(*29*) have been published on the treatment of tardive dyskinesia, even though the majority of clinicians continue to ignore the existence of this complication. It is also revealing that most of the drugs that are responsible for neurologic side effects are being tested for the suppression of tardive dyskinesia. With a few exceptions (*2*, pp. 297–310; *30*), little has been written on the prevention of permanent neurologic effects by a more judicious use of psychoactive agents. This is another indication of how dependent the medical community has become on chemical agents.

Until now, only a few independent investigators have carried out clinical studies on tardive dyskinesia. The problem has become of such a magnitude and complexity that drug companies and certain government agencies will have to take the initiative. A more responsible attitude toward the risks involved in long-term treatment with neuroleptics may necessitate a change in the priorities of drug research and a reallocation of funds. Education of the medical profession and the public by improving package inserts and by mailing informative material to all physicians is essential, but certainly insufficient. The neglect of a serious health problem for so many years has deeper roots than mere ignorance of facts. The problem of tardive dyskinesia should be viewed as another example of large-scale and inefficient application of a potentially useful technical discovery without consideration for its long-term effects on the individual and his environment.

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Energy Conservation through Effective Utilization

Energy consumption could be reduced by improved efficiency of utilization in buildings and in industry.

Charles A. Berg

There are indications that the demand for energy in the United States will soon outstrip both power generating capacity and fuel supply.

The basic problems in energy supply can be divided as follows. In the immediate future (1972 to 1980) the most important problem appears to be inadequate power generating capacity. In the distant future (the year 2000 and beyond) the basic problem is availability of fuel or of energy in another form, such as solar or geothermal energy. In the intermediate time range (1972 to 2000) the conservation of energy by means which do not damage the functioning of the economy could well be the most important consideration.

There are two main approaches to solving the problem of providing sufficient energy for future needs: either the supply of energy can be increased, or the demand for energy can be reduced. However, these approaches are not independent of each other. For example, a decrease in the demand for energy caused by curtailing industrial electrolytic processing could adversely affect the capacity to increase the energy supply 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.

In this article I discuss various ways in which the demand for energy could be decreased, focusing not so much on discouraging demand by increasing prices (the belt-tightening approach) as on reducing energy consumption by improved efficiency of energy utilization in buildings service and in industry. In the long run, effective actions to moderate demand will probably consist of a combination of the belt-tightening approach and improvements in efficiency of energy utilization.

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 that might be taken to moderate demand should begin to take effect in the intermediate time range (1980 to 2000); as a matter of principle, actions proposed to take effect during this time period should be reviewed for possible conflict with solutions of long-term problems of fuel and energy supply. For example, there are frequent proposals that local combustion of fuels should be used to drive power generation equipment and that reject heat should be utilized locally. Such proposals should be considered in light of the fact that centralized combustion facilities, for example, large power plants, can operate at higher combustion efficiency than small low-cost plants appropriate for installation in individual buildings. Also, large power plants can usually be more efficiently operated and maintained. Thus 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 attention. 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, I will show that many of the ways in which energy is now 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 heat wasted in energy consuming processes are seldom applied. Faced with a developing shortage of nonpolluting fuels and with the recognition that fuels of all types are a nonrenewable resource, it is appropriate that we 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." Surplus energy, with all of its economic implications, could have to be produced merely to supply these leaks. Thus, improvement of the effectiveness of energy utilization is seen here to be necessary both as a measure for conservation of natural resources and as a measure for economic optimization of investments in energy.

Technological efforts to moderate demand through improved effectiveness of utilization should consist of a combination of short-range measures, such as the upgrading of 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.

Present Uses of Energy in the United States

The possibility that demands for energy can be moderated by improving the effectiveness of energy utilization without affecting the expected output of present processes can be evaluated by determining (i) how much energy is consumed in various sectors of society, and (ii) 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 wasted were presently available technology applied. The possibility of further reductions of energy requirements for existing processes, through the development of new technology, is an important subject that I discuss later.

Considerable data are available about energy consumption and are well summarized in a report by the Stanford Research Institute (SRI) (*1*). However, data required for the determination of waste energy are known for only a few sectors of the economy.

Data from SRI indicate that, of the total national energy consumption (NEC), 19.2 percent is used in residential building services, 14.4 percent in commercial building services, 41.2 percent in industrial processes, and 25.2 percent is used in transportation. Considerable amounts of data concerning the effectiveness of energy utilization are available for commercial and residential building services, but few such data are available for industrial processes.

Energy Conservation by Improved Thermal Performance of Structures

The major uses for energy in buildings are space heating, air conditioning, and hot water heating (Table 1) (**2**). 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 that 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 rates of air infiltration from outside, and excessive fenestration. To estimate the present effectiveness of building insulation and ventilation one may note that the Federal Housing Administration (FHA) minimum property standards of 1965 permitted heat losses of 2000 British thermal units per thousand cubic feet–degree day (*3*) in residences. The property standards required by Housing and Urban Development (HUD) Operation Breakthrough in 1970 reduced this figure to 1500 and the newly implemented FHA minimum property standards (1972) require heat losses to be less than 1000 Btu per thousand cubic feet–degree day. The

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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. Because few buildings are designed to exceed the standard requirements 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. Heat losses in these neighborhoods therefore represent an especially significant leak in the national energy consumption system (Fig. 1) (*4*).

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 (*5*). Present construction practices yield infiltration rates which exceed by a factor of 4 the average ventilation requirements of typical buildings (*2, 6*). Special areas, such as toilet facilities, kitchens, and conference rooms where heavy smoking may occur, have high ventilation requirements when in use. However, in most buildings the high ventilation rates required for use of these areas are maintained all day.

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

Future standards for insulation, ventilation, and infiltration may offer even greater potential for saving energy. Engineers studying building insulation estimate that it will be technologically and economically feasible to reduce heat losses from buildings to approximately 700 Btu per thousand cubic feet–degree day, through the use of insulation. If these estimates 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.

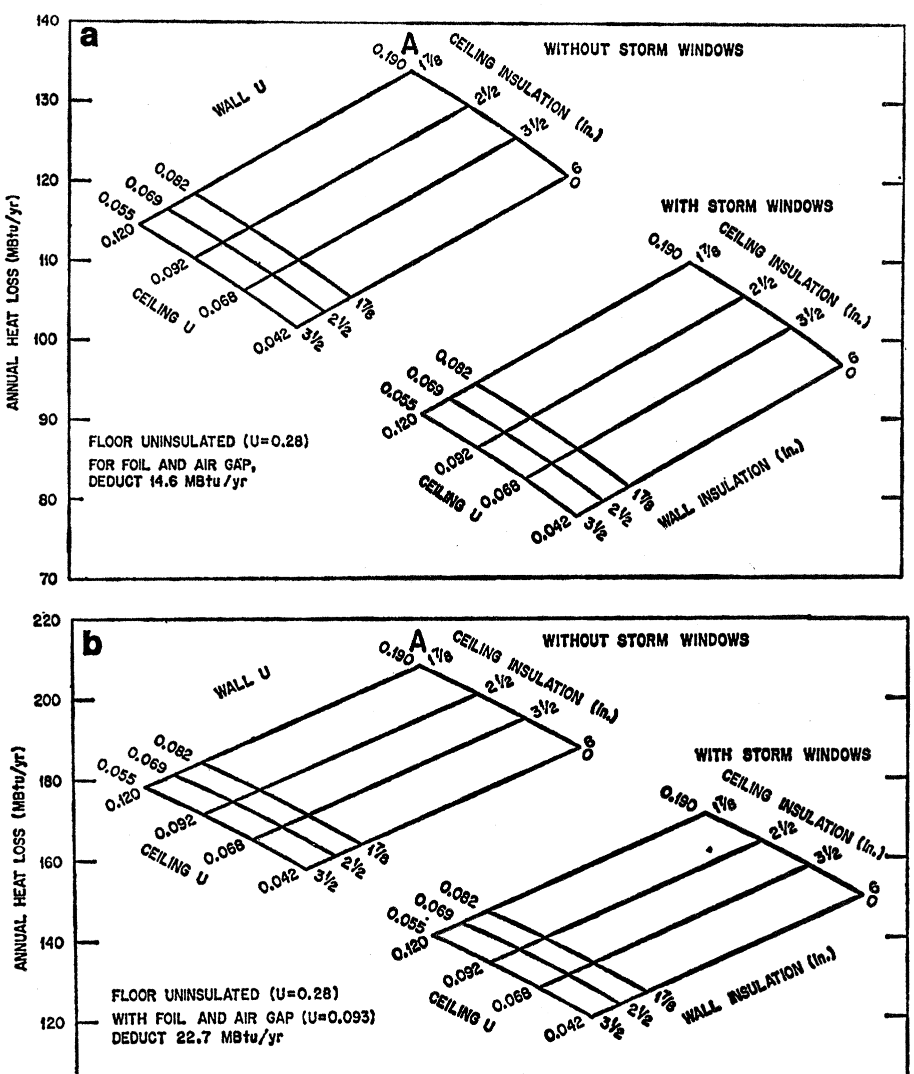

Fig. 1. The annual heat loss from model homes with various weights of insulation in (a) New York, and (b) Minneapolis. A quantitative estimate of the savings in energy for home heating, which are technologically feasible, may be obtained as follows (*4*). The upper point, *A*, in (a) and (b) may be assumed 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 now in service were feasible, the present national demand for fuel consumed in space heating of residences could be reduced by approximately 40 percent (1 MBtu = 10^6 Btu; U = Btu/ft^2·hr·°F). [From Moyers (*4*)]

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. Heating equipment for buildings, 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 lifetime. If one takes the few field data now 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 is 50 percent or less, with units functioning at efficiencies as low as 35 percent not being uncommon [for example, see (*7*)].

The efficiency of air conditioning equipment varies widely. Air conditioners of the same rated output may differ by a factor of 2 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.

Illumination in Buildings

Illumination of residences and commercial buildings accounts for 1.5 percent of the national energy consumption (*1*). In office buildings in the United States, the illumination provided often exceeds, by as much as a factor of 2, the amount of illumination used in similar European buildings, 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 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 exist, and could be more widely applied. Further research to ascertain the most beneficial amounts of illumination to building occupants would be of great value in efforts to reduce excessive energy consumption in buildings.

Hot Water Heating in Buildings

Hot water heating merits special consideration in energy conservation efforts (*2*). Once the hot water is used, the water, with the energy it contains, literally goes down the drain. Furthermore, as shown in Table 1, hot water heating accounts for approximately 4 percent of the total national energy consumption. When viewed in this context, the energy lost in hot water heating is indeed significant. A number of ways to recapture the heat in expended hot water, by using heat exchangers on drains, have been suggested. Although most such proposals are in conflict with local plumbing codes, some could be implemented through minor modifications of such codes. 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.

Other Means of Saving Energy in Buildings

Other components of building operations contribute additional small amounts to national energy consumption (for example, cooking 2.2 percent, clothes drying 0.3 percent) (*1*). Although extensive data on the effectiveness of energy utilization in appliances 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 their efficiency of energy utilization.

The data cited indicate that buildings now consume approximately 40 percent more energy than is necessary. This represents a correctable loss of approximately 13.5 percent of the national energy consumption. Various courses of action by which more effective utilization of energy in buildings might be promoted will be described later in this article.

Table 1. Total fuel energy consumption in the United States by end use [data from (*1*)]. Electric utility consumption has been allocated to each end use.

End use	Consumption (trillions of Btu)		Annual rate of growth (%)	Percent of national total	
	1960	1968		1960	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	93	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
Feedstock	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

Thermal Effectiveness of Industrial Processes

Although data pertaining to the effectiveness of energy utilization in industry are less extensive than those available for building services, there is reason to believe that it would not be unreasonable to assume that energy savings of approximately 30 percent might be realized by applying already developed energy conservation techniques to industrial processes. 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, the design of piping systems to minimize pumping costs and the design of pipe insulation to optimize the trade-off between heat loss and total costs of insulation operation and maintenance are common practices, and are representative of the consideration given to effective energy utilization in large plants for power generation and in other similar industries (*8*).

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 (*9*), 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 now 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.

That energy can be saved in many industrial operations is indicated by many sales offices of large volume gas suppliers having representatives assigned to advise industry how to use less fuel to conduct their operations. The success of these recently instituted programs has yet to be measured, but one may presume that they will prove beneficial.

Certain examples of improved equipment merit attention 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 (*10*). Other studies of the effectiveness of industrial energy utilization indicate that application of available heat recovery devices (for example, heat wheels) and thermal management techniques could yield net energy savings of 30 percent or more in typical industrial operations (*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 by the 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 in a variety of industries have indicated that effectiveness of energy utilization has been of sufficiently little concern in the past that there is ample opportunity for improvement. Approximately 30 percent of the energy used in industrial processes could be saved through the application of existing techniques that are 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 (for example, cement making, refining, chemical processing), and especially the institution of a methodology for the utilization of waste heat in plants may be expected to yield further energy savings in industry, beyond the estimated 30 percent quoted above.

Summary of the Problem

From all the data cited, it is evident that approximately one-quarter of the total national energy consumption may escape effective use because of correctable leaks at the point of utilization. A major reason for this is that at the point of energy utilization, economic justification of energy consuming equipment tends to be governed by initial costs (*13*). Thus, one often 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 must be coupled with steps to induce a change in the methods of economic justification of building and equipment purchases. If the purchaser can be alerted to the significance of the lifetime operating costs of buildings and energy utilizing equipment, as well as the initial costs, the technological possibilities to enhance the effectiveness of energy utilization in buildings and industrial processes might then be brought to field implementation.

Means to Promote Effective Energy Utilization

I now suggest three ways to approach the problem of improving the effectiveness of energy utilization. The first approach focuses upon improved effectiveness of use of present fuels; the results from such an approach could take effect in a relatively short time (about 2 to 5 years). The second approach focuses upon the utilization of unused energy sources and fuels; results from this approach would require new programs and might be expected to take effect in about 5 to 10 years. In the third approach, energy utilization is considered in the broader context of the energy invested in materials and manufactured goods. Results from this approach would require new technological and economic studies and might take effect in about 10 to 20 years.

Improved Effectiveness of Use of Present Fuels in Current Applications

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. Second, a technology for upgrading the thermal performance of existing structures is required. Even with present high rates of construction, approximately half of the buildings in service in the year 2000 will have been built before 1973 (*14*).

To improve energy utilization in buildings of the future, technological attention must be given to insulation, draft sealing, ventilation, proper selection and maintenance of equipment, envelope design, fenestration design, and illumination. The optimization of trade-offs between increased capital outlay and decreased operating costs over the life of a building must be determined with reliable estimates of fuel price increases being taken into account (*9*). Field data to establish the economic benefits of energy conservation measures must be compiled and made known. Preliminary data (*15*) indicate that, at current fuel prices, increased capital expenditures on thermal upgrading of existing structures (for example, installation of additional insulation) can pay off in approximately 5 years. If one assumes that fuel prices will increase, the payoff time may realistically be assumed to be substantially less than 5 years. Although this is encouraging, conclusive data must be compiled 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 (for example, fireproof) insulation of existing buildings require development. In addition, some criteria for estimating the expected life of existing buildings must 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.

Finally, performance standards by which the effectiveness of energy utilization in buildings can be judged must be established. To evaluate the performance of buildings, test methods must first be devised for measuring heat transmission from buildings, for determining ventilation and infiltration rates, and for determining the effectiveness of building equipment; standard duty cycles in accordance with which building systems can be tested must be established; and means of interpreting test results in terms of effectiveness of energy utilization must be developed. It will then be possible to demonstrate that the field practices advocated actually do lead to more effective use of energy.

The possibility of improving the effectiveness of energy utilization in buildings on a national scale, through federal standards maintained by FHA and the Veterans Administration (VA), and through incentives (for example, home improvement loans) is immense. Thirty-seven percent of the construction in the United States is either built for the federal government or financially assisted by the federal government, and the influence of federal regulations in construction extends well beyond this sector. Properly coupled technological and economic efforts by regulatory agencies could have a powerful influence upon improving the effectiveness of energy utilization.

Industrial processes. In the study of energy utilization in industry, the real efficiency of industrial processes must first be determined. More data must be obtained that will indicate precisely what improvements in effectiveness of energy utilization are technologically feasible and economically justifiable. Programs to distribute information on the technological and economic aspects of improved effectiveness of energy use should be developed on a national scale and methodologies of energy conservation should be demonstrated. For example, techniques of waste heat management by means of heat recovery devices, the application of efficient heat transfer devices such as heat pipes, and coupling between presently independent items of plant equipment, should be demonstrated. As the 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, if effective "air slides" using hot gases of combustion as the fluidizing media could be 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.

Fuel efficiency and maintenance of total energy systems. A total energy system is one in which electric power for a small complex of buildings is generated 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 to establish the feasibility of total energy systems must be obtained, and technological problems bearing upon the effectiveness of such systems, such as their maintainability and fuel efficiency, must be studied.

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 or topping cycles to attain high combustion temperatures and the efficiencies of power generation associated with them (*16*). To alleviate local thermal pollution from large plants, use might be made of "bottoming cycles" employing low temperature working fluids, but such cycles have yet to be developed (*17*). 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.

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 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 a 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.

Central power stations, with their high effective temperatures of combustion and consequent high thermal efficiencies, also have certain disadvantages. High temperature combustion produces, in addition to thermal pollution, large amounts of other pollutants, particularly nitrogen-oxygen compounds. 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 (for example, where to obtain or reject heat without upsetting the local environment). Efficient, easily maintainable heat pumps have to be developed.

A broad spectrum of fossil fuels exists, 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 the national energy system through central station power plants using nonfossil fuels 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 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.

Small scale power units of 500 kilowatts or less are 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 total energy systems in the field shows that these small plants have a very high rate of failure (*18*) that is largely attributable to faulty maintenance. For comparison, one may consider that very high quality reciprocating engines in aircraft provide 2000 hours of service between major overhauls; a high quality turbojet engine provides approximately 7000 hours of service between overhauls; a very high quality natural gas-fired reciprocating engine will provide as much as 10,000 hours of service between major overhauls. In the period between major overhauls, numerous minor overhauls are commonly required (for example, the "top" overhaul of reciprocating engines). The engines cited above are typical of the prime movers required in small total energy plants. At best one can expect slightly more than 1 year (8600 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 for small total energy plants, where overhaul of the prime mover requires temporary shutdown or substantial reduction of power generation.

Cost of maintenance is an especially important aspect of small power plants. Public utility companies now sell electrical power at an average price of approximately 3 cents per kilowatt hour. Some utility companies estimate that their maintenance costs are approximately 1 percent of sales prices, or approximately 2.5/100 to 3/100 cent per kilowatt hour (*19*). The level of maintenance costs for total energy units is 3/10 cent per kilowatt hour (*20*). To examine what this maintenance cost means, let us consider a plant with a 200-kw capacity 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 kwh of electrical energy. The maximum maintenance expenditure which can be justified for such a plant is $75 per day. At 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 (for example, reciprocating prime movers, heat transfer apparatus, air conditioning equipment, electrical generators, switching apparatus, and controls) and requires a wider range of skills for maintenance than one can hope to secure through direct employment of staff. The possibility of prime movers, or other items of equipment, being leased from large companies having effective maintenance staffs should be investigated; the maintenance of small power plants requires very careful management planning. All these considerations indicate that there are fundamental unresolved technological questions upon which the evaluation of total energy systems and other matters of energy planning depend.

Utilization of Unused Energy Sources: Solar Energy

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 United States is six to ten times the amount required to heat the buildings (*7*). Solar energy is not only an unused and renewable source of energy, but during the cooling season 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 in such applications is that most of the energy required by buildings is low temperature heat. For example, space heating requires air at approximately 28°C and water heating temperatures are commonly 60° to 65°C. These temperatures are below the reject heat temperatures of most steam power plants. At present, combustion of high energy fuels, such as natural gas or fuel oil, is used to provide this low temperature heat. But in this practice the capacity of the fuel to produce work, which is the precious commodity of energy, is permanently lost. The utilization of solar energy would, therefore, be an important means for conservation.

In addition, solar energy could be used to provide air conditioning. Absorption refrigeration equipment, which appears particularly attractive for solar power, is now 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 equipment are that it requires very little power (mechanical compression is replaced by chemical effects, so that 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.

By using what is known today, it would be technologically feasible 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. To do this, maintenance-free solar equipment which can be manufactured cheaply would have to be produced. The basic scientific requirements, such as the design of collectors that can optimize collection efficiency, have already been satisfied and can be incorporated into designs for maintainability and low cost (*21*, *22*).

In the most sophisticated solar energy devices in use today (the solid-state devices for direct conversion of sunlight to electricity in space exploration applications), two thirds of the cost of each unit is represented by the supporting frame or case (*23*). While much research has gone into improving the efficiency of the electronics and the special materials (for example, selective absorbers) used in solar devices, rather little has been done on designing the prosaic components of solar equipment (such as the cases) 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 use of solar energy which requires intensive study. Regardless of the price of fuel 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 (*24*). Economic justification of a solar energy system depends upon the trade-offs between initial capital requirements of solar devices and operating costs (for example, fuel) of conventional equipment (*25*). At present there is no alternative to one's 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 appropriately 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—the absorption machine being used as a heat pump—in the winter. Heat could be obtained from the intermediate temperature station of the absorption device for hot water heating all through the year. Booster capacity in this case could be provided by low capacity 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, such a system 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.

The major obstacles to local application of solar energy are cultural and institutional. Solar collectors on roofs appear strange and impose certain constraints upon building style and orientation. Reliable data on 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 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 the thermal performance of the 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 buildings will remain conventional (*25*). Because proper thermal design of buildings could reduce the energy required to provide space heating by 40 percent or more compared with energy required by buildings of conventional design it should be possible to build solar homes which derive substantially more than 50 percent of their space heating requirements from the sun. The precise amount of solar heating that could be achieved in a suitably designed home depends upon economic trade-offs between costs of solar energy, storage facilities, and costs of additional insulation, draft sealing, and double glazing, for example. Detailed study of this problem should be made to provide a basis for design.

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 (*26*). 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 currently used to supply energy with the costs of increasing the capacity of the present national energy supply system, it being assumed that continued expansion is indeed possible. The former consideration has been treated extensively in the literature of solar research (*25, 27*). The latter aspect of solar energy appears not to have been treated previously, and I will consider it here. I reemphasize that I consider the local application of solar energy to provide low temperature heat.

Hot water heating by solar energy. At present, domestic hot water heating accounts for approximately 3 percent of the national energy consumption (Table 1). Hot water heating by solar energy has been exploited abroad (*28, 29*). Given the climatic conditions of the United States, it should be feasible to provide at least 50 percent of this demand for energy via solar devices (*28*). Thus, one is dealing with a potential reduction of 1.5 percent of the national requirement for fuels.

Solar collectors of 1 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 (*7, 21, 30*). At present, 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 1 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 a 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 United States 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. The cost of implementing solar domestic hot water heating in all the 60 million dwelling units of the United States, 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 requirement for fuel by 1 percent, through implementation of solar energy to provide low-temperature heat.

To estimate the capital costs of increasing the capacity of the national energy supply by 1 percent to supply low-temperature heat in building services, one must note first that most of the low-temperature heat used in buildings is provided by combustion of natural gas. Thus, expansion of energy supply capacity to meet growth in building services will require an increase in the supply of gas, or the 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 a 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 (*31*). Thus, in a discussion of the need to increase the capacity of the national energy supply to provide low-temperature heat in building services, it is reasonable to consider the possibility of expanding the national capacity to supply gas. Because domestic supplies of natural gas are severely strained, expansion of capacity to supply gas would probably entail the importation of liquefied gas. Current estimates for the capital costs of gas liquefaction 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 (*32*).

If one takes the heating value of the gas (about 1000 Btu per cubic foot) as the basis for estimating the cost of such a plant, one finds that the capital costs of gas liquefaction are approximately $160 to $240 per kilowatt. If one assumes that such a plant can be operated for 8000 hours per year, the capital costs of gas liquefaction may be estimated as 2 to 3 cents to increase the capacity of the national energy supply by 1 kwh per year. These figures reflect only the costs of liquefaction. In addition, one must include costs of increasing the transportation system (for example, refrigerated tankers), storage capacity (refrigerated tanks), and distribution network (pipelines) for this form of fuel, as well as the capitalization of wells to provide raw petroleum for liquefaction 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 liquefaction as being approximately 5 cents per kilowatt hour per year. Thus, to increase the present capacity of the national energy supply by 1 percent, through gas liquefaction, would cost approximately $10 billion.

The fastest growing mode of space heating has been electric heat (*1*). To estimate the costs of increasing the capacity of the national electrical energy supply, one may note 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 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 the capacity of national electrical supply by 1 kwh per year is found to be approximately 8 cents. To increase the capacity of the national energy supply by 1 percent through expansion of electrical power would, therefore, cost approximately $16 billion.

The difference in capital requirements for reducing demand for fuels by 1 percent via utilization of solar energy for low-temperature heat ($3 billion) and the costs to increase present supply capacity by 1 percent (as much as $16 billion), may be debatable in certain details, and, in any event, requires further study. I have tried, not 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 planning. Based upon the data provided, one may conclude that it does.

One of the reasons why the use of solar energy for low-temperature heat would cost less than a corresponding expansion of the capacity of the national energy supply is that the latter requires energy in high quality form (*33*). High-quality energy, such as fuels for high-temperature combustion or electrical energy, is readily convertible to work but 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: (i) by developing effective, reliable, and inexpensive solar collectors, and (ii) by establishing suitable government construction regulations; in particular, the FHA and VA could adopt standards under which domestic solar equipment might qualify for residential construction and loan support.

Utilization of Unused Energy Sources: 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). 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 35,000 megawatts of electrical power (*34*). However, before the apparently rich fuel resources of solid refuse can be put to use, a number of technological problems must be solved. These include the design of combustion plants (in this instance, incinerators) to use widely varying fuels (for example, waste paper, consumer plastics) and the selection of materials to tolerate some of the highly corrosive products of combustion of solid refuse. The supply of solid refuse in a given area may fluctuate seasonally so that incineration plants must be planned to operate effectively with widely varying fuel loadings or equipment must be designed for sorting refuse according to its combustion properties. Electrical generating plants or district heating systems that can use the heat generated by such plants must also be developed before incineration can become a source of useful heat. In addition, techniques must be found for controlling the potentially polluting emissions from incinerator combustion chambers.

It is evident that the incineration of solid refuse can provide useful heat and constitutes a field of technology in itself. The federal government will undoubtedy be substantially involved in incinerator construction in the coming years, but 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.

Conservation of Energy Invested in Materials

The largest single consumer of energy in the United States is industry. Here I consider the possibility of conserving energy by improving the products in which the energy of processing is invested. I will describe three specific examples.

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 the functionality or safety of the product being reduced, 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 adequate for most residences. This and other examples of excessive materials should be studied in the context of conservation both of energy and of natural resources. The 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.

Durable as opposed to 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. However, while reusable glass milk bottles, for example, are beneficial to society in connection with conservation of resources, they may constitute a hazard to the householder. Field interviews with physicians have revealed 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 that 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 shards. 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.

Maintainability of machines. The 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 more careful designs being used for the production of more durable goods in which energy materials are invested with greater effectiveness than at present appears to be an attractive possible measure for the conservation of natural resources.

It is evident that a technological field concerned with maintenance procedures is urgently needed. The quality of machine maintenance at present could be substantially improved by the incorporation of existing techniques of monitoring performance into field practice; methods for the detection of impending failure or malfunction could be developed through application of existing techniques. By such means, unexpected costly and dangerous failures could be avoided, the useful life of equipment could be extended, and natural resources could be utilized more effectively. Machine maintenance, as it is practiced today, does not constitute a technology; the disparity between existing and developable techniques on the one hand, and the techniques used in field practice on the other, is simply too great.

Conclusions and Recommendations

The ineffective utilization of energy in buildings and industrial processes constitutes a major component of the energy problems in the United States. Not only could the effectiveness of energy utilization be improved, but such improvement appears to be justifiable economically, especially when the costs of the alternative of expanding the national capacity to supply increasing 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 technological field concerned with energy conservation through effective utilization. Although techniques for this purpose exist and others can be developed, extant techniques have not been integrated and applied in rational field practice, and there is no disciplinary framework within which further developments might be made. Appropriate measures should be undertaken on a national scale to create and implement a technology for energy conservation through more effective utilization.

References and Notes

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3. Quantities expressed as British thermal units per thousand cubic feet—degree day represent the heating requirements of a building relative to its size and the severity of the climate in which it serves. Conversion factors are: from British thermal units to joules, 1055; cubic feet to cubic meters, 2.83×10^{-2}.
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8. 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, or air conditioning, for example.
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12. J. D. Nesbitt, *Improving the Utilization of Natural Gas in Major Steel Mill Applications* (Institute of Gas Technology, Chicago, 1972).
13. 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.
14. U.S. Department of Housing and Urban Development, International Brief, January 1971.
15. National Mineral World Insulation Association, Impact of Improved Thermal Performance in Conserving Energy (National Bureau of Standards, Washington, D.C., April 1972), p. 35.
16. 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.
17. In nighttime power generation, it would be possible to reject heat at subatmospheric temperatures, through radiative techniques, and thus avert local thermal overloading of the atmosphere.
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20. Few small units can justify spending more than 3 cents per kilowatt hour for maintenance; few can be maintained for less.
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26. In this comparison it is assumed that the consumer will own and maintain the solar device, but such an arrangement may be neither necessary nor desirable.
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28. D. N. W. Chinnery, *CSIR (S. Afr. Counc. Sci. Ind. Res.) Res. Rep. No. 248*, pp. 1–79 (1967).
29. S. J. Richards and D. N. W. Chinnery, *ibid., No. 237*, pp. 1–26 (1967).
30. The average cited here was obtained over a period during which cloudy and sunny weather obtained.
31. 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.
32. 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, I compare the cost of the plant to its capacity to supply gas, which is its principal function.
33. The thermodynamic notion of quality (or more precisely, availability) is a measure of the extent to which the form of energy can be converted to work.
34. "Refuse-fueled power station," *Technol. Rev.* May 1972, p. 62.

NEWS AND COMMENT

Psychical Research: The Incredible in Search of Credibility

Bill Delmore is a dropout from the Yale law school, but he has a grant from Harvard to explore the nature of his psychic abilities. From an early age, he says, he has had a facility for guessing cards. Friends arranged for him to give a demonstration of card-guessing before the Harvard psychology faculty, which controls a small fund earmarked for research on psychic phenomena. At the Foundation for Research on the Nature of Man, in Durham, North Carolina, Delmore's card-guessing powers are being analyzed by Ed Kelly, who switched to psychical research last year after getting a Ph.D. from Harvard in psycholinguistics. An assistant holds up playing cards enclosed in black envelopes, while Delmore guesses at them, sometimes one by one, sometimes for several cards in advance. With certain guesses he is particularly confident of being correct, and says so before the card is taken from its envelope. In an experiment recently reported by Kelly to the Harvard psychology faculty, Delmore made 20 such "confidence calls," 14 of which were correct. Asked how he makes the guesses, Delmore says by luck. How does one make a lucky guess? "By forming a visual image and then rationalizing it. Like having an image of seeing a butterfly, and then seeing the butterfly."

Parapsychology—the scientific study of telepathy, clairvoyance, and other manifestations of the inexplicable—is undergoing a minirenaissance, although without any assurance that the rebirth will be recognized as legitimate by the arbiters of scientific orthodoxy. The card-guessing experiments at Durham illustrate both the hope and despair of the parapsychologists' predicament. Young scientists are still prepared to risk their good name and fortune to work in the field, yet even when results are produced by experimental designs that would be accepted without demur in an ordinary science, the mainstream scientific community refuses to be impressed or even very interested. Rigor-