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Conservation Via Effective Use of Energy at the Point of Consumption

Institute for Applied Technology
National Bureau of Standards
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Final Report

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

CONSERVATION VIA EFFECTIVE USE OF ENERGY AT THE POINT OF CONSUMPTION

Abstract

The practices and equipment employed at the point of energy consumption in buildings and in industrial processes permit excessive consumption of energy. It is estimated that if full application of the economically justifiable technical improvements presently available were made to equipment and practices in buildings and industry, as much 25 percent of the total primary fuel consumption in the U.S.A. could be conserved. The reasons why economically justifiable application of effective technology at the point of energy consumption has not been widely adopted in the past are considered. The needs to facilitate adoption of effective equipment and practices in the future are discussed.

Introduction

With shortages of fuel and electrical power now occurring in various parts of the United States, there no longer remains serious doubt that the U.S.A. faces difficult problems in obtaining the energy needed to sustain everyday life and industry.

The basic energy problem of the U.S.A. is that consumption of high quality nonpolluting fuels is straining the national capacity to provide these fuels. It is clear that new primary sources of energy will be required to meet future needs of the U.S.A. A number of new energy sources are available. These include some which require substantial technological development, such as the breeder reactor and gasified coal. In addition, if adequate pollution control can be developed, the vast sulphur containing anthracite reserves of the U.S.A. can be utilized; these are estimated to be sufficient to sustain the U.S.A. for 500 years or more. Also, oil and liquified natural gas can be imported. The options available for developing new primary sources of energy are indeed numerous and varied. However, they share a common aspect; each is costly. One example of the costliness of new sources of energy is the estimate that by 1985 U.S. imports of petroleum will represent an annual trade deficit of approximately 20 billion dollars (1).

With the passing of the era of abundant inexpensive clean forms of primary energy, rising costs of energy alone, will compel everyone to examine the effectiveness with which energy is used. The conservation of primary sources of energy may be essential to assuring the quality of life, the economic well-being and even the national security of the U.S.A.

The Issue of Conservation and Effective Utilization

There are two basic ways to conserve energy. One is straightforward curtailment of fuels and electrical power.* The other is improvement of the efficiency at the point of consumption. Until recently it has not been widely recognized that improvement in the efficiency of energy utilization at the point of consumption could yield significant reductions in the national requirements for high quality fuels, without requiring sacrifices in the comfort, safety or health of building occupants or in the producitivity of industrial processes. Ultimately, effective measures for conservation will probably require both curtailment and improvement of efficiency of energy consumption. But if the potential for energy conservation through efficient utilization at the point of consumption is recognized and developed, programs of conservation can be instituted with far less stringent effect on industry and society than if conservation were to be attempted through curtailment alone.

Any approach toward economic optimization of the national energy system will require careful examination of the effectiveness with which energy is used at the point of consumption; it does not make good sense, neither in economic terms nor in any other, to continue excess consumption of significant quantities of a vital and increasingly costly natural resource, through ineffective practices.

*At the moment, several regions in the U.S.A. are living under a fuel rationing system, administered by the fuels industry which presently finds itself unable to meet the full demand of regional markets. The mechanism of conservation through curtailment is already being put to use.

Areas of Excess Energy Consumption: A Framework for Discussion

To identify areas in which significant energy savings are possible one must know how much energy is consumed in various practices and how effectively the energy is consumed. The second question, with what effectiveness is energy consumed, involves technical issues to be discussed later. But, the basic data required to answer the first question has been compiled by Stanford Research Institute in their report to the Office of Science and Technology, entitled Patterns of Energy Consumption in the U.S. (2). The summary data of the report, which are given in Table I, provide an itemized breakdown of the amount of energy consumed in various practices throughout the U.S.A. (2). These data represent the most recent and one of the more reliable attempts to account for the use of energy at the point of consumption.

The data of Table I reveal several significant aspects of energy consumption. First, there are three main areas of energy consumption--building services, industrial processes, and transportation. Of these, transportation has been the subject of public scrutiny by government agencies, public interest groups, industry and academic institutions. Energy use of transportation is being investigated at many levels and will not be further treated here.

However, the potential for conservation through improved practices of energy consumption in buildings and in industrial processes has received small notice until recently.* Actually, both building services and industrial processes consume vast quantities of energy, and in both areas ineffective practices allow large quantities of energy to escape utilization.

Table I also reveals significant comparisons between areas of energy consumption. For example, industrial electrolytic processing, which includes aluminum refining, consumes approximately 1 percent of the primary fuels used in the U.S.A.** It is widely known that aluminum refining and other industrial electrolytic processes require large amounts of energy. However, Table I reveals that hot water heating in residences and commercial buildings accounts for approximately 4 percent of the consumption of primary fuels in the U.S.A. It would appear that efforts to conserve primary fuels might be as fruitfully applied to hot water heating as to electrolytic processing, even through much greater public attention has been focused on the latter. This observation really illustrates a basic point which is reflected numerous times by the data of Table I. Many of the seemingly mundane practices of everyday life, such as hot water heating, space heating, and cooking consume vast

*In fact, in many quarters it has been assumed that significant improvements of practices in these fields were either technologically infeasible or economically unjustifiable. Neither of these assumptions is warranted.

**The data of Table I indicate the fuel required to provide electrical energy.

quantities of energy. The effectiveness of practices in these seemingly mundane areas is, as a rule, rather low and also rather easily correctable. Improvements in these practices offer immense opportunities for conservation of primary fuels

To broach the question of effectiveness of energy consumption, one must define both "consumption" and "effectiveness." In this paper, consumption of energy means the ultimate use of energy to operate a process or to provide a service. Specifically, consumption of energy does not mean the conversion of energy from one form to another, as in electric power generation; the energy content of the fuel required to generate electric power is viewed as being consumed at the point where electric power is ultimately put to use.

To assign an effectiveness to an energy consuming process requires some measure of the minimum energy required to operate the process. In some instances, it is possible to determine a physically irreducible minimum energy requirement for a process, as in the case of drying fabrics, thermal conversion of limestone to portland cement, or refrigeration of given items of food. In other instances, it is not clear whether physically irreducible minimum energy requirements can be identified.*

But in any event, while it is useful to know the physically irreducible minimum energy requirements for energy consuming processes in buildings and industry, it is often more useful to know the amount of energy which

*For example, in space heating, heat is required to replace losses, but if perfect insulation and sealing were available, no losses would occur and no heat would be required. However, perfect insulation and draft sealing are not available, and even if they were they would be neither economically justifiable nor desirable. Perfectly sealed buildings would be unlivable.

might be required to operate a process if full application of available technology were made, up to an economically justifiable limit. It is this amount of energy which will be used here to establish a measure of the effectiveness of a thermal process. The criterion for economic justification proposed here is minimum combined initial cost and operating cost of equipment, including, in particular, fuel cost.*

*The term life cycle costing is often used to describe this combination, and will be employed here. Appropriate discounting is, of course, to be applied in calculations of operating costs.

<u>The Technological Potential for Improved Energy Utilization at the Point of Consumption</u>

A few of the outstanding examples of opportunities for improving effectiveness of energy consumption in buildings and industrial processes are offered here to support the plausibility of estimates of the total reduction of national requirements for high quality fuels, which might be achieved if full economically justifiable application of available technology were made to improve energy consumption practices.*

(a) <u>Energy Use in Buildings</u>

The effectiveness of energy use in buildings is determined by three items:

° <u>Design</u> (including insulation, fenestration, selection of heating and ventilating equipment, etc.)

° <u>Construction Practices in Implementing Design</u>

° <u>Occupant Practices in Using Buildings</u>

Moyers (6) has studied the economic aspects of insulation and fenestration of residences. He determined the savings of heat transmission directly through the walls of a building, and calculated the life cycle costs of insulation and storm windows by combining initial costs (with suitable

*Detailed studies of the potential for improved energy use in buildings have been made by a number of investigators (e.g., (3, 4, 5, 6, 7)); in a few instances, specific possibilities for obtaining more effective consumption of energy in industrial processes have been studied in detail (e.g., (8, 9, 10, 11)). For further data and information of greater detail, the reader is referred to these reports.

interest and taxes applied) with fuel costs typical of the time at which the calculation was carried out (1970). Figure 1 shows some of Moyers data, which indicate that by using 3 1/2 inches of wall insulation, 6 inches of ceiling insulation and applying storm windows one can cut the heat losses through the walls of a typical residence in New York or Minneapolis by somewhat more than 40 percent, as compared with the heat losses which would obtain with 1 7/8 inch ceiling insulation, and no wall insulation or storm windows (points A on the figure).

The residences built prior to 1970 were designed for a level of thermal performance typical of the point A. With the issuance of the 1971 FHA Minimum Property Standards the insulation levels of residences affected by these standards was substantially improved;* but these standards do not require storm windows. Thus, for the most of the extant residences in the colder climates of the U.S.A. and for a great number of those yet to be built, application of storm windows and insulation could reduce direct heat loss through walls by approximately 40 percent.

Figure 2 shows Moyers calculation of net savings to the consumer, realizable through insulation and storm windows. There are several observations on these data which bear mention. First, not only is it economically attractive to install insulation and storm windows, but the economically optimal level of insulation for residences in cold climates is found to be the extreme of the range of insulation which Moyers considered (3 1/2 inches of wall insulation, 6 inches of

*Federal standards have a direct effect on approximately 35 percent of new construction; the indirect effect of Federal standards on residential construction is much larger than 35 percent.

ceiling insulation plus storm windows). Second, the data show that not only the net savings at the economic optimal condition but the character of the optimal point is extremely sensitive to the price of energy; in Figure 2 the only difference between gas and electric heat is price. As the price of energy goes up, small departures from the optimal condition, as represented in Figure 2, can cause large decreases in net annual savings. In fact, the true economic optimal design for either electric heating or heating with higher priced gas, may actually be found at some greater levels of insulation and control of fenestration than the extreme of the range shown in the figure. Of course, to install more than 3 1/2 inches of wall insulation would require either modifying the wall cavity or devising some insulation system which could be mounted on the wall rather than in it. Either of these steps might be costly; but, with rising energy prices being a certainty in the future, the character the data in Figure 2 suggests that it might not be too soon to start considering these steps.

During the past few decades energy prices have increased at a slower rate than prices of construction and other prices; relative to other items energy has been an increasingly good bargain. Thus, if it is now economically justifiable to install insulation and storm windows, it was even more easily justified in the past. The fact that insulation was not widely used in the past illustrates that the rational economic criteria of life cycle cost have not, as a rule, been effectively applied in housing purchases. We will return to this point later.

The selection of building equipment is another important aspect of thermal design of buildings, Figure 3 gives performance data for air conditioners of various rated capacity and price (5). The power consumption rate is the ratio of cooling delivered to electrical energy consumed by the device. Air conditioners of 4000 BTU/hr. capacity have electrical energy requirements which decrease by approximately a factor of two as the price increases by 35 percent. On a life cycle cost basis, the least expensive unit to own is the one with the greatest initial price. The same general pattern, with only minor exceptions, can be found in the units of higher rated capacity. These data prompt several observations. First, as with insulated housing, the units with the lower initial price tend to sell very well even though they may be, in the long run, more expensive to own; rational economic criteria are not commonly applied to building equipment. Second, since the market is and has been much more sensitive to initial price than to life cycle costs, the equipment manufacturer is prone to design in high consumption in order to reduce initial price. One interpretation of Figure 3 is that by approximately doubling the energy consumption of a 4000 BTU/hr. air conditioner one can reduce its price by approximately 35 percent. Thus, a great deal of the building equipment in service today, which was bought because of low initial price, makes rather ineffective use of energy.

Construction practices in implementing design have a very important effect on energy use in buildings. Figure 4 shows two scanning thermographs of insulated wall test panels subjected to 0°F on one side and 70°F on the other. A differential pressure of 3 1/2 inches of water is maintained across the panels to simulate effects of draft infiltration. In the thermographs the light areas are warm and the dark areas cold; the dark vertical bars appear where the thermography resolves the studs in the wall. The test wall in Figure 4b was made with a deliberate construction flaw consisting of displacement of the edge of each stud 1/8 inch outboard of the plate. The cold wall area represented by the dark fringe in the figure is caused by infiltration through this flaw. The net effect is sufficient to reduce the effective insulation of the wall significantly below its design level. As energy becomes more costly it will probably become worthwhile to make the extra investment required to attain more careful practices in construction, or to find designs for wall insulation etc., which are not so sensitive to minor construction flaws.

Occupant practices in buildings are very important in attaining effective use of energy. For example, in a recent public discussion it was noted that in government office buildings of essentially the same design and construction, situated in similar climates and used for similar purposes, energy consumption can vary by as much as 40 percent (12). Also, careful management of large refrigeration plants has been shown to conserve as much as 12 percent of the electrical energy required by the plant, without sacrifice of plant performance (13).

The maintenance of home heating equipment is also an item of great importance. The small scale combustion equipment used for home furnaces and hot water heaters is designed so that approximately 70 to 75 percent of the heat of combustion will be transferred to the hot water or air stream (as the case may be) when the equipment is clean, in proper adjustment and operated in steady state. However, transient operation can produce soot formation which can greatly reduce the effectiveness of this equipment. Sample field observations and theoretical estimates of the effects of minor unattended items of maintenance indicate that the actual effectiveness of these small combustion units in field service may be in the range from 50 to 35 percent (14).

If all that could be economically justified in insulation and fenestration of existing structures and new construction were actually to be done, if all that could be done to operate buildings effectively were actually to be done, if economically justifiable application of available technology to heat recovery in ventilation systems were actually made, if careful use of ventilation and illumination were made, then it would not be unreasonable to expect that as much as 40 percent of the primary fuels now used to support building requirements could be conserved. Moreover, these fuel savings would not require sacrifice in the quality of the building environment, nor would they require unjustified costs. On the contrary, the measures spoken of here could, if adopted, reduce net life time operating costs of buildings.

(b) Energy Use in Industry

The use of energy at points of consumption in industry has been much less well studied than energy use in buildings.* Until quite recently it has been assumed that industry must make the most effective

*It is reemphasized that we are concerned here with operations which consume energy rather than energy conversion operations such as electric power generation.

possible use of energy, because to do otherwise would not be profitable. This assumption has now been reexamined, and found to be inaccurate by industry itself. For example, merely by plugging leaks in air and steam lines, by providing steam at the pressures and temperatures required, and by instituting other straightforward energy management practices, consultants have been able to reduce the fuel requirements of large industrial plants by 7 to 15 percent (8). Present efforts for energy conservation through application of waste heat management have hardly scratched the surface of this field. In addition, redesign of process equipment offers a great potential for energy savings. Experts in metal processing have estimated that if full application of presently known economically justifiable technology were to be made in furnace design, heat soaking pit design and thermal management of processes, the overall fuel requirements of steel making could be reduced as much as 20 percent (11). Recent redesign of vacuum furnaces, entailing improved vacuum insulation and the use of direct combustion with a heat pipe to provide heat, in place of electrical heating, has reduced the fuel requirements of vacuum furnace operations by 75 percent (9).

Newly emerging developments in thermal process design are also noteworthy. For example, paper making accounts for approximately 2 percent of the total primary fuel consumption in the U.S.A. (2). The largest part of this energy is consumed in the paper forming process which is essentially a drying operation. Industrialists in Europe (15) and in the U.S.A. (16) are developing techniques for "high consistency" paper forming. Using these techniques, one begins the paper making process with a thicker slurry; there is less water to dry out of the paper and thus less energy is required. For example, for certain types of paper it is possible to change from a slurry having 1/2 percent solids at the outset to one having 3 percent; thus only 1/6 as much water need be removed from a given unit of paper. Engineers who have studied these processes have estimated that as much as 55 percent of the energy requirements of paper forming could be conserved through implementation of high consistency forming technology.

Cement production also accounts for approximately 2 percent of the primary fuel consumption in the U.S.A. The largest part of this energy is used as direct heat in the cement kiln. Modern cement kilns now being introduced on the Western European market are capable of cutting the fuel requirements of kiln operations by approximately 30 percent. More advanced prototype kilns are under development in the U.S.A. These kilns employ fluidized bed technology to achieve rapid heat transfer and intimate mixing. They have the capability of yielding even greater reductions in fuel requirements for kiln operations (17).

The data cited above support the belief that the practices and equipment used at the points of energy consumption in industry can be substantially improved, and that in many cases the improvements can be economically justified. In the case of industry, economic justification of improvements may be even easier to show than for buildings because reduced fuel consumption often carries with it reduced costs of pollution control. In addition, in many instances redesign of thermal process equipment and institution of more careful energy management procedures often enhances productivity as well.

Given the instances cited above, and the instances given in the current literature (8, 9, 10, 11) it would not seem unreasonable to assume that if full economically justifiable application of known energy management techniques were to be made, and if full economically justifiable adoption of the improved equipment which now exists in proven form were to be carried through, the primary fuel requirements of energy consuming processes in industry might be reduced by as much as 30 percent. It is acknowledged that this estimate cannot be defended by statistical methodology as can an estimate for the potential of energy conservation in buildings. While data are too sparse to support statistical estimates of potential energy savings in industry at high confidence levels, an economically justifiable 30 percent reduction in primary fuel requirements for energy consuming processes of industry would seem to be a realistic goal to set for application of effective technology to these processes.

Problems to be Recognized; Needs to be Met

It has been argued that more effective use of energy at the point of consumption is both technically feasible and economically justifiable. If this is true, and if it has been true for sometime, why has not adoption of more effective equipment, practices, building insulation, etc., been widespread. This is a complicated question to which there is no single simple answer. Nevertheless, two combined forces can be seen to have had widespread effect. First, the deliberate efforts in the past to provide high-quality energy in abundance and at minimal price appear to have encouraged excess consumption. Second, in the economic criteria for justification of acquisition of buildings, heating equipment, industrial plant equipment, and other apparatus used at the point of energy consumption, a much higher priority has usually been assigned to initial cost than to life term operating costs; in particular, energy costs for life term operation have often been neglected.* Thus, in order to satisfy the criteria of the marketplace, builders and equipment manufacturers have been prone to design high energy consumption into their products in order to reduce first costs.**

A major reason why first costs are a powerful influence in the building market is that most commercial and residential construction starts are speculative. Often the original builder does not know who the first owner of the building will be. In this situation, the builder who

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*It is important to recognize that we are speaking of items of equipment at the point of energy consumption, not of equipment for energy conversion such as is power generation.

**Recall Figure 3 and earlier remarks pertaining to it.

builds for effective use of energy, but at higher cost, can run very serious risks. In commercial buildings, the builder and first purchaser may be acquainted, but life term costs are not a dominant consideration. Often the goal of the first purchaser is speculative. The potential gain in value of the developed real estate may be a much more important aspect of the speculation than the energy costs of operating the building. In addition, even for those cases in which the first purchaser of a building may be aware of the potential long-term gains relizable through somewhat greater initial investment for better thermal performance, the financial institutions upon which the construction market depends are not presently prepared to deal with financing buildings in such a way as to recognize the trade-offs between greater initial investment and savings in operating costs.

Industrial plant equipment used at the point of energy consumption is subject to similar criteria as buildings. The manager of an operating unit of industry is commonly responsible for his unit's capital budget and maintenance costs, and above all, he is responsible for his units production. However, the costs of fuel or power are not often high priority responsibilities. In fact, in many industrial accounting systems, energy costs are carried as overhead. Thus, even when an industrial unit manager recognizes that adoption of more effective equipment in his unit can yield economic benefits for his firm, the criteria required to justify the equipment may no' be available to him; the justification may require modifications at several levels of management above his unit. This does not necessarily pose an absolute barrier to introduction of more effective equipment, but it certainly can act to retard that process. To modify economic criteria to admit more effective energy consuming equipment requires, at the very minimum, recognition on the part of higher management that more effective use of energy is an important objective. In the recent past, energy prices rose less than other prices and energy progressively became a better and better bargain. It is not surprising that industrial management has not always seized upon the technical opportunities to improve the effectiveness of industrial energy consuming processes. But the era of inexpensive energy has past, and management attitudes toward effective use of energy may change significantly in the near future.

In addition, it should be recognized that industrial management is always presented with a variety of problems and opportunities. Management must decide how best to employ the resources at its disposal to meet these. In the view of industrial management the potential for increasing profitability through investing in more effective equipment and practices for energy consuming operations, may not have appeared as attractive an opportunity for utilizing the funds and talent available as, say, modifying certain of the corporations own management procedures. Indeed, the householder and the consumer undoubtedly make very similar judgments when it comes to investing in additional quality of construction or appliances in order to attain savings in life term costs through effective use of energy. To the private citizen, the attraction of retaining liquidity rather than investing in higher quality buildings may be quite powerful. In any event, the point to be recognized here is that adoption of effective energy consuming equipment often requires increased initial investment, and this investment must be shown not only to pay, but also to compare favorably with other available options for investment.

It may be that industrial managers and consumers have recognized the technical potential for effective use of energy and have properly evaluated the associated investment opportunity. Somehow one doubts this; the present evidence of successful and profitable applications of effective practices such as waste heat management indicate otherwise. Rather, one suspects that the technical and economic implications of effective equipment and practices at the point of energy consumption have not been fully recognized in the past. One also suspects that this lack of recognition has constituted a flaw in the mechanisms of the marketplace. One of the principal needs of conservation efforts for the future is the institution of an effective market-mechanism to facilitate the adoption of efficient equipment and practices at the point of energy consumption. The requirements for instituting such a market-mechanism are numerous. They may include regulatory measures, which are often discussed in the press, but which are beyond the scope of the present writing. In addition to these are the following specific needs.

Information

All who take part in the marketing of energy and in consuming energy need to be apprised of the technical options for more effective use of energy and the economic implications thereof. Marketplace-mechanisms do not work effectively unless the participants in the market are informed.

In particular, there is need for data on incremental cost benefit ratios of various options for improved effectiveness in utilization of energy; the relative merits of insulation as opposed to control of infiltration in buildings need to be determined. Also, realistic formulae by which trade-offs between initial investment and operating costs might be included in criteria for financing construction or new industrial plant equipment are required; these should take into account estimates of energy price increases. Other items of information obviously suggest themselves to those who consider this issue.

Effective Technology

At the base of all efforts to improve use of energy at the point of consumption is application of effective technology. Some of the examples cited above have shown that technology can be devised for more effective use of energy. In addition, in those instances where life term costs of energy utilization at the point of consumption have been determined, the minimum life term cost has been found to be attainable by investing initially in equipment which is at or very near the top of the price-and quality-range available on today's market. This suggests that the technical potential for designing effective performance into the equipment used at the point of energy consumption has not been fully exploited. Had it been fully exploited, there should be some very high performance equipment on the market which would be suitable for very long-life operations (say forty years) but which would be economically unattractive for shorter life applications (say ten years). But this does not appear to be the case. As a specific example, one may consider electrically driven heat pumps. Comparing the measured performance of heat pumps with the limiting Carnot efficiency of the device, one finds that existing heat pumps, operating under mild climatic conditions where they are most effective, attain only approximately 5 percent of their limiting efficiency. Under more severe climatic conditions, in which their actual measured performance is rather poor, existing heat pumps attain approximately 20 percent of their limiting efficiency. Power generation devices, on the other hand, attain 70 percent and more of their limiting efficiency. The basic technology used to approach the limiting efficiency in a power generation device is not at all unsimilar to that required for design of a heat pump, and by appropriate design, one could produce a more effective heat pump. Of course, until the value of such an improvement is appropriately recognized in the marketplace there will be little incentive to do so.

Two major causes of ineffective operation of devices and processes at the point of energy consumption are faulty heat transfer and mixing. Many special techniques exist to overcome these problems, but up until now they have not found many applications outside of energy conversion operations. Among these techniques are fluidized beds, heat pipes, induced vorticity for improving mixing processes or combustion, jet impingement, and heat recovery apparatus. These techniques can be most useful in improving effectiveness of energy consumption. The application of these techniques in an economically justifiable way should be encouraged.

Another technical flaw often found at the point of energy consumption is deterioration of equipment through lax maintenance. This problem could be attacked in at least two ways. The householder should be apprised of the fuel costs he will ultimately pay if he permits deterioration of the heat transfer surfaces of his furnace or hot water heater; he should be informed as to when and how to apply maintenance procedures. In addition designers of equipment should devote some serious efforts to design for maintainability. The general principles of informing the user, and designing for maintainability obviously also apply to most other items used at the point of energy consumption.

Measurement Capability

As sound technology is necessary to improve effectiveness of energy consumption, sound measurement capability is required to support the technology. The capability to measure the thermal performance of buildings in the field and to determine that the potential of the thermal design has actually been realized is a basic requirement for the support of any market system to facilitate investment in effective thermal performance of buildings. Also, the capability to measure the performance of building equipment, major appliances, and items of industrial equipment, in such a way as to reflect actual conditions of field service, is needed to provide those who wish to invest in higher quality performance with the information required to make rational decisions. The present standard test methods which are applied to most major appliances and items of building and industrial equipment are not constructed so as to reflect the actual duty cycle to which an appliance is subject in the field. The maintenability of these items is, usually, not covered by standards, and the susceptibility of equipment to unattended maintenance is not usually determined. In fact, the efficiency of equipment is seldom measured in a standard test method. Reliable and realistic information pertaining to equipment performance is a basic requirement of those who must decide which equipment to purchase. Our present capabilities to provide this information require substantial improvement to support effective efforts for conservation.

Practices of Assessment and Predictive Modeling

Although a great deal of work has begun to assess energy use and to construct predictive energy flow models, much of this work relies upon trend extrapolation, a technique which is based upon the assumption that the future must resemble the past. In particular, the majority of energy assessment studies and predictive modeling efforts initiated to date have contained the assumption that the technical potential for improvement in practices at the point of energy consumption have been exhausted. As has been shown, this is not the case. Moreover, in a very significant respect the future will not resemble the past; primary energy sources will no longer be abundant and inexpensive. With conservation now emerging as an inevitable issue for the future, almost all predictive models are used to study options for conservation. But, a predictive model based upon the assumption of "frozen" technology at the point of energy consumption can yield but one conclusion on conservation, which is that conservation can be achieved only through curtailment. This is simply not true. The models have yielded an inaccurate conclusion because they did not address the complete set of questions.

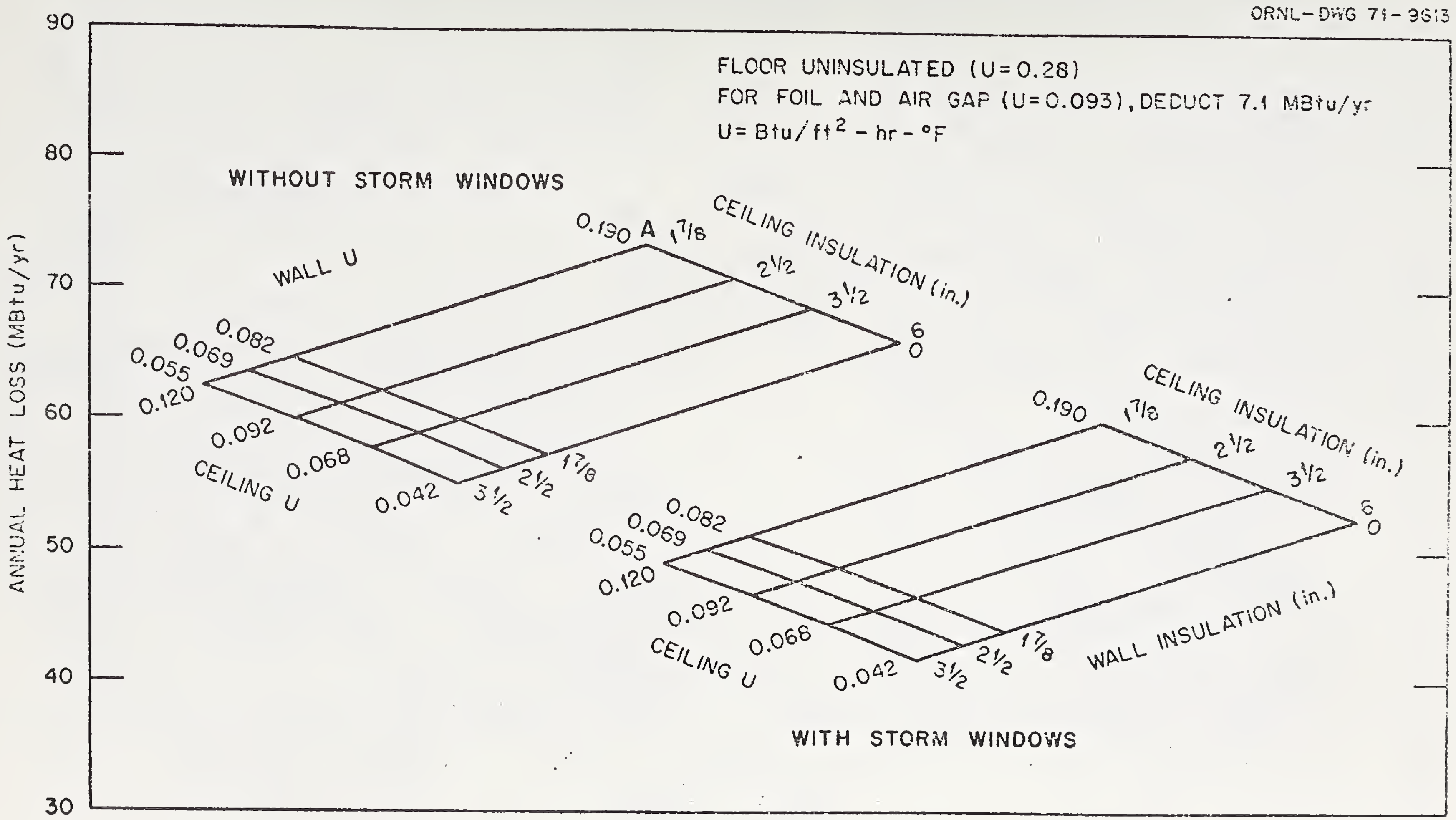
It would be very useful to have predictive models which admit technological flexibility at the point of energy consumption. Such models would be especially helpful in evaluating the balance of investment in development of new energy sources, effective technology at the point of energy consumption, and systems of energy curtailment. Such a capability for evaluation is required if anything approaching optimal utilization of those resources which can be brought to bear on energy problems is to be achieved.

Regarding predictive models, the importance of analysis of direct consumption of energy--as opposed to flow of energy through the economy--may have been underestimated. It is at the point of energy consumption that one can apply technical improvements, and studies of energy flow tend to burden one sector of the economy with the ineffective practices of another. Studies of energy consumption need to be carried out so as to reflect the quality as well as the quantity of energy consumed, and to compare these with the quality and quantity of energy actually required at the point of consumption. Since high (thermodynamic) quality fuels are at the center of energy problems, the measurement of quality is an extremely important, but largely underestimated aspect of assessing energy consuming practices. An important illustration of this point is the heat pipe vacuum furnace described earlier. This furnace is more effective in its use of energy because it wastes less of the thermodynamic availability of the energy source than did its predecessors.

Conclusion

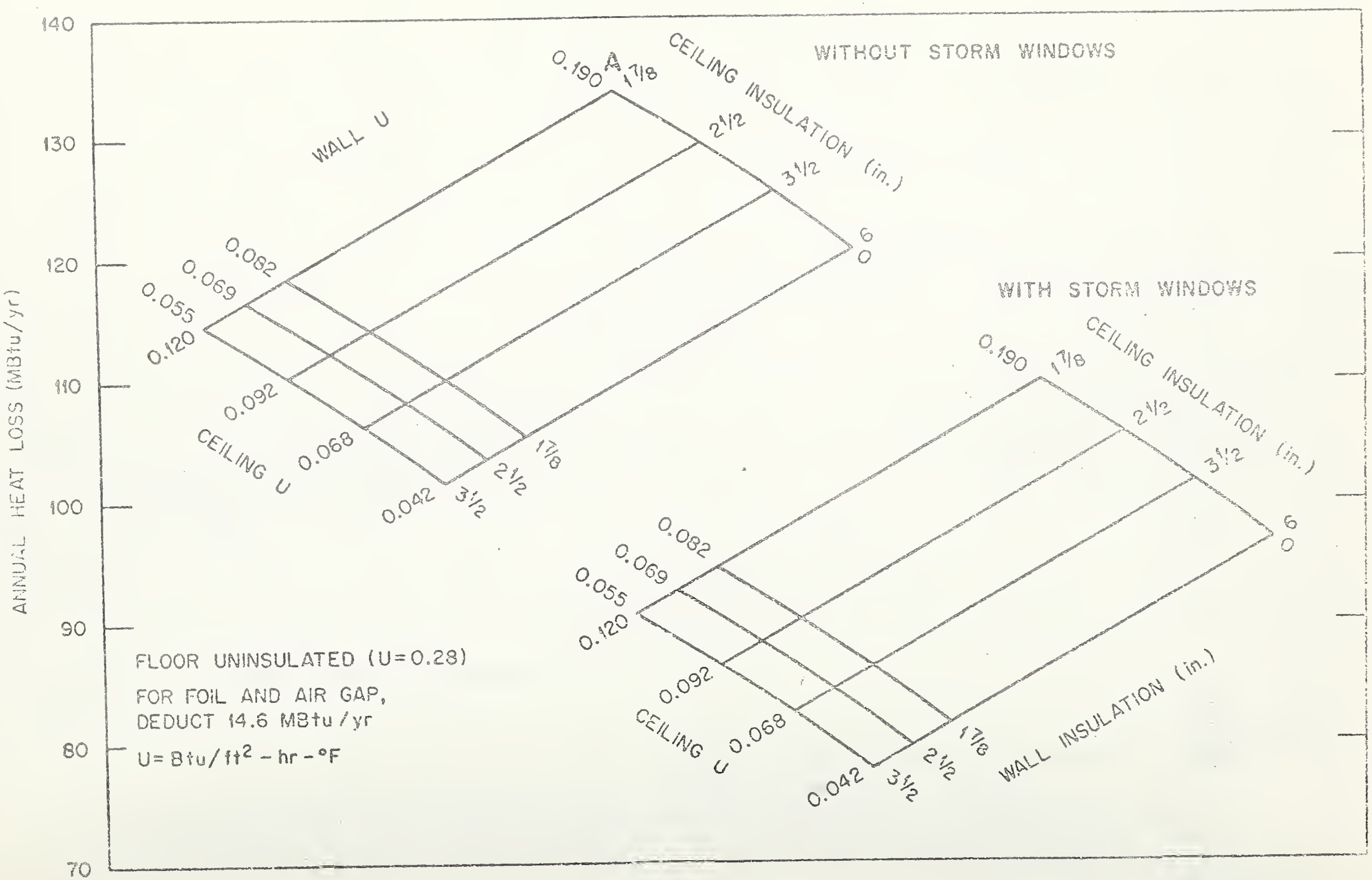
The technical and economic opportunities for energy conservation through improved effectiveness of use of energy at the point of consumption are only now beginning to be recognized. If appropriate steps are taken now to apply technology effectively to energy consuming processes and to institute appropriate market mechanisms to further these applications, measures for energy conservation, which appear to be eventually necessary, can be comprised of an appropriate balance between more effective use of energy and curtailment. The ultimate consequences of energy conservation need not be so dire as might obtain under conservation measures which depend entirely upon curtailment. Moreover, since other nations of the world will certainly face energy problems quite similar to those facing the U.S.A., the technology which we institute for effective utilization of energy at the point of consumption in the U.S.A.--especially for thermal processes of industry and for building equipment--may very well be attractive and marketable in international trade.

Figure 1: Moyer's calculation of the effect of insulation and storm windows on heat loss from typical residences.



Annual Heat Loss: Atlanta Residence.
Figure 1(a)

ORNL-DWG 71-9815



Annual Heat Loss: New York Residence.

Figure 1(b)

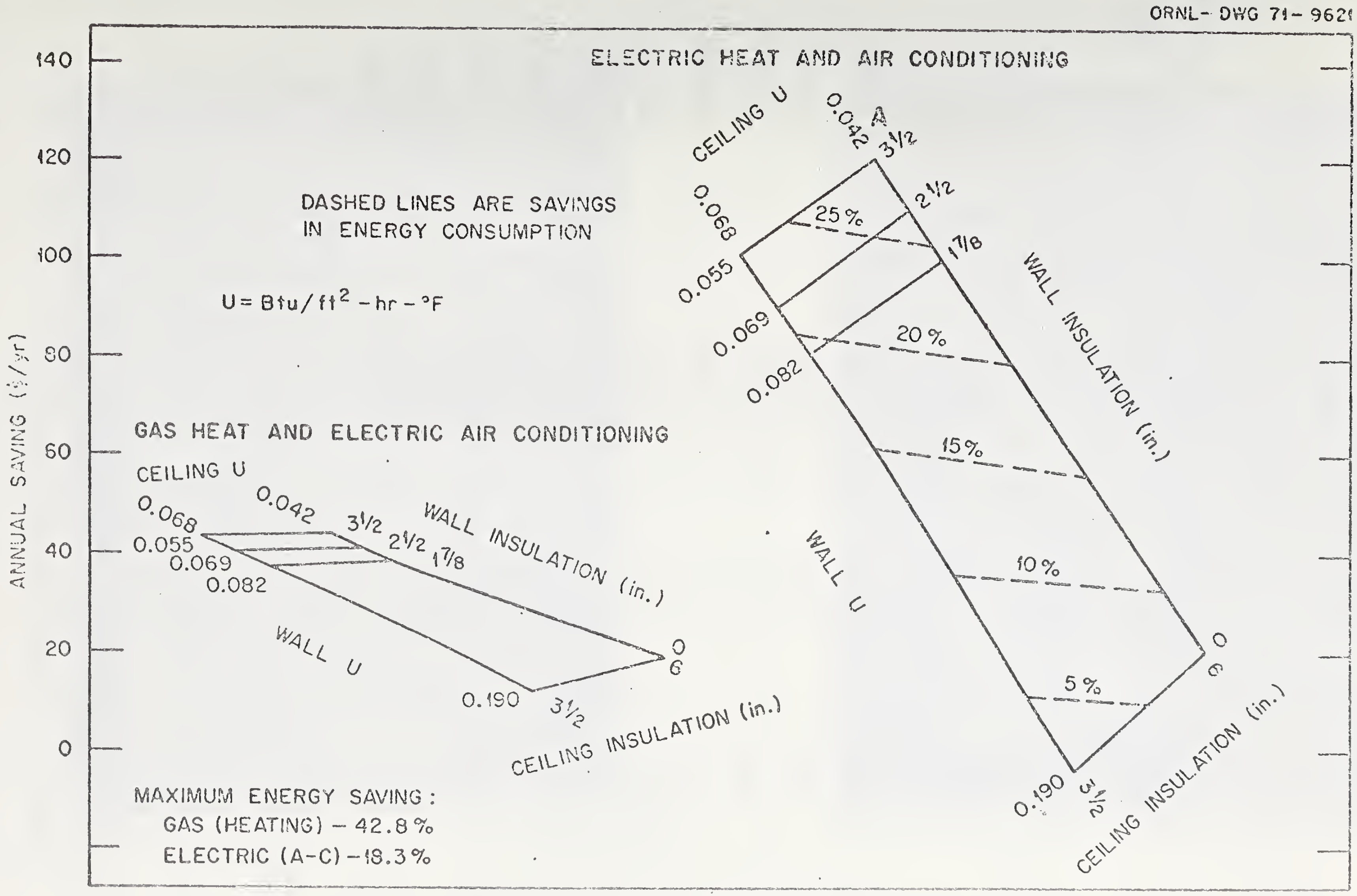


Figure 2: Moyer's Calculation of Annual Saving Due to Insulation and Storm Windows, Minneapolis Residence--Heating and Air Conditioning.

AIR CONDITIONER PERFORMANCE VARIATIONS

RATED COOLING CAPACITY BTU'S	RATED CURRENT AMPS	RETAIL VALUE $	POWER CONSUMPTION RATE BTU/WATT	10 YEAR TOTAL* COST $/1000 BTU
4000	8.8	100	3.96	84
	7.5	110	4.65	77.70
	7.5	125	4.65	81.45
	5.0	135	6.96	67.25
5000	9.5	120	4.58	74.90
	7.5	140	5.80	68.20
	7.5	150	5.80	70.20
	5.0	165	8.70	59.80
6000	9.1	160	5.34	67.30
	9.1	170	5.24	68.90
	7.5	170	6.96	61.80
	7.5	180	6.96	63.50
8000	12	200	5.80	67.30
	12	220	5.80	67.80
24,000 (CENTRAL)	13.1	---	8.25	---
	15.4	---	7.10	---
	17.0	---	5.85	---

* BASED ON 886 OPERATING HOURS PER YEAR

Figure 3: Performance Data for Air Conditioning Units

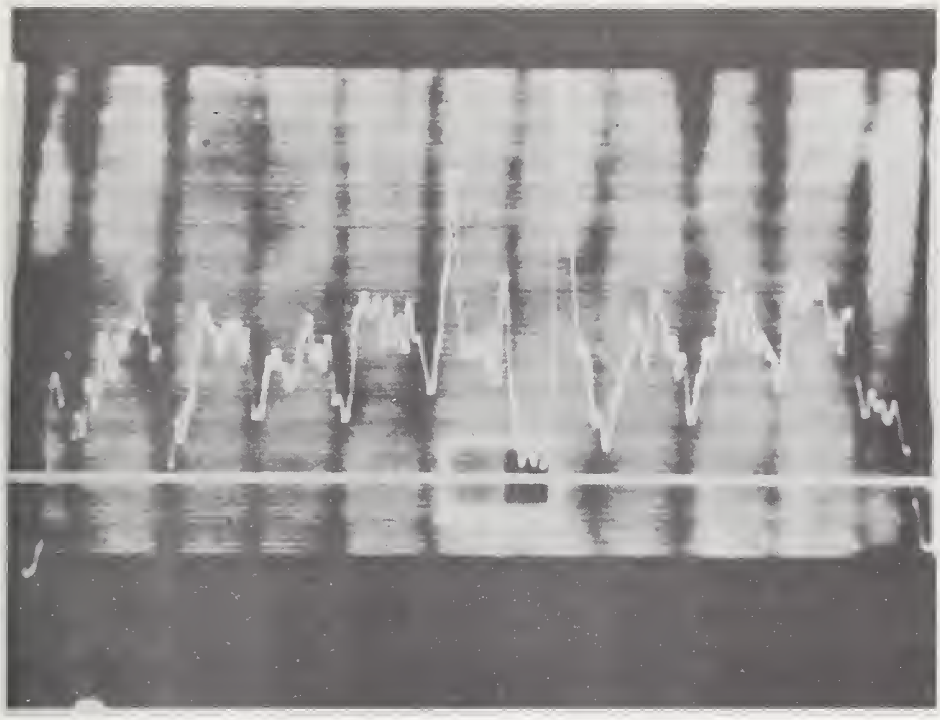


Figure 4(a)

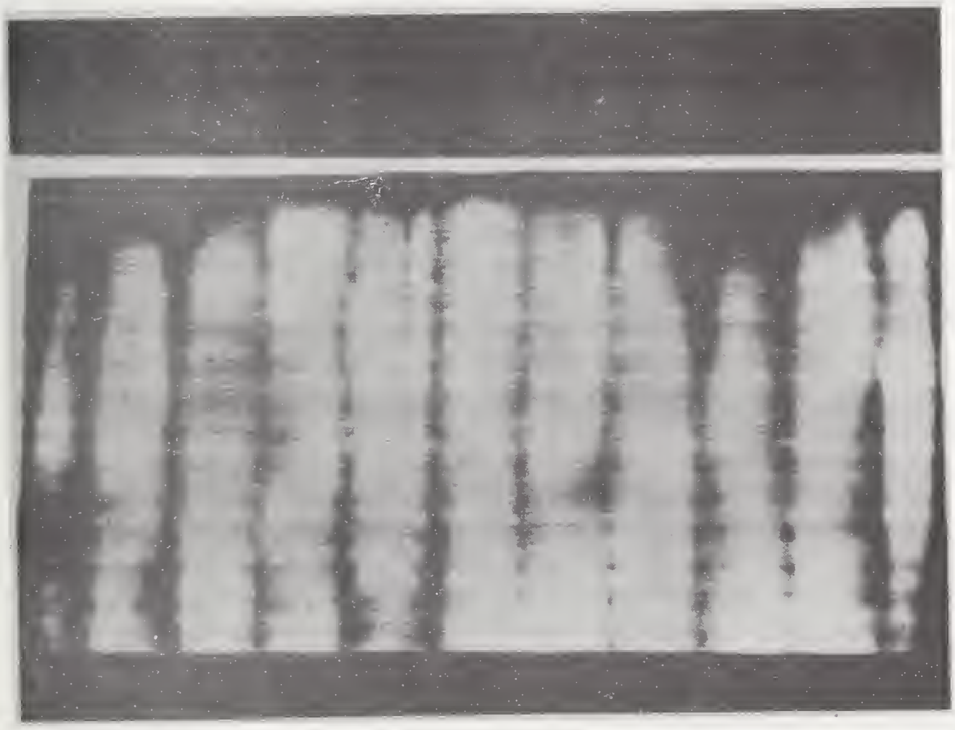


Figure 4(b)

Figure 4: Scanning thermographs of insulated wall test panels. Figure 4(a) shows a well-constructed wall; Figure 4(b) shows a wall with a draft leakage at top.

Table 1

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: Stanford Research Institute, using Bureau of Mines and other sources.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The practices and equipment employed at the point of energy consumption in buildings and in industrial processes permit excessive consumption of energy. It is estimated that if full application of the economically justifiable technical improvements presently available were made to equipment and practices in buildings and industry, as much 25 percent of the total primary fuel consumption in the U.S.A. could be conserved. The reasons why economically justifiable application of effective technology at the point of energy consumption has not been widely adopted in the past are considered. The needs to facilitate adoption of effective equipment and practices in the future are discussed.

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