain test routines, having been agreed to by industry members, are conducted in the laboratories of the manufacturers or, in some cases, by independent laboratories. Test data are filed with the Institute and are so certified and published. The information can be used for comparing performance efficiency among different makes and models. The American Gas Association (AGA) does the same for gas-burning equipment, and in a somewhat different manner Underwriters Laboratories certify oilburners. It is important to remember that data so made available come from laboratory tests of selected models. The data do not tell how much more efficient the equipment could be made, given different sets of conditions; still less can one tell much about ultimate fuel efficiency when in operation.

The variety of equipment available on the market is well described in various types of publications. Texts on home equipment have sections covering the subject. Practically nothing, however, is said of operating costs in terms of energy consumption.[136] Books devoted to the subject cover the many parts of the system, but neglect in their entirety energy consumption and utilization efficiency.[137]

Typically, new heating equipment efficiencies for gas and oil are specified by manufacturers at about 80%. The 20% loss obviously represents heat loss into the environment. Actual installed operating performance is estimated at considerably less.

As already pointed out, information on the actual performance of the

(136) See texts referred to in Ref. (130): Peet, Johnston, Van Zante, etc.

(137) Joseph B. Oliviere, HOW TO DESIGN HEATING-COOLING COMFORT SYSTEMS, Business News Publishing Company, Birmingham, Mich. (1970). Author's note: This reference is one example out of a large number of publications on the subject.

installed residential indoor-climate control equipment is not readily available. Variations among individual installations and practices of residential occupants confound the problem. Some utility companies, though on a relatively small scale, have developed usage data for gas compared with oil, and gas with electricity, i.e., ratios of the utilization efficiencies.[138]

From these data and other in publications and statements, the approximate range of residential utilization efficiency for heating equipment appears to be as shown in Table 21.

TABLE 21. APPARENT EFFICIENCY RANGES OF HEATING EQUIPMENT.

Coal (Bituminous)	45 - 60%
Oil	55 - 65
Gas	60 - 75
Electric	95 - 100

Sources:

(a) In a study ELECTRIC SPACE CONDITIONING IN NEW YORK STATE, Department of Public Service, 1971, a range of 60% to 70% for gas and oil, and a figure of 100% for electric heat were taken and a rationale therefore was given, p. III-5.

(b) AGA Monthly, February 1973, p. 9, places utilization efficiency for gas at 60%.

(c) PATTERNS OF ENERGY CONSUMPTION, op. cit., Table 5, p. 18 lists these estimated efficiencies: coal 55%, gas 75%, oil 63%, electric 95%.

(d) Note: It is assumed that electricity required to operate stokers, circulating fans, oilburner motors, and controls, is included in these percentage ranges.

(e) Note: For electric the "ultimate" efficiency may be as low as 28%.

(138) ______, Gas Engineers Handbook, Chapter 22, Fuel Comparisons, The Industrial Press, New York 1965, p. 12/341.

These estimated ranges suggest that utilization efficiency in fossil-fuel space heating can be improved, with attendant improvement in environmental and resource impacts. Such improvements can be made by eliminating the "standing pilot" flames on gas furnaces[139] -- responsible for up to perhaps 10% of all space-heating gas consumption, -- increase in size and performance of heat exchangers, installation of barometric draft controls, better control of primary and secondary air to the burners (furnishing this air directly from an outdoor source), heat recovery from the flue gases, and chimney design and location. Overall efficiency targets for oil and gas of 80%, or even higher, need to be investigated and tested. Overall efficiency comprises (1) efficiency of combustion, (2) efficiency of heat transfer (to air, water and other), and (3) efficiency of the distribution system (beyond the heating-unit itself).

A study of modulating the heat output of burners to adjust the heat distribution to follow demand as against the present customary on-off operation should be made to obtain cost/benefit data. No such information appears to be available.

One of the material and generally unrecognized limitations on improving space-heating efficiency by reducing heat-loss through insulation and air-sealing of structures, is the air required by occupants, fossil-fuel

(139) Gas consumption of "standing pilots" is a problem of most gas burning house equipment. It applies to heating furnaces, airconditioners, clothes dryers, waterheaters, cooking ranges, and incinerators. Note that most gas dryers do use electric ignition, which does away with the standing pilots. Clothes dryers have to be hooked up to an electricity source anyway, as do furnaces. With pilots, furnaces take 3 to 7 cubic feet of gas per hour, waterheaters 2 to 5 cubic feet. Not infrequently more than one pilot-flame is used. Gas ranges often have three pilots. To reduce the number of service calls due to "snuff-outs," the gas utilities have encouraged larger flames. It has served to increase revenues and at the same time has reduced service calls.

combustion devices, clothes dryers, and other ventilation-requiring devices. Until recently, natural air infiltration into built living spaces could be counted upon to provide the fresh-air supply for these purposes. This mechanism may no longer be adequate with improvments in construction, insulation, and vapor-sealing methods and materials--all efforts to reduce energy consumption. Provision will have to be made for supplying sufficient amounts of outside air in a controlled manner, for maximum comfort and health, and minimum heat-loss (or heat-gain).

The combustion of one cubic foot of gas takes roughly 9 cubic feet of air. When taken from heated living space, this air to some extent entrains an energy loss. The specific heat of air is about .02, which means that .02 $Btu/ft^3/°$ F of temperature differential is the energy content of air subject to such loss. The obvious solution is purposely to supply the proper amounts of make-up air required for combustion, if necessary, directly from the outside.

Man's physiological air requirements are about 18 ft^3/hr (ordinary adult in sedentary occupation). The air expelled in breathing contains 2 to 3% CO_2. For health reasons it should be diluted to near the CO_2 level of atmospheric air, normally equal to .03% CO_2. Dilution so required would be about 10 : 1; therefore the fresh air needed is something like 180 ft^3/hr/adult person when engaged in sedentary occupation. 60 ft^3/hr/ adult person is generally regarded as a minimum. When engaged in heavy work or physical exercise, the fresh air requirement may range as high as 1000 ft^3/hr. Another factor, namely moisture exhaled into the air, may have to be taken into account. This water vapor amounts to about 2 oz/hr/ person, to which must be added the evaporated perspiration from the surface of the body or its covering clothing.[140]

The air supply problem is simplified with electric heat. No combustion air needs to be introduced. In this case, however, the ultimate energy efficiency may be as low as 28%.[141]

Improvement in electric-heating overall performance, can come only by better performance in the generation and distribution of electricity, or by improving consumption by use of heatpumps. Moreover, the efficiency of the heatpump depends on its state of technology and on the heat source (or sink), e.g., the climate which affects the level of available atmospheric heat in the case of air-to-air systems. To illustrate, for New York city the heatpump may save about 60% of the electric energy over electric resistance heat, and in Buffalo or Albany, New York, perhaps 50%.[142] In warmer climates, or with earth- or water- heat sources, the ultimate efficiency may equal or be greater than that of fossil fuels.

Heatpumps are naturally affected by the same efficiency problems met in present-day room airconditioners, where a wide range of efficiences is found. The heat removal may vary from about 5 Btu/hr/watt to about 12 Btu/hr/watt[143]. At least 10 Btu/hr/watt could be considered for adoption as a minimum standard. Unit size, weight and first-cost may have to suffer

(140) Neville S. Billington, BUILDING PHYSICS: HEAT, Pergamon Press, Oxford, 1967, p. 191.

(141) Assumes 27.8% efficiency (for 1970) of generation, transmission, and distribution of electricity. From CONSERVATION OF ENERGY, National Fuels And Energy Policy Study, op. cit., p. 35.

(142) ibid., p. 36.

(143) ibid., p. 38.

a small increase.[144]

For design purposes, maps are available which give climatic data for the North American continent, as well as other parts of the world. For the United States, these maps indicate "outdoor design temperatures" by isothermal zones, or, in a similar manner, "degree days."[145] This information aids the architect, engineer, and designer of a structure. More comprehensive data can be found in the ASHRAE Handbook under "Weather Data and Design Conditions." Here such data are given for over 1000 stations in the United States, Canada, and 102 other countries--over 800 of them in the United States and Canada alone. It covers dry-bulb and wet-bulb temperatures, summer and winter maxima and minima, wind and percent probability targets.[146] The efficiency of heat pumps, when atmospheric air is the heat-source, is in a large part determined by these data.

Compressors operated as heat pumps must be carefully engineered for the highest possible efficiency at the low outdoor temperatures encountered in northern climates. This precaution is to overcome a well-known problem. The capacity of a heatpump falls off as outdoor temperatures go down when atmospheric air is the heat source. Electric resistance heat makes up for deficiencies. Under these conditions the rotary vane-type compressor has

(144) With outside air 95% ", inside air (from evaporator) 40° F, 10° to 20° F loss each in evaporator and condenser, motor efficiency of 80%, compressor efficiency about the same, subcooling the liquid and suction lines, one could reasonably expect a performance factor of around 10.5/hr/watt input.

(145) Tyler Stewart Rogers, INSULATED BUILDINGS FOR VARIOUS CLIMATES, op. cit., p. 14.

(146) ________, HANDBOOK OF FUNDAMENTALS, American Society of Heating, Refrigeration and Airconditioning Engineers, New York, 1968 (1967), Chapter 22, pp. 371-391.

a relatively higher efficiency than the piston-type compressor. Most of the refrigerator-service compressors currently used are piston-type. For economic reasons, these piston compressors have generally been adapted to heatpump service. What is needed are heatpump system designs which meet requirements of energy utilization efficiency without the crude compromises of simple adaptation.

Heatpump systems are generally chosen for airconditioning when cooling is called for. The only premium capital costs involved are those for the valving-mechanisms and the controls for reversing flow of refrigerant or air. These devices have in the past been subject to problems of reliability and service, which have discouraged the use of heatpump systems. Even in the American south, where room airconditioners have been used as heatpumps or vice versa, the units have more recently been sold equipped with electric resistance heaters, thusly avoiding service risks. This strategy again is a compromise apparently not in the best interest of energy economy, nor of economic operating cost to the user.

In another area related to energy efficiency, most present-day compressors in domestic use are 2-pole, and run at a little under 3600 revolutions per minute, on 60 cycles per second current. Up to about 1960 the general practice was to use motors operating at 4-pole speed. The change was made to reduce cost, size, and weight. Electric energy consumption went up by roughly 5%. This practice needs to be re-assessed in the light of energy-scarcity conditions.

In connection with suggested solutions to the energy problem, there have recently appeared studies[147] which attempt to show that many room

(147) J. C. Moyers, ROOM AIRCONDITIONERS: EFFICIENCY AND ECONOMICS, in ELECTRICAL ENERGY AND ITS ENVIRONMENTAL IMPACT, Progress Report December 31, 1972, Oak Ridge National Laboratory, ORNL-NSF-EP-40, Oak Ridge, Tennessee, March 1973, pp. 14-19.

airconditioners could be more efficient in terms of heat transfer measured in Btu per watt of energy input. This solution is not so simple as represented, in that airconditioners can be made much more energy-efficient "aircoolers" by raising evaporator temperatures and increasing heat-transfer surface areas. This change would reduce moisture removal from the air, which in airconditioning practice is often more important than reducing air temperature in order to achieve acceptable comfort levels. Optimum results in this respect are achieved by keeping evaporator temperatures just above frosting or icing. This practice limits the energy input vs. heat transfer parameter as indicated in footnote (144).

The relationship of air humidity to physical comfort has been mentioned. Thermal comfort, in part, depends on the human body's metabolism and resulting heat-dissipation requirements. Under low air humidity conditions, humidification devices can enhance this process, and so permit lower heating temperatures by several degree F (dbt), and thus reduce heat energy requirements. The ASHRAE Comfort Chart (Figure 5, page 84) illustrates this phenomenon. Dehumidification has similar inverse effects when atmospheric humidity conditions are high. No data were found which specifically relates these differential factors to specified quantities of possible reduction in energy consumption. The situation appears to be similar to that already described for the need for research on body-radiation heat-loss to walls (in the section on Thermal Comfort). Water taken from the air in the dehumidification process of airconditioning can improve condenser efficiency by evaporating the water on the condenser surfaces and so benefiting from the effects of evaporative cooling. It is known that condenser efficiencies can be so improved by between 5 and 8%. Many models of room airconditioners do take some advantage of this process. This opportunity for an efficiency gain is lost for most central airconditioning installations where the evaporator is indoors and the condenser is outdoors. Water vapor condensed on the evaporator is generally wasted. Because of the growth in central airconditioning installations, this point also merits study.

As can be noted from census statistics, residential heating by electricity has been gaining. It had its beginning with portable and usually supplementary heaters. Growth accelerated as cheap electric energy became available in areas where electricity was generated on a large scale from hydropower, such as in the Tennessee Valley, the Colorado River Basin, and the Pacific Northwest. Theoretically, electric heat derived from hydropower can be considered efficient in terms of ultimate basic energy-resource utilization. Quite the opposite is the case when electricity is generated from the combustion of fossil fuel. In actual practice, most of the hydropower generated in the United States goes into grids which are also supplied from fossil or nuclear power. Then electric heating must be looked upon essentially as supplied from these sources. Electric heating also achieved impetus in some areas supplied from fossil-fuel-burning power systems, where costs had been rationalized through large and highly efficient generating machinery. Here, electric heating was encouraged by a low step in blockrates, about 1¢/kWh. For more background on this matter, see the discussion of hydropower and electricity in Chapter V.

A few factors favor residential electric heating. Nuclear energy obviously can only be used for residential heating in the form of electricity, or by means of district heating. With fossil fuel, the emission of pollutants can be more readily controlled, economically and technically, at large central stations. Such stations are at the same time more efficient in the conversion process.

Gas, and also oil, must be viewed as basic energy resources in scarce supply. Given present technology, hydro, nuclear, and coal are the principal resources which can be relied upon for the generation of electric power. Coal can no longer be considered practical for individual residential heating because of air-pollution. Domestic availability of oil and gas is diminishing.

Gas is the superior home-heating fuel, but the supply question can not be easily circumvented. Gas derived from the gasification of coal will no doubt be used to greater extent in the future, but its future cost relationship to electric heating is unknown. Oil does not have a large advantage over electric heating, when all related factors are taken into account. A recent study[148] concludes that electrically-heated homes require about the same amount of total fossil fuel as oil-heated homes. At the same time, utilities use residual oil, whereas most residential oilheating equipment require No. 1 and No. 2 heating oil, which compete in the refining process with a series of other petro-chemical products. Further, oil-fired space heating also has adverse environmental effects much greater than fossil-fuel stack-emission from electric generating plants.[149]

From the point of view of social acceptance, electric heating has an advantage also. It is an "elegant" fuel. The idea of "all-electric" residences is a persuasive one. The problem is one of making the "all-electric" residence into an "energy-efficient all-electric residence."

Portable electric heaters evidently exist in large numbers. Degree of saturation is unknown. No data on their use have ever been assembled. Total

(148) National Research Associates, Washington, D. C.

(149) Environmental Research and Technology, Inc., Lexington, Mass.

sales in 1972 were 2,925,000 units.[150] The energy-utilization efficiency of these heaters in their respective uses should be investigated.

Other energy-consuming devices which serve the purpose of indoor-climate control are humidifiers, dehumidifiers, and fans. An estimate of respective energy consumption is shown in Table 22.

TABLE 22. ESTIMATED ENERGY CONSUMPTION, HUMIDIFIERS, DEHUMIDIFIERS, AND FANS.

	Average Wattage	Estimated use kWh annual
Humidifier	257	377
Dehumidifier	117	163
Attic fans	370	291

Source: Edison Electric Institute Estimate 1969.

Adoption of these devices depends on geographic location, prevailing climate, and other factors related to shelter- and thermal-comfort factors. The efficiences are assumed to vary, and need be dealt with as a part of the indoor-climate control system. There is little energy-statistical information on these devices or on their uses. Sales in 1972 were humidifiers 1,150,000, dehumidifiers 566,400; fans of all types 9,850,000.[151]

An alternative to heating individual residential units or unit groups such as found with apartments and condominiums is district heating. This is not a new idea in that district heating has been used for a long time in the United States and Europe. Constraints are heat loss in transmission, range, and economics. Advantages are that higher utilization efficiencies can be achieved at the point of conversion of energy resources into heat, and that it is possible to control better the emission of pollutants.

(150) 1973 Statistical Marketing Report, Merchandising Week, September 26, 1973.

(151) ibid.

Economic pollution-control would make the use of coal or nuclear energy feasible. Use of low-grade heat in the condensate from the turbines of steam-power plants is often mentioned in this connection. One extensive study shows, however, that this practice can have only long-range merit when planning "energy-centers" for new cities.(152)

b. Water ranks next to indoor-climate control as a consumer of residential energy. Except perhaps for the energy needed to heat water, the public generally views water as a "free good." Yet, in reality, this stance is at variance with fact. In the modern home energy is necessary to transport water to the point of actual use. Disposal of sewage and effluent through a municipal system consumes energy. Greater re-use of water would likely take still more energy. Per-capita water consumption in the United States has tripled since 1900.(153) Moreover, as municipal water-supply infrastructures become older, more energy is needed because of increase in friction due to corrosion and mineral deposits in the piping network. Large amounts of energy are consumed in the construction and maintenance of municipal systems.

Residential consumption has increased with higher standards of

(152) H. R. Payne *et al.*, USE OF STEAM-ELECTRIC POWER PLANTS TO PROVIDE THERMAL ENERGY TO URBAN AREAS, Oak Ridge National Laboratory ORNL - HUD - 14, January 1971.

(153) Jim Wright, THE COMING WATER FAMINE, Coward-McCann, New York, 1966, p. 219.

cleanliness, sanitation, comfort, and pleasure.(154) In 1970 a United States Geological Survey Report estimates an average water-use of 166 gallons/day/person as drawn from public supplies. A study in 1963-65 of 41 residential areas of the United States shows a mean annual household-use of 398 gallons.(155) One author observes that almost one-half of the total may be used only to flush away wastes. (156)

Substantial amounts of water are used in some areas for lawn-sprinkling, which accounts for as much as 75% of total water-use during dry hot weather. (157) Lawn-sprinkling has been encouraged in municipal water-rate structures, and may have become excessive. Energy consumption by swimming pools has already been mentioned elsewhere in this study; to this must be added the energy required to pump water to the pool sites when such water originates from a municipal system. In draining a pool thru municipal sewers, more pumping energy may be required.

Rates generally seem to have had little impact on the growth of water consumption. Water use is considered complementary to other household activities. Consumption is a function of consumers' ability and willingness to purchase and use such household goods as baths, sinks, showers, garden space, home laundry equipment, dishwashers, garbage disposals, and

(154) Anne E. Field, A STUDY OF WATER CONSUMPTION PRACTICES IN HOUSEHOLDS, Unpublished doctoral dissertation, Michigan State University, East Lansing, Michigan, 1973.

(155) F. P. Linaweaver, Jr. _et al_., A STUDY OF RESIDENTIAL WATER USE, Federal Housing Administration, Washington, D. C., USGPO 1967, pp. A-2 and A-3.

(156) Sigurd Grava, URBAN PLANNING ASPECTS OF WATER POLLUTION CONTROL, New York, Columbia University Press, 1967, p. 32.

(157) Jerome B. Wolff, PEAK DEMAND IN RESIDENTIAL AREAS, in Journal of American Water Works Association LIII, October 1961.

so on. This willingness is in turn a function of socio-economic status, and naturally of family size. As children grow older, water use tends to increase.[158] As with energy-use, once a habit is acquired, the resulting water consumption becomes a "built-in" factor difficult to change, probably not within the lifetime of the device.

No ready-made data exist which tells energy cost of water provision and effluent disposal. An illustration may be of value then. In Lansing, Michigan, energy cost to pump water from the wells through the distribution network is approximately 3 kWh/1000 gallons, and the corresponding effluent disposal cost is about 2 kWh/1000 gallons.[159] These figures do not include water treatment, nor do they include energy costs associated with construction and maintenance of the infra structure. These energy costs imply that average family use of water constitutes energy consumption on the order of two kWh of energy-equivalent per day. The 1970 Census lists 55 million housing units connected to municipal or corporate water systems, and 48 million units connected to public sewers. Translated, this practice could mean that roughly 1% of national energy consumption goes into municipal water supply and sewage handling from residential use.[160] The 1% is not included in residential consumption data cited in this study. Individual private systems, of which the 1970 Census enumerated about 11 million units (out of a total of 67 million units), do have much smaller energy

(158) Field, _op_. _cit_.

(159) Information from the Superintendents of the Water & Light and the Sewage Disposal Plants, Lansing, Michigan, May 1973.

(160) 50,000,000 housing units x 5 kWh/day (using Lansing, Michigan experience) x 365 days ÷ .5 (efficiency factor, .3 for electric, however, some energy used is fossil fuel) x 3,413 Btu/kWh = .62 x 10^{15} Btu (national total in 1970 = 67 x 10^{15} Btu). This is an approximation.

expenditures than the above. These systems are included in the residential totals cited. What can readily be seen is that water consumption in the United States has departed far from the basic water needs of roughly one gallon per day per capita, and in this way has added to the energy demand.

Hot water, in the context of water consumption, is, of course, a major household user of energy, estimated at 2.9 percent of the national total (1.736×10^{15} Btu).(161) On that basis, and assuming the energy is to raise water-temperature by 100°F, and further assuming a composite conversion efficiency of 70 percent, hot-water use would be about 21 gallons per day on a per-capita basis. This is at variance with information used by home economists: " . . . the average family of four persons uses up to 1200 gallons of hot water per month, or about 10 gallons per day." This same reference lists hot-water needs as shown in Table 23.

TABLE 23. RESIDENTIAL HOT-WATER NEEDS.

Hot-Water Needs	Gallon/day
Automatic washer (full cycle)	25
Tub bath	10
Shower	5
Dishwashing (manual)	6 - 8
Dishwashing (machine)/per normal cycle	12 - 16
Meal preparation, clean-up	4 - 6
Housecleaning	5 - 10

Source: Helen J. Van Zante, HOUSEHOLD EQUIPMENT PRINCIPLES, Prentice-Hall, Englewood Cliffs, N.J., 1964, p. 153.
Consumer Reports, November 1971, p. 662.

(161) PATTERNS OF ENERGY CONSUMPTION, op. cit., p. 6.

The growing use of mechanical dishwashers is accelerating the demand for hot water in the household. As can be seen from the above data, hot water use is doubled in going from manual to machine-dishwashing. Not only that, water for machine dishwashing is hotter by perhaps 50° F.[162]

The large residential uses of hot water present several problems of efficiency. Namely, conversion of energy into heated water, prevention of heat-losses from heater-storage and from the piping network to the point of use. One study looked into water-heating systems and also examined an attic water-preheater arrangement. Relating capital costs to current energy costs, in the case of electric water heaters, shows that even at the present 2.2¢/kWh national average, additional heater insulation is justified,[163] and more so with prospects of rising electric rates. Attic-pre-heating and pipe insulation were reported to have break-even points higher than current-electricity rates could economically support. No data on gas-and oil-water-heaters, presumed to be in the 60 to 70% conversion-efficiency range, are available. Pre-heaters, which take the heat from combustion gases and other houshold functions, need to be investigated. There are three times as many fossil-fueled water-heaters in use as there are electric heaters.

Name plates and sales literature on fossil-fueled water-heaters for residential uses generally carry only an input rating in Btu/hr. Output is not given, and therefore utilization efficiency is unknown to the buyer. Substantial improvement appears possible, although it most likely will

(162) Consumer Reports, November 1971, p. 662.

(163) R. S. Quinn and J. C. Moyers, WATER HEATING STUDY, in Electrical Energy And Its Environmental Impact, op. cit., p. 24 - 31.

have to be considered, taking future fuel costs into account. Solar heat, wind power, and recovery of heat-output from other residential use are often-mentioned possibilities as candidates for evaluation in terms of longer-range overall energy costs.

The relatively large per-capita United States uses of water -- and especially hot water, -- are a cultural phenomena, and therefore difficult to change in the near term. The fact of energy-availability limitations rarely plays a conscious role in the mind of the water user. As with other energy uses, these uses of hot water were encouraged under a philosophy of cheap and abundant energy, as well as by the availability of devices marketed under a lowest first-cost calculus. Life-cycle costing, taking all costs into account, should help toward better energy-utilization practices which improve efficiencies. More study of the subject should be encouraged.

c. Kitchen Appliances are also major energy consumers. There are three factors which command attention. One is the contribution of kitchen appliances to the growth in energy demand. Next, because most kitchen appliances are electric, basic energy resource consumption is at least three times that of the energy actually delivered to the appliances; the loss occurs in conversion and distribution. Last, starting with this one-third, there is the problem of operating efficiency as built into the appliances as well as the efficiency associated with use-practices. The result is a multiplier effect on the demand for the basic energy resources.

A breakdown of growth in electricity consumption from 1800 kWh to 7000 kWh per household during the period from 1950 to 1970 shows that refrigerators accounted for 19% of the growth, food freezers 7%, and cooking 5%.(164) It should be noted that the more recent phenomenal growth in the use of automatic dishwashers does not yet appear in such analysis. The first part of this section is concerned with refrigerators and which -- unlike most other appliances -- generally are time-continuous sources of energy demand freezers. The second part covers domestic cooking, and the third part looks at dishwashers.

Electricity consumption by refrigerators and freezers is shown in Table 24. Unfortunately, aside from such estimates, no comprehensive national data of this sort are being collected by an organization. In fact, from an energy-consumption point of view, little is known about how appliances are used. Name-plates generally do not give such information, nor does the sales literature. One of President Nixon's energy messages to Congress suggested "energy efficiency" labels.(165) This is thought of as a voluntary effort on the part of the industry, is associations, and

TABLE 24. ESTIMATED ENERGY CONSUMPTION, REFRIGERATORS AND FREEZERS.

	Average Wattage	Annual kWh
foodfreezers (15 ft^3)	341	1,195
foodfreezers (15 ft^3, frostless)	440	1,761
refrigerators (12 ft^3)	241	728
refrigerators (12 ft^3, frostless)	321	1,217
refrigerators (14 ft^3)	326	1,137
refrigerators (14 ft^3, frostless)	615	1,829

Source: Estimate by the Edison Electric Institute 1969.

The above wattage ratings are given by the EEI as approximate, and the annual kWh consumption figures are estimates. Unfortunately, no comprehensive national data of this sort are being collected by an organization.

(164) J. E. Tansil, RESIDENTIAL CONSUMPTION OF ELECTRICITY 1950-1970, in Electrical Energy And Its Environmental Impact, op. cit., pp. 45-50.

(165) Richard M. Nixon, in a Message to the Congress of the United States, April 18, 1973.

coordinated by the U. S. Department of Commerce.(166) The National Bureau of Standards has been active in implementing the program, expanded to cover all major home-equipment. It comes in two parts, (1) information on labels, and (2) education. The latter phase is recognized as the more difficult and more important.(167) Unfortunately, results from the effort cannot be expected for many years because of the mass of existing stocks of home equipment.

Refrigerators and freezers do more than store perisable foods. They provide the convenience and economy of rationalizing procurement, they provide ice and the chilling foods and drinks, they aid meal preparation, they store leftovers and medicines. Average size of refrigerator compartments have become larger over the years. More growth has occurred in the size of frozen-food compartments. Growth in size, along with the addition of features like automatic defrost and icecube making, has tended to increase energy consumption. A refrigerator of the 1930's may have consumed 400 kWh of electricity per year (8 ft^3), four times that much may be consumed by today's average refrigerator (14 ft^3). Higher ambient temperatures during the heating season add to the energy-consumption problem.

These increases in energy consumption are not so much due to the energy cost of operating refrigerating systems as they are to the

(166) ______, Procedures for a Voluntary Labeling Program for Household Appliances and Equipment to Effect Energy Conservation, U. S. Department of Commerce, Office of the Secretary, Title 15, Subtitle A, Part 9, Federal Register, Vol. 38, No. 206, October 26, 1973.

(167) From a conversation with the man in charge of the labeling program, Melvin R. Meyerson, National Bureau of Standards, November 8, 1973.

peripheral features. Heaters to prevent sweating, heaters to defrost the evaporator, heaters which permit release of icecubes from molds of automatic cubemakers, fans for internal air circulation and condenser cooling, are energy-consuming devices which have been added over time, -- in addition to increased storage space, notably for frozen foods. The "frostfree" feature for both refrigeration and frozen-food storage compartments imposes energy cost for defrosting. The defrost operation is most often time-clock operated, and is so cycled that the most severe ambient conditions can be met. This mode results frequently in unnecessary operation of the defrost heaters. The use of one evaporator for both refrigerated storage (35° F) and frozen food storage (0° F) adds to the problem of energy consumption.

Forced air circulation in the cabinet interior creates technical difficulties for door sealing, and heat-conduction in the door-opening cross-sectional area. Remedial measures are the addition of resistance heaters to maintain an exterior surface temperature high enough to prevent sweating. Placement of condenser units and compressors underneath the cabinet, mostly done for esthetic reasons, creates efficiency problems for the refrigeration system. For a highly efficient system the temperature differential across evaporator and condenser should be as small as possible. The other side of the argument says that the heat is necessary to evaporate water drained from the evaporator coil when defrosting. The industry has always used better insulating materials when they became available: but to reduce cabinet wall thickness, rather than to reduce energy consumption. Reduced cabinet-wall thickness made it feasible to enlarge food-storage space at the same time that external physical size of cabinets was maintained. The net effect of course was increased energy consumption. Usage associated with family life-style and life-cycle has also added to energy consumption.

Price trends of appliances have tended down for many years, a fact already touched upon in Chapter III. Refrigerator and freezer prices have followed this trend, although it is difficult to be specific with comparisons because of technical changes, quality improvement, and the many added features. These developments can be illustrated more precisely in a shorter time-frame. For example, consider the 1967 Consumer Price Index=100, and the December 1972 index figure for all items was 127.7, whereas the 1972 index for refrigerator-freezers was 108.4.[168]

Use practices are generally not consistent with energy economy. Indiscriminate use of ice may be an illustration. The theoretical energy cost to make ice at 32° F is 144 Btu/lb. Any waste of ice is a corresponding waste of energy. Few realize this to be the case and that, at the power plant, it takes three times that much in basic energy resources for the production of electric energy. Chilling of beverages to temperature levels lower than actually needed, storing materials which need not be refrigerated and are perhaps damaged by it, some fruits and vegetables for example, are practices of questionable use. The compartment air in a frostfree refrigerator-freezer has a very low dewpoint, and is apt to damage most vegetable matter that is not carefully and completely covered to protect it from direct exposure to this dry air. Unfortunately, far too little research has been done in the area of use efficiency and actual consumer needs as related to energy resource expenditures, and as related to family economics and availability of energy resources.

(168) ________, THE CONSUMER PRICE INDEX for January 1973, U.S. City Average, Bureau of Labor Statistics, U.S. Department of Labor, March 1973.

Full freezers, generally classified as one of the major kitchen appliances, are not usually found in the kitchen. Frequently they are located in utility rooms, basements, recreation rooms, garages, or porches. Separate freezers have come into use particularly strongly since World War II. Certain socio-economic conditions such as food shortages or high prices have spurred the sale of such freezer units. They are sold as vertical cabinets similar to refrigerators, or as horizontal chests. Everthing else being equal, the horizontal units are more energy-use efficient by 3 to 5% simply because the cold-air "spillout" does not occur. Chest units are more often more efficient for other reasons. For example, exterior walls can serve as condensers, doing away with separate condensers subject to space limitations. Such space limitations make it necessary to use fans to cool the condensers. When the exterior walls are used as condenser surfaces, dew-point heaters may not be necessary as they are when separate condensers are used.

Use of frozen foods in any form must be classified as relatively energy-intensive. Energy required to freeze foodstuffs is similar in amount to the energy required to freeze water, viz. 144 Btu/lb. To slow the deterioration of foods in the frozen state and keep them for longer than a few days, they must be near 0° F, with commensurate energy costs. Defrosting a freezer adds to energy demand, -- substantially so when using a unit equipped with an automatic defrost system, on the order of 50% more.

Freezers placed in a household can be assumed to run throughout the year independent of load, and may frequently be the source of energy waste. Heat gain inside the compartment of a unit is a function of its size. Again, one finds little published data on how these freezers are operated. Some data may have been collected privately by industry members as a part of their own consumer-research activities, yet it is unlikely that such research would be concerned with energy utilization. How frozen foods, and frozen-food storage space, are handled as related to energy costs and alternatives is suggested as a subject for a worthwhile research project.

The assortment of devices for Domestic Cooking varies widely. The kitchen range is a transition from the age of the cookstove, hand-fired by wood or coal. The cookstove, as the name implies, served also as a room-heating unit, and, almost always, for waterheating as well. As these functions were split up - cooking, space heating, and water heating, -- energy-utilization tended to become less efficient.

Gas as a cooking fuel became dominant during the first two decades of the 20th century. From then on electric cookery came in to compete with gas, the other fuels being almost completely displaced for the purpose of cooking foods. The 1970 Census reports cooking fuels as shown in Table 25.

TABLE 25. DOMESTIC COOKING FUELS, BY OCCUPIED HOUSING UNITS.

Utility gas	31.2 x 10^6 occupied housing units
Bottled, tank, and LP gas	5.3
Electricity	25.8
Fuel oil, kerosene, etc.	0.3
Coal or coke	0.2
Wood	0.4
Other fuel	0.04
None	0.2

Source: Census of 1970, U.S. Summary HC (1) B1, Fuels and Appliances, Table 24, p. 1-254.

In the kitchen there has been a strong trend towards electricity and away from other fuels. This trend persists in the face of an overall efficiency for electricity which is relatively low when compared with fossil fuels like gas.

It should be noted that the above information is at fault in that it fails to account for small electric cooking appliances that are often found extensively in most wired homes.(169) It must be assumed, therefore, that they are found in housing units categorized under gas. Little important data on use-practices with portable cooking appliances could be found.

Because of many variables, energy-utilization efficiency in the use of cooking-ranges is difficult to achieve. Several studies made quite some time ago established a comparative energy-utilization ratio, gas vs. electric, of roughly 2 : 1.(170) These data do not take into account the continuous burning of pilot flames on gas ranges, which may use up 1000 Btu/hr. There are several pilot flames involved. The most efficient, called "mini-pilot," takes about 125 Btu/hr.(171) Relatively simple technical solutions are available which can eliminate the need for pilot flames.

Energy losses in current cookery practices are substantial. It is stated that thermal efficiency for top burners on gas ranges should not be less than 40%, and for surface units of electric ranges less than 60%.(172)

(169) Portable appliances are most often acquired as gifts on certain occasions, bridal showers, wedding gifts, Christmas gifts, and so on. This practice contributes to their proliferation and often duplication.

(170) Gas Engineers Handbook, Table 12-155C, op. cit.

(171) from Service Dept., Consumers Power Co., Lansing, Mich.

(172) Peet, op. cit., pp. 204-205.

The 60% would represent an overall energy-utilization efficiency of about 18%, which roughly confirms the 2 : 1 ratio, gas vs. electric. These values are difficult to measure, however, and their attainment is subject to many variables: cooking utensils, their condition, characteristics and size as related to heating element or flame, and user practices. Ovens and broilers suffer from losses occasioned by the problem of heat transfer to the food. Oven design and construction has rarely placed a high priority on efficiency of heat transfer and energy-utilization.

Because of low return in an economic sense, the study of how energy is employed to prepare foods, and of whether and to what degree cooking is necessary in the first place, has never been intensive. The prevailing philosophy created by the notion of cheap and abundant energy resources has discouraged more careful treatment of the subject.

Some home-equipment texts give suggestions for economical use of gas and electricity:[173]

(1) Keep all parts of the range clean.

(2) Use a small burner or unit instead of a large one, whenever possible

(3) Put the utensil on before turning on the heat, so that the heat goes into the utensil instead of into you. Turn off the heat before removing the utensil.

(4) Boil only the amount of water that is needed; you speed up the job, save fuel, and prevent heat in the kitchen.

(5) When water begins to boil, turn unit or burner to "low" or "simmer" position. Slowly-boiling water is as hot as rapidly-boiling water.

(6) Use covered utensils if feasible.

(173) Peet, *op. cit.*, pp. 204-205.

(7) Use the thermostatic surface heat-control unit for all frying, if such a control is provided. With proper heating, fat will not smoke.

(8) Do not pre-heat the oven too long before use.

(9) Obtain free circulation of air in the oven by placing pans in alternate positions on the racks.

(10) When roasting or baking, use the oven to capacity. Cook food for another day.

(11) Use accurate baking temperatures.

(12) When the oven is well insulated, turn off the heat a few minutes before the end of the baking period, and finish the baking with retained heat.

(13) Avoid raising pot covers and opening the oven door during cooking operations.

(14) Do not pre-heat the broiler. The grid is easier to clean if food is placed on a cold rack.

No data are available which define the above rules as a measure of utilization efficiency. Most of the suggestions simply follow common-sense principles. To what degree these suggestions are a part of actual practice is unknown. Regarding item (7), few ranges, and then only selected surface-units, are equipped with thermostatic surface heat-control units; in still fewer are such thermostatic controls presumed to be effectively operative in combination with suitable utensils.

A more recent innovation, the "Countertop That Cooks" (manufactured by Corning Glass Co.) requires the exclusive use of matching cooking utensils sold by the same manufacturer. In this case, the built-in thermo-sensors work very well, and energy-utilization efficiency is most likely improved. Referring to item (12), few ovens are well enough insulated to utilize residual heat in the oven mass for an appreciable length of time. Timing of the turn-off would have to be automatic in order to be effective.

Energy-utilization efficiencies in cookery can be materially improved through existing knowledge and known technologies. Such knowledge leading to improvement in practices can in some instances provide direct economic gain to the practitioner, though relatively small in monetary terms. These are some of the points made in the list of suggestions cited above. Other improvements, particularly those derived from known technologies, require capital investment which most often cannot be rationalized. To illustrate, buying a micro-wave oven, five times as efficient as a conventional range oven (since almost the entire energy input goes into the food), that costs $300, is difficult to rationalize when the average electricity cost per year for operating a conventional range oven, at a 3¢/kWh electricity rate, may amount to perhaps $20. Similarly, a $25 pressure cooker, with the potential of reducing the energy input to 1/3 to 1/10 of conventional and with annual input of 100 times per year for one cooked dish, thereby saving perhaps 2 million Btu/yr at a cost of $2, is not a good investment in economic terms only. Both devices do save time for the homemaker. Clearly other incentives will have to come into play.

Following the above line of argument, an overriding question comes into focus. It concerns the overall energy budget. All products under discussion here require energy to produce, distribute, and service. Therefore, even though the economics may be favorable--which is not the case in the illustrations cited, -- use of different methods and equipment may be undesirable from such an overall energy-budget point of view.

Similar considerations apply to all small so-called portable appliances for cooking. These, by nature, are all electrically heated.

They have been found more energy-use efficient, but they take more time.(174) Their economic and energy-budget justification nevertheless could be challenged. No hard data appear to be available on the matter.

Related to cookery, a more recent innovation is "self-cleaning" ovens. Cleaning is done by one of two processes. One is pyrolytic, in the case of electric ovens, and the other is catalytic, in the case of gas ovens. In either case, energy is used, in effect, to oxidize organic materials deposited as soil on oven surfaces as a result of the cooking process. This oxidation is accomplished by application of heat for a sufficient length of time. Average use of electricity for one cleaning of an electric oven is about 7 kWh. Ovens have to be constructed to withstand the higher heat levels, about 880° F, as against 500° F maximum for conventional ovens. Additionally, a fan is required to ventilate the oven cavity. Therefore the entire process is a material energy consumer. The situation is similar for gas ranges. In these, however, the number of self-cleaning ovens in use is negligible.

The cooking-fuel choice, when acquiring a kitchen-range, is not always made on a basis which is economically justifiable. In the case of new housing, the choices are often made by the builder. Gas costs less than electricity on a heat-energy-value basis. Yet, in more recent years, preference

(174) From a talk by Genevieve K. Taylor, November 15, 1962, before the 40th Annual Agricultural Outlook Conference, reporting on a study done at the Equipment Laboratory, U.S. Department of Agriculture, Clothing and Housing Research Division, Beltsville, Md.; 2 different meal programs carried out for one year showed an annual kWh consumption of 1033 (Range) vs. 708 (Portable Appliances) and 1135 vs. 905 respectively. In a different statistical arrangement, ranges consumed 10.06 kWh, portable appliances 7.97 kWh for the same task.

The question: "Could portable appliances be substituted for standard or built-in ranges?" was answered in the affirmative.

for electric cooking has gained.

For electric-range cookery, at a rate of 3 cents/kWh and an electricity-utilization efficiency of 60%, the annual energy cost would be about $36/yr for the approximately average consumption of 1200 kWh. The equivalent situation for gas-range cookery, with a range of about $1.50/million Btu and an utilization efficiency of 40%, would result in an annual cost of about $9/yr.

Current sales of new electric-range units exceed those of gas ranges. Average retail price for electric ranges is higher than that for gas ranges.(175) In urban areas, where availability of both gas and electricity can be assumed, electric ranges in use during 1940 were 5% of the combined gas and electric-range total. By 1970 the percentage for electric ranges had risen to 37%. For the same period the percentage of gas ranges declined from 73% to 62%.(176)

Obviously, there are forces at work here that go beyond the economics of the market. The notion of the "elegance" of electricity has already been mentioned in this study. Just what these forces consist of, and what their degree of intensity is, would require more in-depth research than

(175) 1972 sales as reported in Merchandising Week, February 26, 1973, p. 27:

	Units	Average retail price per unit
Electric ranges	3,231,900	$219
Gas ranges	2,659,900	209

All types of ranges are included in the above.

(176) ________, CENSUS SHOWS LATEST FUEL PREFERENCE DATA, in Electrical World, January 1, 1973.

what is possible here. Opportunities for improvement are many, from measuring lines in utensils to cooking by microwave.

Dishwashers have an annual energy consumption estimated by the Edison Electric Institute (1969) at 363 kWh. Not included in this estimate is the energy required to heat water to 150°-160°, about 4 to 5 gallons per cycle. Next, pumping the water to the inlet valve of the dishwasher takes energy. The spray-arm needs a motor-pump unit of 1/4 to 1/3 HP. Finally, drying of the dishes is generally done through the application of heat derived from heating elements rated 500 to 1400 Watts. In other words, to dry the dishes, the water is boiled off not merely from the surface of the dishes, but from the racks and interior walls of the dishwasher compartment as well. In some few cases, wattage of the drying element is reduced to about one-half for the remainder of the dry-cycle, after most of the water has presumably evaporated. A few makes of dishwashers have a fan that moves electrically-heated air through the compartment, a method more energy-efficient than simply boiling off the rinse-water left on the surfaces from the washing process. This method, of course, increases the equipment cost somewhat. It should be noted that the amount of water adhering to surfaces is relatively high because of the wetting agents in the detergent. Some homemakers rinse the dishes before loading them, and thereby simply add to the hot-water consumption. Except for certain utensils, this method is not normally encouraged by manufacturers in their instructions.

It is the special hot-water-using appliances, dishwashers and clothes washers, which make it necessary to set waterheater thermostats at temperatures higher than required for other uses. Dishwasher manufacturers ask in their instructions that the water heater thermostats be set at 150° to 160° F. This temperature is higher than required for clothes washers, where the recommendations call for 140° F, the normal factory setting of water heater thermostats. These requirements lead to heat losses which, though unknown in amount are difficult to justify. It poses the question as to whether it would not be more efficient to raise temperatures to suit requirements at the point of use. A few models of dishwashers on the market are equipped with self-contained heaters for this purpose. European practice is to heat the water in these appliances by direct heating with electricity or gas.

d. Home Laundry and Fabrics Care activities use electricity in the estimated amounts shown in Table 26. Note the dominance of the clothes dryer; also, some dryers use gas as a fuel.

TABLE 26. ESTIMATED ELECTRICITY CONSUMPTION, HOME LAUNDRY AND FABRICS CARE.

	Average Wattage	Annual kWh
Automatic washer	512	102
Clothes dryer	4,856	993
Hand iron	1,008	144
Sewing machine	75	11

Source: Estimate by the Edison Electric Institute, 1969.

Automatic washers, in addition to the electricity consumed as shown above, use water which has an energy-expenditure content, namely that required for delivery and for heating.

Frequency of use, load-capacity of the washer, size of loads, amounts and temperature of hot water per load, stock of washables in the household, and family size, are functions of energy consumption by the washing process. A further load not entirely accounted for in the above is the momentary electricity demand surges at the time of starting or changing cycles of the wash program.

The vertical-axis agitator-washer dominates in the United States and in the few other countries where there are adequate supplies of running hot water for residential units. Elsewhere, horizontal tumbler-type washers are customary, they are generally equipped with built-in waterheating, and on the average, use less water per wash. The difference between the two methods is total immersion for the vertical-axis type, and continuous wetting (but without immersion) for the horizontal-axis type.

Washing machines built in the United States are powered by 1/4- to 1/2-HP capacitor-start motors, which may have 2 or even 3 speeds. Loading capacity of these washers ranges from about 8 lb. to 20 lb. of washables, dry weight. Some washers are equipped to do "mini-loads." When not loaded to full capacity, the energy-utilization efficiency per unit (i.e., per lb. of washables) declines.

As with most appliances, washing machines are designed and marketed to sell on the basis of lowest first-cost. The low cost of electricity consumption on an annual basis does not leave much margin for improving energy-utilization efficiency on strictly economic grounds. Opportunities would appear to lie in raising spin-speeds to reduce water retention and thereby speed drying, in reducing water consumption, and in extending the service life of the machine (now estimated at 8 to 10 years). Increased spin-speed without deliberate modulation of acceleration would tend unduly to increase the consumption of energy and the cost of the mechanism. Therefore, machines would need acceleration control tuned to the load, including its water content.

Washing in cold -- or at least temperate-- water has been demonstrated as technically feasible. Detergents for this purpose are commercially available. Questions of quality, and of cultural and esthetic acceptability, would need to be studied, as would be the case with reduction in laundering frequency. Commercial or community laundering also needs to be investigated from an energy-economics point of view. Detergents pose an energy-budget type of question. Most of the current detergents are derived from fossil-fuel minerals or materials, and as such need to be examined and reviewed for possible alternatives based on renewable natural resources.

The distribution of domestic laundry appliances among households is shown in Table 27.

TABLE 27. WASHERS AND DRYERS IN U.S. HOUSEHOLDS 1970.

Clothes-washing machines	
Wringer or spinner	7.1 x 10^6 units
Automatic or semi-automatic	38.0
None	18.3
Clothes dryers	
Gas-heated	7.8
Electrically heated	18.6
None	37.0

Source: Census of 1970, U.S. Summary HC (1) B1, Fuels and Appliances, Table 24, p. 1-254.

These figures show a washer-to-dryer ratio of about 9 : 5. Current sales of washers and dryers run at a ratio of 5 : 4, indicative of the current relative gain in dryer saturation, inasmuch as lifetimes are comparable.

The situation with respect to choice of fuel is again similar to that for domestic cooking ranges. Despite relatively higher energy costs for electricity, electric dryers outsell gas dryers by roughly a ratio of 3 : 1. (177) At retail, gas dryers cost about $30 more than electric dryers.

(177) 1972: Electric 2,988,700, Gas 936,200, Merchandising Week, Feb. 26, 1973, op. cit., p. 27.

There is also an additional installation cost, say $30, because gas dryers must be hooked up to both gas and electric services. With an average total cost premium of $60, at $1.50/million Btu/yr and 3cents/kWh for electricity, respectively, it would take roughly 300 loads to come out even, up to 3 years to the point of payoff. Almost every case, however, would have to be looked at separately, with consideration of other energy uses and utility block rates.

Domestic clothes drying traditionally has been done in atmospheric air, preferably in the sun, and with only minor exceptions, still is, except in North America and a few other places. Mechanical clothes dryers use energy in its crudest form, namely heat, to evaporate water absorbed or adsorbed by textiles and fabrics during laundering. Heated air is circulated, while the loads to be dried are tumbled mechanically to expose the fabric surfaces to the heated air.

As already indicated, the energy is obtained either by gas or electricity. In the case of gas, the air movement and the tumbling are powered electrically. Electric dryers have a rated input of up to about 5400 Watts, whereas gas dryers may have input ratings of up to 30,000 Btu/hr plus the electricity required by a 1/4 to 1/3 HP motor (about 200 Watts or so) for operating the fan and the tumbling cylinder.

It is not unusual for 15,000 Btu to be consumed in drying an average full load. During seasonal periods when the residence is heated or cooled, additional energy may be used up by pulling air from conditioned spaces at rates up to 200 cubic feet per minute.

Venting of dryers is generally recommended, preferably to outdoors. Indoor venting may cause moisture and heat-accumulation problems. Gas dryers generally pass the gaseous product of combustion directly through the clothes, and therefore must be vented outdoors for health and safety reasons.

There is little difference in drying efficiency between gas and electric on a heat basis.[178] Overall energy efficiency with electricity, however, is 30% or less. Drying efficiency with gas is theoretically quite high, but is impaired by the water-vapor content of the products of combustion and heat losses. Additional electric energy is required for mechanical action, as mentioned in the foregoing.

Some dryers come equipped with water-cooled condensers, to condense the water vapor content of the exhaust, and in part eliminate venting. The condensate goes into a drain.

Overdrying of fabrics and garments wastes energy, and leads to premature destruction of materials. Below 5% moisture retention, lubrication between fibers is lost, with the result that fabric wear is accelerated. In any case, tumble-drying causes more wear than atmospheric air-drying. Attempts have been made to overcome the problem by installing moisture-sensing devices located in the drum or the exhaust airpath. The intent is to reduce heat input over the length of the drying cycle commensurate with reduction in air-moisture content, or to end the drying program before over-drying is reached. These sensing devices increase initial cost and frequency of service. In their functioning, moreover, they are subject to some variables which are difficult to control. Ideally, dryers

(178) Gas Engineers Handbook, Table 12-155C, _op. cit._

should take no more heat input than that prescribed by the water-vapor-holding capacity of the drying air. Present-day operation of dryers is far from this ideal, even with those units equipped with sensing devices.

Some heat losses occur through the mass of the appliance itself which absorbs heat and gradually releases it into the environment, both during and after operation. In connection with large consumers of energy, in this case dryers, heat recovery is sometimes mentioned. Whether this technique has any merit at all would need to be scrutinized in great detail. Invariably, heat recovery takes additional available energy in accordance with thermodynamic principles.

Most housing construction in recent years has assumed that clothes dryers are to be installed. Convenient and clean enough air spaces for atmospheric drying are not often being provided. Public policy could be devised to encourage atmospheric drying whenever possible, both outdoor and sheltered.

Ironing by hand has been decreased by permanent-press finishes and by the introduction of synthetic fibers. But it has not been eliminated, and it takes heat energy, time, and work. Hand irons are electrically heated, the heat being dissipated into the immediate environment. Except for the low overall efficiency of electric energy, during the heating season there is no heat loss. There is a loss at other times, and an additional fractional loss when airconditioning is required. To illustrate the intensive use of hand irons: 1972 sales were 9,510,000 units; the indicated saturation is 91.4% of wired homes.[179] Ironing is closely tied to esthetic and cultural questions. Usually disliked by homemakers,

(179) Merchandising Week, op. cit.

ironing is done to satisfy social convention, homemaker taste and values.

e. Miscellaneous Devices, such as outdoor paraphernalia, small appliances other than cooking appliances, powered devices used for personal care, electrical home-workshop tools, and a host of electrical gadgets, have proliferated in American households. Energy demand varies from very small, in the case of clocks, to as high as hundreds of watts for garbage disposers or waste compactors. Average annual electricity consumption may range from 2 kWh for operating the clocks to 150 kWh for bedcoverings. There is a scarcity of information on the total number of these devices in service, or on their use in terms of electrical energy demand. Little is known regarding the various rationales behind their use. To some persons, they are a necessity, to others only luxuries.

In different words, the degree to which these devices contribute to the quality of life is a complex function of a set of variables. The indisputable fact is that all these devices contribute to the per capita growth in demand for energy. Some may argue that the individual amounts are too small to be given much attention. Such arguments ignore the resultingly large aggregations in demand due to creation of the product or service, the subsequent consumption by product or service, the eventual disposal cost in energy terms, and all the associated costs of environmental impact.

A similar situation prevails with either electrically-or fossil-fuel-powered outdoor equipment: lawn mowers, garden tractors, hedge clippers, edgers, snowplows or snowblowers, lawnsweepers, leave-shredders, and others. Again, information on the energy consumption through these uses is scarce, and it is therefore difficult, if not impossible, to make any determination of energy-utilization efficiency or justification of these energy consumptions. These uses are propelled by forces which seek economic and social welfare--affluence, if you wish--for more and more people, besides reducing labor and saving time. Various forms of energy in combination with technology are used for this purpose without a full assessment of the consequences. Most of the questions raised in this section are candidates for assessment by means of the scheme suggested in Part B.

3. TRANSPORTATION PERIPHERAL TO THE RESIDENTIAL ENVIRONMENT

In most analyses of energy-utilization patterns, transportation has been lumped into a separate category. This choice often appears to be unfortunate in that it tends to sidetrack the significance of energy consumption by households for transportation purposes. In fact, the dominant share of such transportation activities is the result of decisions made by members of family units. In transporting people, these decisions are most often direct. In transporting goods, the underlying decisions are usually indirect, having a chain-effect going back to the origins and through the processing steps for such goods and services. Transportation is inseparable from household activities, particularly those immediately peripheral. Hence transportation by automobile must be brought into focus, in considering energy utilization efficiency in residential uses.

Transportation of goods and people consumes about one-fourth of the total United States energy effort, 16.5×10^{15} Btu out of a total of 68×10^{15} Btu.

How energy is used for transportation is shown in Table 28.

TABLE 28. DISTRIBUTION OF ENERGY WITHIN THE TRANSPORTATION SECTOR, 1970.

1. Automobiles		
Urban	28.9%	
Intercity	26.5	53.3%
2. Aircraft		
Freight	0.8	
Passenger	6.7	7.5
3. Railroads		
Freight	3.2	
Passenger	0.1	3.3
4. Trucks		
Intercity Freight	5.8	
Other Uses	15.3	21.1
5. Waterways, Freight		1.0
6. Pipelines		1.2
7. Buses		0.5
8. Other		10.1*
Total		100.0%

* Includes passenger traffic by boat, general aviation, pleasure boating, and non-bus urban mass transit.

Source: CONSERVATION OF ENERGY, Committee on Interior and Insular Affairs, U.S. Senate, S.R. 45, Serial No. 92-18, USGPO Washington, 1972, p.48.

Nearly all of the transportation demand is met by petroleum; in 1970, 25% of the supply was imported.(180) These imports are rising, and for 1973 the estimate is 35% of total usage. Imports are subject to a number of problems as already covered in Chapter V, namely, source dependability, balance of payments, and availability, among others.

(180) , U.S. Bureau of Mines, "U.S. Energy Use at New High in 1971," News Release, March 31, 1972.

Present transportation is highly dependent on petroleum. As already cited, 46% of the total 1973 energy demand in the U.S. is met by petroleum. Growth in demand progressed rapidly to 1965 when it was 42 barrels per person per year, 61 barrels in 1970; the figure is projected to be 99 barrels in 1985.(181)

Potential world supply, although still large,(182) is finite. Demand is rising all over the world, and is pushing up price. The new sources, moreover, are even more costly to develop. Exploration, production, transportation, refining, and consumption of petroleum products create a host of primary and higher-order impacts. These include: risk of tanker accidents and oil spillage, oilwell fires, blowouts and seepage, brine disposal, air pollution from refinery, and air and thermal pollution from the combustion of petroleum products. Other related difficulties are manifest in urban congestion, inefficient land use, and noise.

Urban and rural settlement and family-activity patterns have evolved during the 20th century in a way that these activities are more and more dependent upon the automobile for transportation. What is significant is that this mode of getting about is highly energy-intensive in comparison with other modes, as can be seen from Table 29.

(181) From a study by THE CHASE MANHATTAN BANK, quoted in U.S. News and World Reports, February 19, 1973, p. 30.

(182) Supply, 641 barrels proved world reserves. Estimate is by British Petroleum 1971. Against a current world consumption rate of 18 billion barrels annually, the supply would last about 30 years. From Christopher T. Rand, THE ARABIAN FANTASY, HARPER'S, January 1974, pp. 42-54.

TABLE 29. ENERGY EFFICIENCY OF PASSENGER TRANSPORTATION.

Intercity Passenger Traffic

	Btu/Passenger-Mile
Buses	1,090
Railroads	1,700
Automobiles	4,250
Airplanes	9,700

Urban Passenger Traffic

	Btu/Passenger-Mile
Bicycles	180
Walking	300
Buses	1,240
Automobiles	5,060

Source: CONSERVATION OF ENERGY, Committee on Interior and Insular Affairs, U.S. Senate, S.R. 45, Serial No.92-18, USGPO Washington, 1972, p.49.

The efficiency of the automobile engine varies widely during start-up, idling, acceleration, and deceleration. It is influenced by design and size of engine, power requirements of accessories, maintenance, and, most importantly, operation practices. Vehicle weight has a direct relationship to fuel consumption. The spark-ignition engine has a theoretical efficiency of about 30% at a compression ratio of 10 : 1, but actually operates at an overall efficiency of about 18% or less.

The outlook for improving these efficiencies appears to be limited. Before weighing the relevant factors, one needs to examine Tables 30 and 31 which give information on how the private automobile, the largest consumer of petroleum, is utilized.

TABLE 30. USE OF PRIVATE AUTOMOBILE, AVERAGE LENGTH OF TRIP BY ITS MAJOR PURPOSE.

Earning a Living	10.2 miles
Family Affairs	5.6
Educational, Civic, and Religious	4.7
Social and Recreational	13.1
(Vacations alone	165.1)

Source: Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Seasonal Variations of Automobile Trips and Travel, U.S. Department of Transportation, Federal Highway Administration, Report No. 3, April 1972, Table 4, p. 13.

TABLE 31. USE OF PRIVATE AUTOMOBILE, TRIP LENGTH BY PURPOSE AND RESIDENCE, OCCUPANCY, AND TRIPS PER WEEK AND PURPOSE.

Average Trip Length by its Major Purpose:

Unincorporated Places (representing 33.8% of trips and 37.9% of vehicle miles)	9.9 miles
Incorporated Places (representing 66.2% of trips and 62.1% of vehicle miles)	8.3

Vehicle Occupancy by Major Purpose of Trip:

Earning a Living	1.4 persons
Family Affairs	2.0
Educational, Civic, and Religious	2.5
Social and Recreational	2.5
Vacations alone	3.3

Average Trips per Week, Distribution by Major Purpose:

Earning a Living	36.1%
Family Affairs	30.9
Educational, Civic, and Religious	9.2
Social and Recreational	22.5
N/A	1.3
	100.0%

Distribution data is based on 1,669,718 trips per week.

Source: Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Seasonal Variations of Automobile Trips and Travel, U.S. Department of Transportation, Federal Highway Administration, Report No. 3, April 1972, Table 1, p. 8.

Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Automobile Occupancy, U.S. Department of Transportation, Federal Highway Administration, Report No. 1, April 1972, Table 7, p. 18.

Other information shows that more than one-half of all trips go less than five miles, and that 82% of commuting workers use automobiles as a means of transport, 56% as single occupants.(183) Estimated annual miles per automobile are shown in Table 32.

TABLE 32. ESTIMATED ANNUAL MILES PER AUTOMOBILE.

Households	one-car	two-car	three-car	all
Miles(1,000)	10.8	12.0	12.8	11.6
Percent car-owning households	61.0	32.2	5.8	100.0
Percent vehicles	42.5	45.4	12.1	100.0
Percent vehicle miles	38.7	47.0	13.3	100.0

Source: Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Annual Miles of Automobile Travel, U.S. Department of Transportation, Federal Highway Administration, Report No. 2, April 1972, Table 1, p. 8.

The average annual miles per vehicle rises from 6,600 for a reported income under $3,000 to 15,000 for incomes over $15,000.(184)

(183) THE POTENTIAL FOR ENERGY CONSERVATION, *op. cit.*, p. C-9.

(184) Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, ANNUAL Miles of Automobile Travel, U.S. Department of Transportation, Federal Highway Administration, Report No. 2, April 1972, Table 5, p. 16.

The average fuel consumption rate is reported as shown in Table 33.

TABLE 33. AVERAGE FUEL CONSUMPTION STANDARD-SIZE, COMPACT -SIZE, AND SUBCOMPACT-SIZE AUTOMOBILES, 1972.

(1)	Standard-size Automobile (a)	13.60 miles/gallon
(2)	Compact-size Automobile (b)	15.97
(3)	Subcompact-size Automobile (c)	21.43

(a) four-door sedan, V-8 engine, automatic transmission, power-steering and brakes, airconditioning, radio, clock

(b) two-door sedan, 6-cylinder engine, automatic transmission, power steering, clock

(c) two-door sedan, 6-cylinder engine, radio

Source: L. L. Liston and C. L. Gauthier, COST OF OPERATING AN AUTOMOBILE, Suburban-Based Operation, U.S. Department of Transportation, Federal Highway Administration, Report No. 2, April 1972, p. 8.

Added to the foregoing energy costs must be those contained in the product, such as:

- Production and marketing chain
- Maintenance, accessories, parts and tires
- Street and highway construction, maintenance, lighting, policing, parking, and garaging
- Disposal

It is of note, that economic energy costs per use of average automobile operation in cents per mile have been relatively modest. This is shown in Table 34.

TABLE 34. AVERAGE AUTOMOBILE OPERATING COSTS, STANDARD-SIZE, COMPACT-SIZE, AND SUBCOMPACT-SIZE AUTOMOBILES, 1972.

	Original vehicle depreciation	Maintenance, accessories, parts and tires	Gas and oil (excluding taxes)	Garage, parking, tolls	Insurance	State and Federal taxes	Total
Standard size	4.4	2.6	2.1	1.8	1.4	1.8	13.6
Compact size	2.7	2.2	1.8	1.8	1.3	1.0	10.8
Subcompact size	2.1	2.1	1.4	1.8	1.2	.8	9.4

Source: L.L. Liston and C. L. Gauthier, COST OF OPERATING AN AUTOMOBILE, Suburban-Based Operation, U.S. Department of Transportation, Federal Highway Administration, April 1972, cover page.

Several researchers have recently reported on possibilities for reducing energy demand from the transportation sector.(185) Suggested recommendations generally center on a change in transportation modes, from automobiles to mass transport as an illustration. Solutions so presented are often oversimplified.

Contemporary family-activity patterns, lifestyles, and the built-up environment have evolved simultaneously with the development of the private-automobile transportation system. If technology changes to accommodate energy availability, social and cultural practices will have to change simultaneously. To state it simply, it is a case of negotiating present trip distances at less energy expenditure, i.e. improving utilization efficiency, or it is a case of reducing the physical distances--and preferably both. The alternative exists, of course, of forgoing some trips altogether by answering the familiar question negatively: "Is this trip necessary?" Cable communications could fit in as a partial solution to this problem. What can be readily seen from these alternatives is how the decision-making processes within family units may affect the outcome.

"Suburbia" and "urban sprawl" are one outcome of such decisions. Communications, in particular the private automobile, have been a major technology in creating the form of present human settlements in the United States. Many of the distances between nodes of activity or interest have become too great for walking. The automobile has evolved into the most desired means for solving the problem, and a systems relationship has been created. For opportunities, then, one has to look at the components of the

(185) for example: Eric Hirst, ENERGY CONSUMPTION FOR TRANSPORTATION IN THE UNITED STATES, Oak Ridge National Laboratories, Oak Ridge, 1972, ORNL-NSF-EP-15.

system.

The critical energy-technological component is the means for providing family transportation on the basis of free choice. The trend to smaller cars and to bicycles is significant. From a modest share in the market during the 1960's, then mostly imports, compact and more recently sub-compact automobiles have made dramatic gains in market share. By early 1972 this share had become about 35%. For 1973 the estimate is about 45%.(186) In 1972 there were 11.5 million bicycles sold in the United States. For comparison, new passenger car sales during the same period were 10.9 million. Not since the beginning of World War I have bicycle sales exceeded automobile sales. As can be noted from the data on trip frequency and trip distance given in this section, vehicles possessing low-energy-budget characteristics would seem to serve the family purposes better than mass-transit solutions. Small electrically-operated vehicles that take advantage of new technology could be more suitable. Solid-state electronic devices can make such an electrical system more effective than in earlier vehicles. In particular, regenerative braking is now practical.

Land-use controls need to be re-examined from the point of view of distance between residence and nodes of activity and interest. Present land-use policies tend to increase travel distances which are now overcome by use of energy under varying degrees of efficiency. This situation is similar to the separation of living units (single-family detached housing including mobile homes), which increases energy demand for indoor climate control. Building, construction, and housing codes are also subject

(186) , Detroit Free Press, December 23, 1973, p. 11C.

to scrutiny in this light.

Energy consumed for purposes of residential-peripheral transportation -- as is the case with nearly all residential energy consumption, direct or indirect -- can be rationalized to become much more efficient over time. The process can be aided by decisions based on higher levels of knowledge and information, and also by appropriate changes in technology and other resources. Restructured and re-oriented for a significant role in this task, home-economics education can be important, especially if paralleled with similarly-oriented engineering education. The apparent dearth of knowledge and information will have to be overcome by research and study. New texts concerned with the subject are needed.

Most uses of energy involve technology. Any contemplated application of technology needs to be assessed in terms of impact on the quality of life, so as to provide for most rational choice among alternatives, a concept to be developed further in Part B.

PART B

TECHNOLOGY ASSESSMENT AS A MANAGEMENT METHOD

Energy-Use Decisions, Their Impacts And Their Measurements

How families and individuals -- that is, society -- utilize and consume energy resources has been described in the last chapter of Part A. Earlier chapters gave an overview of the energy situation, emphasizing that much of the supply in currently-used energy forms is all too finite, that efficiency or efficacy of utilization can at the very least be questioned, that growth in demand -- given prevailing attitudes -- will mostly move the price rapidly upward, that as a result many distribution problems need to be faced, that energy use may well be in conflict with the environment, and that attempts at resolution of these problems will force the development and adoption of an energy policy to effect reasonably equitable access to energy supplies. Policy as foreseen will no doubt include encouraging the development of present sources and technologies, finding new ones, improving conversion and transmission efficiency, and finally, promoting efficiency of utilization and adoption of conservation practices. Stated differently, the unfolding developments demand better management of the resources, under which are included application of the relevant technologies. Management means planning and strategies, dimensions and measurements of energy-utilization in terms of efficiency, both in an economic as well as in a social sense.

Better management implies more and better information to aid the decision-maker. In the business and industry sector, including transportation in support of it, the availability and the economic cost of energy resources can usually be assumed to guide utilization decisions. Business management planning will tend to accommodate current and future situations as they may be affected by demand, price, and availability of energy, and the needs of the particular enterprise. Externalities or social costs will not play a significant role unless they are transformed to internalities in the cost calculus.

The situation is quite different for residential utilization of energy, where knowledge and information, together with planning capabilities regarding energy and its technology, are apt to be quite imperfect. Yet, as pointed out earlier in this study, a very large share of the total demand for energy has its origin within the family-unit decisions to acquire energy-consuming facilities, products, and services, and to engage in activities and practices which are a source for the demand. Many of the energy-related decisions made in the industrial or transportation sectors are merely secondary or intermediate responses following the family-unit decisions which either immediately or ultimately result in energy consumption.

It is this complex of decisions found in the residential sector which builds in a bias toward energy demand and consumption. In the future, a piece of home equipment, a structure, a device, put into operation today, will carry with it an energy-consumption liability for its entire service life as a result of the decision-patterns outlined. Therefore, family-unit decisions appear to be the critical and central locus of the problem. The aggregations of these consumer decisions are called "social choices"; or, restated in broader terms, social choice in a given environment is an aggregation of order preferences. There are two methods by which these choices generally are made, the economic one, through the market, and the political one, by voting.

In the area of energy technology, social choices are likely to be based on a mixture of political and economic decisions. One reason is that large political units have become subject to the promotion by pressure groups representing their own economic interest. These groups often reflect market demand or economic considerations in some form. The nature of the process as it relates to the subject has probably never been carefully explored.

The market and the ballot are amalgamations of individual preferences. The question of whether it is formally possible to construct a procedure for passing from sets of individual preferences to predictable patterns of social decision-making has been well worked over during recent decades.[(187)(188)] There appears to be no definitive evidence that the question can be answered affirmatively, even when assuming rational and well-informed decision-makers. The indications are that it may be impossible to aggregate formally on any theory of value. Whether expressed through market or political choice, many decisions reach beyond measures of physical quantity or economic value and therefore involve value judgments. Often, if not always, the outcomes are <u>de facto</u> situations evolved by and through representative government and the political process. Under the assumption

(187) Kenneth J. Arrow, SOCIAL CHOICE AND INDIVIDUAL VALUES, John Wiley & Sons, New York, 1963 (1951).

(188) James M. Buchanan and Gordon Tullock, THE CALCULUS OF CONSENT, Logical Foundations of Constitutional Democracy, University of Michigan Press, Ann Arbor, 1962.

that representative government acts in response to constituencies of individuals, the level of knowledge on the part of these individuals becomes critical in giving direction to the decisions to be made. To provide such knowledge and information for favorably affecting energy-use decisions is one of the central objectives of this work. The ideas which form the basis of this chapter are intended as one possible means leading toward this important objective.

Energy-related decisions involve costs and/or benefits: (1) to the decision-maker and his clientele; and (2) to the other parties. There are effects on the economy, the environment, individuals, and society. Some of the decisions have technology-built-in long-range effects along the bias already mentioned. Evaluation of all relevant factors must in part rely on subjective judgments, often concerning interpersonal comparison of one state against another state, better off or worse off, + or - . Obviously, preferences for these states may not be shared among individuals. Quantitative treatment is therefore needed, but it presents serious difficulties. Physical properties can be measured, as in natural science. Economic behavior certainly has been in part quantified. But political phenomena are harder to measure. Few will argue that more and better information will not improve on the allocation of resources. But even fewer offer acceptable procedures to achieve this improvement. Prudence, moreover, demands attention to the problem of partial information, wherein inadequate information results in inadequate or even wrong decisions.

Energy as a resource is used or consumed for its contribution to sustaining the level of living, or, if one prefers, to maximizing the quality of life. The degree to which energy and energy-powered devices are utilized in industrial society has long been viewed as a good measure of social progress. The development of systems of measurement and evaluation of this progress, however, has been lagging. The recent years have seen attempts to dimension and measure various social states more comprehensively, going beyond mere economic and physical criteria. The underlying motivation has been to eliminate the dissatisfaction expressed by many observers with respect to the concept that statement of output and consumption in economic and physical terms is an adequate measure of social conditions. Standing complaints are, for example, that most externalities imposed on the environment have not been properly accounted for under existing systems; that effects on human environment, health, and well-being are being given insufficient weight; and that the resulting distribution of benefits derived from production and capital formation leaves much to be desired. Among others, Paul A. Samuelson -- author, teacher, scholar in the field of economics and economic behavior, and Nobel-prize winner -- refers to modern political economy as the calculus of quality of life, not merely of material quantity.(189)(190)

One concept which has evolved for the purpose of measuring the overall condition of man is "Social Indicators." There are now many references in the sociology literature, in the record of Congressional activities,

(189) Paul A. Samuelson, From GNP to NEW, in Newsweek, April 9, 1973, p. 102.

(190) Robert Reinhold, MEW or NEW, How Does The Economy Grow? in New York Times, Sunday, July 29, 1973, p. 2 F.

and elsewhere.[191] The concept has not advanced very far in an operational sense as a device for effectively measuring social conditions, or predicting future developments. Among probable reasons may be the problem of establishing sufficiently specific attainable and acceptable goals against which progress measurements can be made, difficulty in developing a methodology employing the principle to the point of demonstrable usefulness, and difficulty with gaining broad public understanding and support.

Another concept which has become recognized in recent years is "Technology Assessment." It relates to the assessment of impacts associated with current developments in technology, and the forecasting of future technologies and their potential effects on environment and society. Impacts are studied in terms of over-all human or societal goals. Their effects are to be viewed in the light of different time horizons, and they may be good or bad, beneficial or harmful. As of now, the primary purpose of technology assessment is to aid decision-makers, such as members of the U. S. Congress, with needed information with respect to specific legislative action. Macro-projects with wide-ranging implications for U. S. policy are generally seen as potential subject for this technique,

(191) (a) Leslie D. Wilcox et al., SOCIAL INDICATORS AND SOCIETAL MONITORING, An Annotated Bibliography, Jossey-Bass, Inc., San Francisco, 1972.

(b) Genevieve J. Knezo, SOCIAL SCIENCE POLICIES; An Annotated List of Recent Literature, Congressional Research Service, Library of Congress, Washington, July 8, 1971 and Addendum dated August 4, 1971.

(c) Thomas McVeigh, SOCIAL INDICATORS: A Bibliography, Council of Planning Librarians, No. 215, Monticello, Ill., Sept. 1971.

actually a new technology in itself. Technically speaking, social indicators may find use in the technology-assessment process. But here again the complaint has been that technology assessment, as it developed so far, does little for the great multitude of every-day decisions involving technology, such as in energy utilization.

A Proposed Method for Measurement and Assessment of Alternatives

Energy in one form or another is involved in most applications of technology. As pointed out in different parts of this study, the availability of energy resources is increasingly limited by a number of constraints. Constraints operate to control the use of technology in the search for energy resources, in their development and exploitation, and in distribution and utilization efficiencies of the energy produced. The forces at work are diverse and generally not well understood, especially those factors contributing to end-effects of technological activities. Conventional analysis thus presents difficulties in arriving at equitable decisions.

The search for better methods prompted an examination of the idea of technology assessment. It appears to offer a new approach useful for the ordering and dissemination of information for purposes of rationalizing energy utilization and consumption. The scheme proposed herein follows the thinking behind technology assessment, but is modified in an attempt to overcome some of the difficulties mentioned earlier, and to directly serve the purpose of this study. The scheme is in part borrowed from the

"GAAT System",(192) particularly its "Human-Want Categories" and its "Satisfaction Index."

Improvement in the quality of life, or even maintaining it, is signaled by the indicated degree of human-want satisfaction. To render this statement operational, these human wants must be identified. In reality, this process is being carried on all the time, and is therefore hardly new. It is a consciously, but most frequently unconsciously, ongoing process. The proposed scheme aims to improve the process. To illustrate, the engineer, as he seeks to apply science, technology, and other resources to satisfy human wants -- often and perhaps erroneously referred to as human "needs" -- characteristically follows the same process, though in a very narrow sense. He needs better and broader-based sets of factor-integrating guides to replace the narrow hardware-oriented principles which have governed his activities in the past. The same is true for the activities of other professionals and administrators who make technology-related decisions, which differ from the "social choices" already discussed. The proposed scheme is intended, in part, to provide for the deliberate identification of human wants. To make it operational requires development of a tractable method of analysis for everyday uses in engineering and administrative activities. The following scheme, therefore, seeks to improve on the process of providing information for more rational social choices as well as to provide better information patterns for arriving at more rational technology-related administrative decisions.

(192) See, for example, Final Report, "Technology-Assessment Component of the Comprehensive Planning Assistance Project," State Planning Division, Executive Office of the Governor, Lansing, Michigan, December 1972.

In the GAAT System, a methodology, whose stated purpose is the analysis and assessment of alternatives, human wants are categorized by four criterion variables called "Human-Want Categories," designated by P, E, F, and J. The value of the "Satisfaction Index S" is derived from the behavioral performance of the system expressed in the respective levels of categories P, E, F, and J. Described in abbreviated form the categories are:

P Provision of material goods and services [individual human being, material concerns]

E Quality of the physical Environment [human society, material concerns]

F Freedom of individual choice, opportunity for self-development and spiritual growth [individual human, non-material concerns]

J Quality of the "social environment" -- that is, Justice, rectificatory and distributive [human society, non-material concerns]

It would be impractical in this study to detail the categories P, E, F, and J beyond what is needed for the demonstration trials to be covered later in this chapter. Content of the categories is exemplified by two different descriptive sets in Appendix B, entitled HUMAN-WANTS CATEGORIES BREAKDOWN.

In composite, the criterion variables P, E, F, and J determine the quality of life. Maximizing this quality for a society requires collective action through social measures, the management of which again depends on information. Such information is needed by individuals and family units, as well as by corporate and public bodies. The Satisfaction Index is to aid in systematizing such information.

Under limited resources the four categories cannot be independently controlled. The highest level of satisfaction will be achieved by balancing among the four categories. Unfortunately, the necessary trade-offs are complex and subtle. To gain a better understanding of the process, we resort to "Partial Satisfaction Indexes," as illustrated by Figure 5. The particular shape of the curves shown has little significance; it suffices for the moment that the functions increase monotonically, preferably from minus infinity at zero argument, to a finite asymptotic value at infinite argument. The points on the curves have been arbitrarily located for illustrative purposes only.

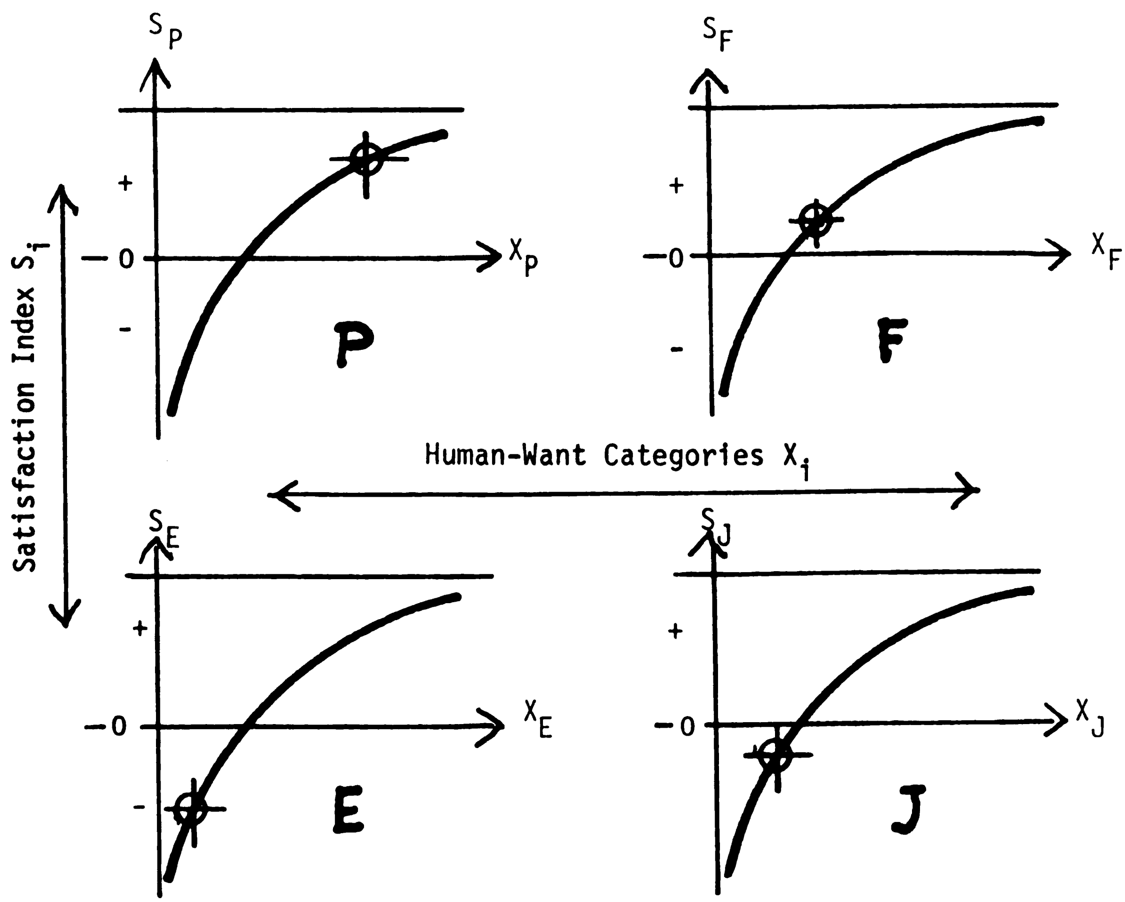

FIGURE 7. PARTIAL SATISFACTION CURVES.

The notation has the following interpretation: X_i = degree of achievement in i-th goal-variable category. (These categories are aggregates of partial goals in each of the P, E, F, J categories. The dimensions X_i are determined by behavioral responses to stimuli which direct actions seeking to satisfy human wants.) S_i = a measure indicating how well human wants are satisfied with respect to the i-th category.

(Behavioral response to the system determines S_i; or, human motivation determines the prevailing value of S_i.)

An adequate quantitative formulation has not yet been developed. What is presented here is only a schematic formulation of the human-wants phenomenon as it relates to human satisfaction. The simplest useful form of the overall satisfaction index S is perhaps a linear combination of weighted partial satisfactions:

$$S(P, E, F, J) = \alpha_P S_P(P) + \alpha_E S_E(E) + \alpha_E S_E(F) + \alpha_J S_J(J) \quad ,$$

where the α's are constants* representing weight factors attached to the respective categories. The actual weighting will depend on the structure of the decision-making system, and on the backgrounds and characteristics of the decision makers.

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* This form is of course extremely simple. It excludes interaction among the partial satisfaction indexes. Such interactions can be taken into account in several ways, say by making each partial satisfaction index depend on all the categories, or by allowing some dependence of the α's on the categories. We prefer at the moment the generalization of adding higher terms in the series. For convenience, let X_i represent

the generic category (i.e., $X_1 = P$, $X_2 = E$, $X_3 = F$, $X_4 = J$). Then, in obvious notation, the simple expression is extended to the following series:

$$S(X_1,X_2,X_3,X_4) = \sum_{i=1}^{4} \alpha_i S_i(X_i) + \sum_{i=1}^{4} \sum_{j=1}^{4} \frac{1}{2} \alpha_{ij} S_i(X_i) S_j(X_j) + \quad .$$

where the α_i, α_{ij}, ... are the weighting factors. This expansion can quickly become unmanageable, and it is an empirical matter to see to what extent it is useful.

Figure 8 illustrates how far a given quantity of effort resulting in a change ΔX_i, the return ΔS_i on any such effort varies with the state of S_i for each category.

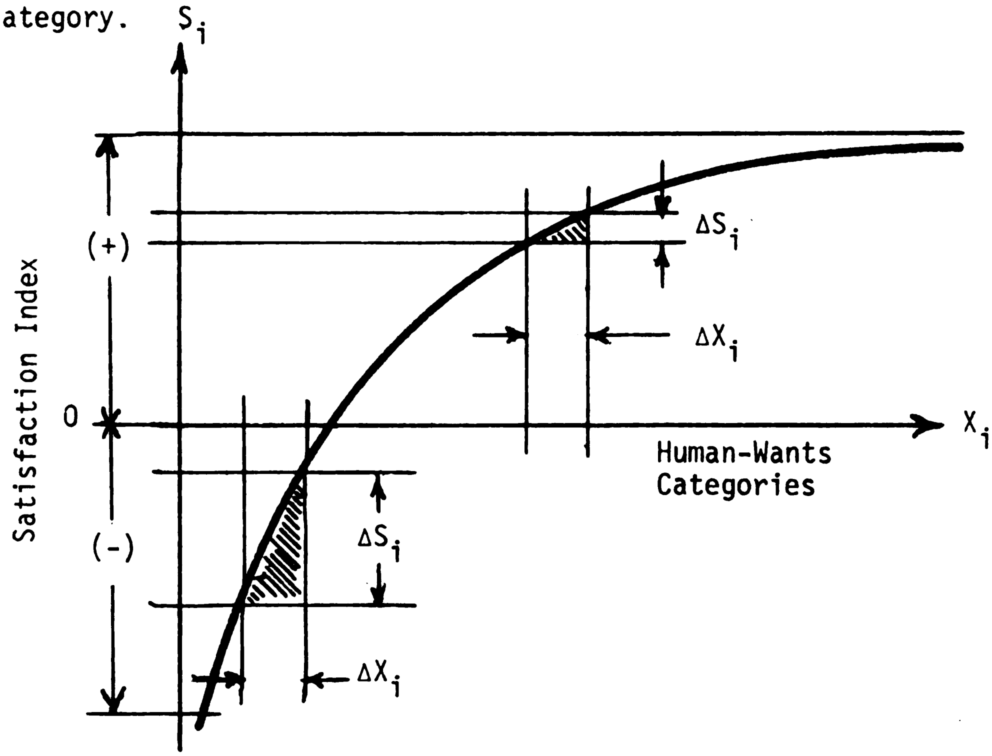


FIGURE 8. RELATIONSHIP OF S_i TO STATE OF HUMAN-WANTS CATEGORIES X_i.

In Figure 7, a change in location of any point on the P-curve will automatically cause changes in location of points on at least one of the E, F, and J-curves, under the condition of fixed resources R. In an ideal world all four categories would be simultaneously located indefinitely far to the right in each diagram. Under finite resources, however, increase in one category implies decrease in at least one other category. With functions of the form shown, diminishing returns set in, and as the area of saturation is approached by one of the variables, relatively greater benefits can be obtained by concentrating effort on one or more of the other categories to maximize the benefit of trade-offs.

One strives to raise the level of S; but corresponding effort is required to do so. The entire spectrum of human wants is the basis for the motivation for the efforts necessary to provide given values of the X_i. These efforts naturally will include human thought and physical effort as derived from the prevailing social structure. Effort may consist of sheer human effort, deployment or investment in time and resources, management of the resources, along with utilizing related technologies to the end of attaining higher efficiency or returns.

The form of the partial satisfaction indexes implies that human wants are never quite satisfied, even if the world were static. In fact, human experience, change in tastes and preferences, even at fixed resources, cause a continuous shifting in emphasis among the categories and their components. As a higher state of satisfaction is reached in one category, other categories will become candidates for improvement. Trading-off will be a continuing phenomenon; by analogy, the process in many respects resembles the market exchange of commodities, with bargaining as one of its principal characteristics. It is one of the major objectives of the proposed scheme to identify and display current situations which prevail for each category, so that the choice among alternatives can be facilitated, as an aid to the decision-maker, performing as a kind of broker among categories.

One other important point now needs to be mentioned, that is, the dynamic or temporal nature of resources, which, over time, tend to move the entire pattern of the four categories upward (or downward). During this movement, a fixed relationship among the categories is usually not maintained. In the aggregate, an increase in resources permits improvement in the level of living for an ever-wider spectrum of society. This is illustrated by Figure 9. Then one (or more) of the X_i's can be increased.

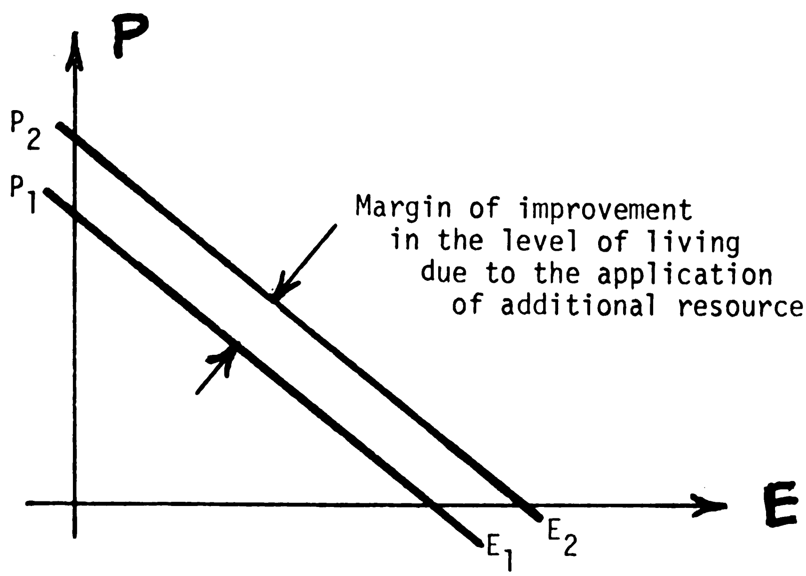


FIGURE 9. EFFECT OF RESOURCES ON HUMAN-WANT CATEGORIES.

without a simultaneous decrease in the others. The key, obviously, is development of new resources and the appropriate management thereof. Again, provision of information is fundamental to this purpose.

Admittedly, monumental difficulties arise in quantifying the four categories, a particular problem with those elements dealing with subjective human values, primarily F and J. As a beginning, the proposed evaluation scheme -- simplified for illustration purposes -- will adopt an arbitrary five-point scale. It depicts levels of satisfaction S_i for each human-want category, arranged by zones of relative intensity. The factors which determine the intensity have already been touched upon. The scale is illustrated by means of Figure 10.

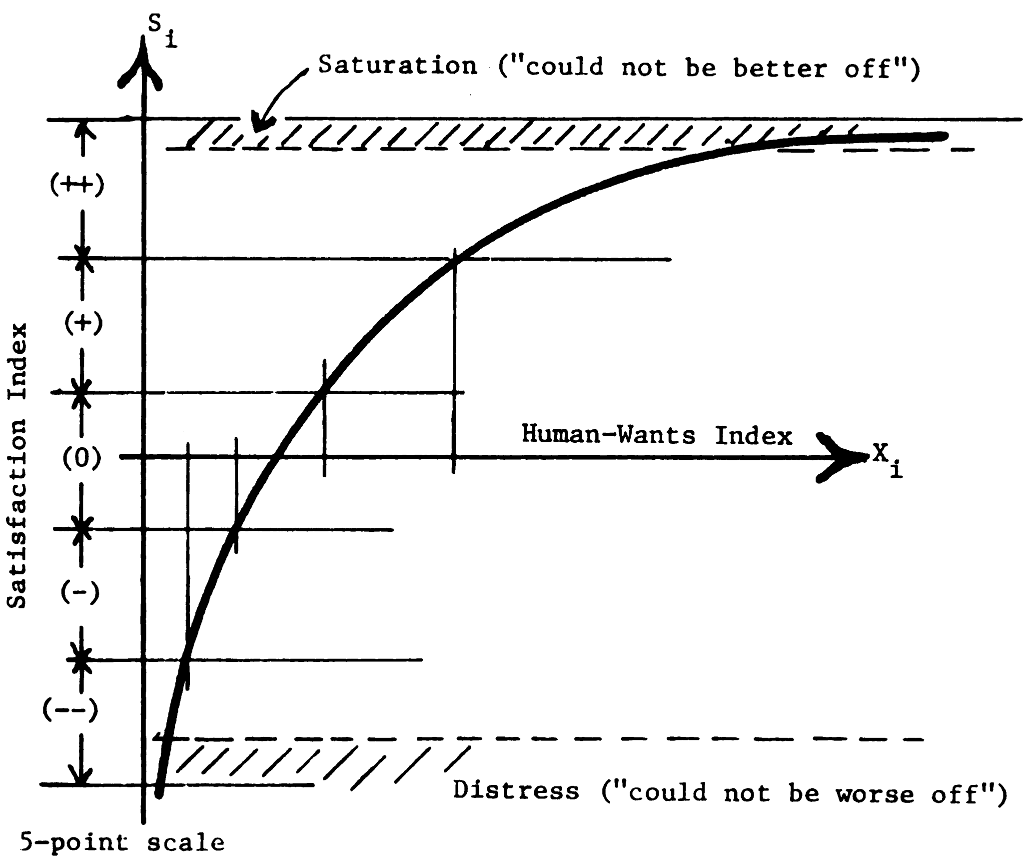


FIGURE 10. LEVELS OF SATISFACTION.

5 - point scale

(++) High level of satisfaction

(+) Satisfaction

(0) Unconcern or indifference

(-) Dissatisfaction

(--) High level of dissatisfaction

The above scheme is a modest expansion of the even simpler better-off or worse-off grading. Obviously, the scale could be refined as far as one desires. The high (++) range lies below saturation, which is unlikely to occur in any society; in a welfare society, any point materially below the (-) level is deemed socially unacceptable. A floor is placed above any point of distress, and hence one would have to use restraint in assigning a (--) assessment.

Under the proposed scheme, assessments are made by comparing two or more alternatives. For each such alternative, points are appropriately assessed, which for purposes of analysis can be located on partial satisfaction curves P, E, F, and J. This procedure will help identify trade-off options which can be followed by suitable adjustments in the respective point locations. Thereafter, the point so arrived at can be transposed into a matrix which arrays criterion categories against the various chosen alternatives. This matrix will then yield information regarding the repsective merits of each alternative.

At this time the individual assessments of factors P, E, F, and J can not be translated into satisfaction indexes which are rigorously supportable. Until further development and refinement occurs, a simple sum of S_P, S_E, S_F, and S_J will suffice as a crude indicator pointing to priorities for further investigation. The scheme, primitive as it is, is surely an improvement over what has been available, an improvement toward giving more orderly direction to working with trade-offs and for identifying conditions which could raise the level of overall satisfaction, and thence, the quality of life.

The scheme can be -- and no doubt will be -- expanded and refined. Rather than attempt at this time to add more to the theory of technology assessment and to the discussion of methodology, it seemed better to try some direct experimentation with the scheme. The rationale for this decision is the realization that technology assessment has to be made operational if it is to be of value to anyone but its students. If technology assessment is to become a discipline, or at least a method, one approach is to start from the bottom up. People have to learn to understand it, work with it and become conscious of the benefits to be derived from systematic and deliberate evaluation, assessment, and ordering of available alternatives in terms of their respective impacts. It might further make sense to have people learn by doing, by working with relatively simple assessments, by the device of acting as novice assessors who have been prepared through minimal sets of instructional information. (After all, to the present, there are few practiced technology assessors at any level!)

This study is primarily concerned with the energy problem as affecting and affected by residential utilization and consumption decisions. Insufficient availability of energy resources to meet demand is with us in the short run, and very likely in the long run. The technology-assessment scheme has been proposed, among its other objectives, for determining how to optimize distribution and utilization efficiency, for guiding most effective development of additional and new resources, and most importantly, for aiding determination of policy. The specific proposal therefore is an attempt to measure well-being by means of satisfaction indexes, limited to regions where energy is especially pertinent.

To avoid the need for coming to grips with the difficult problem of having to establish social goals against which to measure progress, we resort to a comparative analysis only. This analysis will lean on the principle of "better-off or worse-off," the natural phenomenon found in all evolutionary processes, where that which is a little better is adopted, and that which is not so good falls by the wayside.

Alternatives

The multitudes of residential and related energy uses confront the decision-maker with even larger numbers of alternatives. True, alternatives do range outside the residential household sphere--witness: should energy be used for clothes drying in the household, or grain drying on the farm, if there is not enough to go around? Here again, systematic evaluation and assessment should lead to more rational outcomes, or at the very least to mutual understanding and a basis for compromise.

The proposed assessment scheme attempts to cast the problem into a practiced form for a decision-maker confronted with alternatives as to allocation of energy. Granted, alternatives may have to be first identified and defined by experts from the particular field, yet the proposed scheme itself will help identify suitable alternatives or the lack thereof.

One needs a vehicle to determine:

(1) how well novice assessors can work with the scheme;

(2) how individual assessments correlate;

(3) what happens when the assessor is asked to re-assess after a time interval;

(4) what is the minimum information required by the assessor in order to achieve results of any use;

(5) what direction should be taken by further development of the scheme into a rigorous methodology.

As a topic narrowly enough delineated and sufficiently comprehensible to most people, the drying of domestic washables was chosen.

The alternatives selected for the first trial were:

(1) Do nothing overtly, let the market and price mechanisms handle.

(2) Use clothes lines, indoors or outdoors.

(3) If drying other than in natural atmosphere is desired or necessary, use commercial drying.

(4) Decrease frequency of laundering.

(5) Use disposables in place of washables.

(6) Employ technology to optimize dryer efficiency.

Domestic appliances for drying clothes and fabrics by direct gas or electric heat are a rather recent technology, about 25 years old. For decades such methods, on a larger scale, have been employed by commercial laundries. Often, in older coal-fired plants, heat was supplied from steam-heated heat-exchangers.

Generally, the principle involved in the mechanical drying of textile materials is moving air through a load under agitation, commonly called tumbling. The air is made hot enough, and therefore dry enough, to take out moisture rapidly and transport it in the form of water vapor. Since the water-holding capacity of air at atmospheric pressure is controlled by temperature, the rate of heat input is mainly what determines the length of drying time.

The energy required for changing liquid water to vapor is about 970 Btu/lb. A 10-lb dryweight load of fabrics under normal conditions may contain about 8 lb of water when charged into a domestic dryer, which means 970 Btu/lb x 8 lb = 7,760 Btu of energy required. In actual practice roughly twice that amount of energy is taken.[193] Much of the heat goes out through the vent as sensible heat in the exhaust air, some is taken on by the mass of the appliance itself, and some is radiated and converted into the environment; the energy of the motor-drive is dissipated; and so on. A small amount is needed to pull the water out of the fabric, i.e., overcome the heat of sorption of liquid water in the fabric. With gas dryers, more of the input heat energy is lost than with electric dryers, because the products of combustion in the drying air already contain certain amounts of water vapor.

One aspect of domestic clothes dryers commands special attention, namely, the growth rate. In recent years this rate has exceeded 10% annually; it implies new energy demand where before it generally was zero. The 1972 dryer saturation was reported as 51% of wired housing units. The degree of dryer saturation is to be compared with that for washing machines, namely 97%.[194] According to the EEI estimates, a dryer consumes almost ten times the energy that a washer consumes (993 kWh_e vs. 103 kWh_e, on an annual basis. Noted should be that the clothes washing process actually involves other and additional forms of energy consumption, in pumping

(193) PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES, op. cit., Table 5, p. 18 lists "technical" efficiency of energy conversion for gas dryers as 47%, and for electric dryers as 57%.

(194) Merchandising Week, op. cit., p. 30.

water, heating of water, disposing of effluent and the energy content of the chemicals used). For an average of 100 dryer-loads per households per year: 100 loads/households x 15,000 Btu/load (at capacity loads) x 34 million units = 51 x 10^{12} Btu/yr.[195] For electric dryers the ultimate energy demand would be something like 50,000 Btu/load. Accurate national data are not available. One study in California gives energy consumption per dryer in the Los Angeles area as 1,000 kWh_e/yr.[196] At an estimated average of 5 kWh_e/load, this figure is equivalent to 200 loads per year.

(195) PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES, op. cit., Table 1, p. 6 lists 1968 energy consumption (assumed to be ultimate) for clothes dryers as 208 x 10^{12} Btu.

(196) R. D. Doctor et al., CALIFORNIA'S ELECTRICITY QUANDARY: III SLOWING THE GROWTH RATE, op. cit., Table 17, p. 51.

The energy consumed in the clothes-drying process winds up in the environment in the form of thermal loading, i.e., heat. In the case of dryers operated by thermally-generated electricity, the process of generation and distribution of electric energy entails a loss of heat into the environment, a loss amounting to twice as much heat as is used and emitted by the dryer itself. The thermal generation of electricity also produces chemical pollutants, as does drying by gas where combustion products are emitted into the atmosphere. Environmental impacts from the manufacture must be added.

Economic consequences of clothes dryers are by no means negligible. The retail value of the approximately 4 million dryers sold in 1972 was reported as $688 million.(197) To this figure can be added amounts for installation ($200 million), service ($100 million per year), economic cost of energy for operation (perhaps $700 million per year), giving us a total of approximately $1.7 billion per year, or around 0.15% of GNP. This cost brings benefits through the time freed by clothes dryers that is employed in other endeavors, and through the gratification and healthfulness resulting from clean clothing.

Factory shipping weight of a dryer averages about 130 lb., including packaging materials, which are mostly paper products. The principal raw material for construction is iron, but other materials are significant: copper, zinc, aluminum, silver, tin, lead, silicon, nickel, chromium, rubber, and petrochemicals. Energy is consumed in processing, fabricating, distributing, and servicing the product, in an amount crudely estimated at 5 million Btu per unit. Operation may consume on the order of 3 million

(197) Merchandising Week, *op. cit.*, p. 27.

to 10 million Btu of primary energy per unit (overall energy demand) annually. Additional amounts of energy will be required for the ultimate disposal or salvage of the product.

Domestic clothes dryers in the U. S. are on the borderline between necessity and luxury. Most people around the world resort to a simple alternative: the clothes line, indoors and/or outdoors. Or, as already mentioned, drying may be done otherwise in naturally circulating atmospheric air, in the sun, on bushes, shrubbery, lawnchairs, or lawns, It is only in the U. S. and Canada that domestic electric- or gas-heated mechanical clothes dryers have made substantial inroads.

With respect to the alternatives listed earlier, Alternative (1), leaving the problem to the market, requires little explanation. It is what has been going on up to now. The market forces have been behind the rapid growth and demand for energy occasioned by the installation of domestic clothes dryers. Their energy utilization varies; as noted, often 50% of the energy input is lost.

The trends evident in Alternative (1) are likely to continue unless there is some form of policy intervention. Whether routine upward changes in the energy price will have much impact upon the existing trend is questionable. Compact dryers, more recently on the market to cater to growing apartment and other smaller living units are relatively quite inefficient, and therefore raise per-unit energy demand.

Alternative (2), the clothes line, would seem to be most effective in reducing energy consumption. In part, it constitutes direct use of solar energy. Mandatory use of the clothes line would mean either partly or wholly de-activating the 34 million units currently in use. Wash-and-wear fabrics have been developed for use in conjunction with clothes dryers, depending on heat-tumbling for minimum wrinkling, and thereby reducing or eliminating ironing. The clothes line may not be practical for the large number of homemakers now in the work force, as explained in Chapter IV . A dryer located next to or near an automatic washer is a convenience -- to give it up would be difficult. Under conditions of growth in urban living, opportunities for access to clothes lines or the like are diminishing. Space and facilities would have to be provided by homeowners or landlords, as indeed they once were by apartment-landlords in the eastern United States.

Alternative (3), commercial drying, may be a practical alternative. There was a time when commercial laundries or the clothes line were the only facilities available. Commercial drying technology would likely be much more efficient in view of the scale of operation. Furthermore, commercial operations could use fuels not suitable for the home, such as coal, or could perhaps use surplus process steam or power-plant waste heat. There arise questions of cost, extent of pick-up and delivery services, and quality.

Alternative (4), decrease in frequency of laundering would in fact require social change. Laundering frequency is very high in the United States. Reducing the frequency would result in increased soil accumulation, which would be difficult to handle in current American home-laundry practice. In Europe, the problem is overcome by higher temperatures (95° C), presoaking, and different techniques. In the United States, the water temperature ranges roughly from 60° C to 70° C. Soil-removal deficiencies are hidden by extensive use of bleach, which is generally not used in Europe. Bleach is detrimental to some fabrics and to some extent creates environmental problems. Generally speaking, lowering frequency of laundering would require changes in practices and equipment in the home, though not in commercial laundering.

Alternative (5), use of disposables, would actually be an expansion in current practice that embraces paper napkins, paper towels, tissue handkerchiefs, table coverings, bedlinens (as in hospitals), and so on. The available technology is extensive, and questions center on acceptability, cost, and overall energy consumption.

Alternative (6), adoption of technology to increase efficiency, may not be a wholly valid alternative by itself, since the application of technology constitutes the application of/or change in resources. All the other alternatives, however, also require some kind of management, which in essence is a component of resources.

A number of options are available for increasing energy-utilization efficiency of domestic clothes dryers through the application of technology. Among them are:

(a) Automatic monitoring devices for modulating heat-input and rate of airflow to no more than actually required for moisture removal from the dryer load. Shut off the heat at a point where ambient air can do the remainder of the task, thereby utilizing heat stored in the mass of the machine and in the load. (Drying below the humidity level of ambient air is a waste of energy).

(b) Recirculate heat, perhaps for water-heating or for pre-heating of air going into the dryer.

(c) During the heating season, use exhaust heat in residence (probably not all of the moisture, however).

(d) Operate electric dryers off-peak by installing time clocks (which also could time the water heater).

(e) Blow unheated ambient air, partly or entirely, through the clothing mass in the mechanical drying process.

It was decided to consider only sub-alternatives (a), (b), and (c) with an arbitrary but realistic price tag attached to each. Sub-alternative (d) was considered in Trial Assessment No. (6) only in connection with Alternative (2).

Assessment Trials

The assumption was that much could be learned at relatively low cost by some testing of the proposed scheme. With luck, the experiment would yield sufficient information to guide further development. Six sets of assessment trails were carried out. These had to be "quickie" exercises, admittedly quite rough, in order to minimize costs in time and effort. The obvious limitation in such a venture is what participants will of their own free will hold still for. A constraint is that the scheme be simple enough to be executed by novice assessors prepared only through a minimal set of instructions.

The nature of the scheme and the state of its development at this time are such that only composite assessments are likely to have any significance. Theoretically, in the absence of developed and adopted rules, assessments are likely to gain in validity as the number of assessors becomes large. Assessments made by a single assessor, in the absence of rules, surely could be challenged as representing only the single viewpoint of an individual, an elite rather than a societal judgment. The relationship between the number of assessors required to arrive at a valid composite judgment, and the sophistication of rules necessary, could be the subject of another inquiry.

Trial assessment No. 1 was given as a task to seven members of the GAAT Group.(198) Most of these, acting as novice assessors, were more or less familiar with the concept of technology assessment, but not especially with the topic of assessment. Several of the members, however, were not familiar with the scheme prior to seeing the instructions for the assessment. A copy of instructional information given to the assessor can be found in Appendix C.

Summarized by arithmetically combining the seven individual assessments, the trial yielded the following (Table 35).

(198) GAAT minutes, September 1972.

Table 35. Trial Assessment No. 1

Categories	P	E	F	J	Total*
Alternatives					
(1) Do nothing	+ 1	- 9L	+ 1	+ 7H	0
(2) Clothes line	- 9L	+ 11H	- 10L	+ 2	+ 2
(3) Commercial laundry	+ 4	+ 6	+ 2	+ 6	+ 18
(4) Cut frequency	- 5	+ 3	- 8	+ 2	- 8L
(5) Disposables	+ 2	- 4	- 3	- 3L	- 8L
(6) Technology					
(a) Heat-input control	+ 8H	+ 7	+ 1	- 1	+ 15
(b) Heat recovery	+ 5	+ 8	0	- 1	+ 12
(c) Heat house	+ 2	+ 12	+ 5H	+ 1	+ 20H

H or L, respectively, denote either highest or lowest assessment for each category, or each total. Highest and lowest possible values for each category = ± 14, for each total = ± 56.

* Unweighted and unadjusted totals should be viewed only as very crude indicators describing the relationships among categories. Neither can the categories be optimized individually, nor can they be totaled without going through the trade-off process discussed in the text. How to aggregate P, E, F, and J formally on any theory of value and yielding usable results is as yet unknown.

After an interval of several weeks, the same group was asked to repeat the assessment. The results were the following:

Table 36. Trial Assessment No. 2.

Categories	P	E	F	J	Total*
Alternatives					
(1) Do nothing	0	- 6L	+ 5	- 5L	- 6
(2) Clothes line	- 5L	+ 8H	+ 9H	- 1	+ 11H
(3) Commercial laundry	+ 3	+ 5	0	+ 3H	+ 11H
(4) Cut frequency	- 2	+ 3	- 4L	- 4	- 7L
(5) Disposables	- 3	- 3	+ 3	+ 2	- 1
(6) Technology					
(a) Heat-input control	+ 5H	- 5	+ 1	+ 2	+ 3
(b) Heat recovery	+ 5H	+ 5	- 1	- 4	+ 5
(c) Heat house	+ 5H	+ 5	+ 2	- 2	+ 10

Trial assessments No. 1 and No. 2 are compared in Table No. 37.

* See footnote with Table 35.page 196.

Table 37. Comparison Between Trial Assessment No. 1 and No. 2.

Categories	P1	P2	E1	E2	F1	F2	J1	J2	T1*	T2*
Alternatives										
(1) Do nothing	+ 1	0	- 9L	- 6L	+ 1	+ 5	+ 7H	- 5L	0	- 6
(2) Clothes line	- 9L	- 5L	+ 11H	+ 8H	- 10L	+ 9H	+ 2	- 1	+ 2	+ 11H
(3) Commercial laundry	+ 4	+ 3	+ 6	+ 5	+ 2	0	+ 6	+ 3H	+ 18	+ 11H
(4) Cut frequency	- 5	- 2	+ 3	+ 3	- 8	- 4L	+ 3	- 4	- 8L	- 7L
(5) Disposables	+ 2	- 3	- 4	- 3	- 3	+ 3	- 3L	+ 2	- 8L	- 1
(6) Technology										
(a) Heat-input control	+ 8H	+ 5H	+ 7	- 5	+ 1	+ 1	- 1	+ 2	+ 15	+ 3
(b) Heat recovery	+ 5	+ 5H	+ 8	+ 5	0	- 1	- 1	- 4	+ 12	+ 5
(c) Heat house	+ 2	+ 5H	+ 12	+ 5	+ 5H	+ 2	+ 1	- 2	+ 20H	+ 10

Highest and lowest possible values for each category = ± 14, for each total (T) = ± 56.

* See footnote with Table 35, page 196.
These totals merely display the shift between aggregate judgments as they occurred between Assessment No. 1 and No. 2.

Trial Assessment No. 3 was made by sixteen undergraduate students (Junior and Senior level, science-oriented, actually a class in The History of Science). The instructions were changed from the foregoing in several respects: (1) The technology-assessment scheme was explained in more detail, with illustrations of partial satisfaction curves; (2) categories P, E, F, and J were described by listing of components; and (3) an illustrative exercise was included. The instructions for this trial can be found in Appendix D.

Table 38. Trial Assessment No. 3.

Categories	P	E	F	J	Total*
Alternatives					
(1) Do nothing	+ 1	- 6L	- 1	- 4L	- 10L
(2) Clothes line	- 8L	+ 8H	- 7L	0	- 7
(3) Commercial laundry	- 3	+ 6	- 6	+ 1H	- 2
(4) Cut frequency	- 4	+ 6	- 4	0	+ 6
(5) Disposables	+ 3	+ 2	0H	- 1	+ 4
(6) Technology					
(a) Heat-input control	+ 4	+ 7	- 1	- 4L	+ 6
(b) Heat recovery	+ 3	+ 8H	- 2	- 4L	+ 5
(c) Heat house	+ 5H	+ 7	- 1	- 3	+ 8H

Highest and lowest possible values for each category = ± 16.

Highest and lowest possible values for each total = ± 64.

* See footnote with Table 35, page 196.

Trial Assessment No. 4 was a repetition of assessment No. 3, repeated by 9 (haphazardly chosen) out of 16 assessors who had made Trial Assessment No. 3 two months earlier. Identical instructions were given. The result is compared in Table 39, which follows. The data shown are limited to the 9 assessors who repeated; hence the totals are different from those reported for Trial Assessment No. 3.

Table 39. Trial Assessment No. 4.

Categories	P3	P4	E3	E4	F3	F4	J3	J4	T3*	T4*
Alternatives										
(1) Do nothing	+ 3	- 5L	- 9L	- 4L	- 2	- 4	- 4L	- 9L	-12L	-20L
(2) Clothes line	- 9L	- 5L	+ 10H	+ 10H	-10L	- 7	- 1	- 1	-10	+ 1
(3) Commercial laundry	- 2	- 1	+ 8	+ 6	- 4	- 2	0	- 2	- 2	+ 1
(4) Cut frequency	- 6	0	+ 9	+ 8	- 6	- 9L	+ 1H	- 3	- 2	- 4
(5) Disposables	+ 3	+ 3	0	+ 2	0H	- 1H	0	- 2	+ 3	+ 2
(6) Technology										
(a) Heat-input control	+ 6	+ 7	+ 9	+ 6	- 1	- 1H	- 2	- 1	+12H	+11H
(b) Heat recovery	+ 5	+ 8	+ 9	+ 7	- 3	- 6	- 4L	- 5	+ 7	+ 4
(c) Heat house	+ 7H	+ 9H	+ 9	+ 8	- 1	- 3	- 4L	- 3	+11	+11H

Highest and lowest possible values for each category = ± 18, for each total (T) = ± 72.

* Totals (T3 and T4) merely display the shift in judgment as it occurred between assessments No. 3 and No. 4.

See footnote with Table 35, page 196.

Trial Assessment No. 5 was made by eight newer members of the GAAT Group. They were given no written instructions, but only brief verbal ones. Therefore this group should be considered as having been least prepared among the four trial groups.

Table 40. Trial Assessment No. 5.

Categories	P	E	F	J	Total*
Alternatives					
(1) Do nothing	+ 3	- 10L	- 5L	- 7L	- 19L
(2) Clothes line	- 8L	+ 9	- 3	+ 7H	+ 5
(3) Commercial laundry	+ 1	+ 5	- 5L	+ 2	+ 3
(4) Cut frequency	- 5	+ 6	0	0	+ 1
(5) Disposables	+ 7	- 2	+ 4H	+ 3	+ 12
(6) Technology					
(a) Heat-input control	+ 9H	+ 10H	+ 3	+ 1	+ 23H
(b) Heat recovery	+ 7	+ 7	+ 1	0	+ 15
(c) Heat house	+ 9H	+ 7	+ 3	+ 2	+ 21

Highest and lowest possible values for each category = ± 16, for each total = ± 64.

* See footnote with Table 35, page 196.

Trial Assessment No. 6 was made by eight graduate students (in Human Environment and Design). Instructions were the same as for No. 3, except that the alternatives were presented in a form requiring the assessment of various, and therefore additional, sub-alternatives, and, after completing the assessment, the assessors were asked to rank the alternatives. A copy of the instructions can be found in Appendix E.

Table 41. Trial Assessment No. 6

Categories	P	E	F	J	T*	Rank of T	Direct Rank
Alternatives							
(1) Do nothing	-2	- 6L	+ 5H	+3	0	5	12
(2) Clothes Line							
(a) Dryers not allowed	-8L	+12H	-10L	-8	-14	8	5(2)
(b) Use Dryers off-peak	-6	+ 4	- 8	-3	-13	7	13
(c) Tax dryers	-8L	+ 4	- 8	-8	-20	13	9
(d) Tax energy	-8L	+ 7	- 8	-8	-17	11	11
(3) Commercial							
(a) Pick up and deliver	+2	0	0	+7H	+ 9	2	6
(b) Take there	0	0	- 9	-7	-16	10	8
(4) Cut laundering frequency	-4	+ 4	-10L	-9L	-19	12(2)	7
(5) Disposables							
(a) Same cost	-1	- 5	- 5	-4	-15	9	5(2)
(b) Lower cost	-1	+ 4	0	+4	+ 7	4	4
(c) Higher cost	-3	- 6L	- 6	-4	-19	12(2)	10
(6) Technology							
(a) Heat-input control	+6H	+ 4	+ 1	+1	+12H	1	1
(b) Heat recovery	-2	+ 5	- 3	-3	- 3	6	2
(c) Heat house	+2	+ 8	- 1	-1	+ 8	3	3

Highest and lowest possible values for each category = ± 16, for each total (T) = ± 64.

* See footnote with Table 35, page 196.

Trial-Experience and Findings Summarized

The outcome of the trials can perhaps best be understood by looking at three areas: (1) technique, (2) findings, and (3) direction for future consideration and possible development. The proposed technique for the assessment has clearly shown to be workable, in that it was easily and readily handled by the four novice assessor groups. No matter what the ultimate utility of the assessment, it at least could be carried out. When the participants were given a bare-bones outline of the scheme and a very brief description of the alternatives, they showed no hesitancy in proceeding with the assessment. There were no questions before starting. The participants were sympathetic and interested, and displayed neither fear nor antagonism. Alles in Allem, the assessment principle which is a part of the scheme appears to have been easily understood and learned quickly. The time taken for the assessment was relatively short, in every case less than 30 minutes including reading the instructions. After the testing a number of questions were raised, and some comments were made as a reaction to having performed the task. None were negative.

In carrying out Trial Assessment No. 6, an attempt was made to determine whether a ranking (assessment) would correlate with the proposed technique or assessment scheme which, in the case of the reported trials, relies on a 5-point grading plan (see page 183 for details). Grading, of course, does imply some form of ranking. After having completed the assessment by grading the various alternatives with respect to categories P, E, F, and J, the assessors were asked to rank-order the alternatives separately, assigning 1, 2, 3 and so on, to each category. This approach was thought of as a different way to make the assessment. Only one of the participants completed the ranking in this manner, but was much dissatisfied with it. Others asked permission to simply rank the 14 alternatives (not by categories). After completing the task, several assessors complained about difficulties. They suggested that all that they could do with reasonable assurance was to rank best or worst, and perhaps one or two alternatives. The experience suggests that the grading technique of the proposed assessment scheme is materially superior to ranking from the standpoint of yield of information and ease of management.

Repeating Trial Assessment No. 3 (i.e., No. 4) was an uninhibited performance on the part of the assessors. No conscious attempts appeared to have been made to recall the earlier assessment, after a 2-month interval. Whether a similar situation prevailed for Trail Assessments No. 1 and No. 2 is not known, because the assessors were not kept under surveillance while doing the assessment.

Summarized data obtained through the trials are presented in Table 42. It should be emphasized that the data, other than the repeat pairs (No. 1 and No. 2, No. 3 and No. 4), are not comparable because of some changes in the instructions given to the assessors. These changes were made in an attempt to find ways to improve the process. Although these aggregations of assessment judgments can have only limited significance at the present state of development of the scheme, the findings do give certain indications. The application of technology was the preferred alternative for reducing energy consumption. Without trade-offs, this result can be expected as a natural outcome. This approach optimizes personal freedom in that the individual is permitted maximum choice in disposing of his income. He can so pay for technological features which permit him to

Table 42. Summary of Data.

Trial / Alternatives	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
(1) Do nothing	0	- 6	-12L	-20L	-19L	0
(2) Clothes line	+ 2	+11H(2)	-10	+ 1	+ 5	(-16L)
(a) no dryers						-14
(b) dryers off-peak						-13
(c) tax dryers						-20
(d) tax energy						-17
(3) Commercial	+18	+11H(2)	- 2	+ 1	+ 3	(- 3)
(a) pickup + deliver						+ 9
(b) take + fetch						-16
(4) Cut frequency	- 8L	- 7L	- 2	-4	+ 1	-19
(5) Disposables	- 8L	- 1	+ 3	+ 2	+12	(-13)
(a) same cost						-15
(b) lower cost						+ 7
(c) higher cost						-19
(6) Technology						
(a) heat-control	+15	+ 3	+12H	+11H	+23H	+12H
(b) heat recovery	+15	+ 5	+ 7	+ 4	+15	- 3
(c) heat house	+20H	+10	+11	+11H	+21	+ 8

H and L represent highest or lowest values for each assessment.

No. 2 was a repeat of No. 1

No. 4 was a repeat of No. 3(No. 3 was actually done by 16 assessors. Above data is an aggregation of only 9 assessments made by the same 9 assessors who did No. 4. Aggregate totals for No. 3 representing 16 assessors differ somewhat, but not significantly, from above. For details see Table 38. Trial Assessment No. 3, p. 199).

Figures in parentheses in Column No. 6 indicate averages of sub-alternatives for Alternatives (2), (3), and (5).

The above data are unweighted totals. The reader is again referred to the footnote accompanying Table 35, Trial Assessment No. 1, p. 196, which explains the limitations on any possible use of the data presented.

enjoy the use of a more energy-efficient dryer. The price tags attached to the Technical Alternatives (6) (a), (b) and (c) were realistic, and evidently not so big as to create a significant deterrent. That is, when dealing with such relatively small dollar amounts, the price-demand factor is relatively inelastic.

The Alternative (1), "do nothing," appears as the least attractive one, which elicits no surprise as being the "worst" alternative, as against the use of technology labeled as "best." Assessment of Alternatives (2) "clothes line", (3) "commercial", and (5) "disposables", became more definitive when several sub-alternatives were added. Making the clothes line mandatory by specifically excluding or limiting the use of clothes dryers was viewed very negatively. This reaction points up the need for evaluating other competing energy uses in (recall example: clothes drying vs. grain drying). Commercial drying was assessed as being much more attractive when connected with services. Economic effects became clear in Trial Assessment No. 6 in connection with disposables. Alternative (4), a reduction in laundering frequency, can only be construed as a material reduction in the level of living, i.e., a decline in the satisfaction of human wants.

To find out how precisely the individual assessors would duplicate their respective assessments, Assessment Trials No. 1 and No. 3 were repeated. Marked shifts in assessments can be observed between Trials No. 1 and No. 2, showing lesser emphasis on the (6) Technology Alternative and greater emphasis on Alternative (2), the "clothes line." Shifts among Alternatives (3) and (4) were of lower magnitude, yet significant. Correlation among Trials No. 3 and No. 4 turned out to be better. One explanation may be that this group had more detailed and specific instructions, as well as an illustration of the scheme through a simple example (see Appendix D, Exercise No. 1 in the instructions, p. 240). Negative emphasis on Alternative (1) increased in intensity, positive emphasis on Alternative (2) also increased in intensity; both shifts were in a direction which could be expected. Otherwise only slight changes are observed.

Some inconsistencies are difficult to explain, and need further investigation. What must be considered is that the inconsistencies encountered between No. 1 and No. 2, and between No. 3 and No. 4, respectively, may be attributed to a situation similar to the effect of pre-testing on post-test performance in learning, a somewhat controversial issue, well documented in the literature.[199] Performing one assessment builds experience which is likely to affect any succeeding assessment -- the learning process at work. Reflecting on the problem over time is bound to cause a change in how things are viewed. A body of data clarifies itself. This observation would suggest that the assessment scheme provide for repeat assessments in order to improve reliability.

The foregoing remarks concerned with learning point up an important finding, namely, that the proposed scheme appears to have substantial merit as a heuristic device for education and public enlightenment. The already-mentioned facility for a novice readily to understand the scheme lends support to the argument. If the assumption is correct, the scheme could be particularly useful in rationalizing energy utilization where the

(199) James Hartley, THE EFFECT OF PRE-TESTING ON POST-TEST PERFORMANCE, in International Science 2 (1973), pp. 193-214.

education process must constitute an important element in effecting better utilization of available energy resources. Looked at in this light, the potential value of the proposed scheme takes concrete form. The scheme is a manner of bookkeeping to identify and to order areas of possible trade-offs. It can point to undesirable consequences of actions, as related to other actions, that are of particular importance when employing technology. The scheme is explicit with respect to alternatives within the limitations imposed by its current state of development.

What becomes apparent as an outcome of the trials is that the device (1) permits looking at broader sets of criteria, and jogs orderly thinking about complex problems, (2) demonstrates a method for comparing existing and potential alternatives, and (3) promises to form a basis for reaching a consensus toward solutions. As an analytic device it goes at least one step beyond tacit or ignored factors. Subject to some further trials, it can perhaps even serve to predict the outcomes of alternative options, and as a consequence could affect changes in behavior.

A distinct lack of uniformity among individual assessments and also among categories can be observed. Such lack of uniformity is more pronounced in the F and J categories, as surely is to be expected. F and J are made up of intangible values, whereas P and E are made up mostly of tangible values. Inconsistencies tend to decrease as the assessor is given more information. These observations are of course only superficial. To make a determination of any precision would be an impossible task in view of the nature of the trials and their structuring. Random questions among the participants elicited the suggestion that it is imperative for the assessor to understand the problem in depth in order to achieve higher values of uniformity. It was suggested further that the rules for the assessments be made explicit. Further experimentation would be necessary to determine whether adoption of these suggestions would provide greater uniformity among assessors.

In addition to the above response, the trials prompted questions and comments touching upon the following areas:

(1) Weighting. Several participants felt that in order for the assessments to be useful, weighting was necessary.

(2) Components of categories. A clear listing of components was suggested, perhaps related to (1) above.

(3) Matrix - Trade-off balance. The format for the earlier trials contained a bottom line on the matrix asking for a trade-off balance. The intent was for the assessor to arrive at a summary assessment for each category. Some of the assessors questioned this process as a meaningless exercise. In contrast, the matrix itself was regarded as useful.

(4) Definition of the given alternatives was considered insufficient. For example, it was suggested that disposables be explained as clothing, bedlinens, towels, and so on; that relative economic costs be stated; and further, that some information be provided to tell whether disposable items were as attractive as conventional ones, and finally whether the items were made from natural or synthetic (presumably fossil-base) materials.

(5) A time horizon was strongly demanded. It was argued that a short-run plus might be a long-run minus or vice versa, requiring assessment and evaluation in two or more time spans.

(6) The use of trend-direction rather than absolute values as used in the 5-point system, was suggested for trial. Under this suggestion the

trend direction is to be qualified by an indication of trend velocity or the like.

(7) A discussion of pros and cons for each alternative prior to making an assessment was asked for. For example: on the one hand, dryers provide convenience, flexibility, save time and effort, permit choice of time for doing the job, reduce need for ironing, and so on; on the other hand, dryers consume energy and other resources to produce and keep in operation, take space, impose economic costs, create environmental problems, and so on.

(8) Primary vs. higher-order impacts are in need of definition. There was agreement that the scheme should limit itself to first-order impacts at the present scale of study, and that higher-order impacts be identified and listed separately.

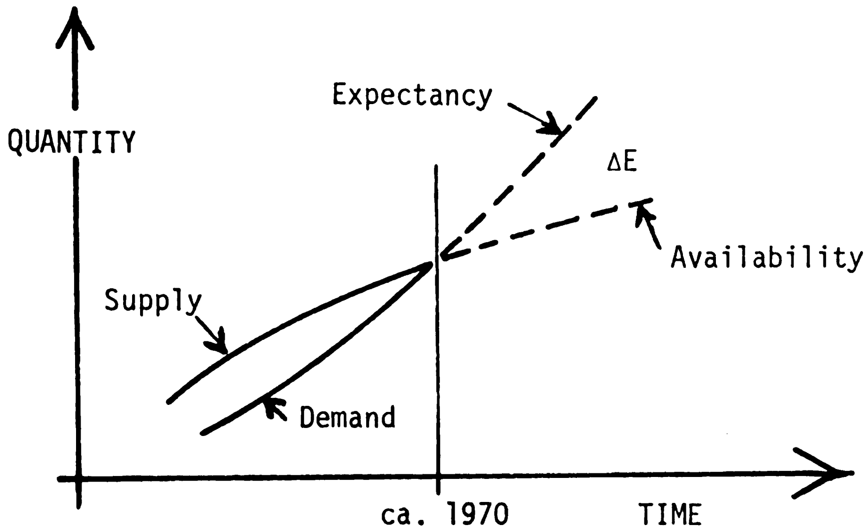
The comment receiving most emphasis was number (4). Hidden under remarks concerning economic costs are, no doubt, questions concerning energy costs (in terms of energy resources). There is a relationship between the two, but they cannot be equated. Offhand, for purposes of making assessments, it would appear wise to maintain a distinction, if the argument for better utilization efficiency has any merit. This subject is also a candidate for further study.

SUMMARY

Two areas have been covered by this study. One area is a general overview of the energy situation in the United States together with an examination of the wide-ranging spectrum of direct and indirect energy utilization by households. The other area develops a proposed management scheme potentially useful for the identification and ordering of alternatives with respect to factors which contribute to the quality of life. Additionally, the scheme could be used for purposes of education.

The first part of the work calls attention to salient aspects of energy-demand, -supply, and -price, as well as the outlook therefor. Here the fact was sought out that price implications have in the past been given only meager consideration in their effect on supply and demand. The notion of "conservation" as it relates to the study was discussed and, it is hoped, clarified. Some of the social forces which underlie the growth of energy consumption have been touched upon. In sum, the review indicates that long-term demand and supply trend-lines have crossed circa 1970, and that the price of energy can be expected to rise rapidly in relative as well as in absolute terms. The shortfall is referred to by some as the "energy gap," or "energy delta (ΔE)." ΔE in this case is the negative differential between potential demand or expectancy and potential supply or availability as it has developed since about 1970.

These relationships are graphically described in the accompanying figure which is reproduced from the body of the text.



ΔE represents real but unfulfilled desires on the part of members of society. Over time, the expectancy of consumers and/or the availability of energy forms have to adjust, but the cost in social cohesion may be excessive, indeed even disastrous. To balance expectancy and availability over time, three forces in combination can be counted upon: (1) market, (2) public policy, and (3) technology. The effectiveness of this trio in creating and retaining social cohesion will depend on the understanding of the people and on the level of technical knowledge.

For peacetime, the problem of large-scale inability of the system to provide for the availability of important physical resources to reasonably satisfy expectancy is relatively new. The problem consequently lacks a base of understanding and information with respect to effective and equitable remedies. Suitable tools for the management of the task have not yet been developed. When energy resources were abundantly available, need for planning for the contingency -- predicted by some as early as two decades ago -- was not given a high enough societal priority. The substantial number of demand projections made by various agencies largely ignored price as a factor.

The energy problem is far-reaching and complex. To accomplish anything at all, this study had to be limited to one specific area. The major options which society can resort to for reconciling supply of and demand for energy are: (1) finding new energy resources not now known, (2) expanding upon present sources of supply, (3) improving conversion efficiencies, (4) unilaterally reducing demand via social measures (reducing the standard of living), and (5) bettering utilization efficiencies of "end-uses." We concentrate on option (5), which has appeal because its effects could be realized relatively soon, its economic and social costs could be relatively small, its effects on the environment could be only beneficial, its effects on the quality of life need not be detrimental, and finally, it embodies greater certainty of delivery.

In dealing with option (5), near exclusive emphasis was placed on the residential or household sector. It is in this utilization sector, where many, if not most, of the decisions are made which not only control the demand originating within that sector (about 1/5 of the total United States demand), but also influence to various degrees the demand originating from the other sectors, that is, Industry (including Agriculture), Commerce, Transportation, and Energy Supply. The decisions which are made by members of family units in the form of social choice appear to be the overriding control. Yet, it is within the family units where such decisions are at present least amenable to management which effectively rationalizes available resources and their utilization.

The major thrust of the study was therefore devoted to the multitudes of energy utilization by family units. Information on uses and use-practices was assembled to form a data base, necessary for the development of the management scheme proposed in the second part of the work. The broad aspects of energy utilization in the household: residential environment and amenities, home equipment, and transportation peripheral to the household are described, at the same time pointing to possibilities for efficiency-improvement. A substantial section was devoted to the thermal-comfort phenomenon, primarily because almost 30% of the total energy consumption in the United States goes for satisfying the human wants with respect to thermal comfort. In sum, this part described how energy is utilized by family units in the United States.

The second part of the present work is more specifically concerned with the decisions made by family units with respect to energy resources and their utilization. An attempt is made to rationalize these decisions by means of improved management methods. The search for such a method resulted in an examination of the technology-assessment principle. Extensively modified for application at micro-level, the concept was enlisted as a basis for the development of a scheme simple enough for manipulation by novice assessors.

Rather than undertaking the most complex measurement against yet unformulated social goals, assessment is done in a comparative manner by using a simple "better-off" or "worse-off" arrangement, analogous to what is occurring in the natural selection processes. The scheme is proposed as an aid to the decision-maker enhancing his ability to make more rational choices among alternatives. Depending on the nature of the energy-use alternatives, a certain degree of expertise is required to choose and define appropriate alternatives.

The scheme proposed for carrying out micro-assessments was tested by engaging novice assessor-groups in making certain trial assessments. The vehicle employed is a selected number of alternatives for domestic clothes drying. The test disclosed that the highest-order preference was the use of technology to increase energy utilization efficiency the dryers, an understandable response. The lowest-order preference among the options was letting market forces handle the situation, again an understandable response.

The micro-assessment attempted by means of the trials is of course only a primitive first step toward our ultimate goal, namely to devise methods for aiding decision-makers to choose among alternative technical strategies designed to improve the quality of life. The chief virtue of the attempt is that it demonstrates the willingness and the ability of members of the society to try to assess the impacts of alternative strategies taking into account what is intended to be a complete set of societal goal categories. Thus the first steps have been taken toward rationalizing choice with respect to objectives that are often held to be supra-rational. The chief shortcoming of the attempt is not the inadequacy of the assessors or of the exposition presented to them -- these matters can be studied and surely improved. The basic deficiency is that although all the human-want categories (P, E, F, J) have been considered, the constraint of limited resources (R) has not properly been taken into account. For instance, it has been assumed that any energy resources demanded by consumers for the drying of household washables will be provided; the assessment has ignored possible alternative demands for perhaps the same energy resources for different purposes, say for grain drying. There is, to be sure, an implicit relation through the cost of the energy consumed, but there is no display of the alternative usages forgone.

If the human intellect were more powerful, these usages could be visualized and taken into account directly. Since this is not the case, we shall instead attempt to make this reckoning by a hierarchy of assessments, in a kind of dynamic programming.

Let us suppose then that we have carried out several sets of micro-assessments of a large number of topics. We shall have at hand a preferential ordering of alternatives for each topic. These sets of orderings become the subject of an assessment at the next higher level; let us call this assessment a mini-assessment. In this higher-order process, some effect of the constraint imposed by limited resources will be implicit. For in simultaneously considering the several topics of the mini-assessment, the competition for resources will be evident. In the simplest case, we should have to consider only the most preferred alternative in each micro-assessment; but it may turn out that the drain on resources in selecting the optimal or preferred choice in a given micro-assessment precludes selecting the optimal choice from one or more of the other topics. Hence various groupings of choices among the alternatives from the topics will have to be considered. In principle, all combinations should be examined. This procedure may prove impractical; if it does, one may have to resort to various tricks, as in dynamic programming. For a beginning, let us hope a first approximation may suffice.

The mini-assessments themselves may still be too limited; in that event one may have to resort to a still higher level of assessment, we will call super-assessment, wherein a wider universe of topics is covered; and so on, until perhaps at still higher levels the ideal of a master-assessment is reached. In another way of speaking, our micro-assessments achieve a sub-optimization. The hazards of such processes are well known.

But sub-optimizations themselves are at least capable of being carried out, and if they are fed into subsequent sub-optimizations at successively higher levels with sufficient caution, they promise to be a practical means of elucidating the ultimate consequences of selected alternatives.

In its essence, the scheme consists of a method for evaluating basic human-wants categories (and their components) in terms of their role in determining outcomes of action (or inaction) designed to maximize the quality of life as signaled by a satisfaction index. It is agreed that any such categories would have to be suitably weighted in combining them into a meaningful composite which has the capability to describe a state of the quality of life; in our special case, it relates to people's using -- or not using -- energy resources to that end. Such weighting has been side-stepped in this study so as to avoid undue complexity at this initial stage of development.

The usefulness of the scheme -- if it is developed further, particularly in the area of factor-weighting and rules -- could be far-reaching. Improvement in "end-use efficiences" of energy consumption in the residential sector could be a first and significant contribution. At the least, benefits are possible from using the proposed scheme as a device for education and public enlightenment concerning the order in which available options are preferred by consumers of energy resources (or the order of any other consumer choices). The scheme is also seen as a device for supporting decisions made by engineers, administrators, and politicians concerned with exploitation or allocation of resources via technology. Interested readers are invited to support or participate in its further development as a new method leading to more rational decisions concerning the utilization efficiency of available resources.

In his WASHINGTON MEMO, Michigan Senator Philip A. Hart, suggests among other matters that " . . . Congress should establish a broadly representative joint committee on energy in which all of the competing claims could be weighed side by side. Today, concern for the energy dilemma is split among countless committees and sub-committees."(200)

No known methodology exists which could effectively do what has been underlined in the above quotation. The micro-, mini-, super- and master-assessment scheme proposed as an outcome of this study is suggested as a tool to help the process toward Senator Hart's goal, as well as similar goals in matters of high importance and significance throughout the social structure. It is argued that in the least, utilization of the proposed scheme in any stage of its development is bound to lead to a better understanding of a technology-related problem, if not a better solution.

(200) Senator Philip A. Hart, in his WASHINGTON MEMO, November 1973, p. 4 (Emphasis supplied).

REFERENCES

BOOKS

Kenneth J. Arrow, SOCIAL CHOICE AND INDIVIDUAL VALUES, John Wiley & Sons, New York, 1963 (1951).

Madalyn Avery, HOUSEHOLD PHYSICS, A Textbook For College Students In Home Economics, MacMillan, New York, 1946 (first published in 1938).

Raleigh Barlowe, LAND RESOURCE ECONOMICS, The Economy of Real Property, Prentice Hall, Englewood Cliffs, N. J., 1972.

J. J. Barton, ESTIMATING THE HEAT REQUIREMENTS FOR DOMESTIC BUILDINGS, Butterworth & Co., London, 1969.

Elizabeth Beveridge, CHOOSING AND USING HOME EQUIPMENT, Iowa State University Press, Ames, Iowa, 1971 (first published in 1952).

Neville S. Billington, BUILDING PHYSICS: HEAT, Pergamon Press, Oxford, 1967.

James M. Buchanan and Gordon Tullock, THE CALCULUS OF CONSENT, Logical Foundations of Constitutional Democracy, University of Michigan Press, Ann Arbor, 1962.

Florence Ehrenkranz and Lydia Inman, EQUIPMENT IN THE HOME, Harper Brothers, New York, 1958.

Richard T. Ely _et al_., FOUNDATION OF NATIONAL PROSPERITY, MacMillan Co., New York, 1917.

P. O. Fanger, THERMAL COMFORT, Analysis and Applications in Environmental Engineering, Danish Technical Press, Copenhagen, 1970.

Sigurd Grava, URBAN PLANNING ASPECTS OF WATER POLLUTION CONTROL, New York, Columbia University Press, 1967.

R. G. Hopkins _et al_., DAYLIGHTING, Wm. Heinemann Ltd, London 1966.

R. J. Hopkinson and J. D. Kay, THE LIGHTING OF BUILDINGS, Praeger, New York, 1969.

Betty Jane Johnston, EQUIPMENT FOR MODERN LIVING, MacMillan & Co., New York, 1965.

Leslie Larson, LIGHTING AND ITS DESIGN, Whitney Library of Design, New York, 1964.

Yves LeGrand, LIGHT, COLOUR AND VISION, Second Edition, Chapman and Hall, Ltd, London 1968 (1948).

M. Luckiesh, ARTIFICIAL SUNLIGHT, Van Nostrand, New York, 1930.

Richard L. Meier, SCIENCE AND ECONOMIC DEVELOPMENT: New Patterns of Living, MIT Press, Cambridge, Mass., 1956.

H. L. Newburgh, ed., PHYSIOLOGY OF HEAT REGULATION AND THE SCIENCE OF COMFORT, Saunders, Philadelphia, 1949.

Joseph B. Oliviere, HOW TO DESIGN HEATING-COOLING COMFORT SYSTEMS, Business News Publishing Company, Birmingham, Mich. (1970).

Louise J. Peet, with co-authors, HOUSEHOLD EQUIPMENT, 6th Edition, John Wiley & Sons, New York 1970 (first published in 1934).

Louise J. Peet, SCIENCE FUNDAMENTALS: A background in Household Equipment, Iowa State University Press, Ames, Iowa, 1972.

M. D. W. Pritchard, Environmental Physics: LIGHTING, American Elsevier Publishing Co., Inc., 1969.

Mary Ellen Roach, DRESS, ADORNMENT AND THE SOCIAL ORDER, Wiley, New York, 1965.

Tyler Stewart Rogers, DESIGN OF INSULATED BUILDINGS FOR VARIOUS CLIMATES, F. W. Dodge Corp., New York, 1951.

Tyler Stewart Rogers, THERMAL DESIGN OF BUILDINGS, John Wiley & Sons, New York, 1964.

Charles Singer et al., eds., A HISTORY OF TECHNOLOGY, Vol. IV, The Industrial Revolution, ca. 1750 to ca. 1850, Clarendon Press, Oxford, 1967 (1958).

Philip Sporn, TECHNOLOGY, ENGINEERING AND ECONOMICS, MIT Press, Cambridge, 1969.

Philip Sporn, VISTAS IN ELECTRIC POWER, 3 Volumes, Pergamon Press, Oxford, 1968.

W. R. Stevens, PRINCIPLES OF LIGHTING, Constable & Co., Ltd, London, 1951.

Helen J. Van Zante, HOUSEHOLD EQUIPMENT PRINCIPLES, Prentice Hall, Englewood CLiffs, New Jersey, 1964.

Leslie D. Wilson et al., SOCIAL INDICATORS AND SOCIETAL MONITORING, An Annotated Bibliography, Jossey-Bass, Inc., San Francisco, 1972.

Jim Wright, THE COMING WATER FAMINE, Coward-McCann, New York, 1966.

HANDBOOKS

ASHREA HANDBOOK OF FUNDAMENTALS, American Society of Heating, Refrigerating and Airconditioning Engineers, New York, 1968 (1967).

ASHRAE HANDBOOK OF FUNDAMENTALS, American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York. 1972.

ASHRAE GUIDE AND DATA BOOK, American Society of Heating, Refrigerating and Airconditioning Engineers, New York, 1968.

GAS ENGINEERS HANDBOOK, The Industrial Press, New York, 1965.

John E. Kaufman, IES LIGHTING HANDBOOK, 4th Ed., Illuminating Engineering Society, New York, 1966.

John E. Kaufman, ed., IES LIGHTING HANDBOOK, The Standard Lighting Guide, 5th Ed., Illuminating Engineering Society, New York, 1972.

GAS FACTS 1971, American Gas Association, New York.

U.S. GOVERNMENT REPORTS AND PUBLICATIONS

, Annual Reports, Immigration and Naturalization Service, U.S. Department of Justice, 1971.

, 1950 Housing Census, Report H - A1, U.S. Summary.

, 1970 Census of Housing, U.S. Summary, HC (1) - B1.

, U.S. Census 1970, HC (1) - B1 Summary.

, U.S.C. Congressional and Administrative News, 92nd Congress, First Session, No. 5, (June 4, 1971).

, CONSERVATION OF ENERGY, Committee on Interior and Insular Affairs, U.S. Senate, A National Fuels and Energy Policy Study, SR 45. Serial 92-18, Committee Print, USGPO, Washington 1972.

, CONSIDERATIONS IN THE FORMULATION OF A NATIONAL ENERGY POLICY, Committee on Interior and Insular Affairs, U.S. Senate, SR 45, Series 92-4, USGPO, Washington, 1971.

, THE CONSUMER PRICE INDEX for January 1973, U.S. City Average, Bureau of Labor Statistics, U.S. Department of Labor, March 1973.

, Current Industrial Reports, U.S. Department of Commerce, AIRCONDITIONING AND REFRIGERATION EQUIPMENT, Series MA-35 M.

, ECONOMIC REPORT TO THE PRESIDENT, Council of Economic Advisors, Jan. 1973.

, ELECTRICAL ENERGY AND ITS ENVIRONMENTAL IMPACT, Progess Report, December 31, 1972, Oak Ridge National Laboratory, ORNL - NSF - EP - 40, Oak Ridge, Tennessee, March 1973.

Eric Hirst, ENERGY CONSUMPTION FOR TRANSPORTATION IN THE UNITED STATES, Oak Ridge National Laboratories, ORNL - NSF - EP - 15, Oak Ridge, Tennessee, 1972.

, ENERGY "DEMAND" STUDIES, An Analysis and Appraisal, Committee on Interior and Insular Affairs, U.S. House of Representatives, USGPO, Washington, Sept. 1972.

Robert F. Mueller, ENERGY IN THE ENVIRONMENT AND THE SECOND LAW OF THERMODYNAMICS, National Aeronautics and Space Administration, Goddard Space Flight Center, X 644-72-130, Greenbelt, Md., May 1972.

, ENERGY RESEARCH NEEDS, Consumption, Production, Technology, Environmental Effects, Policy Issues. A report to the National Science Foundation by Resources For The Future, Inc. and MIT Environmental Laboratories, Oct. 1971, NITS PB-207 516.

, HANDBOOK OF LABOR STATISTICS 1971, U.S. Dept. of Labor, Bureau of Labor Statistics.

, HYDROELECTRIC POWER RESOURCES OF THE U.S., Developed and Undeveloped, Federal Power Commission, Jan. 1, 1968.

H. R. Payne <u>et al</u>., USE OF STEAM-ELECTRIC POWER PLANTS TO PROVIDE THERMAL ENERGY TO URBAN AREAS, Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL - HUD - 14, January 1971.

, THE 1970 NATIONAL POWER SURVEY, Part IV, p. IV-1-71, Federal Power Commission, USGPO, Washington, 1971.

Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Automobile Occupancy, U.S. Department of Transportation, Federal Highway Administration, Report No. 1, April 1972.

Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Annual Miles of Automobile Travel, U.S. Department of Transportation, Federal Highway Administration, Report No. 2, April 1972.

Harry E. Strate, NATIONWIDE PERSONAL TRANSPORTATION STUDY, Seasonal Variations of Automobile Trips and Travel, U.S. Department of Transportation, Federal Highway Administration, Report No. 3, April 1972.

, NATURAL GAS POLICY ISSUES AND OPTIONS, A STAFF ANALYSIS, Committee on Interior and Insular Affairs, U.S. Senate, S.R. 45, Serial 93 - 20, USGPO, Washington 1973.

, PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES, Office of Science and Technology, Executive Office of the President, done by Stanford Research Institute, USGPO, Washington, 1972.

, From A Policy Proposal, CONSERVATION OF NATURAL RESOURCES . . . THE ELECTRIC ENERGY CONVERSION AND PRODUCTION PROCESSES, Docket No. R-454, Federal Power Commission, Washington, Sept. 14, 1972. (Order No. 495 issued Nov. 13, 1973 in modified form).

, PROCEDURES FOR A VOLUNTARY LABELING PROGRAM FOR HOUSEHOLD APPLIANCES AND EQUIPMENT TO EFFECT ENERGY CONSERVATION, U.S. Department of Commerce, Office of the Secretary, Title 15, Sub-title A, Part 9, Federal Register, Vol. 38, No. 206, October 26, 1973.

, RESIDENTIAL ALTERATIONS AND REPAIRS: Expenditure For Additions, Alterations, Maintenance, Repairs And Replacements, Series C-50, Parts 1 and 2, various issues, U.S. Department of Commerce, Bureau of the Census, Washington, various dates.

, A REVIEW OF ENERGY POLICY ACTIVITIES OF THE 92nd CONGRESS, Committee on Interior and Insular Affairs, U.S. Senate, SR 45, A National Fuels And Energy Policy Study, Serial 93-1, USGPO, Washington, 1973.

, SELECTED READINGS ON ECONOMIC GROWTH IN RELATION TO POPULATION INCREASE, NATURAL RESOURCES AVAILABILITY, ENVIRONMENTAL CONTROL AND ENERGY NEEDS, Committee on Interior and Insular Affairs, U.S. Senate, SR 45, Series 92-3, USGPO, Washington, 1971.

Genevieve J. Knezo, SOCIAL SCIENCE POLICIES: An Annotated List of Recent Literature, Congressional Research Service, Library of Congress, Washington, July 8, 1971 and Addendum dated August 4, 1971.

F. P. Linaweaver, Jr. et al., A STUDY OF RESIDENTIAL WATER USE, Federal Housing Administration, Washington, D. C., USGPO 1967.

, SURVEY OF ENERGY CONSUMPTION PROJECTIONS, Committee on Interior and Insular Affairs, U.S. Senate, S.R. 45, Ser. 92-19, USGPO, Washington, 1972.

J. C. Moyers, THE VALUE OF THERMAL INSULATION IN RESIDENTIAL CONSTRUCTION: Economics and the Conservation of Energy, Oak Ridge National Laboratory Report, ORNL-NSF-EP-9, Dec. 1971.

, CITY WORKERS FAMILY BUDGET FOR A MODERATE LIVING STANDARD, Autumn 1966, Bulletin 1570-1, U.S. Dept. of Labor, Bureau of Statistics.

L. L. Liston and C. L. Gauthier, COST OF OPERATING AN AUTOMOBILE, Suburban-Based Operation, U.S. Department of Transportation, Federal Highway Administration, April 1972.

STATISTICAL ABSTRACTS OF THE UNITED STATES, various years.

HISTORICAL ABSTRACT OF THE UNITED STATES, Historical Times to 1957.

PERIODICALS AND NEWSPAPERS

President Richard M. Nixon, in an Energy Message to the United States Congress, June 29, 1973 (as reported in the Detroit Free Press, June 30, 1973).

AGA Monthly, February 1973, American Gas Association, New York.

Richard G. Stein, SPOTLIGHT ON ENERGY CRISIS: How Architecture Can Help, AIA Journal, Vol. 57, No. 6, June 1972.

T. E. MacNall and R. G. Nevins, A CRITIQUE OF ASHRAE COMFORT STANDARD 55-66, ASHRAE Journal, Vol. 13, No. 1, Jan. 1971.

Ralph G. Nevins and A. Pharo Gagge, THE NEW ASHRAE COMFORT CHART, ASHRAE Journal, Vol. 14, No. 5, May 1972.

Eugene R. Ambrose and J. L. Reynolds, AN INVESTIGATION OF ELECTRIC SPACE CONDITIONING FOR MOBILE HOMES, ASHRAE Journal, Vol. 14 No. 11, NOv. 1972.

Roderick R. Kirkwood, President, American Society of Heating, Refrigerating, & Air-conditioning Engineers, in ASHRAE Journal, 15, No. 6, June 1973.

Lorne W. Nelson, REDUCING FUEL CONSUMPTION WITH NIGHT SET-BACK, ASHRAE Journal, Vol. 15 No. 8, August 1973.

F. H. Rohles and R. G. Nevins, THE NATURE OF THERMAL COMFORT FOR SEDENTARY MAN. A. P. Gagge, J. A. J. Stolwigk, and Y. Nishi, AN EFFECTIVE TEMPERATURE SCALE BASED ON A SIMPLE MODEL OF HUMAN PHYSIOLOGICAL REGULATORY RESPONSE, ASHRAE Transactions, Vol. 77, part 1, 1971.

Jerome B. Wolff, PEAK DEMAND IN RESIDENTIAL AREAS, in Journal of American Water Works Association LIII, October 1961.

Edgar S. Cheany and James A. Eibling, REDUCING THE CONSUMPTION OF ENERGY, in Battelle Research Outlook, Vol. 4, No. 1, 1972.

, SWIMMING POOLS, Changing Times, Vol. 27, No. 4, April 1973.

, FREEZERS, Consumer Reports, April 1946.

, WASHING MACHINES, Consumer Reports, October 1947.

, REFRIGERATORS, Consumer Reports, June 1949.

, DISHWASHERS, Consumer Reports, November 1971.

, COLOR TELEVISION, Consumer Reports, Vol. 38, No. 1, Jan. 1973.

, REFRIGERATORS, Consumers Union Reports, Vol. 1, No. 3 July 1936.

, WASHERS, Consumers Union Reports, Vol. 2, No. 4, May 1937.

, HEATING EQUIPMENT, Consumers Union Reports, Vol. 2, No. 8, October 1937.

, 1973: THE YEAR THE LITTLE CAR SHOWED DETROIT HOW BIG IT IS, Detroit Free Press, December 23, 1973.

, CENSUS SHOWS LATEST FUEL PREFERENCE DATA, Electrical World, January 1, 1973.

Christopher T. Rand, THE ARABIAN FANTASY, HARPER'S, January 1974.

Milton D. Rubin, WASTE NOT, WANT NOT, IEEE Spectrum, Vol. 10, No. 1, January 1973.

, RECOMMENDED PRACTICE FOR RESIDENCE LIGHTING, prepared by the Committee on Residence Lighting of the IES, Illuminating Engineering, August 1953.

John O'Grady, Vice-President Fieldcrest Corp. and Paul Shook, General Manager of Consumer Products, CASCO Division, Sunbeam Corp., Investors Reader, November 1973.

James Hartley, THE EFFECT OF PRE-TESTING ON POST-TEST PERFORMANCE, in International Science 2, 1973.

Berlon C. Cooper, A STATISTICAL LOOK AT THE FUTURE OF LIGHTING, Lighting Design & Application, Vol. 1, No. 1, July 1971.

, ENERGY CONSUMPTION AND DESIGN PRACTICES, Lighting Design and Application Forum, in Lighting Design and Application, Vol. 2, No. 8, August 1972.

1973 Statistical Marketing Report, Merchandising Week, Feb. 26, 1973.

Paul A. Samuelson, From GNP to NEW, Newsweek, April 9, 1973.

Peter Chapman, NO OVERDRAFTS IN THE ENERGY ECONOMY, New Scientist, May 17, 1973.

Robert Reinhold, MEW or NEW, How Does The Economy Grow? in New York Times, Sunday, July 29, 1973.

John W. Wilson, RESIDENTIAL DEMAND FOR ELECTRICITY in Quarterly Review of Economics and Business, Vol. 2, No. 1, Spring 1971, University of Illinois, Champaign.

, THE ENERGY CRISIS: Time for Action, TIME Magazine, May 7, 1973.

, Study by the Chase Manhattan Bank, concerning petroleum resources quoted in U.S. News and World Reports, February 19, 1973.

, Wall Street Journal, March 20, 1972, citing reports from AGA, the API and the Canadian Petroleum Association.

M. A. Adelman, HOW REAL IS THE WORLD OIL SHORTAGE? Wall Street Journal, February 9, 1973.

, article concerning MGIC Investment Corp., Wall Street Journal, March 14, 1973.

MISCELLANEOUS

, BECHTEL BRIEFS, Vol. 28, No. 1, Jan. 1973, Bechtel Corp., San Francisco.

R. D. Doctor, THE GROWING DEMAND FOR ENERGY, Rand Corp., P-4759, Santa Monica, Cal., Jan. 1972.

R. D. Doctor *et al*., CALIFORNIA'S ELECTRICITY QUANDARY: III. SLOWING THE GROWTH RATE, prepared for the California State Assembly with Support of the NSF, R-1116-NSF/CSA, Rand Corp., Santa Monica, 1972.

Robert T. Dorsey, in a letter published in LIGHTING, DESIGN AND APPLICATION, Vol. 3, No. 3, March 1973.

Anne E. Field, A STUDY OF WATER CONSUMPTION PRACTICES IN HOUSEHOLDS, Unpublished doctoral dissertation, Michigan State University, East Lansing, Michigan, 1973.

Senator Philip A. Hart, in his WASHINGTON MEMO, November 1973.

Lyndon B. Johnson, Speech at Commencement Exercises, University of Michigan, Ann Arbor, May 22, 1964.

From a Talk by Reginald H. Jones, Chairman and Chief Executive Officer, General Electric Co., Cincinnati, Jan. 17, 1973.

, Wall Street Journal, March 22, 1973 quoting William G. Kuhns, President of General Public Utilities Corp.

John G. McLean, Industrial Oil Co. is a newspaper advertisement ENERGY AND AMERICA, Wall Street Journal, Nov. 30, 1972.

Conversation with man in charge of the labeling program, Melvin R. Meyerson, National Bureau of Standards, November 8, 1973.

Governor William G. Milliken, Special Message to the Michigan Legislature on Energy, Lansing, November 26, 1972.

M. Jack Snyder and Cecil Chilton, PLANNING FOR UNCERTAINTIES: Energy In The Years 1975-2000, in Battelle Research Outlook, Vol. 4, No. 1, 1972, Battelle Memorial Institute, Columbus.

Unpublished remarks by Mr. Stein under the heading of The Optimization of Lighting Energy, at an IES Symposium in New York, November 28, 1972.

Genevieve K. Taylor, November 15, 1962, unpublished talk before the 40th Annual Agricultural Outlook Conference, reporting on a study done at the Equipment Laboratory, U.S. Department of Agriculture, Clothing and Housing Research Division, Beltsville, Md.

Thomas McVeigh, SOCIAL INDICATORS: A Bibliography, Council of Planning Librarians, No. 215, Monticello, Ill., Sept. 1971.

, LIGHTING, Encyclopedia Britannica, 1972, Vol. 14.

, ENERGY CONSUMPTION AND GNP in the U.S., An Examination Of A Recent Change In Relationships, National Economic Research Associates, Inc., New York/Washington, 1971.

GAAT minutes, September 1972.

Final Report, Technology-Assessment Component of the Comprehensive Planning Division, Executive Office of the Governor, Lansing, Michigan, December 1972.

Environmental Research and Technology, Inc., Lexington, Mass.

National Research Associates, Washington, D. C.

Information from the Superintendents of the Water & Light and the Sewage Disposal Plants, Lansing, Michigan, May 1973.

Booklet: FUEL CONSERVATION MADE EASY, How To Save Fuel And Keep Warm, distributed by General Electric Co., Consumer Institute Bridgeport, Conn., no date given.

Booklet: HOME HEATING, Better Buymanship - Use And Care, published by Household Finance Corp., Chicago, 1947.

Letter from Gerald W. Foster, Home Building Products Division Owens-Corning Fiberglass Corp., Toledo, March 7, 1973.

Letter from Henry Omson, Director, Standards Division, MHMA, Chantilly, Va., dated April 13, 1973.

Letter dated February 23, 1973 from Joel Popkin, Assistant Commissioner, PRICES AND LIVING CONDITIONS, U. S. Dept. of Labor, Bureau of Labor Statistics.

Conversation with Jeanette Lee, retired Dean, College of Human Ecology, Formerly College of Home Economics, Michigan State University, East Lansing, Michigan, Jan. 19, 1973.

Conversation with Dr. Robert Summitt, Chairman, Department of Metallurgy, Mechanics and Materials Science, Engineering College, Michigan State University, East Lansing. Dr. Summitt is an expert on light and color, and is currently developing materials for a course in lighting oriented to undergraduate students in Human Ecology and Engineering.

Study: ELECTRIC SPACE CONDITIONING IN NEW YORK STATE, Department of Public Service, Albany, New York 1971.

APPENDIX A

APPENDIX A: ENERGY CONSUMPTION IN THE UNITED STATES BY END USE 1960-1968.

Sector and End Use	Consumption* 1960	1968	Annual Rate of Growth	Percent of National Total 1960	1968
Residential					
Space Heating	4,848	6,675	4.1%/year	11.3%	11.0%
Water Heating	1,159	1,736	5.2	2.7	2.9
Cooking	556	637	1.7	1.3	1.1
Clothes Drying	93	208	10.6	0.2	0.3
Refrigeration	369	692	8.2	0.9	1.1
Airconditioning	134	427	15.6	0.3	0.7
Other	809	1,241	5.5	1.9	2.1
Total	7,968	11,616	4.8	18.6	19.2
Commercial					
Space Heating	3,111	4,182	3.8	7.2	6.9
Water Heating	544	653	2.3	1.3	1.1
Cooking	98	139	4.5	0.2	0.2
Refrigeration	534	670	2.9	1.2	1.1
Airconditioning	576	1,113	8.6	1.3	1.8
Feedstock	734	984	3.7	1.7	1.6
Other	145	1,025	28.0	0.3	1.7
Total	5,742	8,766	5.4	13.2	14.4
Industrial					
Process steam	7,646	10,132	3.6	17.8	16.7
Electric drive	3,170	4,794	5.3	7.4	7.9
Electrolytic processes	486	705	4.8	1.1	1.2
Direct heat	5,550	6,929	2.8	12.9	11.5
Feed stock	1,370	2,202	6.1	3.2	3.6
Other	118	198	6.7	0.3	0.3
Total	18,340	24,960	3.9	42.7	41.2
Transportation					
Fuel	10,873	15,038	4.1	25.2	24.9
Raw materials	141	146	0.4	0.3	0.3
Total	11,014	15,184	4.1	25.5	25.2
National total	43,064	60,526	4.3	100.0%	100.0%

* Trillions of Btu

Note: Electric utility consumption has been allocated to each end use.

Source: , PATTERNS OF ENERGY CONSUMPTION IN THE UNITED STATES, Office of Science and Technology, Executive Office of The President, USGPO, Washington, January 1972, p. 6. (Stanford Research Institute, using Bureau of Mines and other sources.)

APPENDIX B

APPENDIX B

HUMAN-WANTS CATEGORIES BREAKDOWN

Set I

P Economic production, input and output as measured by the National Income and Product Accounting System (GNP), physical aspects only of

Food
Clothing
Shelter
Communications (technology)
Health (medical care)
Domestic security (fire, police, and other means)
Cultural activities (religion, education, the arts and sciences)
International (military and diplomatic) includes net export of goods and services

Capital investment and transportation of goods and services in support of the above is included in the components.

E As a result of action under P, degree of

Exploitation, manipulation or depletion of natural or earth resources
Resulting quality of (1) air, (2) water, (3) land and soil, (4) noise, and (5) visual aspects.

Reversible or irreversible effects

F Is all about the individual self who benefits from and/or pays the cost of actions under P and impacts under E. F deals with the amount of control the individual or family may be subjected to, by other than natural events.

Least social control, formal or informal
Wide choice among, and access to, goods and services produced under P
Work where wanted for individual or family
Live where wanted for individual or family
Play where wanted for individual or family
Maximum communications opportunities (personal part not under P)
Control over disposal of income and investment
Optimum opportunities for self-development, physical, mental and spiritual

J Is all about collective action, society and the social structure including social values, positive or negative, as derived from the social structure. Preventive and distributive justice is a part of this

Dimensions the conditions under which the individual has decided that the benefits of collective action outweigh the costs, therefore, collective action is preferred over individual action for purposes of attaining higher levels of living.

J dimensions the breadth of access to, and the equity of distribution, of the ingredients of I listed below:

Wealth and income derived from P activities
(a) disposable income
(b) investment for future income
Consumption of goods and services (produced under P)
Employment opportunities in P activities
Living amenities (housing, for example)
Cost attached to J (taxes, for example)
Cultural opportunities, religion, education, the arts and sciences (includes recreational)
Social opportunities (includes public affairs and political participation)
Health services
Both technology and energy are involved in all of the above as

resources.

Set II*

P Provision of material goods and physical services to individuals

Components

Sustenance -- food and drink
Shelter against the elements
Clothing
Security against living creatures (human and non-human, domestic and foreign)
Health -- preventive measures and curative measures
Material appurtenances for recreation, entertainment, cultural fulfillment

Transportation, energy, and communications are regarded as contributing to the above.

E Quality of the material environment

Components

Air)
Water) (purity with respect to chemical, radio-active, biological, and particulate contaminants)
Soil)
Control of noise and vibration
Control of insults to the eye and nose
Control of electromagnetic radiation (microwave, infrared, and x-ray)

F Freedom and self-fulfillment of the individual

Components

Desirable variety with respect to items of P and E
Lack of restrictions with respect to items P and E

* From a proposal to the GAAT Group by D. J. Montgomery, Sept. 19, 1973.

Freedom from control over disposal of income and possession

Freedom from social and cultural controls

Desirable variety of jobs

Desirable variety of education

J Justice, rectificatory and distributive (as Aristotle had it)

<u>Components</u>

Equal access to opportunity to enjoy items of P and E

Access to jobs

Access to education

Freedom of religion, speech, assembly

Protection from oppression (de jure and de facto)

Participation in government

APPENDIX C

APPENDIX C

MICRO-TECHNOLOGY ASSESSMENT

Pilot Test Case: Domestic Clothes Drying

The idea in this exercise is to find out in crude form whether the "GAAT System" for estimating impact of various alternatives has any merit, i.e. how will evaluations made by various individuals jibe? Domestic clothes dryers are a relatively recent innovation and are in the gray area between luxury and necessity.

Background information:

34 million units in use = 50% saturation

4 million sold in 1972, retail value	=	$ 688 million
Installation	=	100
Service	=	200
Cost of operation	=	680
Contribution to economy in 1972	=	$1,668 or 0.15% of GNP

Average weight = 130 lb/unit including packaging materials derived largely from petroleum products. Energy content in manufacture = 5 million Btu/unit.

Estimate average 200 loads/year, using 20,000 to 50,000 Btu/load, about 0.5% of total U.S. energy resource consumption aggregated.

Electric dryers outsell gas dryers 3 : 1 and use about 1,000 kWh/year (washing machines use about 100 kWh/year).

Energy input into a dryer is almost completely lost into the environment.

Given 6 alternatives:

(1) do nothing, let market forces handle

(2) clothes line, domestic dryers which consume energy resources are not allowed

(3) commercial drying where energy consumption is rationalized due to operation to scale and using best technology

(4) reduce laundering frequency, say wear or use washables twice as as long as conventional

(5) use disposables, assume less energy is consumed overall than when using dryers

(6) employ technology to

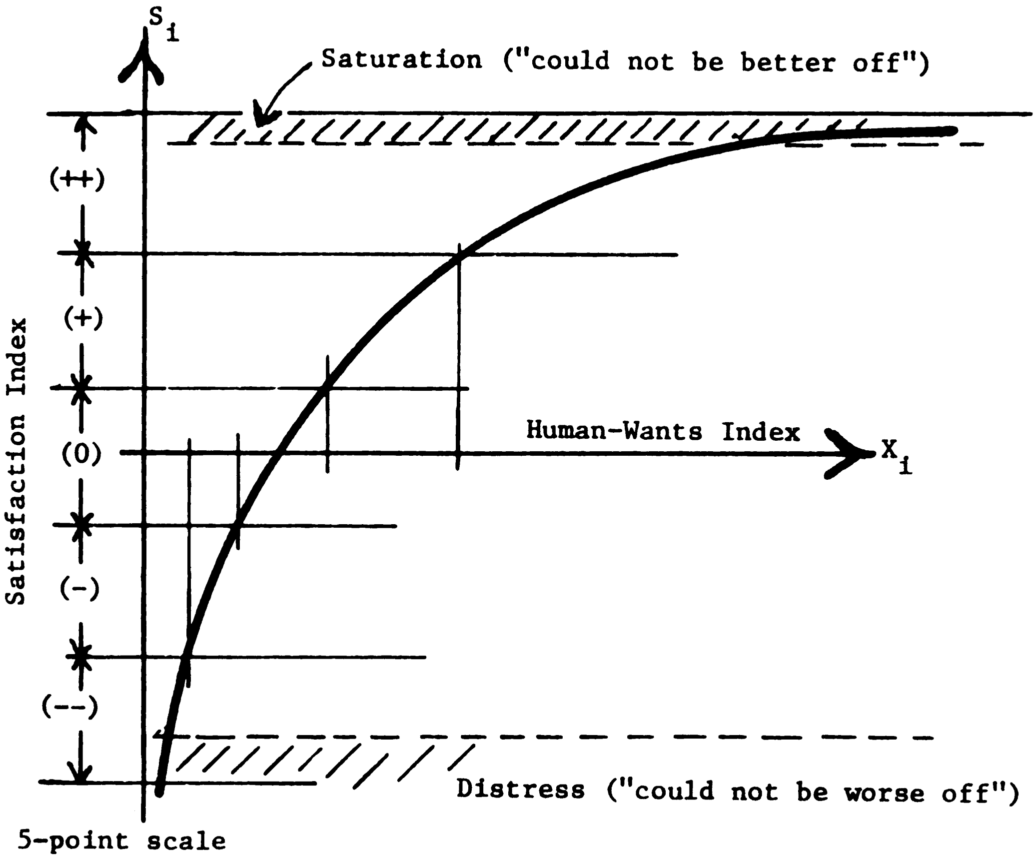
  (a) install moisture-sensing devices in all dryers so that no energy is wasted in overdrying; modulate heat input to rate of moisture removal (additional cost $25/unit)

  (b) use partial heat-recovery mechanism so that energy consumption is cut by 50% (additional cost $100/unit)

  (c) use heat for house heating during winter months (additional cost $100/unit)

Use 5-step valuation scheme as illustrated with partial satisfaction-curve on next sheet.

PARTIAL SATISFACTION-CURVE indicating 5-step scale



	Alternatives							
	(1)	(2)	(3)	(4)	(5)	(6a)	(6b)	(6c)
	Impact							
Criteria								
P								
E								
F								
J								
Trade-off balance								

APPENDIX D

APPENDIX D

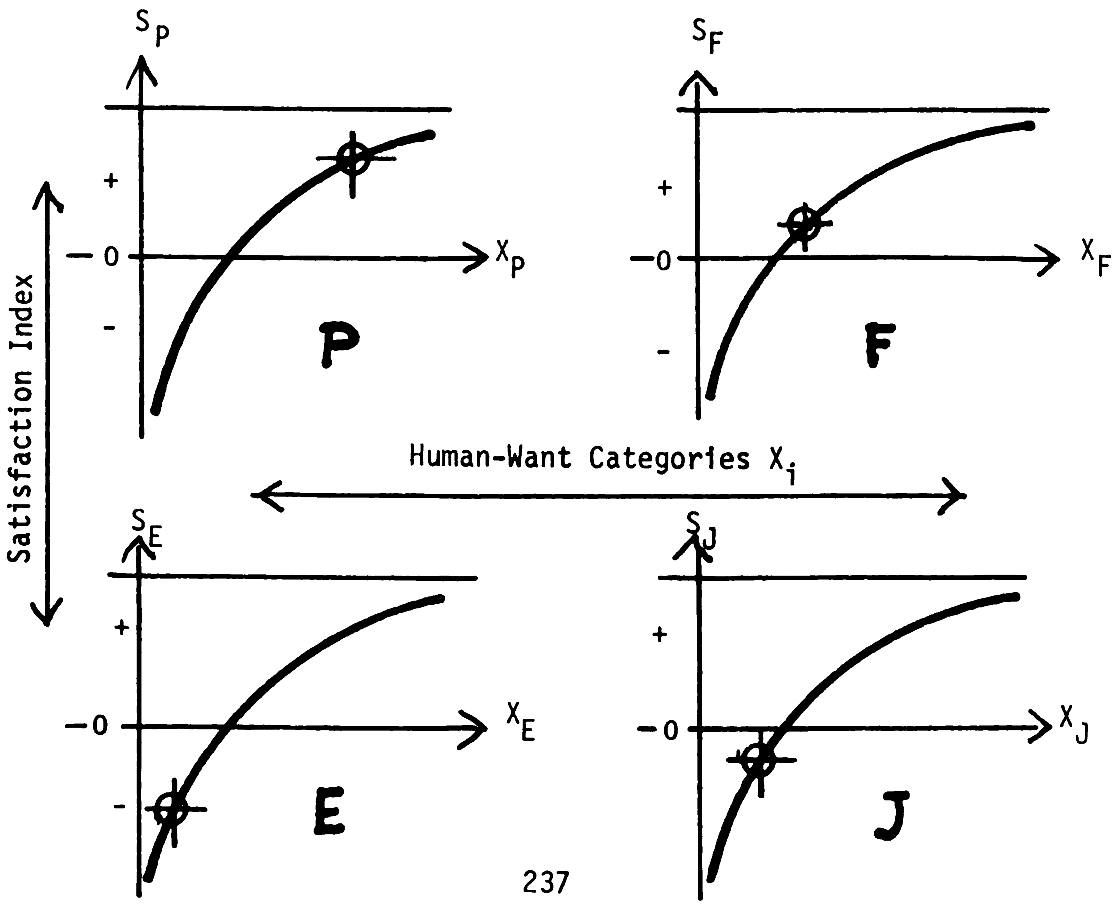
MICRO-TECHNOLOGY ASSESSMENT: DOMESTIC CLOTHES DRYING

S = f(P + E + F + J)

where

- S = index of Satisfaction, i.e. quality of life
- P = Provision of goods and services (physical volume of -)
- E = quality of the material Environment (level of -)
- F = (level of -) Freedom and opportunities for self-fulfillment for the individual
- J = (breadth of available -) social and distributive Justice, i.e. quality of the social environment.

P, E, F and J are a set of interrelated criterion variables. They are in effect social goals and can be visualized by 4 Partial-Satisfaction Curves (points on these curves have been arbitrarily placed for illustration purposes only. Moving one point affects the location of the other three).



P, E, F and J in more detail:

P is about the equivalent of the P in GNP, but is concerned only with physical artifacts and means, energy, communications and transportation utilized in the process.

food, beverage and tobacco
clothing and shelter (the human environment)
health
security
equipment and facilities for recreation, entertainment and cultural activities

E is the level of environmental quality, usually controlled by P

air
water
soil or land
visual and audio phenomena

Note: the substantial difference between reversible or irreversible effects on E and created by P needs to be taken into account.

F is all about the individual self who benefits from and/or pays the costs of actions under P and impacts under E.

F means the optimum (O) or minimum (M) as indicated.

(M) social control, formal or informal rules

(O) choice among, and access to, goods and services from P

(O) latitude of choice of working where wanted, living where wanted, and playing where wanted

(O) degree of mobility (personal transportation not under P)

(O) level of communications opportunities (personal, part not under P)

(M) control over disposal of personal income and investment

(O) level of opportunities for self-development, physical, mental and spiritual

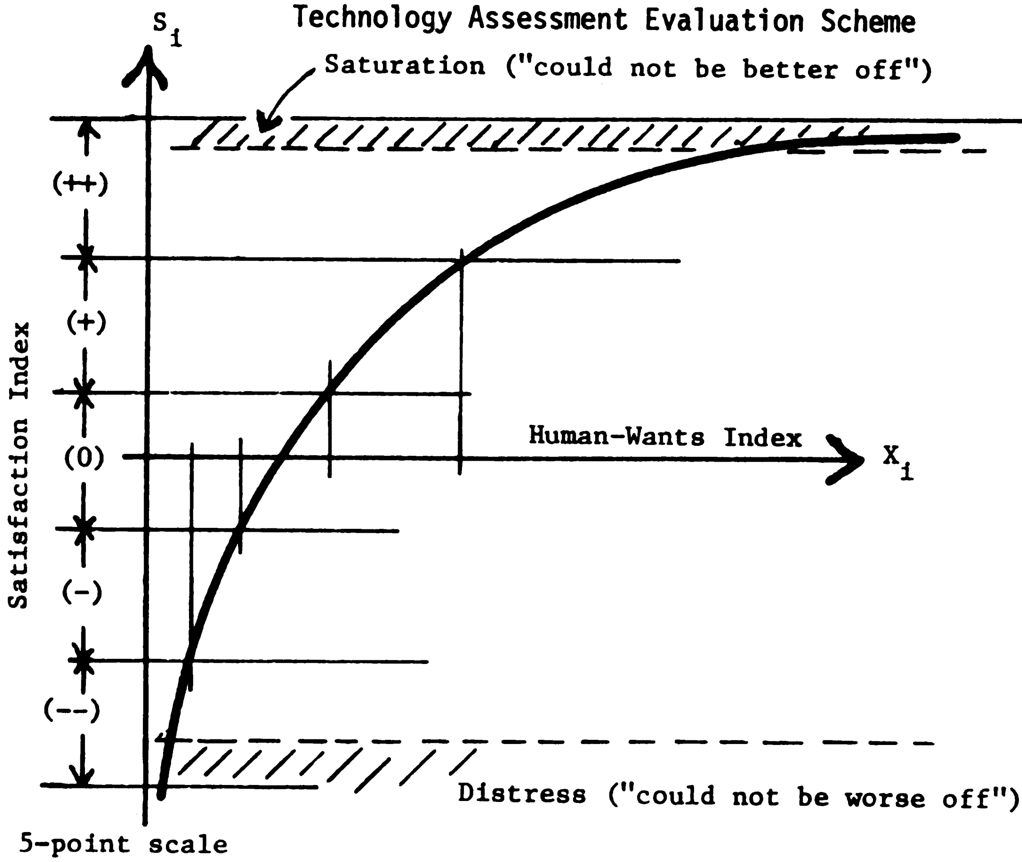
J is all about collective action, society and the social structure, including social values, positive or negative, as derived from the social structure. J dimensions the conditions under which the individual has decided that the benefit of collective action outweighs the costs, therefore is preferred over individual action for purposes of attaining higher levels of living.

J is the social environment

J dimensions the breadth of access to, and the degree of equity in distribution of:

wealth and income derived from P activities
(a) disposable income
(b) investment for future income
consumption of goods and services (produced under P)
employment opportunities in P activities
living amenities (housing for example)
costs attached to J (taxes for example)
cultural opportunities, religion,)
education, the arts and sciences)
social opportunities, includes) includes recreational
public affairs and political participation)
health services

Technology Assessment Evaluation Scheme



(++) intensive satisfaction, could not be better off

(+) satisfaction

(0) unconcern (no effect one way or the other)

(-) dissatisfaction

(--) intensive dissatisfaction, could not be worse off, distress.
Note: in a welfare society this condition is not likely to occur.

Exercise No. 1 Restricting the use of automobiles to reduce fuel consumption:

(1) do nothing, let market forces handle fuel and engine H.P.
(2) taxes to restrict consumption
(3) ration fuel to the individual

	Alternatives		
	1	2	3
	Impact		
Criteria			
P			
E			
F			
J			
Trade-off balance			

Name____________________________Student No.________________________

Technology Assessment

Exercise #2: Alternative to domestic clothes dryers.

Background:

Domestic clothes dryers are a relatively recent innovation and are in the gray area between necessity and luxury.

32 million units used in 50% of the U.S. households.

4 million units sold annually. Approximate retail $170 ea.

Contribution to P -- manufacturing, distribution, service and operation- is about 0.15% of all energy consumed in the U.S.

Per load, a dryer uses 10 x the energy used by a washing machine.

Practically all of the energy input a dryer is lost into the environment.

Given 8 alternatives:

(1) do nothing, let market forces handle

(2) clothes line, domestic dryers which consume energy resources are not allowed

(3) commercial drying, where energy consumption is rationalized due

to operation to scale and using best technology

(4) reduce laundering frequency, say, wear or use washables twice as long as conventional

(5) use disposables, assume less energy is consumed overall than when using energy for drying

(6) employ technology to

  (a) install moisture- sensing devices in all dryers so that no energy is wasted in overdrying; modulate heat-input to rate of moisture removal (additional cost is $25/unit)

  (b) use partial heat-recovery mechanism, so that energy consumption is cut by 50% (additional cost is $100/unit)

  (c) use heat for house-heating during winter months (additional cost $100/unit)

	Alternatives							
	(1)	(2)	(3)	(4)	(5)	(6a)	(6b)	(6c)
	Impact							
Criteria								
P								
E								
F								
J								
Trade-off								
balance								

Name____________________________Student No.__________________________

APPENDIX E

APPENDIX E

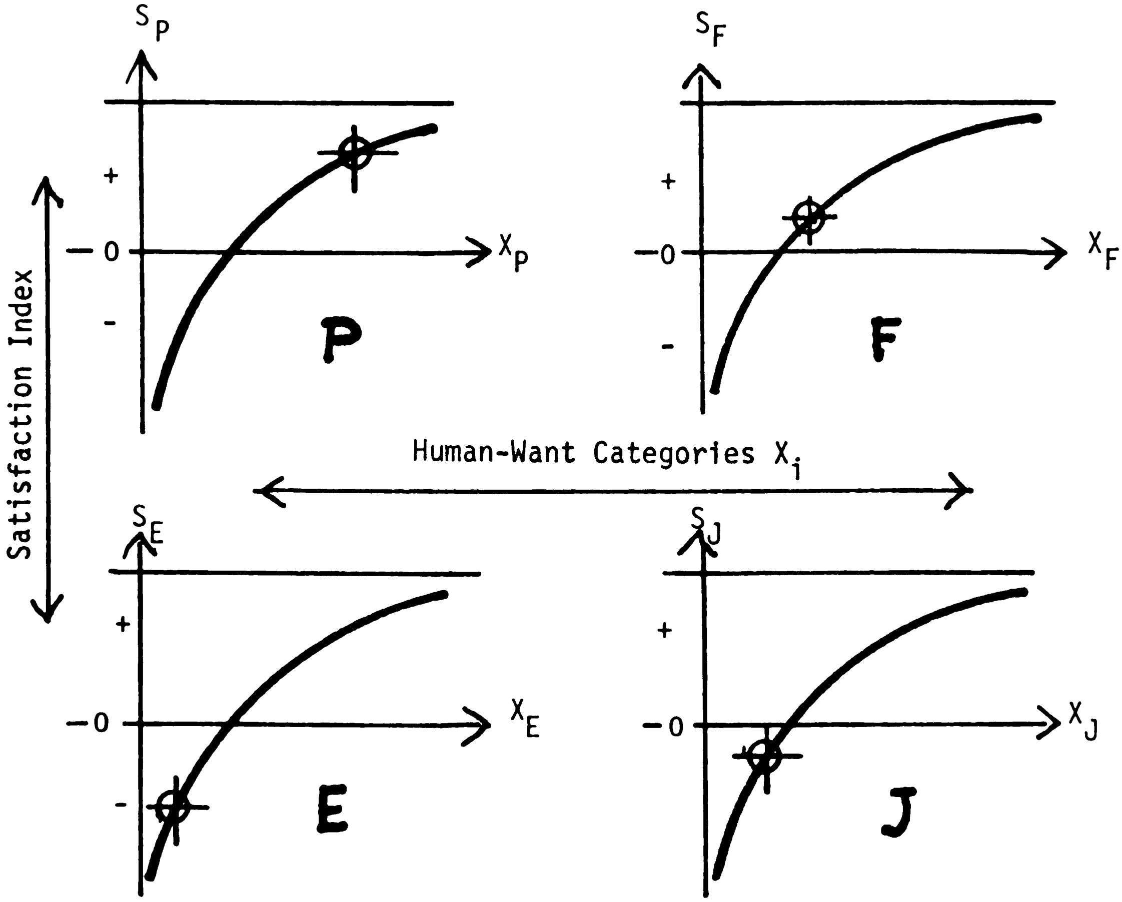
MICRO-TECHNOLOGY ASSESSMENT: DOMESTIC CLOTHES DRYING

$$S = f(P + E + F + J)$$

where

- S = index of Satisfaction, i.e., measure of the "quality of life"
- P = Provision on goods and services (physical volume of --)
- E = quality of the material Environment (level of--)
- F = Freedom and opportunities for self-fullfillment for the individual (level of--)
- J = social and distributive Justice, i.e., (breadth of available--) quality of the social environment.

P, E, F, and J are a set of interrelated criterion variables. They are in effect social goals and can be visualized by 4 Partial-Satisfaction Curves (points on these curves have been arbitrarily placed for illustration purposes only. Moving one point affects the location of the other three).



P, E, F, and J in more detail:

P is roughly the equivalent of the "P" in GNP, but is concerned only with physical artifacts and means, energy, communications and transportation utilized in the process.

food, beverage and tobacco
clothing and shelter (the human environment)
health
security
equipment and facilities for recreation, entertainment and cultural activities

E is the level of environmental quality, usually controlled by P.

air
water
soil or land
visual and audio phenomena

Note: The substantial difference between reversible or irreversible effects on E and created by P needs to be taken into account.

F is all about the individual self who benefits from and/or pays the costs of actions under P and impacts under E. F means the optimum (0) or Minimum (m) as indicated.

(M) social control, formal or informal rules
(0) choice among, and access to, goods and services from P
(0) latitude of choice of working where wanted, living where wanted, and playing where wanted
(0) degree of mobility (personal transportation not under P)
(0) level of communications opportunities (personal, part not under P)
(M) control over disposal of personal income and investment
(0) level of opportunities for self-development, physical, mental and spiritual

J is all about collective action, society and the social structure, including social values, positive or negative, as derived from the social structure. J dimensions the conditions under which the individual has decided that the benefit of collective action outweighs the costs, therefore is preferred over individual action for purposes of attaining higher levels of living.

J dimensions of the breadth of access to, and the degree of equity in distribution of:

wealth and income derived from P activities

(a) disposable income

(b) investment for future income

consumption of goods and services (produced under P)

employment opportunities in P activities

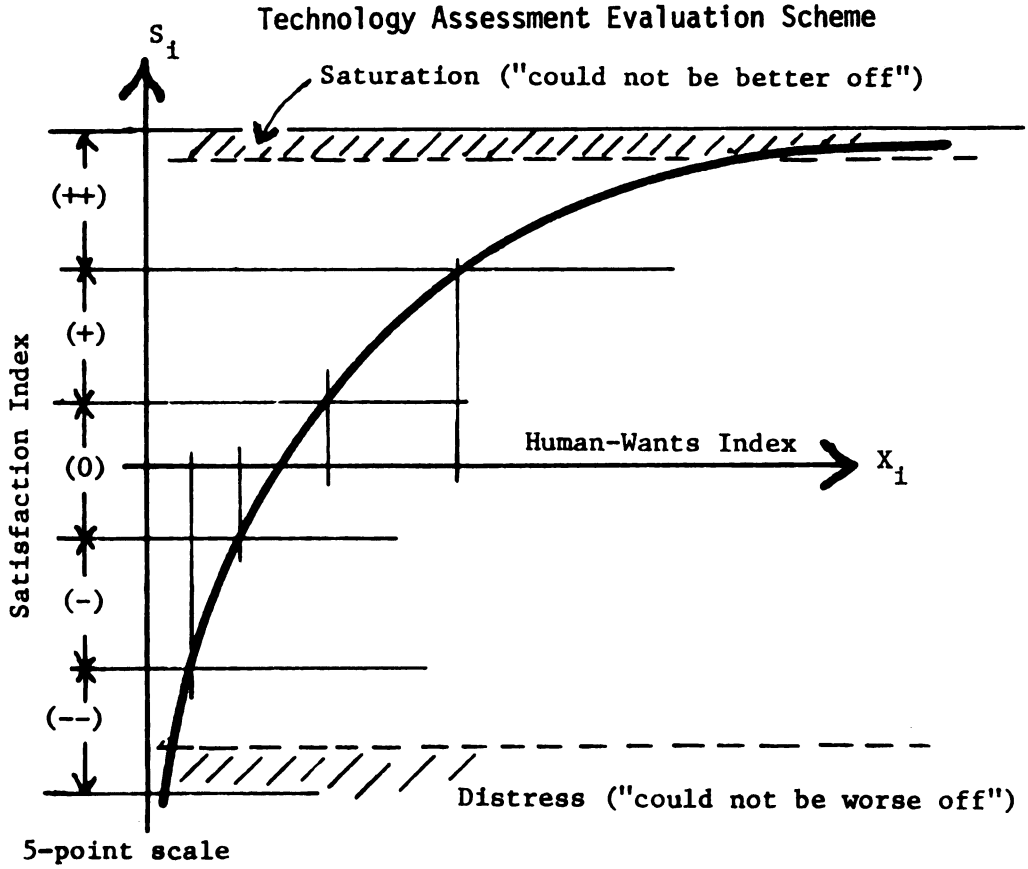
living amenities (housing for example)

costs attached to J (taxes for example)

cultural opportunities, religion,)
education, the arts and sciences) includes recreational
social opportunities, includes)
public affairs and political participation)

health services

Technology Assessment Evaluation Scheme



(++) intensive satisfaction, could not be better off

(+) satisfaction

(0) unconcern (no effect one way or the other, indifference)

(-) dissatisfaction

(--) intensive dissatisfaction, could not be worse off, distress,

Note: in a welfare society this condition is not likely to occur.

<u>Technology Assessment No. 1</u> Restricting the use of automobiles to reduce fuel consumption.

(1) do nothing, let market forces handle fuel and engine H.P.

(2) taxes to restrict consumption

(3) ration fuel to the individual

	Alternatives		
	1	2	3
		Impact	
Criteria			
P			
E			
F			
J			
Trade-off balance			

<u>Technology Assessment #2</u>: Alternatives to domestic clothes dryers.

Domestic clothes dryers are a relatively recent innovation and are at present in the gray area between necessity and luxury.

32 million units are used in 50% on the U.S. households

4 million units sold annually. Approximately retail $170 each.

Contribution to P -- raw materials extraction, manufacturing, distribution, service and operation -- is about 0.15% of GNP.

Energy used in manufacture is about 5 million Btu/unit.

In operation, the dryer uses 20,000 to 50,000 Btu/load, at 200 loads/year this is about 0.5% of all U.S. energy consumption.

Per load, a dryer uses 10 x the energy used by a washing machine.

Practically all of the energy input into a dryer is lost into the environment (impact on E).

Note that P, E, F, and J essentially represent social goals.

Make an assessment of 6 given alternatives, in some cases based on different assumptions.

Consider short-run impact only (5 years approximately).

(1) Do nothing, let market forces handle consumer choice

(2) Clothes line

(a) Domestic clothes dryers which consume energy are not allowed

(b) Can use clothes dryers only at certain hours (off peak) regulated by time-clocks

(c) Tax clothes dryers to discourage use

(d) Tax energy to discourage use

(3) Commercial drying or clothes line

(a) Picked up and delivered

(b) Must take to and pick up from laundry or depositories

(4) Reduce laundering frequency; say, wear or use washables twice as long as is now conventional practice

(5) Use disposables, clothing, bed linens, towels etc. Assume less energy is consumed overall than when using energy for drying. Also assume that under this scheme clothing is reasonably fashionable

(a) Economic cost is same as conventional

(b) Economic cost is 15% less

(c) Economic cost is 15% higher

(6) Reduce energy consumption through technology

(a) Install moisture-sensing devices in all dryers so that no energy is wasted in overdrying; modulate heat-imput to equal rate in overdrying; modulate heat-imput to equal rate of moisture removal from load (additional cost is $25/unit)

(b) Use partial heat-recovery mechanism, so that energy consumption is cut by 50% (additional cost is $100/unit)

(c) Use heat for house-heating during winter months (additional cost is $100/unit)

	Criteria			
	P	E	F	J
		Impact		
Alternatives				
(1)				
(2) (a)				
(b)				
(c)				
(d)				
(3) (a)				
(b)				
(4)				
(5) (a)				
(b)				
(c)				
(6) (a)				
(b)				
(c)				

Simply indicate under each criterion heading your numerical ranking of alternatives. In other words, which of the impacts are most significant in their rank order 1, 2, 3, 4, 5, ... Go as far as you wish, but assign at least 5 ranks, a total of at least 20 entries.

	Criteria			
	P	E	F	J
		Impact		
Alternatives				
(1)				
(2) (a)				
(b)				
(c)				
(d)				
(3) (a)				
(b)				
(4)				
(5) (a)				
(b)				
(c)				
(6) (a)				
(b)				
(c)				

Your Name ______________________________