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Energy Conservation Through Effective Utilization

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Abstract

In two major sectors of the economy (building services and industrial processes), accounting for approximately 75 percent of total national energy consumption, energy utilization is found to be inefficient. It is estimated that in these two sectors, as much as 25 percent of the energy consumed annually by the nation as a whole may be lost through ineffective practices. Possible reasons for existence of ineffective utilization are considered, and possible means of improving effectiveness of utilization are discussed. Three possible levels of effort to promote effective utilization of energy are identified; one promotes effective use of present fuels in present processes; the second promotes utilization of presently unused energy sources; the third promotes more effective investment of energy in durable and maintainable products.

Substantial latitude for improvement of effectiveness is shown to be realizable through technological efforts at these three levels. It is finally recommended that a national program, incorporating efforts at the three levels identified, be undertaken with the ultimate goal of creating and implementing a technology of improved energy utilization.

I. Introduction

Present indications are that the U.S. demand for energy may well outstrip both power generating capacity and fuel supply.

The basic problems in energy supply can be divided as follows. In the short range (1972-80), the most important problem appears to be inadequate power-generating capacity. In the long range (the year 2000 and beyond), the basic problem of energy is availability of fuel or of energy in another form such as solar or geo-thermal energy. In the intermediate range (1972-2000), the conservation of energy by means which do not damage the functioning of the economy could well be the most important consideration.

Broadly speaking, the problem of providing sufficient energy for future needs can be approached along either of two avenues: supply or demand. However, these avenues are not independent of each other. For example, moderation of demand by curtailing industrial electrolytic processing could adversely affect development of energy supply capacity by causing shortages of electrical conductor material. Such interactions between supply and demand must be considered and evaluated in planning how to meet the overall energy needs of the nation.

This report concerns possible actions to affect the demand for energy. Here, again, there are two broad avenues of approach. On the one hand, demand for energy may be discouraged by increases in price; this may be characterized as the "belt tightening" approach. On the other hand, it possible to maintain the output of energy-consuming processes, and at the same time, reduce energy consumption by improved efficiency. In the long run, effective actions to moderate demand will probably consist of a combination of these two approaches.

Efforts to improve efficiency are essentially technological in nature. The implementation of technological improvements in energy-consuming processes would probably require, or at least be greatly facilitated by, appropriate price tax, loan, and regulatory policies, especially as these pertain to new building construction and industrial plant equipment.

The actions one might take to moderate demand should begin to take effect in the intermediate time range (1980-2000); as a matter of principle, actions proposed at this level should be reviewed for possible conflict with solutions of long-term problems of fuel and energy supply. For example, proposals for local combustion of fuels to drive power generation equipment and to provide for local utilization of reject heat frequently arise. Such proposals should be reviewed in light of the fact that centralized combustion facilities (e.g., large power plants) can operate at higher temperature and consequently at higher efficiency and also will usually be more efficiently operated and maintained. Centralized plants can thus usually provide higher combustion efficiency than can small low-cost plants appropriate for installation in individual buildings. Short term measures to relieve demand on power generation via local combustion could, in the long run, result in poor use of fuel on a national basis.

The complementary relationship between efforts to increase energy supply and efforts to improve efficiency of utilization merit specific mention. The increasing national demand for energy reflects, in large part, influences which are not subject to immediate control, such as increasing population. There appears to be no way to meet the future needs of society without increasing the national capacity to supply energy. However, as will be shown, many of the ways in which energy is presently used to satisfy the needs of society are not particularly effective. Large amounts of energy are allowed to "leak" out of the national energy system at the point of consumption, and available techniques for utilization of reject heat and waste heat in energy consuming processes are seldom applied. Faced with a developing shortage of non-polluting fuels and with the recognition that fuels of all types are a non-renewable resource, it is appropriate to give serious attention to improving the effectiveness with which energy is used, as well as to improving the national capacity to supply energy. If the effectiveness of energy utilization were not to be improved, then newly developed supplies of energy would be permitted to escape utilization through presently accepted "leaks." This would require the development of surplus energy supply capacity, with all of its economic implications, merely to supply these leaks. Thus, improving the effectiveness of energy utilization is seen here to be necessary both as a measure for conservation (to prevent the waste of a non-renewable natural resource) and as a measure for economic optimization of investments in energy (to eliminate the need for surplus energy supply capacity).

Technological efforts to moderate demand through improved effectiveness of utilization will consist of a combination of short range measures, such as upgrading housing insulation or furnace performance, and long range measures including the application of thermal management techniques to industrial processes, improved building design and the institution of new technological means of improving the efficiency of energy utilization in devices. In the following section, the term "leak plugging" is used to characterize the technological efforts to improve present and future effectiveness of energy utilization.

II. Present Uses of Energy in the United States

We now turn to the possibility that demands for energy may be moderated by improving the effectiveness of energy utilization, without sacrificing the expected output of present processes. To evaluate this possibility, we must know (a) how much energy is consumed in various sectors of society, and (b) how much of the energy consumed could be saved by the use of more efficient practices. The term, "waste energy," will be used here to mean energy which need not be used were presently available technology applied. The possibility of further reductions of energy requirements for existing processes, through development of new technology, is an important subject to be dealt with later.

Considerable data are available about energy consumption and are well summarized in a report by the Stanford Research Institute (SRI) entitled, "Patterns of Energy Consumption in the U.S.," which was prepared for the Office of Science and Technology" (January 1971). However, data required for the determination of "waste energy" are known for only a few sectors of the economy.

SRI data indicate that, of the total national energy consumption (NEC), 19.2% is used in residential building services, 14.4% in commercial building services, 41.2% in industrial processes, and 25.2% is used in transportation. For commercial and residential buildings services, considerable information concerning the effectiveness of energy utilization is available; for industrial processes, only sample information concerning the effectiveness of energy utilization is available. The possibilities of improved energy utilization in transporation systems will not be considered in this paper.

III. Possible Savings in Use of Energy in the U.S.

A. Energy Utilization in Buildings: Correctable Losses

(1) Thermal Performance of Structures

The major uses for energy in buildings are space heating, air conditioning, and hot water heating (Appendix A).* Space heating of residences accounts for 11 percent of the total national energy consumption, while space heating of commercial occupancies represents an additional 6.9 percent of that total. Air conditioning in commercial and residential buildings represents 2.5 percent of the total national energy consumption (1). The "leaks" which affect the effectiveness of heating and air conditioning in buildings are essentially the same, the major sources of heat loss or heat gain being inadequate insulation, excessive ventilation, high air infiltration rates in buildings, and excessive fenestration. To estimate the effectiveness of present levels of building insulation and ventilation in energy conservation in buildings,

*Hot water heating is treated separately in (4).

one may note that the FHA minimum property standards of 1965 permitted heat losses of 2000 BTU/thousand cubic feet-degree day* in residences. HUD Operation Breakthrough property standards of 1970 reduced this figure to 1500 and the newly implemented FHA minimum property standards (1972) require heat losses to be less than 1000 BTU/thousand cubic feet-degree day. The reduction in energy consumption implied by these standards is to be achieved largely by thermal insulation and control of air infiltration.

The 1972 FHA minimum property standards, of course, bear upon new construction. Few buildings are designed to exceed the performance levels of these standards, and therefore one may assume that most of the residential buildings in use today may consume approximately 40 percent more energy for heating and air conditioning than they would, had they been insulated and sealed in accordance with present day minimum property standards. In fact, in certain areas of the country, whole residential neighborhoods were built prior to the advent of either FHA or housing insulation, and consist of buildings with little or no insulation and with very high air infiltration rates. These neighborhoods are, as a rule, located in areas of high heating requirements. In these neighborhoods the fuel consumption for heating is at least twice as great as would be required if insulation and infiltration control required by modern standards were applied. Since the neighborhoods in question are in areas of high heating requirements, their

*This quantity--BTU/thousand cubic feet-degree day--represents the heating requirements of a building, relative to its size and the severity of the climate in which it serves.

heat losses represent an especially significant "leak" in the national energy consumption system. (See page (2) of Appendix B).

Sample field observations indicate that the state of insulation and draft sealing in existing commercial buildings is not significantly different from that in existing residences. Similar savings of space heating fuel--approximately 40 percent--may be assumed to be attainable through insulation and draft control in commercial buildings.

The infiltration of outside air accounts for approximately 25 to 50 percent of the heating and cooling requirements of individual buildings, depending upon the type of insulation installed in the buildings (3). Present construction practices yield infiltration rates which exceed by a factor of four the average ventilation requirements of typical buildings (4, 5, 6). Special areas in buildings, such as toilet facilities, kitchens, and conference rooms where heavy smoking may occur, have high ventilation requirements when in use. However, in present designs and in most present buildings the high ventilation rates required for use of these areas are maintained all day.

Reduction of infiltration to presently accepted levels of ventilation requirements could be assumed to yield a 10 to 20 percent reduction in national fuel requirements for space heating and air conditioning of buildings. Control of ventilation in critical areas so that high levels of ventilation were supplied only when required could provide an additional relief of up to 5 percent in total fuel requirements for space heating and air conditioning of commercial buildings.

In the above, the energy savings to be realized by bringing existing buildings up to presently recommended standards of performance have been considered. Future standards for insulation, ventilation, and infiltration may offer even greater potential for saving energy. Engineers presently studying building insulation estimate that it will be technologically and economically feasible to reduce the heating losses from buildings to approximately 700 BTU/thousand cubic feet-degree day, through use of insulation. These estimates need to be substantiated through research and field testing; if they prove to be correct, it would be feasible to reduce total energy requirements of buildings by more than 50 percent through well-designed insulation and careful control of ventilation.

(2) Heating and Air Conditioning Equipment

The efficiency of heating and air conditioning equipment is especially sensitive to the percent of full load at which the equipment is operated and to how well it is maintained. Building heating equipment, including the home furnace as sold, is typically 75 percent efficient when run at full load. However, the full load capacity of the equipment is seldom needed, and the equipment is most often operated intermittently in which mode it is much less efficient. In addition, small accumulations of soot on boiler surfaces and other minor unattended items of maintenance continuously reduce the efficiency of heating equipment during its life time. Taking the few field data presently available together with what is known about the effects of unattended maintenance and intermittent operation upon combustion apparatus in heating plants, it would appear reasonable to estimate that the actual efficiency of heating equipment in the field to be 50 percent or less, with units functioning at efficiencies as low as 35 percent not being uncommon (e.g., 16).

The efficiency of air conditioning equipment varies widely. Air conditioners of the same rated output may differ by a factor of two in their power requirements. Thus, substantial savings in energy could be realized through inclusion of energy consumption in the criteria for selection of equipment, and by diligent maintenance of equipment.

(3) Illumination

Illumination of residences and commercial buildings accounts for 1.5% of the national energy consumption (1). In some cases, present levels of illumination are higher than necessary. The levels of illumination used in the U.S. office buildings exceed, by as much as a factor of two, levels of illumination used abroad, and there is no concrete evidence that the increased illumination is of any benefit to the building occupants. Also, much greater use could be made of daylight in providing illumination in office buildings and residences. While the heat generated by illumination may lighten the heating load during the colder part of the year, during the time when indoor space is cooled by air conditioning systems, increased illumination imposes double energy costs upon building operations. Design techniques to permit greater use of daylight and optional use of artificial light exists, and could be more widely applied. Further research to ascertain the benefits of illumination levels to building occupants would be of great value in design to reduce excessive energy consumption in buildings.

(4) Hot Water Heating

Hot water heating merits special consideration in energy conservation efforts. Once the hot water is used, the water, with the energy it contains, literally goes down the drain. Furthermore, as Appendix A shows, hot water heating accounts for approximately 4 percent of the total national energy consumption. When viewed in the context of overall national energy consumption, the energy lost in hot water heating is indeed significant. A number of suggestions of ways to recapture the heat in expended hot water, using heat exchangers on drains, has been offered. Although most such proposals are in conflict with present local plumbing codes, some could be implemented through minor code modifications. However, solar hot water heaters (which are commercially available in many countries) could be employed without raising such conflicts, and could provide a relief of 2 percent or more of the total national energy requirements.

(5) Other Areas

Other components of building operations contribute additional small amounts to national energy consumption (e.g., cooking 2.2%, clothes drying 0.3%)(1). Although extensive data on the effectiveness of energy utilization in these areas are not available, sample observations indicate that energy is used with no greater effectiveness than in other building services. Improved design of appliances could significantly enhance the efficiency of these operations.

(6) Summary of Energy Leakages in Buildings

The data cited indicate that present buildings consume approximately 40 percent more energy than would be required to maintain present levels of services and comfort, if the best present standards had been used in construction and if careful selection and diligent maintenance were applied to heating and air conditioning equipment. This represents a correctable loss of approximately 13.5 percent of the national energy consumption.

The possible courses of action by which more effective utilization of energy in buildings might be promoted will be described below.

B. Thermal Effectiveness of Industrial Processes

Data pertaining to effectiveness of energy utilization in industry are less extensive than those available for building services. However, sample data indicate that, on the whole, the effectiveness of energy utilization in industry is no greater than in buildings. It would not be unreasonable to assume that energy savings of approximately 30 percent might be realized through application of present day energy conservation techniques to industrial processes. Some of the information on which this assumption is based is reviewed below.

The effectiveness with which energy is used in industry varies greatly, depending upon the nature of the industry and the size of the plant. In industries such as electric power generation and chemical refining, the nature of the industry is to convert the energy content of fuel to some more readily salable form. As a rule, optimal design of large plants in such industries is based on both initial costs and operating costs, especially fuel costs. Thus, design of piping systems to minimize pumping costs and design of pipe insulation in order to optimize the trade-off between heat loss and total costs (including maintenance) of insulation are common practices, and are representative of the consideration given to effective energy utilization in large plants for power generation; and other similar industries.*

*However, even in large power plants much heat is lost. In a typical modern power plant approximately two-thirds of the heating value of the fuel consumed must be rejected to the atmosphere. This reject heat is not "waste" in the present context; the rejection of this heat is required by the second law of thermodynamics. But, by siting a plant near a consumer, much of this heat could be put to use in waste processing, water purification, space heating, air conditioning, etc.

In other industries, including machine manufacturing, materials processing, and metal forming, the role of energy as an essential ingredient seems to be less clearly recognized, perhaps because energy costs have not been a major part of overall costs of operation, and the effectiveness with which individual items of plant equipment use energy has not been a major concern. Indeed, in some instances where energy costs have been taken into account in selection of plant equipment and plant design, industry has found that because of the prevailing low price of energy it has been cheaper to permit a leak of energy than to modify or replace inefficient equipment. The assumption that this rule applies broadly appears not to be justifiable. Moreover, with the prospect of substantial increases in fuel prices by 1985 (7), industrial concern for effective utilization of energy may be expected to increase sharply. In particular, the management of small plants, to which effective energy utilization seems presently to be an item of small concern, may be expected to take a much greater interest in obtaining more effective use of the energy. It is appropriate to point out that price is not the only factor influencing industrial concern for effective energy utilization. In some districts of the country, gas suppliers have assigned industries fuel quotas which may not be exceeded. Already one can observe an intense effort on the part of the affected industries to improve the effectiveness of energy utilization in their plants.

As examples of industrial efforts indicating the potential for energy savings in industrial operations, one may cite the following:

Many large volume sales offices of gas suppliers currently have representatives assigned to advise industry how to use less fuel to conduct their present operations. The success of these recently instituted programs has yet to be measured. But, presumably the possibilities for energy savings in industry are sufficiently obvious that the gas suppliers can identify them.

Certain examples of improved equipment merit mention here. Gas fired vacuum furnaces have recently been developed for industry. Through the use of well-designed vacuum insulation, heat pipe technology, and modern heat transfer and combustion techniques, these furnaces operate with 25 percent of the total fuel consumption of previous vacuum furnaces (8). Other studies of the effectiveness of industrial energy utilization indicate that application of present-day heat recovery devices (e.g., heat wheels) and thermal management techniques could yield net energy savings of 30 percent or more in typical industrial operations (9,10,11).

Surveys of energy utilization in steel making and in related industrial operations indicate that fuel savings of as much as 39 percent could be realized in operation of certain items of equipment and that average fuel savings of 25 percent or more could be realized through application of current techniques of waste heat management and up-to-date equipment design to the industry as a whole (12).

Interviews with engineering consultants and plant supervisors have indicated that effectiveness of energy utilization has been of sufficiently little concern in the past that ample latitude for economically justifiable improvements in effectiveness presently exists.

Based upon the observations cited above and upon interviews with engineers and technologists who are currently studying the possibility for energy savings in industry, it is estimated that approximately 30 percent of the energy used in industrial processes could be saved through application of existing techniques, and that the use of these techniques will be economically justifiable at today's fuel prices. Predicted increases in fuel prices are expected to make energy conservation measures even more attractive to industry in the near future. The invention of more efficient devices, more efficient processes (e.g., cement making, refining, chemical processing) and especially the institution of a methodology for waste heat management in plants may be expected to yield further energy savings in industry, beyond the estimated 30 percent quoted above.

IV. Summary of the Problem

Of the total national energy consumption, 33.6 percent goes to operate buildings and 41.2 percent goes to operate industrial processes. Present data indicate that building services consume approximately 40 percent more energy than would be required had optimal use of available technology been applied to building design and selection of equipment. In addition, sample data indicate that industrial processes consume approximately 30 percent more energy than would be required had optimal use of techniques of insulation, heat recovery, and heat management been applied. Altogether, this means that approximately one-quarter of the total energy consumed may be assumed to escape effective use, through correctable "leaks" at the point of utilization.

Viewed in the context of a developing energy shortage, the identification of "leaks" which permit such a large loss of the national energy supply provokes one to ask just how such leaks came to be accepted. The answer appears to lie in the criteria of economic justification applied in energy utilization, which have been touched upon above. In energy conversion industries (e.g., power generation) economic justification of plants is based upon both initial costs and lifetime operating costs (which represent energy consumption). However, when one comes to the point of energy utilization, economic justification of energy consuming equipment tends to be governed by initial costs.* Thus, one commonly finds that high energy consumption has been designed into devices and buildings in order to reduce initial costs. Whatever technological steps might be taken to increase the effectiveness of energy utilization will have to be coupled with steps to induce a change in the methods of economic justification of building and equipment purchases. The purchaser should be alerted to the significance of lifetime operating costs of buildings and energy utilizing equipment, as well as initial costs. If this can be accomplished, then the use of excessive energy consumption to decrease the initial costs of energy utilizing equipment can most probably be eliminated. The technological possibilities to enhance the effectiveness of energy utilization in buildings and industrial processes can then be brought to field implementation.

V. Means to Promote Effective Energy Utilization

Ineffective utilization of energy is a major component of national energy problems. Here, we suggest three levels of effort at which the problem of improving effectiveness of energy utilization may be approached. Level I focuses upon improved effectiveness of use of present fuels in present

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*It is not intended to imply here that quality of performance is not considered in acquisition of industrial equipment. But rather that of two devices which yield the same product, the cheaper will tend to be preferred, irrespective of energy consumption. Those industrial accounting systems in which energy requirements are carried as overhead appear to reinforce this tendency.

application. Efforts at this level can be mounted through extension and coordination of present government and industry activity, and may be expected to be seen in relatively short time (∿2-5 years). Level II focuses upon the utilization of presently unused energy sources and fuels; efforts at this level will require new programs within government and industry, and may be expected to take effect in a longer range period (∿5-10 years). Level III considers energy utilization in the broader context of the energy invested in materials and manufactured goods. Efforts at this level will require new integrated studies of the technological and economic implications of such possibilities as more efficient use of materials in construction and the design of the manufactured goods for durability and maintainability. The studies to be conducted at this level will, inevitably, bear upon the conservation of all natural resources, including energy, and will take effect over a long range period (∿5-10 years).

Important interactions exist between the efforts at these three levels. Programs for energy conservation can be constructed by implementing efforts at the three different levels simultaneously. If sufficient resources for simultaneous efforts at the three levels were not available, programs should be constructed by nesting of the three levels (e.g., Level II should be pursued in conjunction with Level I; Level III should be pursued in conjunction with Levels I and II).

Level I - Current Fuels in Current Applications

A. Building Design

Two basic branches of activity are required in building design. First, design criteria and standards for energy conservation in new construction are required. However, even with present high rates of construction, approximately half of the buildings in service in the year 2000 will have been built before 1973 (13). Thus, a technology for upgrading the thermal performance of existing structures is also required.

The principal problems of building construction in need of technological attention are insulation, draft sealing, ventilation, proper selection and maintenance of equipment, envelope design, fenestration design, and illumination.

In addition to the purely technological aspects of improved energy utilization in buildings, there are economic questions to be considered. The optimization of trade-offs between increased capital outlay and decreased operating costs over the life of a building is one such question. In this connection, reliable estimates of fuel price increases should be taken into account (7). Field data to confirm the economic benefits of energy conservation measures should be compiled and made known, to alert the public to the gains realizable through improved building performance. Preliminary evidence on these matters presently exists (14); this evidence indicates that, at present fuel prices, increased capital expenditures on thermal upgrading of present construction (e.g., installation of additional insulation) can pay off in approximately five years. Assuming that fuel prices will increase, the pay-off time may realistically be assumed to be substantially less than five years. Although this preliminary evidence is encouraging, conclusive evidence must be gathered and made known before one can expect the building purchaser to embrace the theory that it is to his financial benefit to invest in energy conserving aspects of buildings.

Thermal upgrading of existing buildings entails technological, economic, and social considerations. Materials and techniques to permit inexpensive, reliable, attractive and safe (e.g., fireproof) insulation of existing buildings require development. The economic trade-offs of thermal upgrading of existing construction require study. In addition, some criteria for estimating the expected life of existing construction need to be developed; this involves social as well as technological considerations. Certain neighborhoods of older buildings undoubtedly should not be torn down and replaced with new construction even though modern technology could offer physical improvements. The social effects of demolition and reconstruction would prove unacceptable. Thus, in considering the applicability of improved standards of building performance to financing of building purchases, or in judging the eligibility of neighborhoods for possible financial assistance in thermal upgrading, questions of social stability should be taken into account.

Finally, it is noted that the development of performance standards, as opposed to construction standards, by which the effectiveness of energy utilization in buildings can be judged, are required. A methodology of performance evaluation for buildings is a prerequisite for such standards. This methodology must include test methods for measuring heat transmission from the buildings, methods for determining ventilation and infiltration rates in buildings, methods for determining the effectiveness of building equipment, standard duty cycles in which to test building systems, and means of interpreting test results in terms of effectiveness of energy utilization; all of these components require development, and in turn are required in order to ascertain that field practices actually do lead to more effective use of energy.

The possibility of enhancing the effectiveness of energy utilization in buildings on a national scale, through federal standards (by FHA, VA) and through incentives (e.g., home improvement loans) is immense. Thirty-seven percent of the construction in the U.S. is either built for the Federal government or financially assisted by the Federal government and the influence of federal policy in construction extends well beyond this sector. Proper coordination of technological and economic efforts with regulatory agencies can have a powerful influence upon improving the effecitveness of energy utilization.

(B) Industrial Processes

The first step to be taken in the study of industrial energy utilization is to determine just how efficient industrial processes really are. The sample data cited earlier indicate that, on the average, industrial processes may consume approximately 30 percent more energy than would be required to sustain present production if the processes had been designed for effective energy utilization. Although the sample data are persuasive, further field studies are required to determine precisely what improvements in effectiveness of energy utilization are technologically feasible and economically justifiable. A national focus is required for such studies. In addition, programs to distribute information and to alert industry to the technological and economic aspects of improved effectiveness of energy utilization are required.

An additional important function which is required is the development and demonstration of methodologies of energy conservation. For example, techniques of waste heat management using heat recovery devices, application of efficient heat transfer devices such as heat pipes, and coupling between presently independent items of plant equipment, need to be deomonstrated. These demonstrations would probably be most effective if they were to be conducted as industrial experiments.

Invention and innovation may be expected in industrial processes as concern for energy conservation increases. Federal laboratories may be able to contribute directly to innovation in industrial processes by developing certain generic processes useful to industry. For example, "air slides" using hot gases of combustion as the fluidizing media require development. If properly developed, these could enhance a number of materials processing operations. The Federal government may be able to facilitate invention and innovation in industrial processes by providing assistance in questions of patent policy and related matters.

C. Total Energy Systems

A Total Energy System is one in which power generation for a small complex of buildings is done locally, and the reject heat is used to provide comfort conditioning and hot water for the dwelling units. Total energy has been enthusiastically embraced by some as a means for effective fuel utilization. Indeed, the promise of reducing the total fuel requirements of building complexes by 25 to 50 percent has been shown to be possible in principle. However, reliable field data on which public confidence in total energy could be established are scarce. Field testing of total energy systems is necessary to establish the feasibility of such systems. Moreover, technological problems bearing upon the effectiveness of total energy systems should be identified and carefully studied. Among these are the following:

(1) Fuel Efficiency: Total energy plants are, of necessity, small installations, and, as a rule, the effective temperature of combustion of a small plant is less than that in a large central power station. In large stations, one can afford to make use of heat recovery equipment and topping cycles to attain high combustion temperatures and the efficiencies of power generation associated with them.* To alleviate local "thermal pollution" from large plants, one might make use of "bottoming cycles." In small plants the use of such equipment is not economically justifiable. By using efficient central station power generators and employing heat pumps to provide comfort conditioning, it is possible, in principle, to attain greater effectiveness of fuel consumption than by using small scale total energy plants with their limited thermal efficiencies.

In addition, the combination of efficient central power generation with local heat pumps permits flexibility in the choice of fuels for power generation. This may be an important policy consideration, especially in connection with future shifts toward nuclear power. Local applications of nuclear power, as in a total energy system, seem not to be feasible for many reasons. The wisdom of long-range investments in an energy utilization

*A topping cycle is an additional power generation plant which receives heat at the temperature of combustion, and rejects heat at the maximum temperature required by the main power plant. The topping cycle utilizes the temperature drop between the combustion chamber and the boiler of the plant, to generate power.

system, such as total energy, which is both dependent upon fossil fuels and of limited thermal efficiency must be carefully studied even though the total energy concept appears to offer certain advantages in the short range.

On the other hand, central power stations, with their high effective temperatures of combustion and consequent high thermal efficiencies, have certain disadvantages. Thermal pollution, as was mentioned above, can be alleviated through the use of bottoming cycles which employ low temperature working fluids.* But these cycles need still to be developed. In addition, high temperature combustion which yields high thermal efficiency also yields high levels of pollutants, particularly nitrogen-oxygen compounds (NO_x). Finally, while the combination of central power and heat pumps appears extremely promising, certain environmental questions about large aerial densities of heat pumps still have to be resolved (e.g., where to obtain or reject heat without upsetting local natural conditions). Efficient, easily maintainable heat pumps have to be developed.

Finally, it is noted that there presently exists a broad spectrum of fossil fuels, some of which are low energy fuels which will not yield high temperature combustion. If it may be assumed that a sufficient quantity of the low energy fuels will be available for some reasonably long period compared with the useful life of small scale total-energy power-generation equipment, then it may be appropriate to plan total energy systems to use low energy fuels while reserving high energy fuels for central stations. Compatibility of such total energy equipment with expansions of

*In nighttime power generation, it would be possible to reject heat at subatmospheric temperatures, through radiative techniques, to avert local thermal overloading of the atmosphere.

the national energy system through nonfossil fuel central station power plants may not pose serious problems if the supply of low energy fuel will survive the equipment. However, the supply of such fuels, is not well determined at present; the present technology for utilizing such fuels in power generation needs development; and, in any event, supplies of all fossil fuels, including low energy fuels, are exhaustible.

The above has not been offered to advocate either central power or total energy, but to illustrate that there are fundamental and unresolved technological questions upon which decisions as to implementation of total energy systems, and other matters of energy policy depend.

(2) Maintainability: Small scale power units of 500 kw or less are very important to total energy planning, for these are the units which can power small complexes of (say) 300 residences or less. However, a survey of records of performance total energy systems in the field shows a very high rate of failure of these small scale ventures (15). Moreover, field interviews reveal that a very large number of these failures can be ultimately attributed to faulty maintenance. To place the problem of maintenance in proper perspective one may consider that very high quality aircraft reciprocating engines provide 2,000 hours of service between major overhauls; a high quality aircraft turbojet engine provides approximately 7,000 hours of service between overhauls;

a very high quality natural gas-fired reciprocating engine will provide as much as 10,000 hours service between major overhauls. In the period between major overhauls numerous minor overhauls are commonly required (e.g., the "top" overhaul of reciprocating engines). Now, the engines cited above are typical of the prime movers required in small total energy plants. At best one can expect slightly more than one year (8,600 hours) of continuous service from these prime movers before a major overhaul will be required. In the interim, several minor overhaul procedures may be required. This poses severe maintenance and management problems in operation of small total energy plants, where overhaul of the prime mover requires temporary shut down, or at least substantial reduction, of power generation.

Cost of maintenance is an especially important aspect of small scale power generation. At present, public utilities sell electrical power at an average price of approximately three cents per kw hour. The utilities estimate their maintenance costs at approximately 1 percent of sales prices, or approximately 3/100 cents per kw hour.* The level of maintenance costs found in total energy units is 3/10 cents per kw hour. Few small units can justify spending more than 3/10 cents per kw hour, and few can be maintained for less. To examine what this maintenance costs means, consider a 200 kw capacity plant operating on the average of 50 percent of full load to supply electrical power for a complex of 100 residences. In a day, the plant will produce 2400 kw hours of electrical energy.

The maximum maintenance

*Professor K. Boer, University of Delaware, Institute for Energy Conversion, in private communication.

expenditure which can be justified for such a plant is $75.00 per day. Given today's labor prices this amount is barely sufficient to support the salary and benefits of one skilled mechanic. The equipment in a total energy plant is technologically advanced (e.g., reciprocating prime movers, heat transfer apparatus, air conditioning equipment, electrical generators, switching apparatus, controls, etc.), and requires a wide range of skills for maintenance, certainly a wider range than one can hope to secure through direct employment of staff. The maintenance of small power generating units, therefore, requires careful management planning. Furthermore, technological efforts directed toward maintenance are required. For example, monitoring systems to give advanced warning of impending mechanical failure need to be developed. Also, possible management schemes wherein prime movers, or other items of equipment, might be leased from large companies having maintenance staffs of the size and breadth of competence to be effective, need to be investigated. In general, the consideration of maintenance both in design of equipment and in its utilization needs to be developed as a component of technology. The particular case at hand, total energy systems, is but one example of the broader problem of conservation of resources through manufacture of effective, durable and maintainable equipment; this problem will be considered further below (Level III). At this juncture, we merely point out that the development of suitable technology and methodologies (e.g., monitoring systems, management planning, determination of economic trade-offs) for establishment of maintainable plants and for determination of guidelines as to practicality of maintenance procedures, is required.

Level II: Utilization of Unused Energy Sources

A. Solar Energy at the Point of Utilization

The use of solar energy for space heating, air conditioning and hot water heating is one of the extremely attractive possibilities for conservation of nonrenewable energy resources. The annual incidence of solar energy on average buildings in the U.S. is six to ten times the amount required to heat the buildings (16). Solar energy is not only a presently unused and renewable source of energy, but during the cooling season the unused incident solar energy imposes a high load on air conditioning equipment which consumes energy from nonrenewable sources. It would, therefore, be appropriate to mount efforts to utilize solar energy in local applications for building services.

An important consideration pertaining to local application of solar energy is that most of the energy required by buildings is low temperature heat. For example, space heating requires air at approximately 80°F and water heating temperatures are commonly 135°F to 150°F. These temperatures are below the reject heat temperatures of most steam power plants. In present practice, combustion of high energy fuels, such as natural gas or fuel oil is used to provide this low temperature heat. But when high energy fossil fuel is used to provide low temperature heat, its capacity to produce work, which is the precious commodity of energy, is permanently lost. Utilization of solar energy in local applications to provide the low temperature heat required by buildings, is, therefore, an important possible means for conservation.

In addition, solar energy can be employed to provide air conditioning in buildings. Absorption refrigeration equipment appears particularly attractive for solar power. Present absorption equipment is very low in efficiency, but the prospects of substantial improvements in efficiency through application of modern heat transfer technology are promising. The chief advantages of absorption refrigeration equipment, in the present context, are that it requires very little power (mechanical compression is replaced by chemical effects so pumping for circulation is the only work required) and it is easy to maintain. These advantages weigh heavily in favor of development of solar-powered absorption machinery of improved efficiency.

Although a few technological problems require solution before one may expect solar energy in local applications to receive the enthusiastic acceptance of the consumer, many of the basic technological problems of solar energy have been solved. By using what is known today, it would be technologically feasible and economically justifiable to apply solar energy to space heating and water heating on a national scale; approximately 50 percent of these energy requirements (representing approximately 11 percent of the national energy consumption) could be met through local application of solar energy. The technological problems remaining in solar energy for local application are those connected with manufacturing, advances in collector design, and maintenance. The design of solar collectors for simplicity of manufacture and ease of maintenance needs to be developed. Solar collectors are currently custom-built. Modular collectors which could serve for water heating or home heating can be designed for mass manufacture, but this has yet to be done. Maintenance-free equipment or exhangeable equipment could be produced, but this also has yet to be done. The engineering design of collectors so as to optimize collection efficiency has recently undergone significant advances, which can be incorporated into designs for maintainability and low cost (17), (18), (19).

To illustrate the importance of manufacturing technology in the development of solar energy systems for local application it should be noted that in the most sophisticated solar energy devices in use today (the solid-state devices for direct conversion of sunlight to electricity in space applications) two thirds of the cost of each unit is represented by the case (20). While a great deal of research has gone into improving the efficiency of the electronics and the special materials (e.g., selective absorbers) used in solar devices, rather little work has been done on designing the prosaic components of solar equipment, such as the cases cited above, so that they can be manufactured cheaply. And yet, it is the cost of such components which largely determines the cost of the solar equipment, upon which public acceptance and economic justifiability of local solar energy applications ultimately depends. A major effort to address the technological problems of designing solar equipment for ease of manufacture and simplicity of maintenance is urgently needed.

Systems design is an additional important technological aspect of local solar energy which requires intensive study. Given any level of fuel price within the foreseeable future, the economic optimization of solar energy systems for buildings will require some "booster" heating or air conditioning capacity which utilizes other energy sources; the collection and storage facilities necessary to provide all building services by solar energy are simply too expensive to justify (21). Economic justification of a solar energy system depends upon the trade-offs between initial capital requirements of solar devices and operating costs (e.g., fuel) of conventional equipment. It is common practice to use stock item home furnaces as booster heating equipment in solar-heated buildings; also stock item hot-water heaters and air conditioners are used as "booster" equipment for other services in solar powered buildings (22). Of course, at present there is no alternative to installing a full size stock item home furnace as the "booster" in an experimental solar home. But this means that the capital costs of the solar heating system are simply an addition to the capital costs of a nonsolar building. The design of integrated solar energy systems for buildings, in which approximately small booster equipment--with sufficient capacity to "boost" but without surplus capacity which mostly remains idle--could have an immensely favorable influence upon the economic justification of solar energy in building services. For example, the combination of solar power with absorption refrigeration machinery, designed with reroutable circulation, could provide solar-powered air conditioning in summer and solar-powered building heating--using the absorption machine as a heat pump--in the winter. Heat could be bled from the intermediate temperature station of the absorption device for hot water heating all year. Booster capacity in this case could be provided by low cost electrical strip heaters applied to the distillation chamber of the absorption device. In such a system, substantial capital savings appear to be possible, especially if current expectations for improved effectiveness of absorption devices are realized. In addition, a system similar to the one described above could provide for control of humidity as well as temperature, through solar energy. This would be a significant attraction to the home owner or building operator.

Although the technological problems cited above do require attention, the major obstacles to local application of solar energy are cultural and institutional. Solar collectors on roofs appear strange and impose certain constraints as to building style and orientation. Reliable data as to maintenance requirements and measured performance of solar energy equipment in actual field service are lacking. In general, solar energy appears to the building buyer, the financier, and the building constructor as an interesting but as yet unproved idea. Testing and evaluation of field equipment can provide the information with which the institutional and cultural obstacles to the realization of these benefits might be overcome.

Solar Energy and Building Design

The use of solar energy to provide low temperature heat for buildings should be coupled with efforts to improve thermal performance of buildings themselves. Estimates in the literature pertaining to the extent to which solar energy can be used to provide space heating are generally based upon the assumption that the basic thermal design of the building will be carried out along conventional lines (22). For example, insulation, ventilation, infiltration, and fenestration are usually assumed to be the same as would be found in a building of conventional design and heat loss factors are taken to be the same as in conventional structures. In a preceeding section it was pointed out that through proper thermal design of buildings the energy required to provide space heating could be reduced by 40 percent or more, compared with energy required by buildings of conventional designs. With present estimates indicating that solar energy should be capable of providing 50 percent of the space heating requirements of a conventional building, it would appear that through upgraded thermal design of the building itself it would be possible to build solar homes which derive substantially more than 50 percent of their space heating energy requirements from the sun. The precise level of solar heating which one may hope to achieve in a suitably designed home depends upon economic trade-offs between costs of solar energy, storage facilities, and costs of additional insulation, draft sealing, double glazing, etc. Detailed study of this question should be pursued to provide a basis for design of solar buildings.

Some Economic Aspects of Solar Energy in Local Application

One may consider the costs of utilizing solar energy to provide low temperature heat in local applications, such as domestic hot water heating, in (at least) two ways. First, the cost to the consumer of installing a solar device may be compared with the total costs which the consumer would have to pay for fuel or electric power were the solar device not to be installed.* A second way to consider the costs of solar energy is to compare the net capital outlay required to effect a reduction in demand upon fuels presently used to supply energy with the costs of increasing the capacity of the present national energy supply system, assuming continued expansion is indeed possible. The former consideration has been treated extensively in the literature of solar research (22), (23), (24). The latter aspect of solar energy appears not to have been treated previously, and will be considered here. It is reemphasized that we consider local application of solar energy to provide low-temperature heat.

Hot Water Heating as an Example

At present, domestic hot water heating accounts for approximately 3 percent of the national energy consumption (Appendix I). Solar hot-water heating has been exploited abroad (25), (26). Given the climatic conditions of the USA, it should be both technologically feasible and economically justifiable to provide at least 50 percent of this demand for energy via solar devices (25). Thus, in considering the application to solar energy to domestic hot-water heating one is dealing with a potential reduction of 1.5 percent of the national demand for fuels.

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*This comparison assumes that the consumer will own and maintain the solar device, but such an arrangement may be neither necessary nor desirable.

Solar collectors of one square meter surface area and having the capacity to retain an average of 3.5 kwh per day of solar energy in the form of low-temperature heat have been demonstrated (16), (17).* Presently, such a collector, suitable for domestic hot-water heating can be produced for approximately $18 per square meter. Through the application of modern materials and manufacturing techniques, it should be possible to reduce this cost to $15 per square meter, or less. At the former figure, the capital cost of collecting one kwh per year of solar energy, in the form of low-temperature heat, is 1.4 cents. To make use of solar energy for hot-water heating in typical residence, the addition of a collector may be sufficient. For solar space heating, an energy storage facility, which may double the price of the system, would be required. To see what the costs estimated above would mean to the individual householder, consider that a typical dwelling in the USA uses approximately 10,000 kwh per year for hot-water heating. A collector to provide half of this energy annually would be approximately 4 square meters in area and would cost approximately $76. For the nation as a whole, the cost of implementing solar domestic hot-water heating in the 60 million dwelling units of the USA, to effect a 1.5 percent reduction in demand upon fuels, would be approximately $4.5 billion. Thus, we may take a figure of $3 billion as an approximate estimate of the capital requirements of reducing national demand for fuel by one percent, through implementation of solar energy to provide low-temperature heat.

*The average cited here is taken over a period during which cloudy and sunny weather obtained.

To estimate the capital costs of increasing the national energy supply capacity by one percent to supply low temperature heat in building services, we note that the low temperature heat used in buildings is provided, almost entirely, by combustion of natural gas or by electricity.* Thus, expansion of energy supply capacity to meet growth in building services will require expansion of supply of gas and electrical power, or conversion of domestic equipment for utilization of more readily available fuels such as coal. The costs of converting domestic or industrial equipment are very high. It would not be unreasonable to take $200 as the cost of converting gas-fired residential space heating plant to permit combustion of residual oil or coal. In addition, in some regions it may not be desirable, or even feasible, to convert equipment for combustion of other types of fuels.** Thus, in treating expansion of national energy supply capacity to supply low temperature heat in building services, it is reasonable to consider expansion of the national capacity to supply gas and electrical power.

Domestic supplies of natural gas are severely strained. Expansion of capacity to supply gas will probably entail import of liquified gas.

*Approximately 80 percent of domestic space heating is done by gas-fired equipment. Virtually, all domestic hot water heating is provided by gas or electricity.

**For example, in certain industrial areas local efforts to decrease air pollution started with conversion of both industrial domestic combustion equipment from coal and oil to gas. It would be difficult to justify reconversion at this point. The same argument applies to domestic heating equipment.

Current estimates for the capital costs of gas liquification plants indicate that a plant capable of delivering 100 million cubic feet of gas per day will cost between $200 and $300 million to build.*

Taking the heating value of the gas (~1000 BTU per cubic foot) as the basis for estimating the cost of such a plant, one finds that the capital costs of gas liquification are approximately $160 to $240 per kilowatt. Assuming that such a plant can be operated at 8000 hours per year, the capital costs of gas liquification may be estimated as 2 to 3 cents to increase the national energy supply capacity by 1 kwh per year. These figures reflect only the costs of liquification. In addition, one must include costs of increasing the transportation system (e.g., refrigerated tankers), storage capacity (refrigerated tanks), and distribution network (pipe lines) for this form of fuel, as well as the capitalization of wells to provide raw petroleum for liquification and the energy required for transporting the fuel to the point of utilization. Taking all considerations into account, it would appear reasonable to estimate the costs of increasing gas supply capacity through liquification as being approximately 5 cents per kilowatt hour per year. Thus, to increase the present national energy supply capacity by one percent, through gas liquification, would cost approximately $10 billion.

To estimate the costs of increasing electrical supply capacity, one notes that a modern power plant costs between $200 and $300 per kilowatt to build. In addition to building the plant, one must provide additional fuel and additional electrical distribution capacity

*Such a plant will also be able to supply a large quantity of residual fuel oil to those installations capable of using it. However, for the purposes of estimating the costs of supplying energy for domestic consumption, we will compare the cost of the plant to its capacity to supply gas, which is its principal function.

for the plant. If one assumes that these additional capital requirements can be met by $100 per kilowatt of plant capacity, the net cost of increasing electrical power capacity may be taken to be approximately $400 per kilowatt. If one further assumes that newly constructed plants may run, on the average, at 65 percent of peak capacity, the capital cost of increasing national energy supply capacity by 1 kwh per year is found to be approximately 8 cents. To increase national energy supply capacity by one percent through expansion of electrical power would, therefore, cost approximately $16 billion.

The difference in capital requirements for reducing demand for fuels by one percent via utilization of solar energy for low-temperature heat ($3 billion) and the costs to increase present supply capacity by one percent (as much as $16 billion), may be debatable in certain details, and, in any event, require further study. The purpose of this section has not been to offer a definitive estimate of these costs, but rather to provide a preliminary estimate to assist one in judging whether local utilization of solar energy for low-temperature heat offers an effective investment opportunity, in the context of national energy policy. Based upon the above, it is concluded here that solar energy for supply of low-temperature heat in buildings does offer an effective investment opportunity.

One of the reasons why use of solar energy for low-temperature heat costs less than corresponding expansion of national energy supply capacity is that expansion of the present national energy supply capacity requires energy in high quality form.* High quality energy, such as fuels for high temperature combustion or electrical energy, are readily convertible to work, which is the precious commodity of energy. Such energy is generally expensive to generate. Low quality forms of energy, such as low-temperature heat, are usually inexpensive to generate; in fact, low quality energy is often discarded.

Investment in the use of solar energy can be furthered two ways. Development of effective, reliable, and inexpensive solar collectors should be pursued. In addition, the role of government construction policy, particularly in FHA and VA, in adopting standards under which domestic solar equipment may qualify for residential construction and loan support could be immensely effective in mobilizing investment in solar energy.

B. Incineration

The use of solid waste as fuel has attracted favorable attention of many technologists. Solid waste products are known to have heating values varying from one half that of fuel oil (paper) to as much as that of fuel oil (consumer plastics, tins). In addition, solid waste represents a form of unexploited fuel which will probably remain in relative abundance for some time to come. It has been estimated that by the year 1990 the heating content of collected urban refuse could be used to generate as much as 35 thousand megawatts of electrical power (27). However, before the apparently rich fuel resources of

*The thermodynamic notion of quality (or more precisely, availability) is a measure of the extent to which forum of energy can be converted to work.

solid refuse can be put to use, a number of technological problems require resolution. These include the design of combustion plants (in this case, incinerators) to use widely varying fuels (e.g., waste paper, consumer plastics). In addition, the selection of materials to tolerate some of the highly corrosive products of combustion of solid refuse poses another important technological problem to be resolved in incineration technology. The supply of solid refuse in a given area may fluctuate seasonally. The planning of incineration plants to operate effectively with widely varying fuel loadings and the design of electrical generating plants or district heating systems to use the heat generated by such incineration plants poses a set of demanding technological problems. Sorting of refuse according to combustion properties (e.g., separation of paper, plastic, glass and metal) poses an additional set of challenging technological problems, solutions of which are required as prerequisetes to wide spread use of incineration as a source of useful heat. In addition, the control of potentially polluting emissions from incinerator combustion chambers, which must accept fuels of widely varying character constitutes an area of required technological development.

The preceeding list of examples of technological problems to be addressed is offered to indicate that the use of incineration to provide useful heat constitutes a field of technology in itself. This field requires an integrated technological effort to bring it to fully useful form. The federal government will undoubtedly be substantially involved in incinerator construction in the coming years. And yet, at present there is no identifiable resource, either within the federal government or private industry to provide the technological basis for construction standards, environmental regulations or rules for qualification for federal support which may apply to incineration plants. Such a facility would appear to be called for.

Level III: Energy Conservation in a Broader Context

The largest single consumer of energy in the U.S.A. is industry. The potential for moderating national demand for energy by improving the effectiveness of present industrial processes has already been discussed. Here we consider the possibility of conserving energy by improving the products in which the energy of processing is invested. To illustrate the questions contemplated for study, the following three specific examples are offered.

A. The Use of Materials as Dictated by Design Standards

In building construction, plumbing, and several other areas, the codes governing design are overly conservative for most applications. This simplifies design procedures, but leads to excessive use of materials, which in turn requires excessive use of energy. The possibility that more accurate design standards can be devised, which would permit construction, plumbing, and manufacturing operations to proceed without excessive use of material and without sacrifice of the functionality on safety of the product merits detailed study. For example, the size of air-vent piping used in plumbing systems is chosen so that it can satisfy the needs of toilet systems in large apartment complexes or office buildings. An air-vent pipe of one-fifth the conventional size (with correspondingly smaller investment in energy of manufacture) would be complete adequate for most residences. This case and other examples of excessive materials should be studied in the context of conservation of energy and other natural resources. Economic implications of shifting industrial emphasis from areas of materials production to areas of effective materials utilization, should be considered as an integral part of such a study.

B. Durable vs. Disposable Goods.

The disposable goods to which the public has become accustomed are widely recognized to constitute a drain on natural resources in general and energy in particular. The case for adoption of reusable bottles and containers, as a conservation measure, has been advocated by many. This example, while it is but one of many one might cite, does serve to illustrate that sound arguments on both sides of the question of durable goods can be given, and that this question requires thorough objective study. For, while reusable glass milk bottles are beneficial to society in connection with conservation of resources, they may constitute a hazard to the householder.

Field interviews with physicians reveal that glass milk bottles, which are wet, slippery, and heavy when removed from the refrigerator, often slip from one's grasp, fall and shatter, producing shards which can inflict serious wounds. The seriousness of the accidents was compounded by the fact that the spilled milk made footing slippery and led at times to the accident victim's falling on the glass shreds. With the advent of paper milk cartons the frequency of this type of accident appears to have diminished. However, conclusive evidence is not available at present. The object of citing the glass milk bottle here is just to point out that important ramifications of any major change, such as converting from durable to disposable goods, exist and require study. For example, the design of glass containers for both reusability and safety should be studied if an effective conversion from disposable to durable containers is to be proposed.

C. Maintainability of Machines

Manufacturing of machines is one of the largest components of U.S. industry. The possibility that the average life of machines might be extended through design for durability, careful utilization of durable materials and, especially, design for effective maintenance should be considered. If the average life of machines and other manufactured goods could be extended by, say 25 percent, then the energy requirements of the manufacturing industry might be reduced by a corresponding fraction. The technological prerequisites for such an alteration of design and manufacturing have yet to be satisfied. Moreover, the social and economic ramifications of such a step require careful study. Nevertheless, the possibility of using more careful design to produce more durable goods in which materials, energy and in fact all natural resources are invested with greater effectiveness than in present practice appears to be an attractive possible measure for conservation of natural resources.

In connection with the technological aspects of a possible shift from disposable to durable materials and manufactured goods as a measure for conservation of natural resources, it is pointed out that the technology of maintenance and design for reliability urgently needs development. Maintenance of machinery, as a technological field, could be substantially advanced by incorporation of existing techniques of monitoring performance into field practice. In addition, the establishment of methods for detection of impending failure or malfunction could be developed through application of existing techniques. Advanced detection techniques--e.g., the acoustic signature of reciprocating machinery or wear particle analysis--for determination of maintenance needs require development. As a general rule, one may say that the entire field of maintenance, as it is practiced today, does not constitute a technology; the disparity between existing and developable techniques on the one hand and field practice on the other, is simply too great. And yet, maintenance of the complicated equipment upon which the advanced society of the U.S.A. depends, appears to be essential to any effort to insure effective use of natural resources. Furthermore, maintenance and monitoring of equipment so as to avoid unexpected failures is an effective measure for reducing the hazards of personal injury and saving lives as well as for conserving natural resources. As such, development of effective technology of maintenance merits support. The establishment of a functioning effective technology of maintenance, addressed to the problems of extending the useful life of equipment, avoiding costly and dangerous failures, and providing for effective utilization of natural resources could represent an important contribution to resolving a number of critical national problems.

Efforts to study the problems outlined above could be undertaken along the following lines. Coordinated technological and economic studies of the questions indicated are required. Technological options such as development of maintenance technology, design for maintenance and durability, and utilization of durable materials require study. Economic trade-offs entailed in implementing the technological options must be determined. Goals which are both technologically feasible and economically justifiable need to be identified; the optimal distribution and programming of investment to attain these goals needs to be determined. The application of simulation technology to study of overall behavior of the national energy system, and the response of the system to the alterations under study, should be pursued.

Conclusions and Recommendations

In the above it has been shown that ineffective utilization of energy in buildings and industrial processes constitutes a major component of the national energy problem. There is ample latitude for improvement of effectiveness of energy utilization, and moreover such improvement appears to be easily justifiable economically, especially when the costs of the alternative of increasing energy supply capacity to meet rising energy demands are considered. The measures to improve effectiveness of energy utilization are basically technological in nature. However, at present, there does not exist an identifiable functioning technology for energy conservation through effective utilization. To be sure, techniques for this purpose exist and more advanced techniques are developable. But, as yet, extant techniques have not been integrated and applied in rational field practice, and there is no disciplinary framework within which to pursue possible further developments. It is recommended that appropriate measures be undertaken to create and implement a technology for energy conservation through more effective utilization.

Appendix A

ENERGY CONSUMPTION IN THE UNITED STATES BY END USE
1960-1968
(Trillions of Btu and Percent per Year)

Sector and End Use	Consumption 1960	Consumption 1968	Annual Rate of Growth	Percent of National Total 1960	Percent of National Total 1968
Residential					
Space heating	4,848	6,675	4.1%	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
Air conditioning	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
Air conditioning	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%

Note: Electric utility consumption has been allocated to each end use.

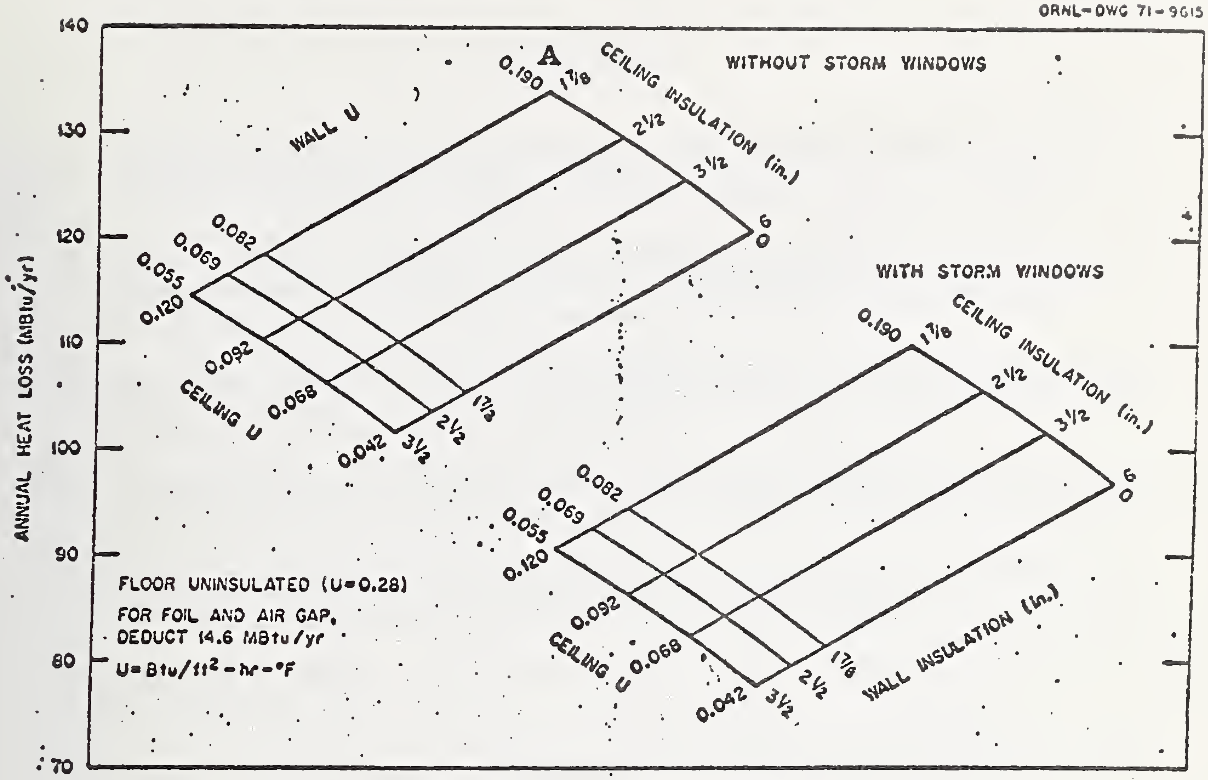
Source: Patterns of Energy Consumption In The United States (1).

Appendix B

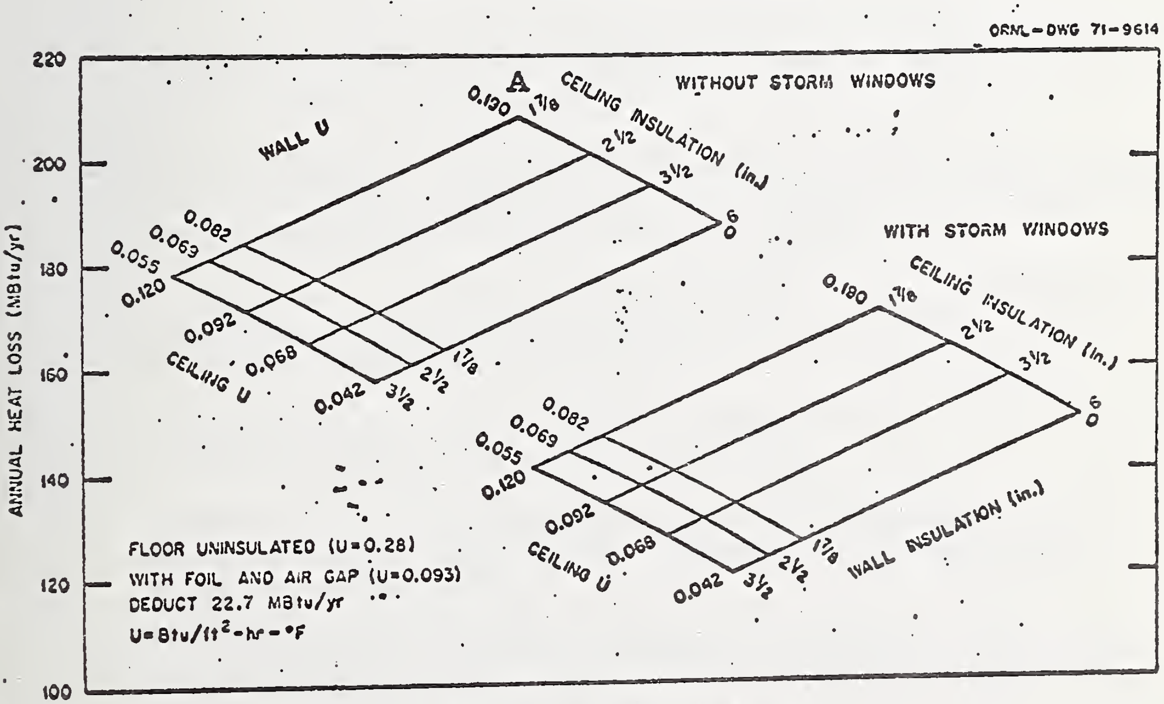
A quantitative estimate of the savings in energy for home heating, which are technologically feasible, may be obtained from the graphs of Figure 1.[2] The upper point in these graphs (Point A) may be assumed to represent the approximate state of insulation and storm window sealing in approximately 90 percent of housing built prior to issuance of minimum property standards. The heat losses from these houses can be reduced by approximately 45 percent, by application of heavy ceiling insulation, side wall insulation and installation of storm windows. Thus, it would not be unreasonable to assume that if installation of insulation and storm windows on housing units presently in service were feasible, the present national demand for fuel consumed in space heating of residences could be reduced by approximately 40 percent.

Appendix B

Annual Heat Loss From Model Homes in Two Cities



Annual Heat Loss: New York Residence.



Annual Heat Loss: Minneapolis Residence.

Figure 1:
Annual heat loss from buildings with various weights of insulation (2)

Source: The Value of Thermal Insulation in Residential Construction

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In two major sectors of the economy (building services and industrial processes), accounting for approximately 75 percent of total national energy consumption, energy utilization is found to be inefficient. It is estimated that in these two sectors, as much as 25 percent of the energy consumed annually by the nation as a whole may be lost through ineffective practices. Possible reasons for existence of ineffective utilization are considered, and possible means of improving effectiveness of utilization are discussed. Three possible levels of effort to promote effective utilization of energy are identified; one promotes effective use of present fuels in present processes; the second promotes utilization of presently unused energy sources; the third promotes more effective investment of energy in durable and maintainable products.

Substantial latitude for improvement of effectiveness is shown to be realizable through technological efforts at these three levels. It is finally recommended that a national program, incorporating efforts at the three levels identified, be undertaken with the ultimate goal of creating and implementing a technology of improved energy utilization.

17. KEY WORDS (Alphabetical order, separated by semicolons)

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