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The Role of Economic Analysis in the Development of Energy Standards for New Buildings

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

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FOREWORD

This is one of a series of reports planned to document NBS research efforts in developing a methodology for the establishment of Building Energy Conservation Criteria. This report was jointly supported by the Department of Energy and the Department of Housing and Urban Development.

The author would like to acknowledge the help of many individuals who have reviewed this report at its many stages of preparation, in particular, Dr. Harold Marshall, Dr. Stephen Weber, and Dr. John McConnaughey of the Applied Economics Program; Mr. Jim Heldenbrand of the Building Energy Criteria Program; and Mr. Robert Kapsch and Mr. James Pielert of the Codes and Standards Program; all of the Center for Building Technology, National Bureau of Standards.

Executive Summary

Energy conservation standards for new buildings have become a high priority element of an emerging Federal energy policy. The potential energy savings due to increased energy efficiency in new buildings is large, not only because energy consumption in individual buildings can be reduced by 40 percent or more, but because approximately one-third of the annual energy consumption in the U.S. is directly attributable to building operations. Both the Energy Policy and Conservation Act of 1975 (Title III, Part C), and the Energy Conservation Standards for New Buildings Act of 1976 (Title III of the Energy Conservation and Production Act) were enacted by Congress in order to ensure that this potential would be realized over time as new buildings make up a larger and larger part of the total building stock.

The Energy Conservation Standards Act specifically requires the development of building performance standards which are aimed at achieving "maximum practicable" improvements in the energy efficiency of new buildings. This report suggests that the explicit consideration of life-cycle benefits and costs related to energy use in buildings be incorporated into the development of such standards or into their future improvement as time allows. Energy consumption in buildings can be varied to a very large extent through the use of energy conservation improvements in building design. However, the extent to which energy use can be "practicably" reduced depends largely on the costs and benefits incurred in doing so. Thus, while energy conservation design is a technical problem, economic analysis is essential in determining the extent to which additional conservation modifications are cost justified, as well as the least costly means by which a given conservation goal can be satisfied. Life-cycle benefit-cost analysis can provide a systematic framework for decision-making in building design. Higher energy costs and more severe climatic factors will each result in greater cost justification for increased conservation in building design. Higher conservation costs will have just the opposite effect.

Economic decision-making criteria useful in the energy conservation design of new buildings are discussed in this report. Both life-cycle-cost minimization and the concept of economic balance among conservation options are examined and the marginal cost and savings criteria for their satisfaction are presented. The expansion of these criteria from application to the design of a single building to the design of all new buildings is discussed in order to lay the groundwork for their possible use in the development of standards for energy conservation in buildings.

Just as the energy-related life-cycle costs of an individual building can be reduced at the design stage, so can the life-cycle costs implicit in the specification of building standards be reduced or minimized through use of economic analysis in their development. Due to the generalized nature of building standards, benefits and costs cannot be

ABSTRACT

The Federal Government and a number of States are currently developing energy conservation standards for new buildings. This report suggests that economic considerations be incorporated directly into this standards development process. A life-cycle benefit-cost approach to standards development can provide a systematic and objective framework for standards specification. Differences in climate, building type, energy cost, and operational requirements can be directly incorporated into the standard as they impact energy related benefits and costs. It is shown that the life-cycle costs associated with any given overall conservation goal can be reduced by developing an economically balanced standard. In addition, it suggests that a standard which has as its goal the minimization of life-cycle costs will likely lead to greater effective energy savings than alternative approaches. Specific suggestions for the incorporation of economic analysis into the standards development process are made.

SI CONVERSION

In view of present accepted practice in this country in this technological area, common U.S. units of measurement have been used throughout this paper. In recognition of the position of the USA as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, we assist readers interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this paper.

<u>Length</u>

1 ft = 0.3048 meter* (m)

<u>Area</u>

1 ft^2 = 0.0929 square meter (m^2)

<u>Temperature</u>

degree Celsius (°C) = 5/9 (°F - 32)

<u>Quantity of Heat</u>

1 Btu = 1055.87 joule (J)

<u>Thermal Resistance</u>

1 °F h ft^2/Btu = 0.176 square meter degree Celsius/Watt ($m^2 \cdot$°C/W)

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* exactly

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

Improved energy efficiency in buildings has been recognized for many years as an important goal in formulating a Federal or State energy policy. Even before the oil embargo of late 1973, the President's 1971 and 1972 Energy Messages to Congress addressed the need to reduce energy losses from buildings by a substantial margin. Mandatory energy conservation standards for new building design have been proposed by the Federal Government as well as some States and local governments. Thermal efficiency standards for government-insured housing have been upgraded several times in recent years, while some States and local governments have promulgated similar standards for new construction subject to the building regulatory process.

Several pieces of legislation at the Federal level are likely to expand mandatory energy conservation standards to include all new residential and commercial construction in the U.S. Both the Energy Policy and Conservation Act of 1975[1] and the Energy Conservation Standards for New Buildings Act of 1976[2] encourage the States and local governments to adopt and enforce new energy conservation standards. Moreover, the latter requires the development, at the Federal level, of performance standards for new residential and commercial buildings which are designed to achieve the "maximum practicable" improvements in energy efficiency and increases in the use of nondepletable sources of energy. Thus it is likely that such standards will be stricter than most standards existing at that time, which generally did not exceed what was considered to be good design practice even before the oil embargo.

1.2 PURPOSE AND SCOPE

The purpose of this report is to outline the potential role of economic analysis in the development of economically efficient energy conservation standards for buildings. In particular, economic efficiency criteria are are suggested for the development or improvement over time of a national energy conservation standard for new residential and commercial buildings. It is shown that standards based on consistent economic criteria will likely result in greater energy savings and ultimately result in less cost to building users than alternative standards. More importantly, it is shown that the resulting dollar-valued energy savings cannot be achieved at less cost through any alternative standard. Finally, the rationale for using economic efficiency criteria in the development of a national standard is discussed as it relates to the legislative requirement for "maximum <u>practicable</u> improvements in energy efficiency."

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[1] Public Law 94-163, Title III, Part C.

[2] Public Law 94-385, Title III.

To clarify the scope of this report, a comment about what is not attempted seems appropriate. The report does not include arguments for or against the development or promulgation of energy conservation standards for new buildings, nor does it compare energy standards with other mechanisms for improving the energy efficiency of new buildings. It simply recognizes and describes the conditions that have led to an interest in such standards and proposes economic efficiency criteria for use in their development.

1.3 ORGANIZATION

This report is divided into several sections, as follows. Those provisions of the Energy Conservation Standards for New Buildings Act of 1976 that are relevant to the standards development process and to the scope of this report are discussed in Section 2. Section 3 presents a general economic interpretation of the tradeoff between energy use and energy conservation in buildings. Section 4 provides implications for the development of economically efficient standards and specific problems associated with such an undertaking. Section 5 briefly considers the use of Resource Impact Factors (RIF's) in assigning real economic costs to the energy that could potentially be conserved by an energy standard. Finally, Section 6 summarizes the findings of this report, makes recommendations for the standards development process, and outlines some research requirements which must be undertaken to develop a standard which reflects economic efficiency in building energy use.

2.0 THE STANDARDS ACT OF 1976

2.1 POTENTIAL IMPACT

The Energy Conservation Standards for New Buildings Act of 1976[1] provides a good insight into the objectives of the Federal initiative in developing national energy conservation standards. The resulting standards, if made mandatory, may result in considerably more investment in the design and construction of new buildings than would otherwise have been undertaken. At the same time, the benefits from this increased investment, in terms of reduced energy use over the life of new buildings, will likely be much larger than the costs incurred.

The impact of these reduced energy requirements on total U.S. energy demand will be large. Currently, 32 percent of all energy used in the U.S. is consumed in the Household and Commercial sectors, the vast majority of which involves activities in buildings. Of this, 70 percent is used by the Household sector and 30 percent in the Commercial sector.[2] Between 1975 and 1985 approximately 26 million new residential units are projected, representing about 29 percent of all units existing in 1985.[3] During this same time, commercial floor space will increase by approximately 14 billion square feet, representing about 35 percent of all existing commercial floor space in 1985.[4]

The potential reduction in energy use in new buildings from that of most existing buildings due to mandatory standards has been variously estimated to range from 10 to 60 percent, depending on the building type considered and the standard implemented.[5] Such estimates have been largely based on an upgrading of new buildings to a level which was, in fact, often considered to be "good" design practice even before the oil embargo of 1973. These estimates rarely reflect the economic potential for even greater reductions in energy use due to the higher cost of energy since that time.[6]

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[1] Hereafter referred to as the "Standards Act."

[2] Federal Energy Administration, Project Independence Report, Washington, D.C., November 1974, p. 164.

[3] Ibid, p. 167.

[4] Ibid, p. 169.

[5] See, for example, "An Impact Assessment of ASHRAE Standard 90-75, Energy Conservation in New Building Design," A.D. Little, Cambridge, 1975.

[6] For an estimate of the higher economic potential for energy conservation in existing housing due to higher energy prices, see Petersen, S.R., "Retrofitting Existing Housing for Energy Conservation: An Economic Analysis" BSS-64, National Bureau of Standards, 1974.

2.2 CRITERION FOR DETERMINING CONSERVATION GOALS

The Standards Act, in requiring ". . . the development and implementation, as soon as practicable, of performance standards for new residential and commercial buildings which are designed to achieve the maximum practicable improvements in energy efficiency. . .," apparently seeks to raise energy conservation goals beyond design practices typical in current construction. However, in doing so, the Standards Act provides an objective criterion for establishing these new conservation goals in that it specifies that maximum practicable improvements be considered in the development process. If the term "practicable" is interpreted to imply "cost justifiable," and if all energy-related costs (initial construction costs as well as operational costs) are relevant, then the Standards Act may be interpreted to constrain new energy conservation requirements to those justifiable in a life-cycle-cost context. However, energy-related life-cycle costs vary considerably as a function of climate, building type, energy costs and other technical and economic factors. Thus the extent to which energy conservation requirements are cost-justified varies considerably as well, depending on their application.

In the following sections the detailed implications of a life-cycle-cost approach to the development of energy conservation standards are discussed. The remainder of this section outlines certain other requirements and implications of the Standards Act.

2.3 PERFORMANCE CONCEPT

The Standards Act requires that a "building energy performance" standard be developed and implemented. This term is defined in the Standards Act as "an energy consumption goal or goals to be met without specification of the methods, materials, and processes to be employed in achieving that goal or goals. . ." Such an energy consumption goal might be expressed in terms of an energy "budget," i.e., the maximum allowable energy consumption related to defined energy-related building operations. While the concept of a building energy performance standard is not new, to date there have been few building standards for energy conservation which go beyond the specification of energy performance requirements for discrete building components. These "component performance" standards are usually expressed in terms of the maximum allowable rates of heat loss (or gain) through the various components of the building shell, or in the case of service equipment, in terms of minimum allowable conversion efficiencies, rather than in terms of actual energy consumption, *per se*.

The building energy performance standard, as envisioned in the legislation, is not meant to set limits on all types of energy consumption in buildings but rather on energy use related to the actual design and quality of construction of new buildings. These uses are primarily space heating, cooling, and ventilating; domestic water; and illumination. Rather than actually *rationing* energy for these purposes, the legislation seeks only to limit annual energy use as calculated at the design stage. Design energy consumption calculations for large unconventional buildings will likely require computer analysis. However, in the majority of cases compliance with a Manual of Accepted Practice (MAP), made available along with the standard to demonstrate acceptable design approaches to the performance standard itself, will likely suffice. Such a manual might allow designers to make trade-offs among specific building components without needing an entire computer analysis of building energy requirements.[1]

Building energy performance standards have several important economic and energy resource implications. If the primary conservation requirements are manifested by an overall energy budget, the designer/builder can make a wide range of design trade-offs in order to arrive at a configuration which can satisfy an energy budget constraint at a minimum cost. This approach provides considerably more design freedom than component performance standards and will likely stimulate cost-saving conservation innovations. At the same time, building energy performance standards are more difficult to implement from an administrative, or regulatory, point of view. Most building code authorities do not now have the technical resources needed to assure compliance with such performance standards at the design and construction stages. Yet the standard, while national in scope, is expected to be enforced within the existing regulatory system at the State and local levels.

The development of acceptable energy conservation standards for buildings will necessitate a considerable amount of research and analysis. Much of this will be entirely technical in nature. However, the ultimate question, "How far can conservation goals be practicably increased?," extends beyond the range of technical research into the realm of economic analysis. Ultimately the costs and benefits of the resulting standards must be addressed if they are to be politically and administratively viable. The remainder of this report addresses the economic aspects of the building design process and how economic efficiency criteria can be explicitly reflected in the standards development process.

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[1] This is the procedure allowed in ASHRAE Standard 90-75, Energy Conservation In New Building Design, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., New York, 1975.

3.0 ECONOMICS AND THE ENERGY PERFORMANCE OF BUILDINGS

The most outstanding characteristic of energy consumption in buildings is how widely it varies from building to building. Four major factors influence this variation: building design (including quality of construction), operational and maintenance procedures, occupant habitability criteria, and climatic conditions.

Except for climate, all of these factors can be modified to achieve significant reductions in energy use in buildings. However, mandatory energy standards are likely to apply only to the building design, with operational and maintenance procedures and occupant habitability criteria assumed fixed at recommended levels. This section examines some of the underlying technical and economic realtionships between energy consumption and building design in order to provide the framework for development of an energy standard that implicitly reflects economic considerations.

In this report occupant habitability criteria with respect to comfort, health, and safety are assumed to meet existing standards for all buildings of the same purpose. Design changes that reduce energy consumption in buildings are to be considered only if the habitability criteria remain satisfied. Operational and maintenance practices are assumed to be consistent with recommended procedures for each building type and location considered.

The analysis in this section addresses only those design modifications which reduce energy requirements related to heating, ventilating, and air conditioning (HVAC) operations. However, such HVAC operations typically consume sixty percent or more of the energy used annually in buildings[1] and represent the energy consumption most closely related to overall building design. Moreover, the underlying technical and economic relationships are quite similar for other energy-consuming operations in buildings.

3.1 TECHNICAL ASPECTS OF ENERGY PERFORMANCE

Building energy performance (BEP) is an integral, but abstract, concept related to the development of future standards for energy conservation. BEP may refer to the efficiency of any or all of the energy-related activities in a building. In this report, however, BEP is expressed in terms of HVAC-related operations only. In general, as HVAC-related energy requirements are decreased, given a specified operational profile, energy performance increases, and vice versa. However, a precise definition of BEP has not been developed. Therefore, for the purpose of this report, building energy performance is defined as the inverse of the HVAC-related energy consumption of a building under a prescribed

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[1] Stanford Research Institute, "Pattern of Energy Consumption in the U.S.," Nov. 1971.

operating schedule. This operational profile may be of short term duration but should include habitability requirements, a schedule of internal heat release, and climatic factors that are representative of the range of seasonal heating and cooling conditions.

By definition, BEP is directly proportional to the extent to which energy conservation features are usefully incorporated into a building design. Thus, as BEP is increased, HVAC-related energy consumption requirements are correspondingly reduced but at a decreasing rate. This fundamental inverse relationship between BEP and energy consumption is shown by the "trade-off" curve in Figure 1. In this figure, the vertical axis represents the energy consumption for HVAC-related operations and the horizontal axis represents BEP. As one moves down the curve to the right, increased BEP is traded off for decreased energy consumption. However, this relationship is characterized by diminishing returns; that is, constant-size improvements in BEP result in smaller and smaller reductions in energy consumption. Note that the habitability criteria must be satisfied at any point on this trade-off curve.

While no attempt is made to measure BEP in absolute terms, it serves as a useful concept for analytical purposes because it allows us to express in common terms the extent to which many different energy conservation modifications can be usefully incorporated into a building design. In concept, BEP is very closely related to the measurement of the energy performance of individual energy-related components but on a more comprehensive (whole-building) basis. For example, while thermal resistance is a measure of the thermal performance of building shell components made of different materials, it is in fact defined as the inverse of thermal transmittance, or the time-rate of actual heat flow through those components. Similarly, the Coefficient of Performance (COP) of heating and cooling equipment is inversely proportional to the energy input required to satisfy given energy output requirements under prescribed operating conditions: the higher the COP, the lower the energy input required. Thus, BEP, as used in this report, is simply an index of the overall level of energy conservation achieved in the design of a building, measurable under prescribed operating conditions.

In fact, while the BEP concept is useful for analytical purposes in this report, energy consumption constraints for new buildings will likely be promulgated in terms of an annual "energy budget." This energy budget would be based on energy consumption requirements as they correspond to a given level of BEP. Throughout this report, energy consumption is expressed in terms of thermal energy units as delivered to the building site. Energy losses in production, refinement, or transmission are not considered. Such energy losses are assumed to be accounted for in the delivered price of energy. (Where the price of energy does not properly reflect such costs, it may be modified by a "Resource Impact Factor," as described in Section 5.) The significance of energy prices in the determination of the appropriate BEP goal (or energy budget) will be discussed at length in this section.

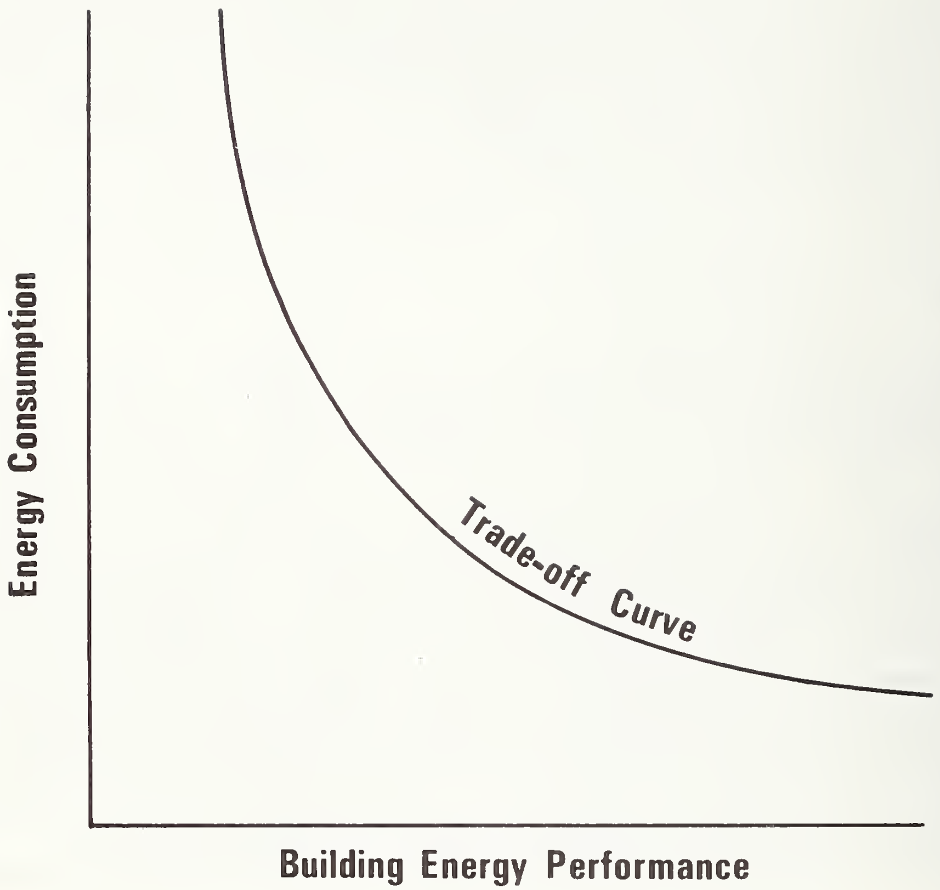

Fig.1. Trade-off relationship between Energy Consumption and Building Energy Performance

3.2 ECONOMIC ASPECTS OF ENERGY PERFORMANCE

Although the technical trade-off relationships between energy conservation and energy consumption can be determined for most energy-related modifications to a building design, they do not provide the information needed to resolve the following design problems, which are more fundamentally economic in nature:

(1) To what extent should energy conservation features be traded off for reductions in energy consumption requirements; i.e., what is the "proper" BEP goal and corresponding design energy consumption?

(2) How does this BEP goal change as energy resources become scarcer and more costly relative to the resources used for energy conservation?

(3) How does this BEP goal change as a given size and type building is considered for different climatic locations?

(4) What is the best combination of the many available energy conservation techniques for satisfying any given BEP goal or energy consumption constraint?

These considerations are economic in nature because they directly involve the efficient allocation of scarce resources. In this limited context, efficient resource allocation requires that the present-value cost of all resources used to satisfy thermal comfort criteria over the expected useful life of a building be minimized. In a more global sense, efficient resource allocation includes the very determination of such thermal comfort criteria as well, since they may compete with other desirable consumer wants and needs. This further step is beyond the scope of this report, however, since the stated objective is to provide an economic basis for standards development, given "acceptable" thermal comfort criteria.

Efficient resource allocation is made possible only when the real economic costs of the resources utilized are known. This in turn is the task of the price system. In a well-functioning, free-market economy, prices determined competitively by supply and demand represent the real economic cost (or relative scarcity) of a resource.[1] For this reason, energy prices reflect more than the thermal energy content of a a physical quantity of energy extracted, refined, and delivered to the building site. Energy prices include non-energy resources consumed in this process as well, including the cost of capital, equipment, material and labor required in the supply process. In addition, energy prices for specific energy forms reflect the degree to which other

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[1] Reference is made here to supply and demand conditions in the U.S., where the effect of foreign monopoly power is, in fact, a real cost. Still, some real costs, such as pollution, may not be reflected in market prices. The case where energy prices do not adequately reflect all real costs will be treated specifically in Section 5.

energy forms can serve as substitutes. Demand for specific energy forms for other uses will have a direct impact on the price of those energy forms used in the building sector.

3.2.1 Economic Efficiency and Optimal BEP Goal

Economic efficiency as a design objective provides an analytical framework for dealing with the four design problems outlined above. This analytical framework can serve as the basis for energy conservation standards, since they implicitly address these same issues. The following analysis demonstrates the general application of economic efficiency criteria to the energy conservation design related to HVAC operations. In Section 4 the implications of this analysis for the development of building standards for energy conservation are discussed.

We begin with the first of the design problems outlined above: How high should the HVAC-related BEP goal be in the design of new buildings? This requires a relatively straightforward economic analysis, graphically developed in Figure 2. In this analysis it is assumed that only one type type of energy is used in HVAC operations. In Section 3.3 the problems inherent in multi-energy-type usage will be discussed.

In Figure 2a, total HVAC-related conservation costs[1] (TCC) incurred and the total dollar value of energy savings (TS) realized through the conservation improvements are shown on the vertical axis as a function of building energy performance on the horizontal axis. Energy conservation improvements are made in order of their relative cost effectiveness. That is, improvements with a higher savings-to-cost ratio are employed before improvements with a lower savings-to-cost ratio. All costs and savings are expressed in present-value, life-cycle terms, using a discount rate which represents the best alternative use of available investment funds or the cost of borrowing, if required. The magnitude of TS is related to climatic factors, projected energy costs, habitability requirements and operational procedures, as well as to the discount rate and the expected useful life of the building.[2]

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[1] One must consider that conservation costs may not only be tangible (in terms of the increased construction cost) but intangible as well (e.g., where preferences for a view or architectural form must be foregone).

[2] Total savings can be expressed as average annual savings at current energy prices multiplied by a present worth factor (PWF), where

$$PWF = \sum_{t=1}^{n} \left(\frac{1+p}{1+d}\right)^{t},$$

n = useful building life in year,
p = annual rate of fuel price increase in real terms, and
d = discount rate in real terms.

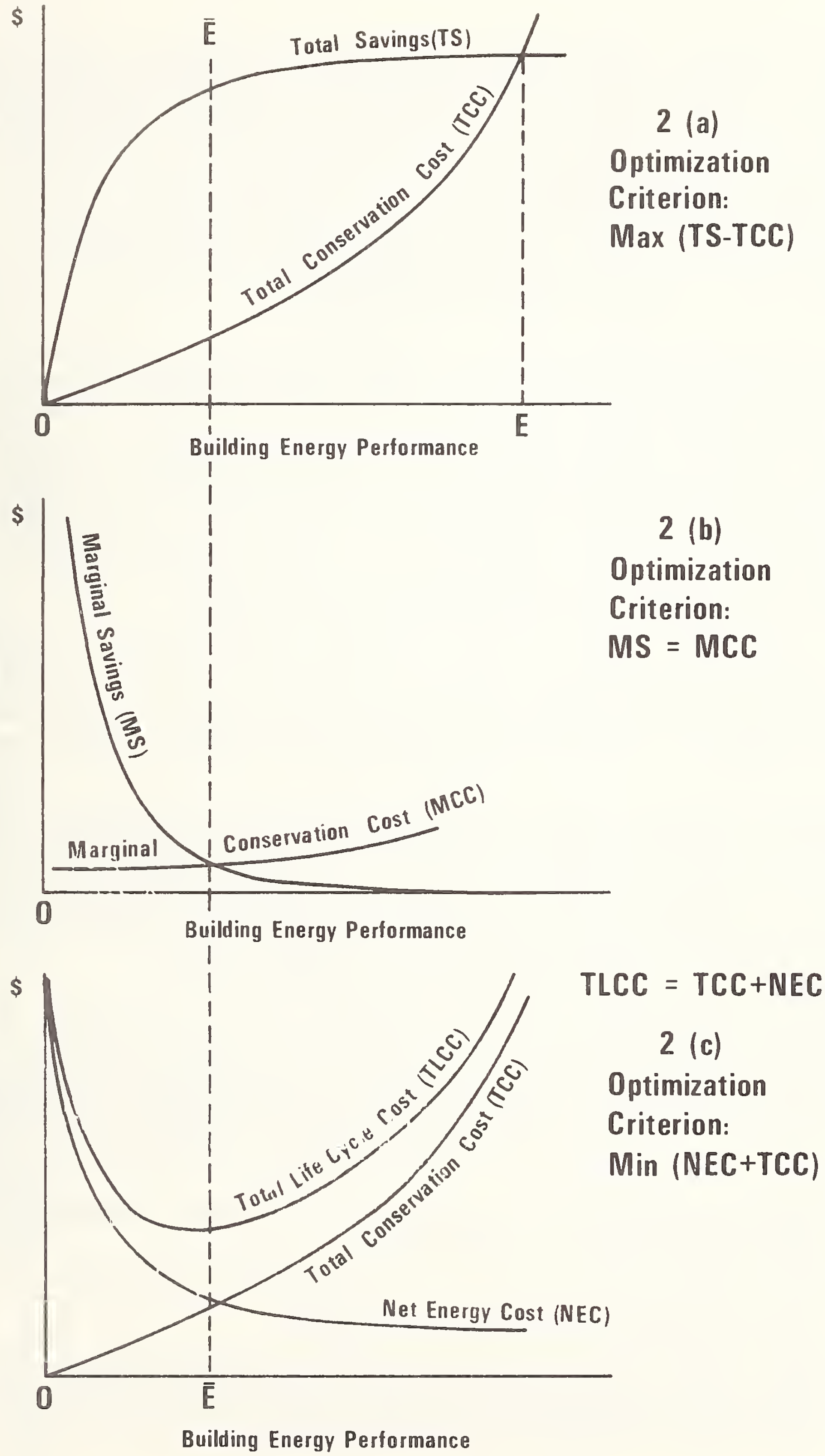

Fig. 2. Optimization Criteria for B[illegible]lding Energy Performance (BEP) determination

In Figure 2a, TS is considerably greater than TCC for lower levels of BEP. But TS increases at a decreasing rate as BEP is increased, due to the diminishing returns that characterize energy conservation improvements. Thus TS is eventually matched by TCC at E, and thereafter falls below TCC. At any point between the origin and E, TS exceeds TCC, so that any level of BEP within this range may appear to be profitable. However, economic efficiency requires the use of the most profitable level of BEP. This efficiency requirement is satisfied only at $\bar{E}$, the level of BEP for which TS exceeds TCC by the greatest amount, i.e., where net saving (TS-TCC) are maximized.

This same "optimal" HVAC-related BEP goal can also be found by examining the marginal conservation costs (MCC) and the marginal savings (MS) related to the total cost and total savings function.[1] (Marginal costs or savings are the costs or savings due to each additional increment of BEP.) This is shown in Figure 2b. As BEP increases, marginal savings decrease, but at a decreasing rate. At any point to the left of $\bar{E}$, MS exceeds MCC, and thus a further increase in BEP is economically justified. At any point to the right of $\bar{E}$, MCC exceeds MS and thus a decrease in BEP is justified. Thus, only where MS just equals MCC, at $\bar{E}$, is no change in BEP economically justified.

In Figure 2c, we see that total life-cycle costs (TLCC), the sum of total conservation costs (TCC) and net energy costs (NEC), are indeed minimized at $\bar{E}$.[2] NEC at any level of BEP is equal to total energy costs before energy conservation improvements are made less total savings at that level.[3]

The relationship shown between marginal cost and marginal savings in Figure 2b is very useful in establishing energy conservation design goals that are economically efficient. Because marginal savings and costs are usually easier to identify and estimate than total savings and costs, this approach can greatly simplify the task of determining the optimal HVAC-related BEP for a building design.

Table 1 provides a hypothetical example of the determination of the economically efficient levels of BEP and corresponding energy consumption for the case of space heating in a 1200 square-foot, detached, single-family house. BEP is defined for this example as the inverse of the purchased Btu requirements for space heating on a day with a

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1 Note that MS and MCC in Figure 2b are the first derivatives of TS and TCC respectively in Figure 2a.

2 Note that the intersection of the NEC and TCC curves has no significance in terms of minimization of TLCC.

3 NEC in Figure 2c has the same shape as the trade-off curve Figure 1; however, it is expressed in present value, life-cycle dollar terms rather than in terms of energy consumption.

TABLE 1. Heating-Related Costs as a Function of BEP - Base Case
Electric Heat @ 2.5¢ per kWh

BEP[a] (million Btu)$^{-1}$	Annual Heating Energy Requirement[b] (million Btu)	Present-Value, Life-Cycle Dollars[c]: Conservation Cost	Net Energy Cost	Marginal Conservation Cost	Marginal Savings[d]	Total Heating-Related Cost	Loss Due to Sub-optimization
1.0	100	$ 0	$21,975	$ 0	$ 0	$21,975	$16,835
2.0	50	250	10,987	250	10,988	11,237	6,097
3.0	33.3	500	7,325	250	3,662	7,825	2,685
4.0	25	800	5,494	300	1,831	6,294	1,154
5.0	20	1,150	4,395	350	1,099	5,545	405
6.0	16.7	1,550	3,662	400	733	5,212	72
7.0	14.3	2,000	3,140	450	522	5,140	0
8.0	12.5	2,500	2,747	500	393	5,247	107
9.0	11.1	3,050	2,442	550	305	5,492	352
10.0	10	3,650	2,197	600	245	5,847	707

[a] BEP here is measured as 1/E, where E is the daily purchased energy requirement for heating a 1,200 sq. ft. house under defined climate and operating conditions.

[b] Annual heating energy requirement is the number of Btu required annually to satisfy thermal comfort conditions during the heating season. For the purpose of this table it is assumed to be directly proportional to E.

[c] Present worth factor assumed equal to 30. Examples:
- i. 30 year life, real discount rate = 4%, annual energy real energy price increase = 4%
- ii. 43 year life, discount rate = 10%, annual energy price increase = 8%

[d] Marginal Savings is the incremental reduction in energy cost attributable to the incremental increase in BEP.

defined climate and operating profile. BEP is increased as insulation is upgraded, multiple glazing is installed, more efficient HVAC equipment is used, and air infiltration is reduced. Total and marginal conservation costs, net energy costs and marginal energy savings are given in present value, life-cycle terms as they correspond to different levels of BEP. Total heating-related comfort costs are the sum of conservation costs and energy costs.

Note that beyond BEP levels 2 and 3 the marginal conservation costs are increasing. This reflects the need to use more costly materials, to make make structural changes to the building shell, and to further improve the heating equipment combustion efficiency.

In this example, $7x(10^6 \text{ Btu})^{-1}$ is the optimal level of BEP because it results in the lowest total heating-related cost. The last column in Table 1 shows the additional life-cycle cost to the building user for failure to achieve this optimal level of BEP. Had BEP been examined in smaller increments (or continuously) the optimal level would have been found between 7 and 8. Note that where discrete increments are examined, the optimal level of BEP occurs where marginal savings is closest to marginal cost without falling below it.

3.2.2 Energy Costs and Climatic Factors

This same analytical approach can be used to deal with the second and third design considerations outlined above. Specifically, how do energy prices, energy conservation prices, and climatic factors affect the optimal HVAC-related BEP goal and resulting design energy consumption?

In Figure 3, the vertical and horizontal axes again represent dollar costs and BEP respectively. The marginal conservation costs (MCC) and marginal savings (MS) curves are sufficient to demonstrate the relationship among the variables examined here. MS_2 is double the level of MS_1, due either to doubled energy prices or doubled climate-related heating/cooling load factors. The MCC curve remains fixed by assumption in both both cases. $\bar{E}_1$, corresponding to the intersection of MCC and MS_1, is the economically efficient BEP design goal for the lower MS curve; similarly, $\bar{E}_2$ corresponds to the higher MS curve, MS_2. Thus the effects of energy prices and climatic factors on the optimal BEP goal can be readily quantified. Likewise, shifts in the MCC curve will result in a shift in the optimal BEP goal: increased TCC and MCC will result in a decreased BEP goal and and vice-versa.

Note that a doubling of the MS curve does not result in a doubling of the optimal BEP goal. Its effect is considerably less because of diminishing marginal returns to increases in BEP. As a result, relatively small differences in energy costs or climatic factors will have only a slight impact on optimal BEP levels. For this reason, general conservation guidelines can be useful in applications where climates and energy prices are similar, but not necessarily identical.

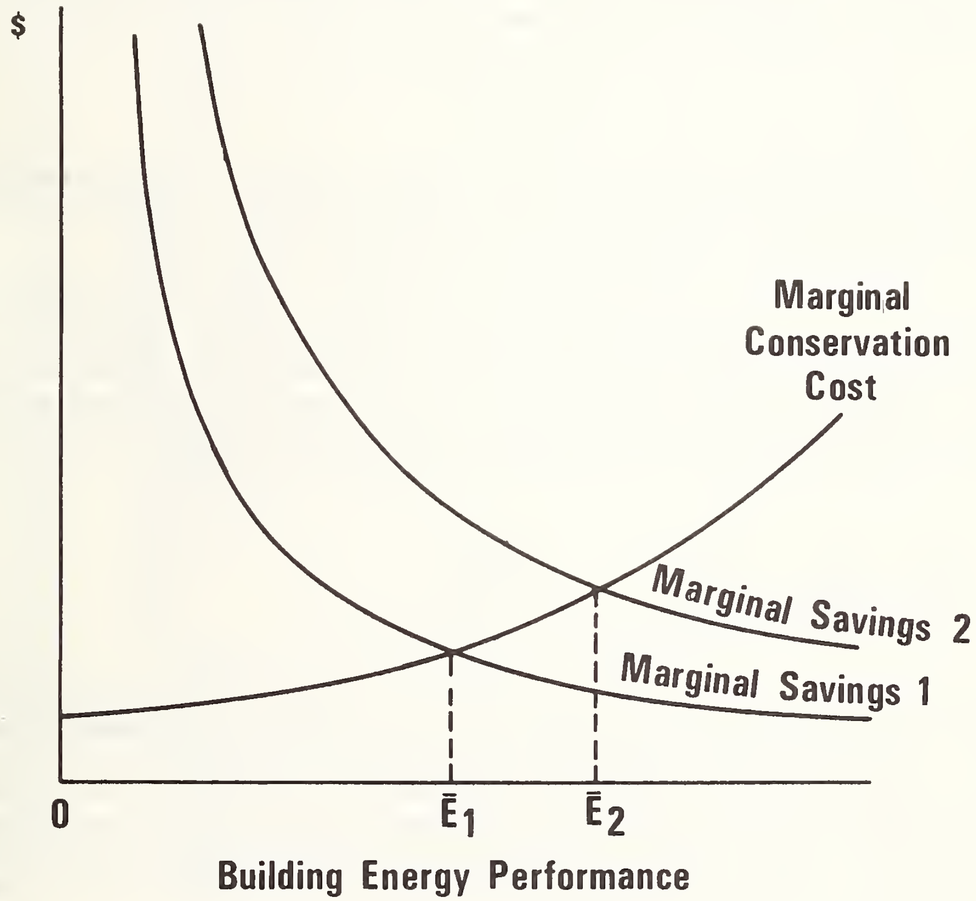

Fig. 3. Optimal BEP level shifts as a function of Marginal Savings

Table 2 provides a hypothetical example identical to Table 1 except that energy expenditures have doubled for a given level of BEP due to doubled energy costs, now 5 cents per kWh. The optimal level of BEP is now 9 x $(10^6 \text{ Btu})^{-1}$. Table 3 provides a similar example for the case of doubled climatic conditions, i.e., annual heating requirements for a house of the same BEP as Table 1 are doubled. In Table 3, energy costs are the same as in Table 1, but the optimal BEP is 9 x $(10^6 \text{ Btu})^{-1}$ as in Table 2. The design impact of doubled heating requirements due to climatic differences is the same as that of doubled energy costs.

3.2.3 Energy Conservation Combinations

Finally, consider the fourth of the design considerations stated above: What combination of energy-conserving design features will minimize the cost of achieving the optimal HVAC-related BEP design goal?

In this case, the marginal savings and marginal costs attributable to each potential energy-conserving design factor must be examined to determine its optimal utilization level. This optimization criterion results in an economic "balance" among the energy-conserving measures utilized, in that the last dollar expended on each of the variable components generates the same marginal savings, or equivalently,[1]

$$\frac{MS_1}{MCC_1} = \frac{MS_2}{MCC_2} = \frac{MS_3}{MCC_3} = \cdot \cdot \cdot = \frac{MS_n}{MCC_n} \; . \qquad (2)$$

In establishing such an economic balance, non-variable energy-conserving measures should be utilized whenever their TS/TCC ratios exceed the MS/MCC ratios of the variable measures. (Non-variable measures are those conservation features which are generally fixed in the degree to which they can be utilized; e.g., a storm door. However, quality and design improvements can make most conservation features variable in application; for example, a storm door can have varying insulating or air leakage values, depending on the quality of construction.)

To some extent these measures may act in an interdependent manner so that the savings generated by one measure may be partially dependent on the extent to which others are utilized. In such a case, the economically optimal level of investment and its allocation among all interdependent measures must be determined simultaneously.

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[1] Further conditions require that $TS_i \geq TCC_i$ for each conservation feature, that $(MS_i - MCC_i)$ be decreasing, and that, if the techniques are interdependent, the Hessian matrix of cross partial derivatives be negative definite.

TABLE 2. Heating-Related Costs as a Function of BEP - Energy Price Increases[a]
Electric Heat @ 5¢ per kWh

BEP (million Btu)$^{-1}$	Annual Heating Energy Requirement (million Btu)	Present-Value, Life-Cycle Dollars					
		Conservation Cost	Net Energy Cost	Marginal Conservation Cost	Marginal Savings	Total Heating-Related Cost	Loss Due to Sub-optimization
1.0	100	$ 0	$43,950	$ 0	$ 0	$43,950	$36,015
2.0	50	250	21,975	250	21,975	22,225	14,290
3.0	33.3	500	14,650	250	7,325	15,150	7,215
4.0	25	800	10,988	300	3,662	11,788	3,853
5.0	20	1,150	8,790	350	2,198	9,940	2,005
6.0	16.7	1,550	7,325	400	1,465	8,875	940
7.0	14.3	2,000	6,280	450	1,045	8,280	345
8.0	12.5	2,500	5,495	500	785	7,995	60
9.0	11.1	3,050	4,885	550	610	7,935	0
10.0	10	3,650	4,395	600	490	8,045	110

[a] See footnotes in Table 1.

TABLE 3. Heating-Related Costs as a Function of BEP - Annual Climatic Factor Increases[a]
Electric Heat @ 5 ¢ per kWh

BEP (million Btu)$^{-1}$	Annual Heating Energy Requirement (million Btu)	Present-Value, Life Cycle Dollars					
		Conservation Cost	Net Energy Cost	Marginal Conservation Cost	Marginal Savings	Total Heating-Related Cost	Loss Due to Sub-optimization
1.0	200	$ 0	$43,950	$ 0	$ 0	$43,950	$36,015
2.0	100	250	21,975	250	21,975	22,225	14,290
3.0	66.7	500	14,650	250	7,325	15,150	7,215
4.0	50	800	10,988	300	3,662	11,788	3,853
5.0	40	1,150	8,790	350	2,198	9,940	2,005
6.0	33.3	1,550	7,325	400	1,465	8,875	940
7.0	28.6	2,000	6,280	450	1,045	8,280	345
8.0	25.0	2,500	5,495	500	785	7,995	60
9.0	22.2	3,050	4,885	550	610	7,935	0
10.0	20	3,650	4,395	600	490	8,045	110

[a] Seasonal heating requirements are twice those of Table 1 and 2 due to climate differences. See other footnotes in Table 1.

This "balanced" combination of energy conservation measures is implicit in the TS and TCC curves of Figures 2 and 3. That is, incremental energy conservation improvements with higher savings-to-cost ratios are implemented before those with lower savings-to-cost ratios. Otherwise, the substitution of a more cost-effective measure for the less cost-effective measure will reduce the cost of achieving a given conservation goal. In fact, the optimal BEP goal and the optimal combination of conservation measures suitable to achieve that goal can be determined simultaneously. Thus, a more general economic efficiency criterion for energy conservation investments in buildings can be stated as follows:

$$\frac{MS_1}{MCC_1} = \frac{MS_2}{MCC_2} = \frac{MS_3}{MCC_3} = \ldots = \frac{MS_n}{MCC_n} = 1. \qquad (3)$$

That is, MS must be equal to MCC for each variable measure utilized. All non-variable measures are utilized as long as their total savings equals or exceeds their total costs.

Satisfaction of this more general criterion requires that available investment funding be sufficiently large to accomodate such energy conservation expenditures. Where available investment funds fall short of this optimal goal (i.e., there exists a conservation budget constraint), equation (2) provides the criterion for the maximization of savings consistent with such a budget constraint.[1]

In Table 4, the costs and savings for two independent energy conservation measures (C_1 and C_2) are displayed to help determine the best allocation of an energy conservation budget between them. Table 5 provides alternative allocations among these two conservation measures for two selected budget constraints. If the total budget available were constrained to $250, the most efficient allocation would require C_1 to be used at level 2 and C_2 to be used at level 1. That is, the greatest combined savings would be realized when MS/MCC is the same for both measures (3.2), even though full optimization (at MS=MCC) would not be possible. When the total budget is increased to $450, the best allocation requires C_1 to be used at level 4 and C_2 to be used at level 3. In this latter case, MS/MCC is still equal for both measures. Now, however, MS/MCC is equal to 1.0 so that any additional investment in either would not be cost effective under the assumptions made. The last column of Table 5 shows the potential loss incurred in terms of increased total life-cycle costs if the allocation of investment is not made in accordance with these economic efficiency criteria.

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[1] In some cases, due to a budget constraint, a more profitable investment may have to be foregone and a less profitable one be substituted if the former requires more additional funding than is available. This is most likely to occur when available conservation components vary in large discrete units rather than in continuous, or nearly continuous, fashion.

Table 4. Cost and Savings Schedule for Two Variable Energy Conservation Measures

	Application Level	Total Cost	Total Savings	Marginal Cost	Marginal Savings	$\frac{MS}{MC}$
	1	$100	$500	$100	$500	5.0
	2	150	660	50	160	3.2
Measure 1	3	200	740	50	80	1.6
	4	250	790	50	50	1.0
(C_1)	5	300	820	50	30	0.6
	6	350	845	50	25	0.5
	1	100	320	100	320	3.2
	2	150	400	50	80	1.6
Measure 2	3	200	450	50	50	1.0
	4	250	480	50	30	0.6
(C_2)	5	300	505	50	25	0.5
	6	350	525	50	20	0.4

Table 5. Alternative Allocations of Conservation Budgets[a]

Conservation Budget	Potential Allocations	Combined Savings	Potential Loss
$ 250	$C_1=4$; $C_2=0$	$ 790	$ 190
	$C_1=2$; $C_2=1$	980	0
	$C_1=1$; $C_2=2$	900	80
	$C_1=0$; $C_2=4$	480	420
$ 450	$C_1=6$; $C_2=1$	$1,165	$ 75
	$C_1=5$; $C_2=2$	1,220	20
	$C_1=4$; $C_2=3$	1,240	0
	$C_1=3$; $C_2=4$	1,220	20
	$C_1=2$; $C_2=5$	1,165	75
	$C_1=1$; $C_2=6$	1,025	$ 215

[a] Based on Table 4.

Equation (3) is a general criterion that can be of considerable value to those concerned with the energy-related design of new (and existing) buildings. Using this criterion as a design tool, a wide range of energy conservation measures can be systematically considered for incorporation into new building designs in order to reduce the impact of rising energy costs and different climatic factors to the maximum extent economically practical. While a great deal of research is needed to provide designers with information which can assist them in quickly identifying such optimal design configurations, this research is within the reach of present technology. Much of this research is currently being undertaken under Federal sponsorship.

3.3 BEP AS AN INDEX FOR MULTIPLE ENERGY TYPES

Consideration must now be given to the case where more than one energy type (e.g., gas, oil, and electricity) are used in a building. If the dollar value of all energy types used were identical, there would be no problem from an economic efficiency standpoint with a generalized BEP index based on the thermal value of energy units delivered to the building site. In fact, however, the dollar value of different energy types is often quite different and may even differ for the same energy type used at different times of the day or year. As a result, the dollar value of a given overall level of energy consumption, measured in thermal units, will vary depending on the relative amounts and price of each energy type used. The dollar value of the energy used (or saved) in a building must be known if its energy-related, life-cycle costs are to be minimized. Thus a generalized BEP index based solely on thermal values will not be consistent with an economic efficiency approach to building design. If only the thermal value of the energy used is considered, equations (2) and (3) will not provide a least-cost solution to the satisfaction of the energy consumption constraint because they address the dollar value of the energy saved.

A more appropriate performance index would therefore require that the thermal units of each energy type used be weighted by their unit prices.[1] For example, if the delivered price of a kWh of electricity is 5¢ and the price of an equivalent thermal unit of oil (3413 Btu) is 2.5¢, each kWh of electricity would be considered to equal two equivalent units of oil. Because equations (2) and (3) provide the least-cost solution to a given dollar-value energy consumption constraint, this weighted BEP approach is consistent with an economic efficiency approach to building design. This same weighting approach could be equally useful in specifying design energy budgets for buildings where more than one type of energy is utilized.

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[1] Alternatively, thermal units could be weighted by Resource Impact Factors, as discussed in Section 5.

3.4 ECONOMIC ASPECTS OF ENERGY CONSERVATION AT THE NATIONAL LEVEL

Equations (2) and (3) specify economic efficiency criteria for the determination of building energy performance consistent with minimum life-cycle cost. In a broader sense, these same equations specify economic efficiency criteria for the determination of energy performance levels simultaneously among all new buildings. Not only is a balanced approach to the selection of energy conservation measures within a building important, but a balanced approach to the determination of levels of energy performance among all buildings is desirable as well. This is especially significant when viewed from a Federal or State policy level, if mandatory thermal efficiency requirements are to be imposed on building designs.

In this broader context, equation (2) specifies that the last dollar expended to improve overall energy performance in every building must generate the same marginal dollar-value energy savings. No other specification of overall conservation requirements for buildings will generate the same or greater dollar-value energy savings at the same or less total conservation cost. When BEP for all new buildings is increased to the point where the last dollar expended toward energy conservation in each building generates one dollar in energy savings (over the life of each building), the maximum economic conservation goal for all new buildings is found as well, consistent with equation (3).

In evaluating conservation investments in many new buildings simultaneously, some consideration must be given to differences in appropriate discount rates and useful building life expectancies. Because investment decisions are based on the present value of energy savings over the useful lifetime of a building, both of these factors play an important role in determining energy conservation investment priorities among buildings. Both the discount rate and useful life expectancy may vary significantly among the private, commercial, and government sectors. For this reason the economically optimal level of BEP may vary among otherwise similar buildings.

At the national level, the expression of an overall energy conservation goal in terms other than thermal units is important if the most economically efficient allocation of energy resources is to be achieved. For example, at present, conservation goals are often stated in terms of barrels of oil per day equivalent. Such a measurement, based on thermal units, does not reflect the fact that some types of energy are more scarce (or costly) than others and thus a higher priority should be given to their conservation. Ultimately the dollar value of the energy resources consumed in the U.S. must be addressed if a national energy policy is to be consistent with other national objectives.

4.0 IMPLICATIONS FOR STANDARDS DEVELOPMENT

4.1 ECONOMIC EFFICIENCY CONSIDERATIONS

The economic efficiency criteria outlined in Section 3 can play an important role in the development of standards for energy conservation in buildings. They provide several objective guidelines useful in the overall development process: (1) They are useful in developing economically efficient conservation goals for buildings. (2) They are useful in the specification of economically balanced component performance requirements. (Component performance requirements are not specified in building energy performance standards but they would be useful in illustrating methods of compliance in an accompanying Manual of Accepted Practice.) (3) They are useful in determining economically balanced energy performance requirements for different building types, located in different geographical locations, with different occupancy requirements, and utilizing differently valued energy resources.

Economically balanced standards have an advantage over other approaches to standards development in that they generate any given level of total dollar-value energy savings at a lower total conservation cost. This is because the standard implicitly requires that energy conservation improvements with higher benefit-cost ratios be employed before those with lower benefit-cost ratios. This is generally true whether or not the economically efficient conservation goal is selected for promulgation.

A good example of the cost advantage of an economically balanced approach to standards generation is shown in Table 6. In this example, there are two otherwise identical houses which fall under the design requirements of a building energy performance standard. The first is heated with electricity generated at a cost of 2.5¢ per kWh. The second is heated with electricity generated at a cost of 5¢ per kWh. Climatic and operational factors are held the same for both houses. Energy conservation costs, annual energy consumption requirements, and life-cycle energy costs are based on Tables 1 and 2 of Section 3.

Alternative approaches to the generation of standards that results in the same total heating energy consumption (25.4 million Btu annually) are examined in Cases A and B of Table 6. The first case requires different levels of heating-related BEP for each house, based on the economically efficient (and, therefore, balanced) levels of BEP in Tables 1 and 2. The second requires that BEP (and thus conservation costs) be the same in each case, ignoring the cost of energy. While total conservation costs are somewhat lower in the second approach, total life-cycle costs related to space heating are lower in the first approach.

Alternative approaches to the generation of standards that result in the same total dollar-value energy consumption ($8025) are examined

Table 6. Alternative BEP Specifications for Two Buildings[a]

	House I (2.5¢/kWh)	House II (5¢/kWh)	Total
A. Economically Balanced Approach			
BEP $(10^6\ \text{Btu})^{-1}$	7	9	N.A.
Annual Energy Use (10^6 Btu)	14.3	11.1	25.4
Conservation Cost	$2,000	$3,050	$5,050
Life-Cycle Energy Cost	$3,140	$4,885	$8,025
Total Heating-Related Cost	$5,140	$7,935	$13,075
B. Equal BEP Approach - Total Btu Constant			
BEP $(10^6\ \text{Btu})^{-1}$	7.9	7.9	N.A.
Annual Energy Use (10^6 Btu)	12.7	12.7	25.4
Conservation Cost	$2,450	$2,450	$4,900
Life-Cycle Energy Cost	$2,791	$5,582	$8,373
Total Heating-Related Cost	$5,241	$8,331	$13,272
C. Equal BEP Approach - Total Energy Cost Constant with A			
BEP $(10^6\ \text{Btu})^{-1}$	8.22	8.22	N.A.
Annual Energy Use (10^6 Btu)	12.16	12.16	24.32
Conservation Cost	$2,621	$2,621	$5,242
Life-Cycle Energy Cost	$2,675	$5,350	$8,025
Total Heating-Related Cost	$5,296	$7,971	$13,627

[a] Based on Tables 1 and 2

in Cases A and C. Again, Case A requires different levels of heating-related BEP for each house, while Case C requires that BEP be equal in each case. Now, not only are total life-cycle costs related to space heating lower in the first approach, but total conservation costs are lower as well. Thus the total cost of achieving a given dollar-value energy conservation goal is less with the economically balanced approach. Again, this is true whether or not the economically efficient conservation goal is selected. The need to reflect national energy conservation goals in terms of the dollar-value of the energy used (or saved) has already been discussed.

Moreover, the economically balanced standard is more equitable than other approaches to standards development for it is based on consistent benefit-cost criteria. That is, all requirements for increased energy performance are based on the same marginal benefit-cost criteria. Thus the "burden" imposed on each building owner is equal in terms of the marginal cost-benefit ratio of the required conservation actions. Buildings using more expensive fuels would be required to have greater conservation measures because those measures would be more cost effective than in buildings using lower cost energy, other assumptions held equal.

4.2 DEVELOPMENT OF A COST-EFFECTIVE STANDARD

Development of a "cost-effective" energy conservation standard based on the economic efficiency criteria outlined in Section 3 is theoretically possible as long as (1) the technical relationships between energy consumption and energy conservation features of buildings can be quantified, (2) the real cost of energy resources over the life of the building and the current and recurring costs of energy conservation measures can be projected, (3) an appropriate rate of discount is identified, and (4) the useful life expectancy of the building (and its conservation measures) is known. To the extent that more accurate information on building energy conservation opportunities and future energy costs is now more readily available than has been in the past, these economic efficiency considerations can be better incorporated into the standards development process.

However, there are practical limitations to the development of cost-effective standards that should be considered. Energy conservation standards must, by their nature, be sufficiently generalized that they can be applied to large numbers of similar, but not identical, building designs. Yet the actual energy savings potential of various energy conservation improvements, as well as their costs (both tangible and intangible) may vary from building to building and over time as well. In addition, there is some uncertainty as to future energy costs and the useful life expectancies of buildings. Thus a more generalized approach to the use of economic analysis in the development of standards is warranted.

A classification scheme for buildings and building operations is fundamental to such a generalized approach. This classification scheme should recognize design differences that have significant impacts on either energy use or long-term energy-related owning and operating costs. These differences might include building size, habitability requirements, hours of operation, type of service equipment, special operations (such as a computer center), and the types of energy use. In addition, a climate classfication scheme is needed to account for significant differences in the duration and severity of heating and cooling seasons.

Energy performance requirements, or energy budgets, would then be developed for each class of buildings, using energy and economic data most appropriate for that class of buildings. These performance requirements might be based on a "representative prototype" building, typical of buildings belonging to the class represented. The prototype would be designed using the economic efficiency criteria examined in Section 3. The energy required to operate the prototype building under prescribed operational procedures would be the basis of an energy budget to be applied to all new buildings of the same class in the same climate. A schedule of energy budgets for each class of buildings might be developed for a range of climates, hours of operation, type of energy used, etc., using cost-benefit analysis to modify the representative prototype accordingly. Such a schedule might be presented in tabular (discrete) or equation (continuous) form.

In developing representative prototypes to serve as the basis of regulating energy use in buildings, consideration should be given to the limitations that they impose on atypical building designs which fall into the same class as other more typical designs. The purpose of the standard is not to give rise to a new uniformity among building designs. Therefore, an analysis of the practical level of design freedom remaining after energy budgets have been developed based on prototypical designs should accompany the standards development process.

Another problem inherently associated with the development of an appropriate building classification scheme involves the selection of those design or operational parameters that are to be used in differentiating classes of buildings for the purpose of establishing different performance requirements. For example, if buildings using space heating equipment that is inherently less energy efficient than other types available (e.g., resistance heat versus a heat pump) are classified differently and given a higher energy budget allowance, there is less incentive to use the more efficient equipment. On the other hand, if no differentiation is made, energy budgets based on the use of the more efficient equipment may be impractical for buildings using the less-efficient equipment. This would impose greater costs on those who wish to use the less-efficient equipment type where it has a life-cycle cost advantage. Similarly, if the energy budget were to be based on the use of less-efficient equipment, the economic potential for increased conservation in those buildings where the more efficient equipment is used would be foregone (except through voluntary efforts).

A similar example can be made for heavy versus light construction materials and their energy-use implications in otherwise similar buildings. From an economic efficiency standpoint, energy budgets should be differentiated by these major design variables. However, one could argue on the same grounds that different energy budgets should be developed for buildings of different relative window areas as well, which is not likely to be acceptable from an administrative viewpoint. Thus, an administrative decision (probably at the executive level) will be required in drawing the line between economic efficiency and energy efficiency considerations in selecting those design features that will be the basis of different energy budgets. This administrative prerogative will be manifested in the number of building classifications established for energy budget calculations.

In developing a generalized approach to the use of economic analysis in the development of standards, consideration must be given to the selection of technical and economic factors appropriate to energy conservation measures in each class of buildings. These factors may vary significantly, even locally. In addition, some of these factors are based on projections of future costs which, in fact, are largely influenced by unforseeable events.

This does not imply that economic analysis is of little use in developing economically efficient standards. Economic analysis does provide an objective and consistent approach to the determination of the requirements of a standard once acceptable assumptions for these factors have been agreed upon. In fact, this provides a much more objective basis for the concensus process, in that discussion is focused on the determination of acceptable assumptions rather than on the final results. Moreover, as changes in these assumptions become warranted, they can be systematically incorporated into the standard during periodic updates.

In general, an approach to the selection of these factors which is conservative from a conservation-cost viewpoint can be justified on several grounds. The most important of these is risk aversion. For example, if energy prices rise more slowly than projected, or building lifetimes fall below their expected length, a standard based on the original assumptions will have resulted in over-investment in energy conservation, with little recourse on the part of building owners. On the other hand, if energy prices rise faster than expected, or building lifetimes extend beyond original projections, building owners can take action by voluntary retrofit actions in order to further improve the thermal performance of their buildings. Thus the life-cycle cost of over-estimating the actual optimal energy performance level is likely to be considerably greater than the costs of underestimating that same level at the design stage. While it is unlikely that a performance standard could specify that options for economical retrofit be incorporated into the initial building design, it might suggest that they at least be considered. In addition, a conservative approach will be less likely to result in energy performance requirements that exceed economic justification for building designs that differ significantly from the representative prototype selected for their class of building.

4.3 ADMINISTRATIVE COSTS

It has been shown that an economically balanced approach to energy conservation requirements for buildings will cost building users less than alternative approaches which result in the same total dollar-value energy savings. However, the potential impact of such an approach on the administrative costs associated with an energy conservation standard for new buildings must be considered. Administrative costs include costs incurred in the development and promulgation of a new standard as well as the costs associated with compliance and with enforcement of the standard. Each of these is discussed in turn.

(1) Development: Development costs for standards which require a benefit-cost analysis of all requirements will likely be higher than those that do not, largely because much of the needed analysis does not yet exist. However, considerable data on energy and conservation costs will likely be researched in determining the cost effectiveness of any new standards after their development. Thus, the principal additional requirement here is to incorporate this data into the standard development process rather then as an addendum to it.

(2) Promulgation: The prospect of increased government intervention in the construction industry resulting from new standards for energy conservation is not entirely welcome by many groups having an interest in that industry. Many would prefer a free-market approach to energy conservation, based on the need to offset higher energy costs. Energy conservation standards proposed or promulgated by some State governments have come under sharp attack, often on the grounds that they are not cost effective, even in life-cycle terms, in many applications.

New standards developed by the Federal government are likely to receive a great deal more attention and analysis from interested parties than State standards. For this reason new standards must be objectively based and of demonstrated cost effectiveness, especially if they are significantly more stringent than existing standards. This gives a standard which inherently reflects the consideration of both long term benefits and costs a considerable advantage over those that do not.

If life-cycle-cost effectiveness is required in order to assure successful promulgation, the economically balanced approach to standards generation is likely to result in greater energy savings than alternative approaches. This is especially true when considering conservation requirements for different energy sources based on their delivered costs. If an approach is adopted which results in equal energy consumption limitations despite significant differences in energy costs, the consumption limitations will likely be based on the lowest-cost energy type used in new buildings. If a higher requirement were imposed, the standard would not be cost effective for the lowest-priced energy type used and thus the standard would be difficult to promulgate successfully. Standards based on the lowest-cost energy source would not be able to realize the conservation potential related to other, more highly priced, energy types. Some resistance to energy conservation requirements which vary as a function of energy costs (and therefore, by type of energy used) might be encountered from builders/designers who feel that this will complicate the standard and from utility companies and manufacturers who may feel that it is biased towards less costly energy forms or more efficient equipment types.[1] Careful explanation of the objective benefit-cost basis of such a standard must be provided. Consumer groups and financial institutions will generally support such a standard if they recognize that it will lead to lower total owning and operating costs.

(3) Compliance and Verfication: The costs of compliance with an energy conservation standard and verification of such compliance depends almost entirely on the manner in which its requirements are formulated rather than on the extent of those requirements. Building energy performance standards (BEPS) are inherently more difficult to work with than component-oriented standards. If BEPS are made mandatory, design energy requirements must be determinable with sufficient accuracy to meet any legal challenge. For some types of buildings this may require the use of computer programs that still need further development and verification if they are to be satisfactory. The impact of BEPS on a regulatory system that is largely dependent on local or State support and ill-equipped to deal with such an advance in the technology of building standards will likely require considerable Federal support. However, the extent to which such support will be needed is not likely to be affected by the economic basis for determining the level of the performance requirements.

It is extremely important that the classification schemes for buildings and climates be sufficiently clear that there be no difficulty or confusion in determining the appropriate energy conservation requirements for a new building. Schedules of conservation requirements (or energy budgets) for buildings of the same class located in different climate zones, using different energy types or having significantly different operating schedules should be easily understandable. Manuals of Accepted Practice can provide examples of designs which satisfy energy conservation requirements at minimum first cost. By following these examples, the need for an engineering analysis of energy requirements in the case of routine building designs would be eliminated.

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[1] Where energy prices are artifically low due to price controls or other non-market forces, Resource Impact Factors might be used to better reflect true social value of the energy used. This is discussed in more detail in the following section.

In addition, energy budgets for building energy performance requirements might be formulated in terms of energy use over short periods of time (e.g., one week in each season) that typify operational conditions. This would eliminate the need to estimate annual energy requirements and thus reduce both compliance and verification costs.

However, all of these factors are associated with compliance with and verification of BEPS, regardless of the basis of their requirements. Although the requirements may be more extensively classified in a benefit-cost approach to standards development, once the requirements for a given building are understood, the basis of such requirements should have no impact on compliance or verification costs.

4.4 POTENTIAL ENERGY SAVINGS IN THE RESIDENTIAL SECTOR

An estimate of the impact of standards based on economic efficiency considerations on energy use in residential buildings was made by Eric Hirst in a recent study made at Oak Ridge National Labs.[1] In that study, Hirst estimated that energy use in residential buildings would total 543×10^{18} joules between 1975 and 2000, without improvements in the energy efficiency of the service equipment or shell of the structure over pre-1975 levels. By incorporating an ASHRAE 90-type standard to improve the thermal efficiency of new and existing building shells, energy use could be reduced to 525×10^{18} joules. Upgrading the energy efficiency of new equipment through the year 2000 would further reduce energy use to 478×10^{18} joules, about 2.6 times more than the improvement in the shell. However, Hirst states that the energy saving impacts from an ASHRAE-type standard are "much lower than could be achieved with standards that minimize life-cycle costs rather than maintain initial costs." He estimates that "a tough, but economically efficient, set of thermal standards for new and existing residential units would yield savings comparable to those for the equipment efficiency programs."

Thus Hirst implies that the economic efficiency approach to building standards would likely increase energy savings due to thermal improvements of residential shells by considerably more than twice that available through the adoption of an ASHRAE 90-type standard. Further savings are likely by taking a similar (economic efficiency) approach to the improvement of service equipment performance. Such an analysis implies that a standard for residential buildings that is to make a significant impact on residential energy use must focus on both the shell and the service equipment, using economic efficiency criteria in determining the extent to which conservation measures should be required for both.

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[1] Eric Hurst, "Residential Energy Use Alternative: 1976 to 2000," Science, vol. 194, p. 17, December 1976.

5.0 REAL ENERGY COSTS VERSUS MARKET ENERGY PRICES

In Section 3 the projection of energy prices over the life of a building was shown to be an essential element in determining the optimal size of energy conservation investments in buildings. These conservation investments are, in turn, a major determinant of the building's annual energy requirements. Thus the price of energy is an important factor in determining at the design stage how much energy should be used in building operations.

Similarly, in the development of standards for energy conservation based on a benefit-cost approach, energy prices are an important determinant of conservation requirements. However, since energy standards may be mandated in response to national needs in addition to private needs, a different basis for valuing energy resources may be warranted.

The prospective building owner can minimize his expectation of present-value, life-cycle, energy-related costs by making design decisions based on the best available projection of energy prices to be incurred over the useful life of the building. As a result, his allocation of energy and energy conservation resources is optimal from his own (i.e., private) economic perspective. Where market prices represent the real cost of supplying those resources to the building site, the allocation of expenditures between energy and energy conservation resources will be optimal from the national, or social, point of view as well. That is, the real cost to the nation, in terms of scarce resources consumed in satisfying given habitability requirements, cannot be further reduced by reallocating expenditures among the resources employed. These real costs are a measure of more than the thermal content of the energy units consumed, *per se*. They include the land rents, capital, labor and necessary profits involved in extracting, refining, and transporting those resources; environmental hazards; and national security considerations as well as foregone opportunities for using that energy in other buildings and/or sectors of the national economy.

When energy prices do not properly reflect these real costs, that allocation of resources considered optimal by the building owner will not be the same as that optimal for the nation. For example, if the price of some energy form is held below its real cost, the optimal level of conservation in buildings will be lower for the owner than for the nation as a whole. As a result, the units of energy that would be conserved by a building owner at the higher price are allocated to operations in his building instead of to more socially valuable applications in competing sectors or in other buildings. (If the price of energy resources is held below the real costs incurred in making them available, we can expect some shortfall in the amount of that resource produced over the amount demanded at that lower price. This may ultimately lead to some form of energy rationing.)

There are many reasons why delivered prices and real costs for energy resources may fail to coincide. Some of these reasons may work in opposite directions. The most important of these factors are:

(1) unit taxes, such as sales tax or special energy taxes;
(2) price controls, such as government regulation of wellhead prices, transportation rates, and utility rates;
(3) environmental impacts, such as thermal, water and air pollution; oil spills; strip mining; and the risk of catastrophic accidents at power plants, where these are not internalized into the market price of energy;
(4) monopoly powers, if and where they may exist. (This does not include the impact of foreign energy cartels, if we consider only the efficient allocation of resources within the U.S. Higher energy costs due to monopoly power abroad represent real costs to the U.S. in terms of export requirements to pay for energy imports.)
(5) national security considerations and the potential economic disruption that would result from an oil embargo; and
(6) failure to accurately assess the fossil fuel reserves of the U.S. and the world and the rate of technical progress that may provide new sources of energy at affordable cost.

A national standard for energy conservation, if it is to address national resource allocation problems or avoidance of counterproductive impacts, must therefore consider the real economic cost of energy resources in determining energy conservation goals for new buildings. If these real costs are expressed in dollar terms they can be used directly in determining the energy conservation goals for new buildings that are optimal from the national (or social) standpoint.

Resource Impact Factors (RIF's) have been suggested as one way of incorporating all economic costs into a cost-sensitive energy standard.[1] A RIF is an index which can be used to adjust an actual energy price so that the true social value of the energy resource is better represented. A RIF would be developed by an appropriate Federal agency for each type of energy used and for each geographical region where there would likely be a significant difference in the real cost of producing and delivering a unit of that energy type. The RIF would reflect, to the extent practical, differences between real and market energy costs as well as anticipated changes in relative costs over time. The RIF would not be used to modify actual energy prices but would serve as a "shadow price" in determining the most cost-effective level of investment in energy conservation for standards development purposes.

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[1] Weber, Stephen F., The Effect of "Resource Impact Factors" on Energy Conservation Standards for Buildings, National Bureau of Standards Interagency Report 77-1199, 1977.

RIF's can be formulated directly in terms of dollar costs or indirectly in terms of a multiplicative factor to be used with market (actual) energy costs. Formulation of RIF's directly in dollar terms to achieve uniformity over wide geographic regions would likely be more appropriate because this approach would avoid local, short term differences in energy prices. Such differences are largely due to the discrete nature of contractural supply agreements and rate schedules and are not indicative of long term differences in real energy costs. Thus another advantage of the RIF approach, when formulated in dollar terms, is to ignore these temporary differences, providing a more uniform and rational long-term basis for the energy cost data used in generating costsensitive standards.

An additional attraction for RIF's is their potential to coordinate standards development with other Federal government energy policies. For example, if the Federal government wished to encourage the use of coal over imported oil for the generation of electric power, this could be reflected in standards for buildings through the assignment of RIF's. In such a case, electricity generated by coal would be assigned a lower RIF than electricity generated by oil. As a result, buildings in areas served by coal-generated electricity would have lower conservation requirements.

6.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 SUMMARY AND CONCLUSIONS

Even before the oil embargo of late 1973 and subsequent energy shortages the Federal government and several State governments had considered energy conservation standards for new buildings to be an important element of a comprehensive energy policy. Several States have already adopted such standards into their building regulatory systems. At the Federal level, the President and the Congress have given high priority to enacting legislation that would lead to the development of national standards for energy conservation in new buildings.

The Energy Conservation Standards for New Buildings Act of 1976, Title III of Public Law 94-385, specifically requires the development of performance standards which are designed to achieve the "maximum practicable" improvements in energy efficiency in new buildings. This report suggests how this goal can be accomplished through the explicit consideration of life-cycle costs and benefits related to the improved energy performance of new buildings. Moreover, the economic efficiency criteria presented can be utilized in minimizing the long run cost of achieving any overall conservation goal, whether "maximum practicable" or not. In fact, the use of economic efficiency criteria to "balance" the requirements of a standard as it is applied to different buildings may be more significant than the actual determination of the maximum practicable conservation goal itself.

Two basic economic efficiency criteria for new building design were examined and their implications for standards development discussed:

(1) The economically efficient energy performance goal, whether for a given building or all buildings, is found at the point where the last dollar invested in energy conservation in each building results in a dollar's worth of energy savings over the life of the building; i.e., at the point where marginal savings just equal marginal cost (Section 3.2.1); and,

(2) The least-cost combination of energy conservation measures in a given building, consistent with any given energy performance goal, is found at the point where the last dollar invested in the modification of each component results in the same dollar-value energy savings, i.e., the ratio of marginal savings to marginal conservation cost (MS/MCC) is equal for all components (Section 3.2.3).

This second criteria can be adapted to specify economically balanced performance goals for all new buildings whether or not such goals achieve the maximum degree of cost effectiveness:

(2a) The specification of building energy performance goals that minimize total conservation costs incurred in satisfying a given overall conservation goal for all new buildings requires that MS/MCC be equal for every new building; i.e., the last dollar invested in every building should generate the same life-cycle, energy-related savings (Section 3.3). In addition, if that overall conservation goal is expressed in terms of thermal energy units weighted by their respective costs, the actual conservation costs incurred in achieving that goal will be minimized with such an approach (Section 4.1).

Implications were examined for the use of these economic efficiency criteria and benefit-cost analysis in general in the development of energy conservation standards for new buildings. Due to the generalized nature of standards, which must be applicable to a wide range of buildings, economic efficiency criteria cannot be exactly satisfied in every application, but they can provide a meaningful and consistent framework in which to develop standards. Given such a framework, a systematic method can be established for the generation of standards for different building types, located in different climates, using differentially-valued energy resources, and having other features that significantly affect life-cycle costs. Once such a framework is established, focus can be directed on the particular technical and economic assumptions which drive the standards generation process. As significant changes in these assumptions occur over time, the standards can be systematically changed during periodic updates.

A classification scheme for building which reflects those factors that have a significant impact on the costs and benefits of energy conservation improvements is essential to a benefit-cost approach to standards development. Technical and economic assumptions, critical to the determination of appropriate levels of energy conservation investment within the economic efficiency framework, should be conservatively estimated so that they will not force conservation requirements that are not economically justified in most atypical applications.

The development costs of standards based on a benefit-cost approach are likely to be somewhat higher than alternative approaches because sufficient data on the economically efficient levels of conservation improvements in new building design is not available. However, the costs associated with promulgation, compliance, and verification should be no higher than those for similar performance standards not based on economic analysis, since in either case the resulting standards will likely be stated in energy budget terms. At the same time, standards based on economic efficiency criteria should result in considerably more energy savings than other approaches. This is because the economic potential for energy conservation (in terms of reduced energy-related life-cycle costs) is considerably higher in most new buildings than has been generally recognized. Moreover, because the resulting standards will be economically balanced, no alternative standards can achieve the same overall level of dollar-value energy savings (nationwide) at a lower conservation cost.

Economic balance among the conservation requirements also results in more equitable cost-benefit burdens on building users than alternative standards. This is especially true if economically balanced standards are used instead of standards which maintain constant conservation requirements despite significant differences in climate, energy costs, and other operational factors.

Energy consumption estimates in the residential sector with and without an economically efficient energy conservation standard were examined. It has been estimated elsewhere that the economic efficiency approach to standards development would result in significantly greater energy savings, especially with respect to the building envelope. These savings may be more than twice that realizable from an ASHRAE 90-75-type standard.

Finally, the problem of discrepancies between real energy costs and actual energy prices was discussed in Section 5. The use of Resource Impact Factors was suggested as one way to take account of some of these discrepancies and to provide a more uniform base for reflecting local energy costs in an energy standard. In addition, these same Resource Impact Factors can provide consistency with other government energy policies.

6.2 RECOMMENDATIONS FOR FURTHER RESEARCH

As was stated near the outset of this report, the technical relationships between energy conservation and energy consumption are better understood than the economic relationships. And yet any decision as to the allocation of scarce resources between these two factors is, by its nature, an economic decision. For this reason reliable data of both a technical and an economic nature are needed in order to provide a sound basis for standards making.

Building energy performance standards based on an energy budget concept are inherently difficult to formulate as evidenced by the fact that there are few such standards in existence today. Considerable research has been directed towards the development of an acceptable approach to such standards at the National Bureau of Standards. However, much additional research needs to be undertaken.

At present, one major obstacle to the development of building performance standards appears to be the lack of a comprehensive knowledge of the energy performance of buildings and their design components. This is essential if energy budgets are to be verified at the design stage. Other research prerequisites to the generation of an acceptable standard must be accomplished as well. A classification scheme for buildings must be developed and representative prototype building designs for different clases of buildings must be found. Climate classification methods, operational and usage assumptions, and normalization factors to account for differences in building size must all be developed in order to support the standard. A Manual of Accepted Practice must be prepared in order to show a variety of illustrative solutions to the energy budget constraint of the standard so that a computerized energy analysis is not required of every new building.

All of these technical requirements are necessary to the development of building energy performance standards, regardless of their economic orientation. However, these same requirements will serve as the basis of much of the data needed for economic analysis, especially with regard to estimating the energy savings to be derived from the standard. Transformation of potential energy savings to potential dollar savings on a life-cycle basis will require additional research into appropriate discount rates, useful building lifetimes, and projected energy costs for different energy types. In addition, cost data for the energy conservation improvements assumed in the prototype buildings are needed, including installed costs, finance costs, depreciation rates, replacement costs, insurance costs, and operational and maintenance costs. This data is needed for many different types of buildings and must be regionalized for different parts of the United States as well.

Incorporation of this data into an energy standard might be achieved through the design of representative building prototypes. These representative prototypes would be designed with the goal of reducing energy use and life-cycle, energy-related costs, using technology and building practices presently available to the building community. For each building type represented, a range of designs appropriate to the range of climates and energy costs (or RIF's) in the U.S. would be prepared. Actual energy budgets for corresponding climates and energy costs would be generated by computer analysis of these prototypes. In addition, these prototypes would serve as the basis of a Manual of Accepted Practice.

The major difference between building energy performance standards based on economic analysis and those generated without such analysis is in the design of the representative prototypes. Where the prototype designs used in the generation of alternative standards might be based on existing component-specific energy standards (e.g., ASHRAE 90-75) or on an administratively directed goal, the prototype designs would instead be determined using consistent economic decision criteria.

Because the energy budget generated through the use of economic analysis will tend to vary to a greater extent than those generated through alternative means, a clear, unambiguous method of selecting the appropriate energy budget for any given building must be developed. Finally, assumptions implicit in the standard must be reviewed periodically in order to reflect changes in long run energy costs, conservation costs, building technology, and other factors which might have significant impact on the cost-effectiveness of energy conservation modifications in building designs.

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The Federal Government and a number of states are currently developing energy conservation standards for new buildings. This report suggests that economic considerations be incorporated directly into the standards development process. A life-cycle benefit-cost approach to standards development can provide a systematic and objective framework for standards specification. Differences in climate, building type, energy cost, and operational requirements can be directly incorporated into the standard as they impact energy-related benefits and costs. It is shown that the life-cycle costs associated with any given overall conservation goal can be reduced by developing an economically balanced standard. In addition, it suggests that a standard which has as its goal the minimization of life-cycle costs will likely lead to greater effective energy savings than alternative approaches. Specific suggestions for the incorporation of economic analysis into the standards development process are made.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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