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ABSTRACT

This energy conservation workbook series was developed to provide specific data on the effect of various design and operating decisions on both cost and energy consumption. It is designed to make clear the energy consumption and cost implications of various building design and operating decisions in terms that both the layman and design professional can understand. The workbook will be released in three sections -- Energy Conservation and the Building Shell, Mechanical Systems, and Problems of School Lighting and Energy Conservation. The intent of the series is to provide a simple means for determining the consequences of the various possible decision options open to designers and school officials. This section, the first of the series, examines what can be done in designing or redesigning the building's shell to make the wisest long-run use of resources. The text explains how the building shell affects the building's energy consumption, identifies energy conserving ideas for use in the design (or redesign) of the shell, gives examples showing how these ideas could be applied to new construction and modernization projects, provides a simple method for determining the effects of each of these ideas, and identifies sources of further information to assist design professionals in complete analysis of the effect of the building shell on energy consumption. (Photographs may reproduce poorly.) (Author)

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BSIC/EFL ENERGY WORKBOOK

SECTION 1

ENERGY CONSERVATION

AND

THE BUILDING SHELL

Published by

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Building Systems Information Clearinghouse was estabished by Educational Facilities Laboratories to undertake research on matters pertaining to the development and use of building systems; accumulate and distribute information about systems projects to architects, educators, and manufacturers; and to serve as a medium to encourage communication among those interested in building systems.

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INTRODUCTION TO WORKBOOK SERIES

The winter of 1974 brought the realities of what scarce fuel supplies and rapidly increasing energy costs are likely to mean to the school districts of the nation. With a return to warmer weather and "normal" gasoline supplies it remains to be seen whether or not school districts got the message and, if they did, whether they will face up to their responsibility to exert the leadership required to set an example of energy conservation for the nation.

Because the facilities they plan and operate are high consumers of energy and because they are most directly answerable to the public, planners, designers, manufacturers and owners must take the lead in developing and using energy conservative practices in the design, building, equipping and use of school buildings.

EFL and BSIC have undertaken a number of activities designed to provide decision makers with the information necessary to make intelligent decisions with respect to energy conservation practices. This effort began in 1973 with the publication of EFL's *Economy of Energy Conservation in Educational Facilities*. This document provides a basic introduction to energy conservation problems and life-cycle cost analysis. It forms the basis for more detailed studies of various energy consuming systems.

In order to provide specific data on the effect of various design and operating decisions on both cost and energy consumption, BSIC undertook the development of an energy conservation workbook. This workbook is designed to make clear the energy consumption and cost implications of various building design and operating decisions in terms that both the layman and the design professional can understand.

While recognizing that energy conscious design must consider the entire building as one system, BSIC has, for reasons of manpower, time and money, decided to release the Workbook in sections. The first section of this work is *Energy Conservation and the Building Shell*. This will be followed by Section 2 which deals with mechanical systems and Section 3 which explores the problems of school lighting and energy conservation.

The intent of this series is to provide a simple means for determining the consequences of the various possible decision options open to designers and school officials. The methods used to achieve this end are of necessity imprecise and are not intended to replace detailed architectural and engineering studies by the district's professionals. They will, however, when properly used, provide the degree of accuracy necessary to make comparisons between alternatives and to make decisions that will set the course of the design process.

To provide real life examples of the implications of energy conservation practices, BSIC will also publish a series of energy use studies.

INTRODUCTION

Throughout the ages man has sought to protect himself, his belongings and many of his activities from the forces of nature and his fellow man. For early man, these initial and immediate purposes of enclosure could be served by relatively simple shells allowing extensive use of natural forces for conditioning.

As Western man progressed and his building technology increased, he became more and more isolated from this simple situation. In addition to providing protection from natural forces, the building was now expected to reflect technological sophistication and to fulfill rising expectations of comfort and performance generated by contact with these same higher technologies.

The evolution of the American school building reflects these considerations. Traditionally the schoolhouse, as have other building types, has been oriented so that the majority of its spaces have had access to natural light and ventilation. With advances in mechanical environmental control and artificial lighting, designers have considered this dependence on natural forces to be severed. The widespread application of these convenient technologies has led to a tremendous rise in modern Americans' expectations of their environments.

These developments and the concurrent rise of educational philosophies embracing concepts of openness and flexibility have led to the design of school buildings in which many and even a majority of the occupants may not have access to an outside wall and therefore natural light and air. In these buildings, teachers and students have of necessity become totally dependent upon artificially created and maintained environments.

The creation of these environments and the maintenance of expected comfort conditions within them cannot be accomplished without the expenditure of vast quantities of energy. This energy is needed to produce building elements, to assemble these elements and to operate the buildings thus created. Technological man in his attempt to provide the ideal environment has paid little heed to the present and future consequences of his acts—until the present scarcities forced him to count the cost and reexamine how he builds and lives.

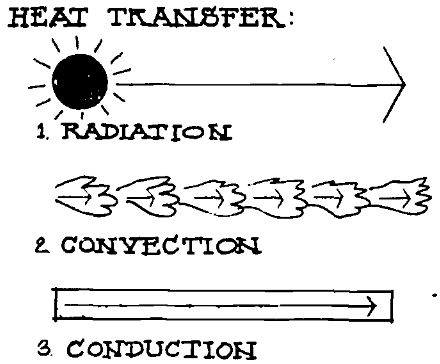
This section will examine what can be done in designing or redesigning the building's shell—the battle line between man's pockets of comfort and nature—to make the wisest long run use of our resources. Specifically, this section will:

1. Show how the building shell affects the building's energy consumption.
2. Identify energy conserving ideas for use in the design (or redesign) of the shell.
3. Give examples showing how these ideas may be applied to new construction and modernization projects.
4. Provide a simple method for determining, during the preliminary stages of the design process, the effects of each of these ideas.
5. Identify sources of further information to assist design professionals in complete analysis of the effect of the building shell on energy consumption.

ENERGY CONSUMPTION AND THE BUILDING SHELL

A building may be thought of as a collection of elements each of which performs certain roles in the general functioning of the facility. Some of these elements—the heating, ventilating and cooling (HVC), lighting and electrical distribution systems—require the addition of energy to perform their functions. The approximate proportion of a school plant's energy consumption by each of these systems is shown in Figure 1.

The building shell consists of all those building parts—roof, exterior walls and glazing, and floor slabs—which provide separation and protection from weather and other natural forces. In most cases, the shell itself does not consume any of the fuel energy used by the building. However, by its nature and its imperfections, the shell imposes demands on two of the building elements which do consume energy: the heating, ventilating and cooling, and lighting systems. If, for example, the shell prevents natural light from entering the building, then light must be provided by artificial means.

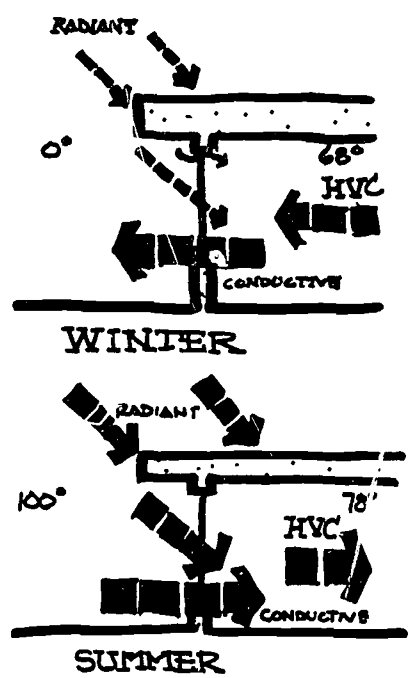


The Shell and the HVC System. According to laws of thermodynamics, heat normally travels from a place of high energy (commonly "hot") to a place of low energy ("cold"). There are three mechanisms by which this transfer can take place:

1. By radiation from a warm or hot body, such as the heat felt when facing the sun or a hot surface.
2. By convection, or movement of the medium holding the heat, such as movement of warm air within a room.
3. By conduction or the flow of heat through a material which separates or connects a hot and a cold area.

Because the building shell separates a fairly controlled interior environment from an uncontrolled outdoor environment, the precondition for heat transfer, temperature difference, is often present. When associated with the building shell, the three mechanisms of heat transfer appear as:

1. A flow of heat through the shell because of a temperature difference between the indoor and outdoor environments.
2. The accidental introduction of outdoor air into the building, known as "infiltration," through opening doors, badly sealed windows, etc.
3. The warming of the building shell by the radiant energy of the sun.
4. Nighttime radiant loss of building heat to the sky and surroundings.
5. The warming of the building's contents by sunlight entering through unshaded windows, etc.



In winter, the net result of these mechanisms is typically a flow of heat out of the building. In order to maintain indoor conditions, the HVC system must add sufficient heat to balance these losses. The amount of heat added by the HVC system is the "heating load."

In summer, there is usually a net heat flow into the building, and the load on the HVC system is the removal of this surplus heat in sufficient quantity to maintain the desired interior environment. In between times, the system may be coping with heating conditions in one part of the building occurring at the same time as cooling conditions elsewhere.

As the amount of energy and thus fuel consumed by the HVC system is related to the size and duration of loads placed on it, most effort to reduce the uncontrolled movement of heat through the building shell

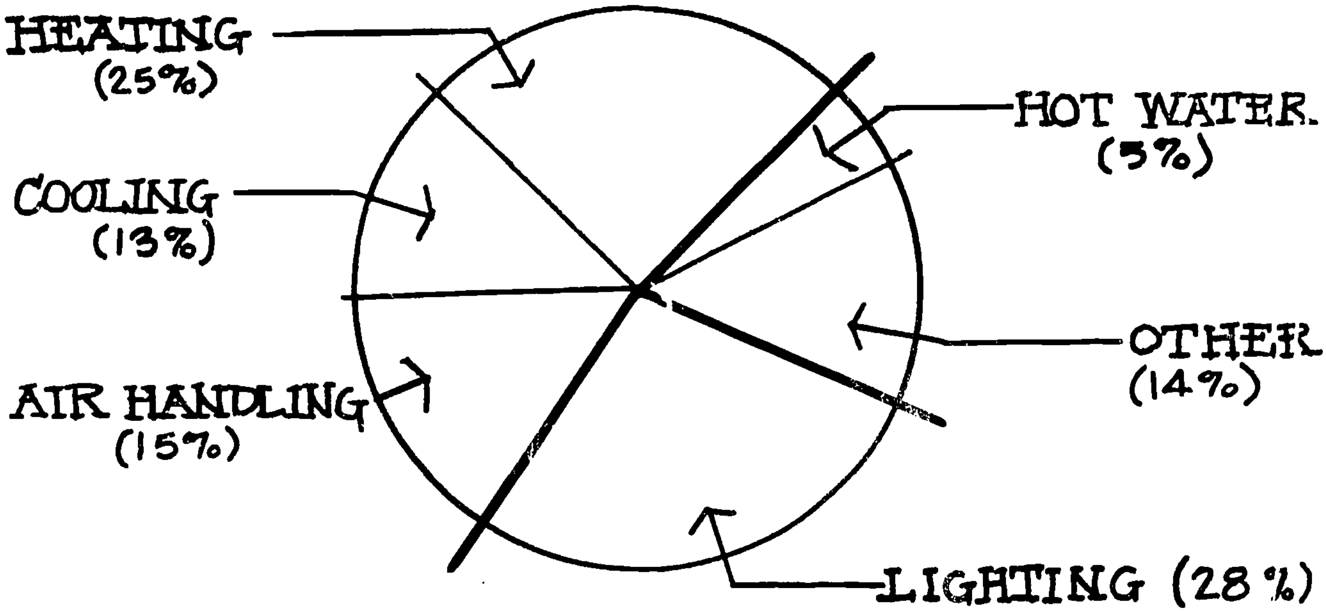


FIGURE 1
ANNUAL ENERGY CONSUMPTION OF SCHOOL, NORTHERN U.S.

will have beneficial effect on the the facility's fuel consumption. The reader is cautioned that this explanation is somewhat oversimplified and does not take into account internal building heat gains from people, lights, equipment, and the HVC system itself (the reader is referred to Figure 2 for a visual summary of these factors).

The Building Shell and the Lighting System. Because the shell often imposes opaque elements between the occupant and natural light, artificial lighting must be provided. In a modern school plant, designs which make use of natural lighting could result in savings in the electricity required by lights of 30 to 100 kilowatt-hours per year per linear foot of properly designed windows. The problem is not this simple, however, as windows which allow savings in lighting costs may, unless carefully designed, introduce extensive heating and cooling problems which may negate the energy saving.

Because of the number of variables involved, each condition should be studied carefully before deciding to introduce window elements solely to admit natural light. Where buildings already have large glass areas, however, the windows should be used as a light source during daylight hours with artificial lighting switched and controlled to supplement the natural light.

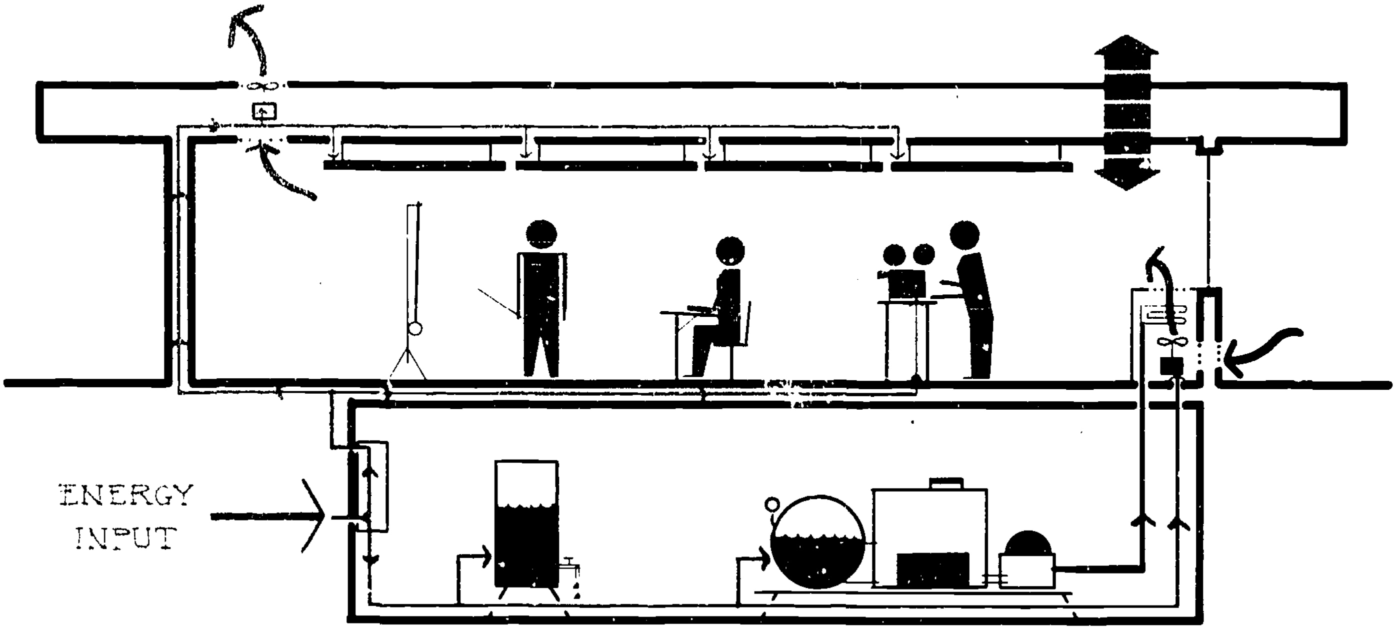


FIGURE 2
BUILDING ENERGY FLOW

ENERGY SAVINGS IN SHELL DESIGN (OR REDESIGN)

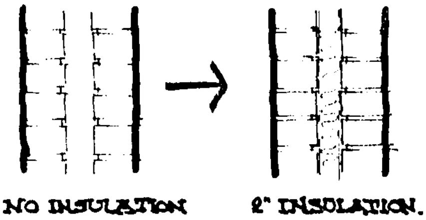
Design solutions based on an understanding of the heat transfer mechanisms can minimize the amount of fuel the HVC system must expend in adding and removing heat to compensate for losses and gains through the shell. Although most of these solutions and their advantages have been known for years, in the past they were often not applied because they usually increased the first cost of the building. It is only with the current increasing awareness of the cost and limited availability of energy and the emergence of an economic evaluation method which can estimate long-term cost savings that these solutions are being widely studied.

Studying both first and operating costs of solutions leads to two interesting observations which should be introduced here. The first is that *increasing the initial expenditure of a construction project in some areas may permit long run real money savings through more economical operations*. The second is that *some methods which conserve fuel may cost more overall than less efficient ones because of high first costs.*

As with any collection of generalities, the ideas described in the following sections are not universally true. Professional designers and consultants will be in the best position to evaluate the usefulness and effects of any solution for a specific project. Also, the discussion has been intentionally limited to the effect of decisions on energy consumption. There are many other factors, such as those having to do with programmatic requirements, which must also be considered but which are beyond the scope of this discussion.

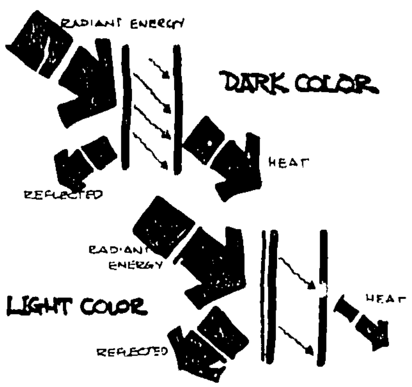
Opaque Walls and the Roof

Increasing Insulation. All materials used in the shell resist the conductive flow of heat from or to the interior of the building. This resistance provides insulation to the occupied spaces. Some materials, notably glass and metals, are very poor insulators while other materials reduce the heat flow so greatly that they are included in the walls and roof solely for this purpose. These latter materials include mineral and glass fiber and various expanded plastic insulations.



Increasing the resistance of the shell to heat flow by increasing the level of insulation or using wall and roof structures with higher intrinsic insulation reduces the conductive flow of heat through the shell. This results in lower fuel costs on both the heating and cooling cycles of the HVC system. For example, adding 2" of insulation to a brick cavity wall can reduce the fuel required to offset losses and gains through the wall by as much as 60 per cent.

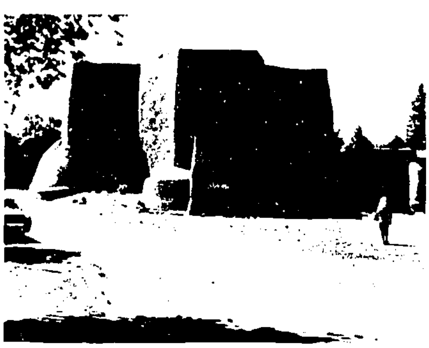
Because many of the decisions in areas affecting energy consumption were made in the dim past, existing buildings present difficult problems in energy conservation. Adding insulation to the walls of existing schools is not often possible. However, insulation can normally be added to the roof of an existing building at a time of roof replacement.



Use of Light Colored Finishes. A light colored wall or roof finish will reflect a portion of the sunlight falling upon it, thereby reducing the warming of the building. This reflection of heat is desirable during the summer months when all heat gains are to be avoided. However, during the winter, warming by sunlight is economical, and a reflective surface will result in increased fuel costs.

A dark colored surface, on the other hand, will absorb solar heat—a desirable condition when heating is required. Ideally then a building would have a light colored surface in the summer and a dark finish in the winter. Since this is normally not possible—reversible shading devices have been tried—it is necessary to examine each case to see what the net effect of surface color will be over the entire year.

As with the preceding example of increased roof insulation, an existing school can usually be painted for greater heat reflection, if this is desired. It must be remembered that, in order to be reflective, light surfaces must be kept clean, a difficult problem in urban areas.



Use of Massive Construction. Tourists in the southwestern United States are familiar with how cool the interiors of Spanish colonial missions and other adobe structures remain even on very hot days. This is largely the result of the tremendous ability of the thick and heavy walls and roofs of these buildings to store heat. As a result the interior environments of the adobes remain fairly constant in the face of widely fluctuating outside temperatures and baking sunlight.

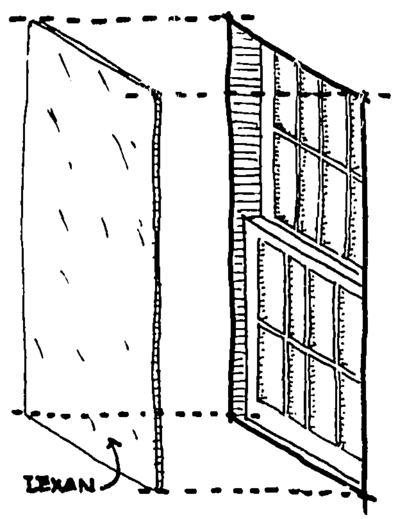
Because of its mass a heavy wall or roof takes longer to heat through, thus reducing the amount of heat entering the interior during summer daylight hours. Walls and roofs of conventional heavy construction—concrete and masonry—will store the heat of incident solar radiation for up to eight or ten hours. This heat is stored within the wall or roof and is radiated both into and out of the building. At night, as the temperature falls and the sky darkens the rate of radiation out of the heavy elements increases. In winter, the heavy elements will also store part of the heat generated within the building, offsetting part of the heat loss.

Windows and Glass Areas

The energy saving results of the proper usage and control of glass areas in a building are far more dramatic than those that can be achieved by improvements to the solid walls and roof. This is due to three factors:

1. Glass is a notoriously poor insulator.
2. Glass transmits the effects of incident solar radiation more readily than opaque materials.
3. Glass permits a considerable portion of the sunlight that strikes it to enter the building.

Insulating Glass. The winter heating fuel bill can usually be reduced considerably by using insulating glass instead of ordinary single sheet glass in windows. To a lesser extent, this substitution will be effective in hot climates in reducing the summer heat gains through the glass. The most common form of insulating glass is double glass which is simply two sheets of glass with a dead-air space between them. As might be expected, double glazing reduces conductive heat flow by almost fifty per cent.

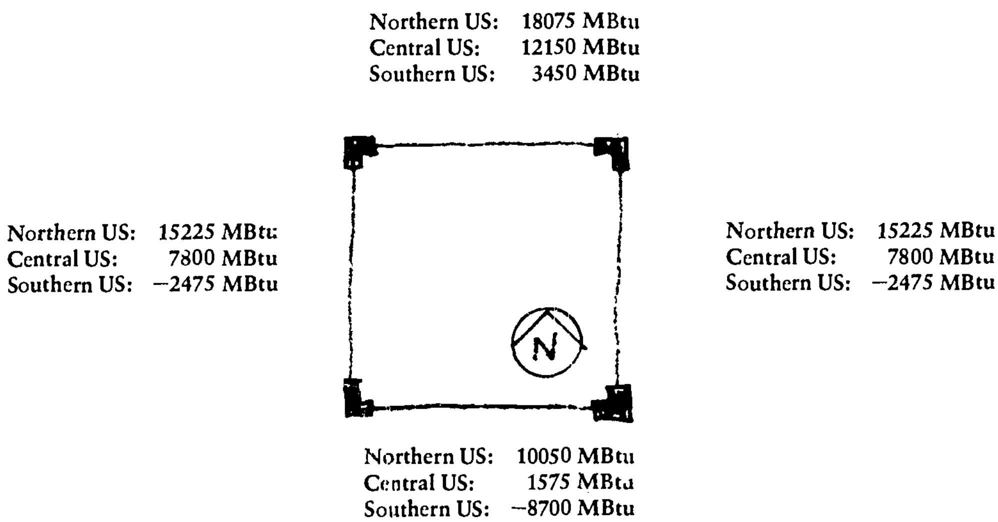


Other forms of insulating glass are available but are generally more costly than double glass. These insulating glasses include factory sealed double sheet panels and special formula glasses with high thermal resistance and heat absorption. In extreme climates, triple glazing may be used to further reduce the heat flow. As most of the specially formulated insulating glasses also offer solar reflection and light transmission reduction characteristics as well, they are often combined with plain glass or each other in double glazed window units.

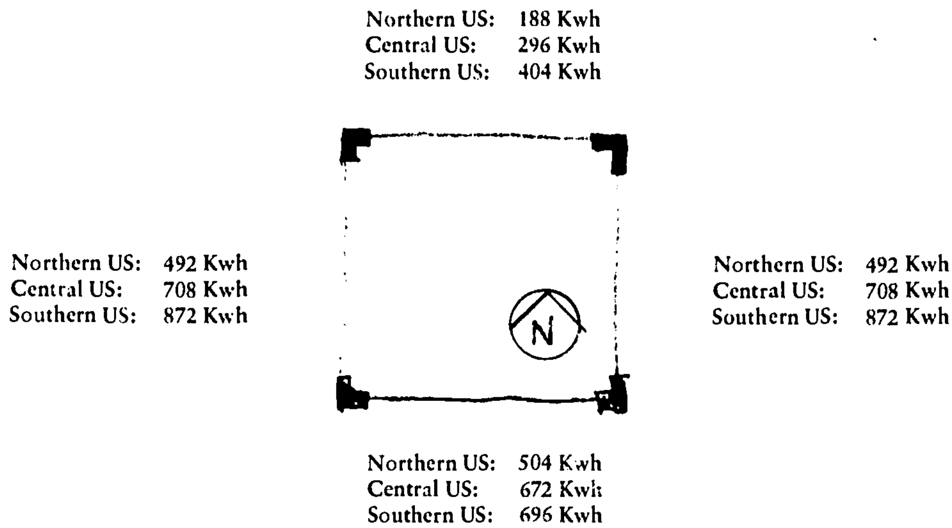
Replacing double-hung and/or single glass windows with units containing insulating glass is usually possible during school modernization projects. Sealing existing windows with a second sheet of glass or lexan is another method of quickly and inexpensively double glazing an existing school. Although this approach may not produce the full results of double glass, it can bring about considerable fuel savings.

Glass Orientation. Depending upon the type, glass transmits up to 85 per cent of the heat from sunlight falling upon it to the inside of the building. In the winter, this natural warming is beneficial and reduces the heating bill; during the summer months, however, this heat is unwanted and will cause additional fuel consumption in a cooled building.

Because windows facing different directions receive varying amounts of sunlight during the year, the orientation of glass areas is a very important consideration in energy consumption. In general, where heating is the major concern, glass areas should be faced to the south to catch the most winter sunlight. How this natural heating can affect the annual heating energy expenditure per 100 square feet of glass area is illustrated in the following diagram:



On the other hand, where cooling is the major concern, windows and glass areas should be faced north, away from the sun and its heat. For a mechanically cooled building, the expenditure of energy for cooling per 100 square feet of glass area shows the effect of this sun-shunning:



Following these ideas does not mean that all glass must be in either the north or the south wall, however. In fact, windows can be in any wall and still be oriented for energy savings. The sawtooth wall suggested by the National Bureau of Standards and illustrated in Figure 3 is an energy saving element which has expressive potential. As will be seen in the next section, shading provides an answer to some of the problems of orienting glass where both summer and winter conditions are a problem.

Shading of Glass Areas. For the reasons discussed in the preceding section, an ideal shading device from an energy conservation point of view is one that keeps sunlight off a window in summer months, yet allows sunlight to warm the window during the winter. A number of devices which fulfill these requirements are available, some of them illustrated in Figure 3. Many of these shading devices can be applied to existing buildings as well as to new construction.

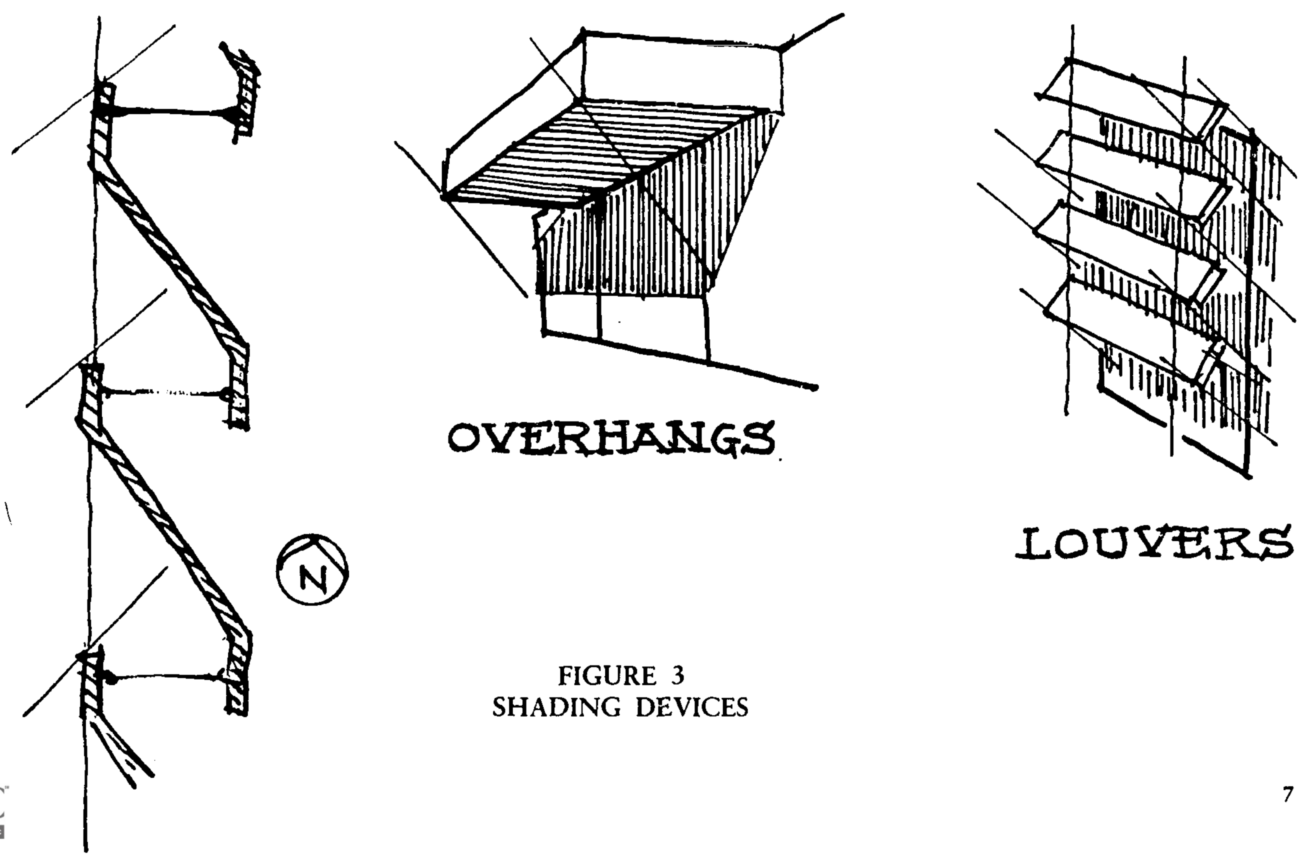
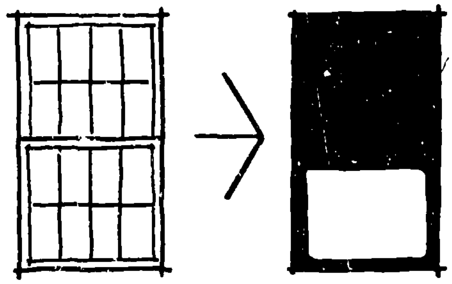


FIGURE 3
SHADING DEVICES

Although the most effective place for shading devices is outside the glass, considerable energy savings can result from the proper use of draperies, shades and blinds. Because they deal with heat after it has entered the building, these interior shading devices are about one-half as effective as exterior devices. Draperies of heavy fabric also offer some insulation against conductive heat loss through the window.

Reduction in Glass Area. Many existing schools have entire walls of glass, often, as seen in the light of the discussions, facing in the worst possible directions and exposed to direct sunlight at the wrong times. One straightforward and effective means of reducing fuel costs in these buildings is simply to reduce the area of the windows.



Even if the windows are necessary as a light source, some reduction may be possible without compromising this use. According to at least one source, a 50 per cent reduction in glass area will result in only a 30 per cent reduction in light.

Sealing the Shell Against Air Leakage

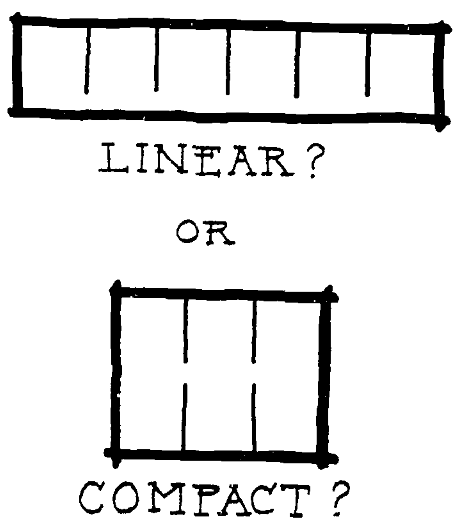
Outside air is introduced into the building in two ways: intentionally for purposes of ventilation and air freshness, and unintentionally through cracks, openings, doors and windows—"infiltration." If a building which relies on artificial heating and cooling is not effectively protected by sealing and pressurization by the HVC system against infiltration, the cost of heating and cooling this air can rise as high as fifty per cent of the total heating and cooling fuel bill.

In a well sealed building—caulked windows, few cracks and vestibule style doors—infiltration amounts to about one-half of the building's air volume per hour (0.5 air change). A poorly sealed building may leak five to six times this amount.

The topic of infiltration and ventilation will be discussed in detail in another section of this workbook. It is necessary, however, to mention here that the amount of infiltration air depends in large part upon the design and integrity of the shell.

The Shell as a Whole

Compact vs. Linear Plan. Overall building configuration may be characterized as linear or compact. The choice between these plan types may be based upon either climatic or programmatic criteria or a combination of the two. In a mild climate, the need for artificial air conditioning and lighting may be minimized by using a linear plan type which allows maximum access to natural light and use of through ventilation.

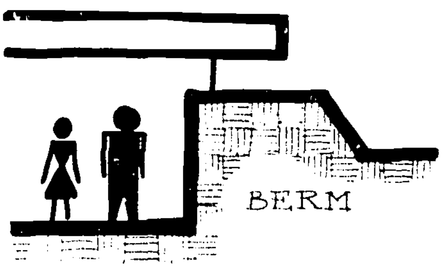


Even in mild climates, however, programmatic requirements may dictate the selection of a more compact plan form. In a compact building, such as most open plan schools, some spaces will be isolated from access to outside walls and will not be able to draw on natural sources of lighting and ventilation. These buildings will require some mechanical ventilation, artificial lighting and, in some cases, cooling.

Because part of a facility's climate control equipment and fuel costs may be directly related to the area of its exterior surface, in more extreme climates a compact plan which minimizes the area of the shell will be more economical than the linear. The price paid in not being able to use natural light and ventilation in these climates is more than balanced by the cost of heating and/or cooling a building designed for such apparent efficiencies.

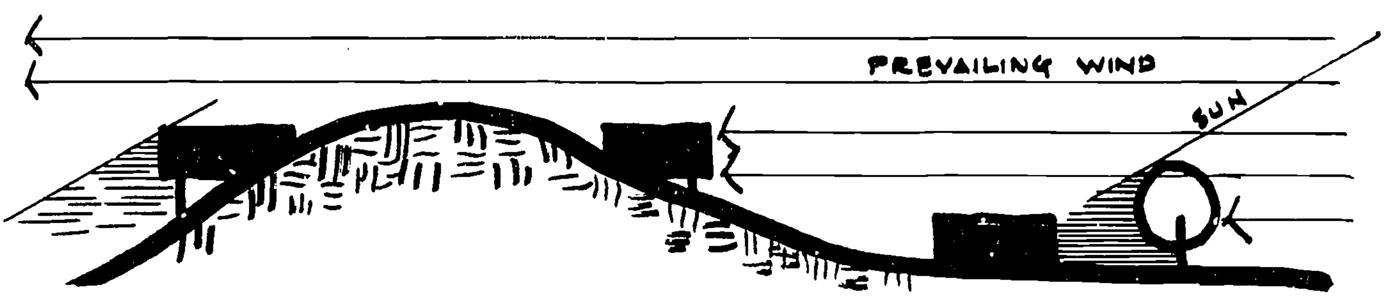
Proper Orientation. For optimum energy performance, a building should be oriented carefully in relation to the sun and other weather forces. For a site with a strong prevailing wind, proper orientation can reduce the chill resulting from this wind blowing on wall surfaces and the infiltration induced by pressure differences—thereby considerably reducing fuel consumption during both the heating and cooling season.

Although the cost savings from proper orientation of the total building in relation to the sun are not as dramatic as those that can be achieved from proper orientation of certain shell elements, in particular glass, it is an idea that can be applied early in the design process at little or no cost and with considerable life-time benefit.



Closely related to orientation is the proper utilization of advantageous site features. Slopes, vegetation, adjacent structures all present opportunities for energy savings if properly exploited. The appropriate use of vegetation not only improves the humanistic qualities of a design, but it should be noted that trees and large shrubs can both shade a building and cool the air surrounding it, resulting in energy savings during the cooling season.

Finally the heating and cooling energy requirements of a building can be greatly reduced if the structure is wholly or partially buried in the ground. A similar effect is achieved by placing extensive earth burns against its exterior walls.



WHAT DOES ALL THIS MEAN?

In the foregoing discussions, the point of view of maximum fuel energy savings has been used. However, the intent of this section of the workbook is not to argue that the only road to follow is to build cubical schools buried deep underground with only north or south facing lightwells. Rather it is an effort to make the owner and the designer more aware of the implications of some of their mutual decisions. With this knowledge they may be able to make wiser decisions and to fully exploit the advantages of these decisions.

Often the programmatic needs of the facility will require a design in which some possible energy saving methods cannot be used. Then the needs of program and energy conservation must be examined to see if the requirement is truly necessary, to assess its probable outcomes, and to see how it may be accommodated at minimum cost.

Other needs may also be determinant. For example, if a school site has an excellent view in only one direction and that direction is west, what should be done? It is possible to argue that one should forego the view because of the problems associated with west facing windows. But there are alternatives. A west facing window may be double glazed or tinted, it may be shaded, or the same view may be afforded by carefully placed north and south facing windows. All of these alternatives will give relief from the maximum energy cost without necessarily compromising the view.

SUMMARY OF ENERGY SAVING IDEAS FOR THE BUILDING SHELL

GENERAL

- Design consistently for primary reliance on either natural or artificial means of heating, cooling and ventilation.
- Design insulation, moisture protection, materials, etc., to the highest appropriate technical and design standards.

OVERALL BUILDING DESIGN

- Design building with compact plan to minimize exposed outside surface (not necessarily applicable if natural lighting and ventilation are used).
- Orient building long axis and configure plan to make maximum use of, or to provide maximum protection from, solar and wind forces.
- Use configuration and design of walls and roof to provide shading and wind breaks.

WALLS, ROOF AND FLOOR

- Select insulation values to minimize building energy consumption by means of a life-cost analysis or reference to recommended guidelines.
- Where reduction in summer heat gain outweighs the increase in net winter heat loss, use reflective or light-colored finishes on walls and roof.
- Where reduction in net winter heat loss outweighs the increase in summer heat gain, use absorptive, dark-colored finishes on walls and roof.
- Use heavy construction for walls, roof and floor to store heat and slow heat transfer.
- Provide a double roof with ventilated space between.
- Insulate perimeter of slab on-grade.
- Shade east, south and west walls to reduce sunlight on walls in summer and to allow sunlight on walls in winter—vegetation, especially deciduous (hardwood) trees may be used.
- Design exterior walls and roof to reduce infiltration.

GLASS AREAS

- Use minimum glass area consistent with function; in existing buildings, glass area may be reduced without materially reducing available natural light.
- Evaluate trade-off between natural lighting and costs of heating and cooling glass areas with life-cost analysis.
- Orient building glass areas to make maximum use of, or to provide maximum protection from, solar and wind forces.
- Shade all glass facing east, south and west with outside devices which keep the sun off the glass in summer months and allow it on the glass in winter.
- If outside shading is not possible, use inside shading devices such as drapes or blinds, or use tinted or low transmission glass.
- In areas of high gain or loss through glass areas, use insulating glass-double or triple-glass or special insulating glass—a life-cost analysis may be necessary to justify selection.
- Provide operable windows to permit natural ventilation, when possible; however, make sure that these windows can be tightly closed to prevent infiltration when mechanical cooling and heating is in use.

OTHER

- Use vestibules or double doors at building entrances to reduce infiltration.

EXAMPLES

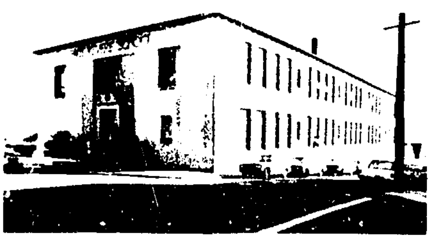
To illustrate how these ideas may be applied to design projects, two examples are presented in this section—one a modernization project and the other a new school design project. In these examples, four items are compared to determine the lifetime owning cost implications of these energy saving decisions. These four items are:

1. The cost of the building shell elements required.
2. The effect of the decision on the cost of the HVC equipment.
3. The effect of the decision on the amount of fuel consumed during the building's life and the cost of this fuel.
4. The total building life effect which is the sum of items (1), (2), and (3).

The method of analysis is to develop a base model and then to compare the cost outcomes of energy saving strategies with it.

To simplify this process, the cost of fuel is considered to be constant over the useful life of the building. In both examples, natural gas has been used as the heating fuel. The use of other fuels will affect the total cost of fuel used over the life of the building.

Modernization



In this example, a district located in the northern U.S. plans to modernize an existing 25,000 square foot, two-story school for year-around usage by adding a cooling system. For simplicity, it is assumed that the existing building heating plant can be completely salvaged.

As a result of preliminary studies, the architects have determined that four possible fuel saving strategies can be applied to this modernization. Page 12 shows the effects of each of these strategies and of their combined use over the estimated twenty-year useful life of the modrnized facility. The reader will observe that the application of these strategies, while adding about $51,000 to the cost of building shell elements, results in estimated savings of 74 per cent in HVC equipment costs and of nearly fifty per cent in fuel used.

New Construction

In another northern U.S. district, a new 45,000 square foot elementary school is projected. The facility is to be open-plan, to be used year around and to have minimum window area. Light steel frame construction with veneer exterior walls will be used. The architects have identified six energy saving strategies which are illustrated on Page 13.

Using the four most beneficial strategies in combination, it is estimated that the owner will spend an additional 20 per cent in first costs for the shell, but will save a great deal more than this in the cost of fuel over the building's forty year life. The application of these strategies will reduce the HVC equipment cost, including cooling equipment, by nearly two-thirds and the fuel consumed over forty years by over 58 per cent.

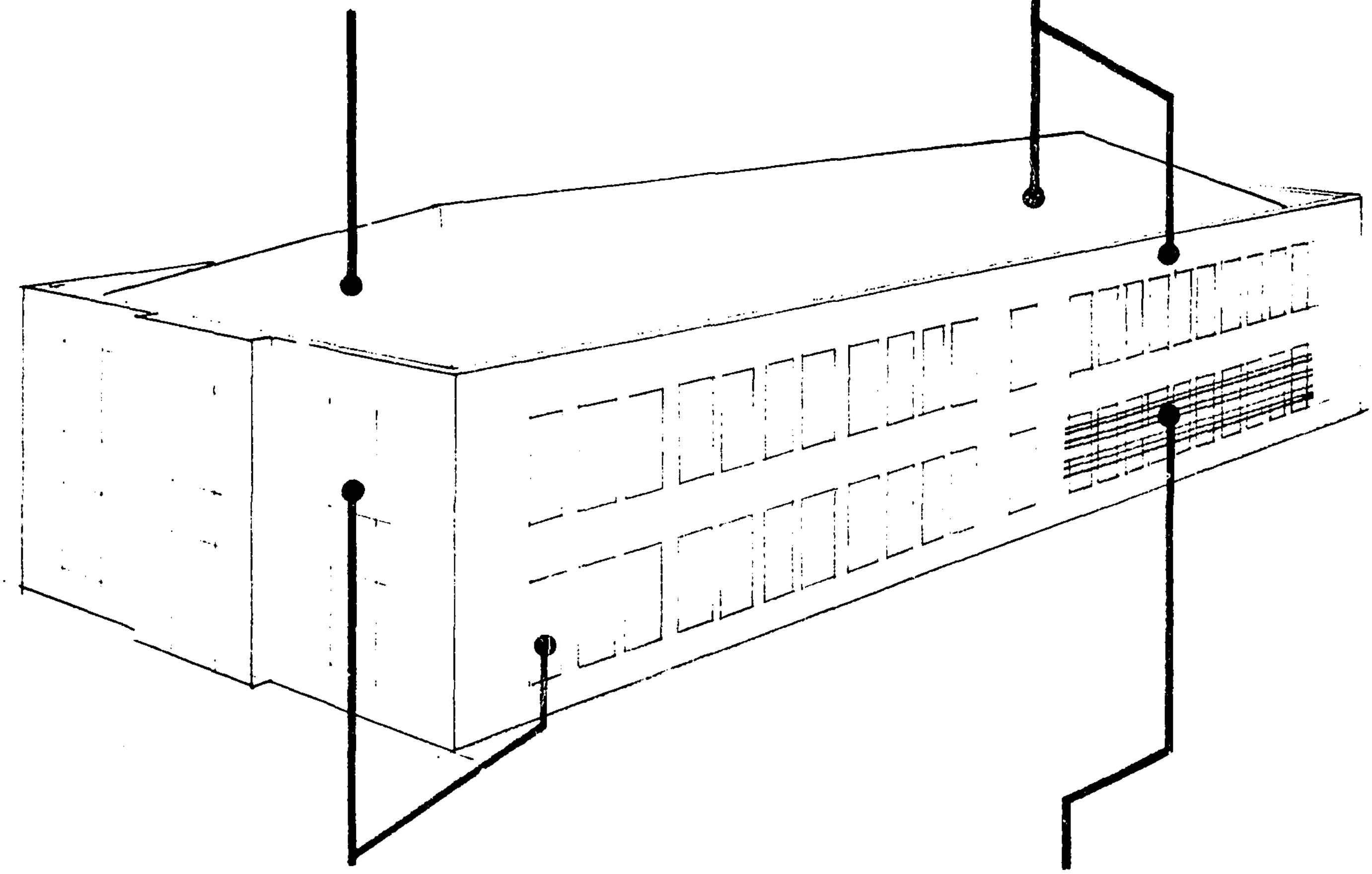
The cost calculations for these examples were performed using the BSIC Preliminary Design Life-Cost Estimating procedures outlined on Pages 14-16. Reproductions of the forms used in the new construction example are found on Pages 18 and 19.

a. Increase Roof Insulation to U = 0.05

Element First Cost	+$ 4,315
Cooling Equipment Cost:	−$ 5,484
20-Year Fuel Cost:	−$ 7,840
20-Year Net Savings:	$ 8,649

b. Paint Walls and Roof White

Element First Cost:	+$11,417
Cooling Equipment Cost:	−$ 5,934
20-Year Fuel Cost:	−$ 1,920
20-Year Net Cost:	$ 3,563



c. Replace Windows with Double Glass

Element First Cost:	$+22,185
Cooling Equipment Cost:	−$ 6,961
20-Year Fuel Cost:	−$11,500
20-Year Net Cost:	$ 3,724

d. Provide Exterior Shading Louvers

Element First Cost:	+$13,311
Cooling Equipment Cost:	−$20,092
20-Year Fuel Cost:	−$15,040
20-Year Cost Saving:	$21,821

EXAMPLE ONE: MODERNIZATION PROJECT

	BASE: As Is, Cooling Added	*Combination of Alternatives*	*Net to Owner*
Element First Cost:	$ 000	$51,228	+$51,228
Cooling Equipment Cost:	$42,652	$10,886	−$31,768
20-year Fuel Cost:	$56,620	$30,280	−$26,340
20-Year Total Cost:	$99,274	$92,394	−$ 6,880

a. Increase Insulation to U = 0.05

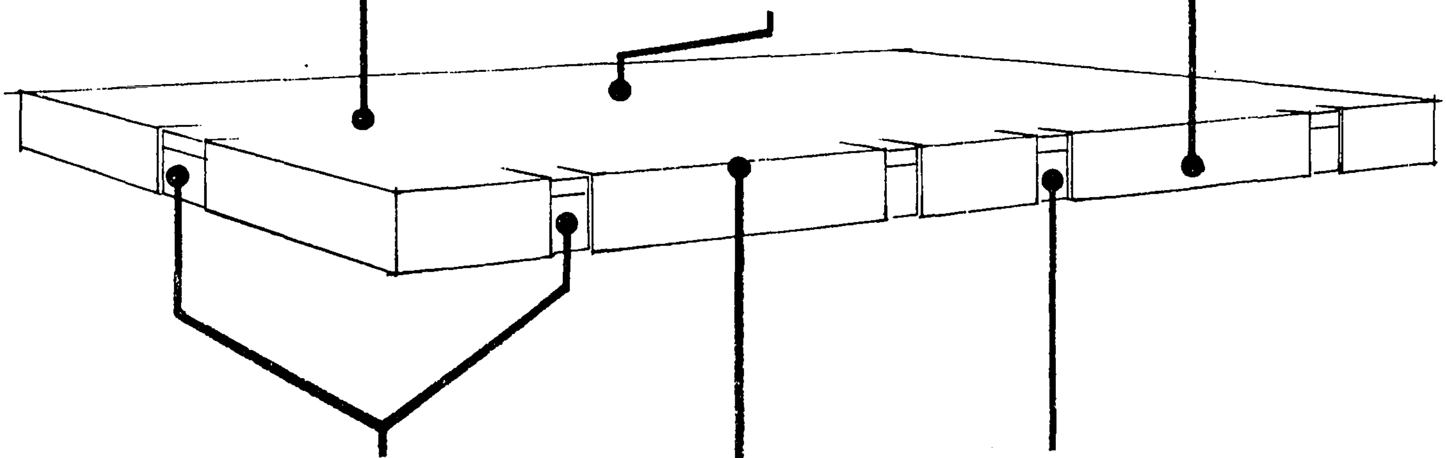
Element First Cost:	+$27,840
HVC Equipment Cost:	−$16,577
40-Year Fuel Cost:	−$25,200
40-Year Net Savings	$13,937

b. Use Light Finish on Walls and Roof

Element First Cost:	+$ 000
HVC Equipment Cost:	−$11,214
40-Year Fuel Cost:	−$ 6,960
40-Year Net Savings:	$18,174

c. Face All Glass to the North

Element First Cost:	+$ 000
HVC Equipment Cost:	−$ 3,682
40-Year Fuel Cost:	−$ 1,800
40-Year Net Savings	$ 5,482



d. Shade E, S and W Windows

Element First Cost:	+$ 3,400
HVC Equipment Cost:	−$ 3,877
40-Year Fuel Cost:	−$ 4,120
40-Year Net Savings	$ 4,597

e. Use Double Glass in Windows

Element First Cost:	+$ 2,260
HVC Equipment Cost:	−$ 2,644
40-Year Fuel Cost:	−$ 7,320
40-Year Net Savings	$ 7,704

f. Use Heavy (Concrete) Construction

Element First Cost:	$121,000
HVC Equipment Cost:	−$ 9,569
40-Year Fuel Cost:	−$ 4,040
40-Year Net Cost:	$107,391

EXAMPLE TWO: NEW CONSTRUCTION PROJECT

	BASE: U = O.10, Dark, No Shade	*Combination a, b, d, e,*	*Net to Owner*
Element First Cost:	$165,766	$199,370	+$33,604
HVC Equipment Cost:	$ 42,235	$ 14,151	−$28,084
40-Year Fuel Cost:	$ 64,880	$ 26,800	−$38,080
40-Year Total Cost:	$272,881	$240,321	−$32,560

The method developed by BSIC for analyzing the effects of building shell decisions during the preliminary stages of design makes use of life-cycle cost analysis. Before discussing the BSIC approach, it will be useful to briefly review the nature of life-cost analysis.

As a Means of Estimating Owning Costs. A life-cycle cost (often simplified to "life-cost" analysis is an attempt to estimate the total costs of owning a building or building element over a given period of time. For school projects, this time period is typically chosen to be the time required to repay the bonded indebtedness, or, less often, the anticipated life of one of the building's operating systems.

A life-cycle cost analysis consists of two parts: an estimate of the capital costs of a decision and an estimate of its operating cost implications including maintenance and fuel costs. The capital costs of a building solution are the first cost of building elements plus the cost of borrowing the money to pay for them. For a school building project, the first cost is what appears on the contractor's breakdown, while the finance cost is what is paid for the bonds sold to finance the construction. Where the life-cycle period exceeds the life of system elements, salvage value and replacement costs may also be considered as capital costs.

Operating costs are all the costs of running the building including fuel and utility costs, maintenance costs, minor repair costs, expenditures on required materials and associated salaries. These costs are usually estimated on an annual basis.

The estimate of fuel and utility costs will be strongly affected by a number of factors, key among them are the type of fuel selected and the rate of cost escalation for fuels. This latter is difficult to predict because fuel costs tend to jump rather than edge up and because the prices of different fuels rise at different rates and times. Table I gives characteristics of the commonly available fuels.

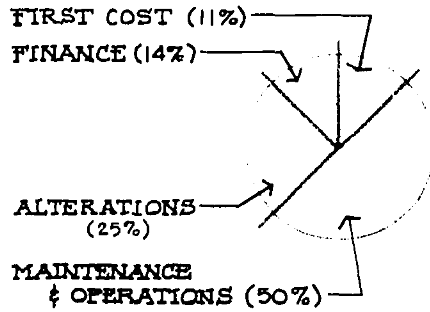
These factors are important because the rate of operating cost inflation used will affect the results of the life-cost analysis. One accepted way to deal with this problem is to use several inflation rates and see what happens to the results.

The life-cost analysis is completed by adding the capital and operating cost estimates for the facility together. This is done on either or both of two bases:

1. A *life-cycle owning cost basis* in which the first cost is added to the present worth of the total operating cost over the life-cycle study period;
2. An *annual owning cost basis* in which the annual capital cost (largely the annual debt retirement) is added to the annual operating cost.

As a Means of Comparing Alternatives. Alternative solutions may be studied by comparing their life-cost analyses. Because it takes into consideration operating cost inflation, the *life-cycle owning cost* method should be used for this comparison. Usually the solution with lowest estimated life-cycle owning cost is considered the most beneficial, assuming all to have comparable performance.

In a similar manner, the outcome of an increased expenditure to reduce operating costs may be analyzed. In this case, an analysis of the situation before the expenditure, the base, is compared with the analysis of the outcome of the expenditure. It should be carefully noted by the reader that the alternative with the lowest fuel consumption is *not* always the alternative with the lowest total owning cost.



4[illegible] YEAR COSTS

The two life-cost analysis methods may be illustrated with the following example. A school district buys a unit at $1,000 using 20-year bonds at six per cent. The annual operating costs of the unit are $100 over its useful life of twenty years.

The life-cycle owning cost analysis provides an estimate of the cost of the unit to the owner over its useful life:

First Cost:	$1000
20-Year Operating Cost:	$2000
Life-Cycle Cost:	$3000

An annual owning cost analysis provides an estimate of the cost to the owner per year. The annual capital cost is, in this case, the cost of retiring the bonded indebtedness.

Annual Capital Cost:	$ 87.20
Annual Operating Cost:	$100.00
Annual Owning Cost:	$187.20

The reader will note that, because of differences in calculation, the two figures differ. Various factors may be applied to these analyses to estimate future loss of value of money, cost inflation, etc.

TABLE I

CHARACTERISTICS OF COMMON HEATING FUELS

Fuel	*Unit of Sale*	*Usable Heat per Unit of Sale**	*Typical Cost per Unit*	*$0.01 Buys*
Natural Gas	1000 cubic feet (Mcf)	750,000 Btu-hr	$1.00	7500 Btu-hr
#2 Fuel Oil	1 gallon (gal.)	84,000 Btu-hr	$0.25	3360 Btu-hr
Electricity	1 Kilowatt-hour (Kwh)	3,415 Btu-hr	$0.025	1366 Btu-hr

* When consumed in a plant of typical efficiency.

The Meaning of a Life-Cost Analysis. A life-cost analysis will provide the owner with a reasonable estimate of the cost of a building or element of the building over a given period of time, provided he has reasonable estimates of first costs, bond sale conditions, fuel and utility consumption rates for the facility, and maintenance and personnel costs. By the same token, it is a reasonable method of comparing alternatives which takes into account operating cost and fuel consumption differences.

The BSIC Preliminary Analysis Method

To prepare an owning cost analysis, a reasonably accurate projection of fuel consumption and cost is required. Because of the complexity of analyzing the outcomes of programming and design decisions, the fuel projection is often not undertaken until well into the design process. Modification of the scheme at this point is often difficult and changes, which could be easily integrated into the design at an earlier point in the process, may necessitate major alterations.

As a result of the need to integrate energy consciousness at an early stage in the design process, BSIC has developed a method of comparing the fuel consumption effects of building shell decisions which is intended for use during programming, schematic design and early phases of design development. If an energy awareness can be built into the design process from the beginning, then energy conservation will be an integral part of the design at all phases and will not consist of a hurried purge of marginal gallons and kilowatts at the last minute.

Factors affecting fuel use:

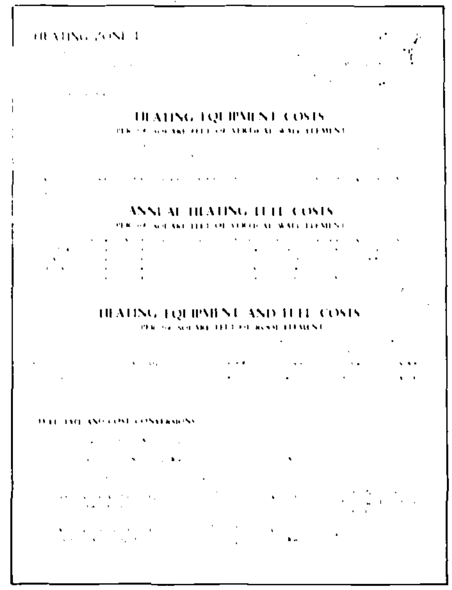
- Element Area
- Orientation
- Mass
- Insulation
- Color
- Shading
- Use Pattern

The BSIC method is a simplified form of *life-cycle owning cost analysis* which emphasizes the effect of factors which cause differences in fuel consumption. Key among these factors are: element area, orientation, mass, insulation, color, shading and pattern of building use. BSIC has developed this approach using basic ASHRAE hand calculation methods, modified where necessary in the light of current engineering thinking.

This method is not intended to replace the estimates which must be prepared by the mechanical engineer at later stages in the process. Nor does BSIC claim that a more detailed analysis by a professional engineer or computer using precise weather and scheme data will always show similar results. What is provided is a tool to use in the preliminary development stages where most of the decisions about the building shell are made.

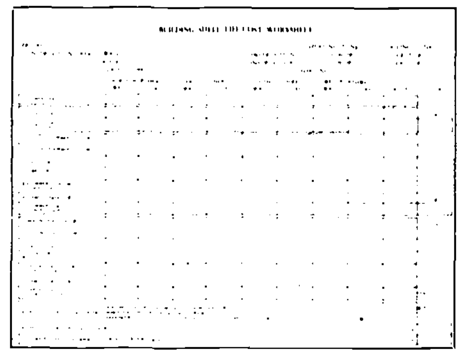
By reducing the analysis to cost terms, BSIC hopes to encourage communication between the design team and the owner. Many of the points about building design and energy conservation are arcane and difficult to communicate to laypeople. Anticipated cost consequences are something everyone can understand.

About the Method. To prepare a preliminary owning cost analysis, three things are required: the Worksheets and appropriate Zone Data Charts from this publication and data about alternatives provided by the design team. For each alternative, a Worksheet is completed by filling in the appropriate data obtained from the Zone Data Charts or the design team. The annual or total fuel-consumption or owning costs for different alternatives may then be compared using the results from the Worksheets.



Fully worked out Worksheet examples are presented on pages 18 and 19. Completion of the Worksheets requires only simple addition, subtraction and multiplication once the data sections are filled in. Unfortunately, further simplication of the method results in the loss of the ability to study the effects of the factors for which it was originally developed. Information on how to convert the data given in the tables to other wall and roof constructions, thermal resistances and fuel types and unit costs is given on the Data Sheets.

In preparing the life-cycle operating cost estimate, for simplicity's sake the annual fuel cost can be multiplied by the anticipated life of the building, given as 40 years for new construction or 20 years for modernization projects. This method does not take fuel cost escalation into account. For greater accuracy, fuel cost multipliers which take into account fuel cost escalation are given in Table II.



The Cooling Zone Data Sheets provide tables of fuel costs for both 9 and 12 months annual building operation, based on a 7 a.m. to 9 p.m. usage five days a week. Facilities with cooling, however, are typically designed for year around use regardless of their present operating profile. This is done as means of securing economical operation should a year around program be implemented.

For anyone who would like to prepare their own data tables BSIC will make available Zone Data Charts showing energy consumption instead of fuel costs and will provide further information on how these tables were prepared. Requests for this information and any questions should be addressed to BSIC/EFL, 3000 Sand Hill Road, Menlo Park, California 94025.

TABLE II
FUEL COST MULTIPLIERS FOR INFLATING FUEL COSTS

	Annual Inflation Rate				
Years	*2%*	*4%*	*6%*	*8%*	*10%*
5	5.3	5.6	6.0	6.3	6.7
10	11.2	12.5	14.0	15.6	17.5
15	17.6	20.8	25.7	29.3	35.0
20	24.8	31.0	40.0	49.4	63.0
25	32.7	43.3	59.2	79.0	108.0
30	41.4	58.4	84.8	122.0	181.0
40	61.6	98.8	165.0	280.0	487.0
50	86.3	159.0	309.0	620.0	1280.0

Although each Zone Data Sheet provides a map to indicate the range of the Zone, master Heating and Cooling Zone Maps will be found on the back cover of this publication.

The following chart will assist in determining which columns of the Zone Data Sheets to use:

Use Column	*for*
HEAVYWEIGHT ROOFS	concrete roof structures
LIGHTWEIGHT ROOFS	steel and other metal frame roof structures wood frame roof structures
HEAVYWEIGHT WALLS	brick cavity walls brick on block heavy concrete block heavy concrete panel
LIGHTWEIGHT WALLS	curtain wall (solid elements) light concrete panel light concrete block lightweight panel walls stucco on lath veneer walls, including brick
SINGLE SHEET GLASS	
NO SHADE	unshaded window glass
INTERIOR SHADE	single glass with interior drapes or blinds heat absorbing glass
EXTERIOR SHADE	single sheet glass with exterior shading reflective glasses tinted glasses
DOUBLE GLASS	
NO SHADE	unshaded double glass insulating glass
EXTERIOR SHADE	double glass with exterior shading double glass, outer sheet heat absorbing double glass, outer sheet reflective

Several loose copies of the Worksheet are included with each copy of this publication, as additional sheets are *not* available from BSIC, full reproduction rights are given to users of this report.

BUILDING SHELL LIFE-COST WORKSHEET

PROJECT NEW CONSTRUCTION PROJECT (BASE) HEATING ZONE I COOLING ZONE I
CONSTRUCTION DATA WALLS: VENEER CONSTRUCTION LIGHT COLOR DARK U-FACTOR 0.10
ROOF: STEEL FRAME & DECK CONSTRUCTION LIGHT COLOR DARK U-FACTOR 0.10
GLASS: TYPE SINGLE GLASS SHADING NONE

	NORTH ~~NORTHEAST~~ WALL	GLASS	EAST ~~SOUTHEAST~~ WALL	GLASS	SOUTH ~~SOUTHWEST~~ WALL	GLASS	WEST ~~NORTHWEST~~ WALL	GLASS	ROOF	TOTAL
1 ELEMENT AREA	3042	338	2048	227	3042	338	2048	227	45500	
2 ELEMENT FIRST COST/SQ FT	$3.00	2.90	3.00	2.90	300	2.90	3.00	2.90	2.90	A
3 ELEMENT FIRST COST (Line 1 × Line 2)	$9126	980	6144	658	9126	980	6144	658	131950	165766
4 HEATING EQUIPMENT COST/100 SQ FT	$8.80	212.00	8.80	212.00	8.80	212.00	8.80	212.00	18.80	
5 COOLING EQUIPMENT COST/100 SQ FT	$16.70	260.00	[illegible]1.40	260.00	13.50	723.00	[illegible]7.80	1241.00	47.20	
6 Line 4 + Line 5	$25.50		30.20		32.30		36.60		66.00	
7 U FACTOR / 0.50	1		1		1		1		1	
8 EQUIPMENT COST/100 SQ FT (Line 6 × Line 7)	$25.50	472.00	30.20	472.00	32.30	935.00	36.60	1433.00	66.00	
9 ELEMENT AREA/100 SQ FT	30.4	3.38	20.5	2.27	30.4	3.38	20.5	2.27	455.0	B
10 EQUIPMENT FIRST COST (Line 8 × Line 9)	$775	1595	619	1071	982	3160	750	3253	30030	42235
11 HEATING FUEL COST/100 SQ FT	$2.40	24.10	2.40	20.30	2.40	13.40	2.40	20.30	1.50	
12 COOLING FUEL COST/100 SQ FT	$0.11	4.70	0.24	12.30	0.18	12.60	0.27	12.30	0.67	
13 Line 11 + Line 12	$2.51		2.64		2.58		2.67		2.17	
14 U FACTOR / 0.10	1		1		1		1		1	
15 ANNUAL FUEL COST/100 SQ FT (Line 13 × Line 14)	$2.51	28.80	2.64	32.60	2.58	26.00	2.67	32.60	2.17	
16 ELEMENT AREA/100 SQ FT	30.4	3.38	20.5	2.27	30.4	3.38	20.5	2.27	455.0	
17 ANNUAL FUEL COST (Line 15 × Line 16)	$76.30	97.34	54.12	74.00	78.88	123.34	56.79	74.00	987.35	

18 LIFE-CYCLE FUEL COST MULTIPLIER: ☒ New Construction, Life-Cycle = 40 years, Fuel Cost Multiplier = 40; ☐ Modernization, Life-Cycle = 20 years, Fuel Cost Multiplier = 20; ☐ Escalating Fuel Costs, ___ years, ___% annual escalation, from Table II, Fuel Cost Multiplier = ___	C	1622
	D	× 40
19 LIFE-CYCLE FUEL COST (Line 17 × Line 18)	E	64880
20 ESTIMATED LIFE-CYCLE OWNING COSTS (BOX A + BOX B + BOX E)	F	272881

EXAMPLES OF COMPLETED WORKSHEETS

The two Worksheets illustrated on these pages are those for the Base and Combination alternatives of the New Construction Project Example on page 13. The reader will note that the figures in the TOTAL columns of these sheets match those in the summary box at the bottom of page 13.

The fuel and equipment cost information on these sheets is taken from the Data Sheets for Heating and Cooling Zones I. Data in Lines 1 and 2 are provided by the project architect or by examination of plans. Detailed instructions for completing the analysis process are found on the back of the Worksheet. Alternative solutions are compared by examination of the TOTAL columns.

These life-cycle cost estimates are very sensitive to two factors: the type of fuel to be used and the estimate of annual fuel cost inflation. If, for example, electricity is used to heat the building instead of natural gas, the HEATING FUEL COST/100 SQUARE FEET would be in-

BUILDING SHELL LIFE-COST WORKSHEET

PROJECT: NEW CONSTRUCTION PROJECT COMBINATION .... HEATING ZONE [illegible] COOLING ZONE [illegible]

CONSTRUCTION DATA

WALLS: [illegible] .... CONSTRUCTION [illegible] COLOR [illegible] U-FACTOR [illegible]

ROOF: STEEL FRAME & DECK .... CONSTRUCTION [illegible] COLOR [illegible] U-FACTOR [illegible]

GLASS: TYPE DOUBLE GLASS .... SHADING [illegible]

	NORTH ~~NORTHEAST~~ WALL	NORTH ~~NORTHEAST~~ GLASS	EAST ~~SOUTHEAST~~ WALL	EAST ~~SOUTHEAST~~ GLASS	SOUTH ~~SOUTHWEST~~ WALL	SOUTH ~~SOUTHWEST~~ GLASS	WEST ~~NORTHWEST~~ WALL	WEST ~~NORTHWEST~~ GLASS	ROOF	TOTAL
1 ELEMENT AREA	3042	338	2048	227	3042	339	2048	[illegible]	[illegible]	
2 ELEMENT FIRST COST SQ FT	$ 3.50	8.00	3.50	8.00	3.50	8.00	3.50	8.00	[illegible]	A
3 ELEMENT FIRST COST Line 1 × Line 2	$10647	2704	[illegible]	1816	10647	2704	[illegible]	[illegible]	[illegible]	[illegible]
4 HEATING EQUIPMENT COST 100 SQ FT	$18.80	[illegible]	18.80	[illegible]	18.80	[illegible]	[illegible]	[illegible]	[illegible]	
5 COOLING EQUIPMENT COST 100 SQ FT	$ [illegible]	92.50	6.30	[illegible]	7.0	208.00	[illegible]	[illegible]	23.80	
6 Line 4 + Line 5	$22.40		[illegible]		25.90		28.[illegible]		42.[illegible]	
7 U FACTOR ÷ .10	0.5		0.5		0.5		[illegible]		[illegible]	
8 EQUIPMENT COST 100 SQ FT Line 6 × Line 7	$ [illegible]	97.50	2.55	97.50	[illegible]	[illegible]	4.05	443.00	[illegible]	
9 ELEMENT AREA ÷ 100 SQ FT	30.4	3.38	20.5	[illegible]	[illegible]	3.38		[illegible]	[illegible]	B
10 EQUIPMENT FIRST COST Line 8 × Line 9	[illegible]	[illegible]	257	[illegible]	[illegible]	[illegible]	288	[illegible]	[illegible]	[illegible]
11 HEATING FUEL COST 100 SQ FT	$2.40	[illegible]	2.40	[illegible]	2.40	[illegible]	[illegible]	[illegible]	[illegible]	
12 COOLING FUEL COST 100 SQ FT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
13 Line 11 + Line 12	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
14 U FACTOR ÷ .10	0.5		0.5		0.5		[illegible]		[illegible]	
15 ANNUAL FUEL COST 100 SQ FT Line 13 × Line 14	$ [illegible]	3.80	[illegible]	[illegible]	[illegible]	7.80	[illegible]	[illegible]	[illegible]	
16 ELEMENT AREA ÷ 100 SQ FT	30.4	3.38	20.5	2.27	30.4	3.39	[illegible]	[illegible]	[illegible]	
17 ANNUAL FUEL COST Line 15 × Line 16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

18 LIFE-CYCLE FUEL COST MULTIPLIER
- ☒ New Construction, Life-Cycle = 40 years, Fuel Cost Multiplier = 40
- ☐ Modernization, Life-Cycle = 20 years, Fuel Cost Multiplier = 20
- ☐ Escalating Fuel Costs, ... years, ... % annual escalation, from Table II, Fuel Cost Multiplier = ...

C [illegible]

D 40

19 LIFE-CYCLE FUEL COST Line 17 × Line 18 .... E [illegible]

20 ESTIMATED LIFE-CYCLE OWNING COSTS BOX A + BOX B + BOX E .... F [illegible]

creased by a factor of 5.50. Table III duplicates the summary on page 13 but using electricity instead of natural gas.

Also, for simplicity's sake, the Worksheets assume an unescalated fuel cost over the building life. If, instead of this stable rate, an annual inflation rate of six per cent (slightly less than is currently being experienced) is assumed, the Fuel Cost Multiplier from Table II, page 16, becomes 165.0. This is more than four times that used in the Examples.

TABLE III

SHELL RELATED LIFE-CYCLE OWNING COSTS, ELECTRIC HEAT

Element First Cost:	$165,766	$202,153	+$ 36,387
HVC Equipment Cost:	$ 42,235	$ 14,519	−$ 27,716
40-Year Fuel Cost:	$296,640	$161,200	−$135,440
40-Year Total Cost:	$504,641	$377,872	−$126,769

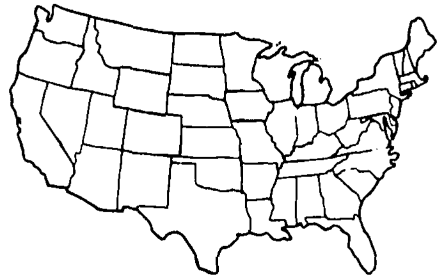
HEATING ZONE I

HEATING SEASON: 7000 degree-days

DESIGN CONDITIONS: Δt = 75 F

INSIDE: 68 F   OUTSIDE: −7 F

SUNLIGHT PROBABILITY: 0.35



HEATING EQUIPMENT COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

	OPAQUE WALLS (U = 0.10)				SINGLE SHEET GLASS			DOUBLE GLASS	
	LIGHT WEIGHT		HEAVY WEIGHT						
Facing	*Dark*	*Light*	*Dark*	*Light*	*No Shade*	*Interior Shade*	*Exterior Shade*	*No Shade*	*Exterior Shade*
All	$18.80	$18.80	$18.80	$18.80	$212.00	$152.00	$212.00	$105.00	$105.00

(Based on an equipment cost of $25.00 per MBh).

ANNUAL HEATING FUEL COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

Facing	Opaque Light Weight *Dark*	Opaque Light Weight *Light*	Opaque Heavy Weight *Dark*	Opaque Heavy Weight *Light*	Single Glass *No Shade*	Single Glass *Interior Shade*	Single Glass *Exterior Shade*	Double Glass *No Shade*	Double Glass *Exterior Shade*
N	$ 2.40	$ 2.40	$ 2.30	$ 2.30	$ 24.10	$ 16.30	$ 24.40	$ 12.00	$ 12.60
NE/NW	2.40	2.40	2.30	2.30	23.40	16.10	23.80	11.40	11.70
E/W	2.40	2.40	2.30	2.30	20.30	15.00	21.30	8.80	9.70
SE/SW	2.40	2.40	2.30	2.30	15.60	13.40	17.70	5.10	6.70
S	2.40	2.40	2.30	2.30	13.40	12.60	15.80	3.10	5.10

(Based on natural gas at $1.00 per Mcf).

HEATING EQUIPMENT AND FUEL COSTS

PER 100 SQUARE FEET OF ROOF ELEMENT

	LIGHT CONSTRUCTION		HEAVY CONSTRUCTION	
(U = 0.10)	*Dark Color*	*Light Color*	*Dark Color*	*Light Color*
Heating Equipment Cost (@ $25/MBh)	$18.80	$18.80	$18.80	$18.80
Annual Heating Fuel Cost (Natural Gas)	$ 1.60	$ 1.70	$ 1.50	$ 1.60

FUEL TYPE AND COST CONVERSIONS

To convert to #2 Fuel Oil at $0.25 per gallon, multiply fuel cost above by 2.25.

To convert to Electricity at $0.025 per Kwh, multiply fuel cost above by 5.50.

To convert to other fuel unit costs, use the following equations:

$$\text{ANNUAL HEATING FUEL COST PER 100 SQ. FT.} = \left(\begin{array}{c}\text{Heating}\\ \text{Fuel Cost}\\ \text{from Table}\end{array}\right)\left(\begin{array}{c}\text{Actual Fuel}\\ \text{Unit Cost}\end{array}\right)\left\{\begin{array}{c}\text{1.0 for Natural Gas}\\ \text{9.0 for \#2 Fuel Oil}\\ \text{220.0 for Electricity}\end{array}\right\}$$

$$\text{ANNUAL COOLING FUEL COST PER 100 SQ. FT.} = \left(\begin{array}{c}\text{Cooling}\\ \text{Fuel Cost}\\ \text{from Table}\end{array}\right)\left(\begin{array}{c}\text{Actual Cost}\\ \text{per Kwh}\end{array}\right)\left(40.0\right)$$

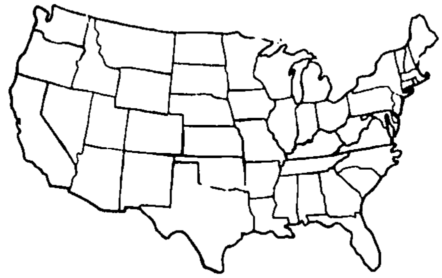
HEATING ZONE II

HEATING SEASON: 5000 degree-days

DESIGN CONDITIONS: $\Delta t = 65°F$

INSIDE: 68°F OUTSIDE: 3°F

SUNLIGHT PROBABILITY: 0.45



HEATING EQUIPMENT COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

	OPAQUE WALLS (U = 0.10)				SINGLE SHEET GLASS			DOUBLE GLASS	
	LIGHT WEIGHT		HEAVY WEIGHT						
Facing	*Dark*	*Light*	*Dark*	*Light*	*No Shade*	*Interior Shade*	*Exterior Shade*	*No Shade*	*Exterior Shade*
All	$16.30	$16.30	$16.30	$16.30	$184.00	$132.00	$184.00	$ 91.00	$ 91.00

(Based on an equipment cost of $25.00 per MBh).

ANNUAL HEATING FUEL COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

N	$ 1.70	$ 1.70	$ 1.60	$ 1.60	$ 16.20	$ 10.90	$ 16.60	$ 7.40	$ 7.70
NE/NW	1.70	1.70	1.60	1.60	15.00	10.40	15.60	6.30	7.00
E/W	1.70	1.70	1.60	1.60	10.40	8.30	11.90	2.50	3.90
SE/SW	1.70	1.70	1.60	1.60	4.90	5.80	7.50	−2.00	0.30
S	1.70	1.70	1.60	1.60	2.10	4.60	5.30	−4.30	−2.00

(Based on natural gas at $1.00 per Mcf).

HEATING EQUIPMENT AND FUEL COSTS

PER 100 SQUARE FEET OF ROOF ELEMENT

	LIGHT CONSTRUCTION		HEAVY CONSTRUCTION	
(U = 0.10)	*Dark Color*	*Light Color*	*Dark Color*	*Light Color*
Heating Equipment Cost (@ $25/MBh)	$16.30	$16.30	$16.30	$16.30
Annual Heating Fuel Cost (Natural Gas)	$ 1.00	$ 1.20	$ 0.90	$ 1.10

FUEL TYPE AND COST CONVERSIONS

To convert to #2 Fuel Oil at $0.25 per gallon, multiply fuel cost above by 2.25.

To convert to Electricity at $0.025 per Kwh, multiply fuel cost above by 5.50.

To convert to other fuel unit costs, use the following equations:

$$\begin{array}{l}\text{ANNUAL HEATING FUEL}\\ \text{COST PER 100 SQ. FT.}\end{array} = \left(\begin{array}{c}\text{Heating}\\ \text{Fuel Cost}\\ \text{from Table}\end{array}\right)\left(\begin{array}{c}\text{Actual Fuel}\\ \text{Unit Cost}\end{array}\right)\left\{\begin{array}{r}\text{1.0 for Natural Gas}\\ \text{9.0 for \#2 Fuel Oil}\\ \text{220.0 for Electricity}\end{array}\right\}$$

$$\begin{array}{l}\text{ANNUAL COOLING FUEL}\\ \text{COST PER 100 SQ. FT.}\end{array} = \left(\begin{array}{c}\text{Cooling}\\ \text{Fuel Cost}\\ \text{from Table}\end{array}\right)\left(\begin{array}{c}\text{Actual Cost}\\ \text{per Kwh}\end{array}\right)\left(40.0\right)$$

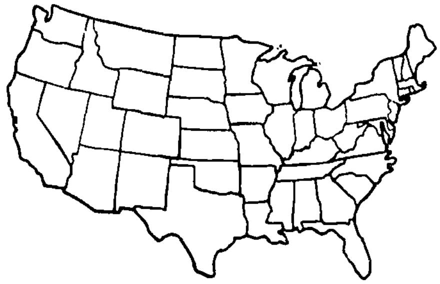
HEATING ZONE III

HEATING SEASON: 2000 degree-days

DESIGN CONDITIONS: $\Delta t = 55^\circ F$

INSIDE: $68^\circ F$ OUTSIDE: $13^\circ F$

SUNLIGHT PROBABILITY: 0.55



HEATING EQUIPMENT COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

	OPAQUE WALLS (U = 0.10)				SINGLE SHEET GLASS			DOUBLE GLASS	
	LIGHT WEIGHT		HEAVY WEIGHT						
Facing	*Dark*	*Light*	*Dark*	*Light*	*No Shade*	*Interior Shade*	*Exterior Shade*	*No Shade*	*Exterior Shade*
All	$13.80	$13.80	$13.80	$13.80	$155.00	$111.00	$155.00	$ 77.00	$ 77.00

(Based on an equipment cost of $25.00 per MBh).

ANNUAL HEATING FUEL COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

N	$ 0.70	$ 0.70	$ 0.70	$ 0.70	$ 4.60	$ 3.20	$ 5.10	$ 1.50	$ 2.00
NE/NW	0.70	0.70	0.70	0.70	2.80	2.20	3.70	0.00	0.80
E/W	0.70	0.70	0.70	0.70	−3.30	−1.20	−1.20	−0.50	−3.20
SE/SW	0.70	0.70	0.70	0.70	−9.10	−1.40	−5.80	−9.80	−7.00
S	0.70	0.70	0.70	0.70	−11.60	−5.70	−7.80	−11.90	−8.70

(Based on natural gas at $1.00 per Mcf).

HEATING EQUIPMENT AND FUEL COSTS

PER 100 SQUARE FEET OF ROOF ELEMENT

	LIGHT CONSTRUCTION		HEAVY CONSTRUCTION	
(U = 0.10)	*Dark Color*	*Light Color*	*Dark Color*	*Light Color*
Heating Equipment Cost (@ $25/MBh)	**$13.80**	**$13.80**	**$13.80**	**$13.80**
Annual Heating Fuel Cost (Natural Gas)	$ 0.50	$ 0.70	$ 0.40	$ 0.70

FUEL TYPE AND COST CONVERSIONS

To convert to #2 Fuel Oil at $0.25 per gallon, multiply fuel cost above by 2.25.

To convert to Electricity at $0.025 per Kwh, multiply fuel cost above by 5.50.

To convert to other fuel unit costs, use the following equations:

$$\text{ANNUAL HEATING FUEL COST PER 100 SQ. FT.} = \left(\begin{array}{c}\text{Heating}\\ \text{Fuel Cost}\\ \text{from Table}\end{array}\right)\left(\begin{array}{c}\text{Actual Fuel}\\ \text{Unit Cost}\end{array}\right)\left\{\begin{array}{r}\text{1.0 for Natural Gas}\\ \text{9.0 for \#2 Fuel Oil}\\ \text{220.0 for Electricity}\end{array}\right\}$$

$$\text{ANNUAL COOLING FUEL COST PER 100 SQ. FT.} = \left(\begin{array}{c}\text{Cooling}\\ \text{Fuel Cost}\\ \text{from Table}\end{array}\right)\left(\begin{array}{c}\text{Actual Cost}\\ \text{per Kwh}\end{array}\right)\left(40.0\right)$$

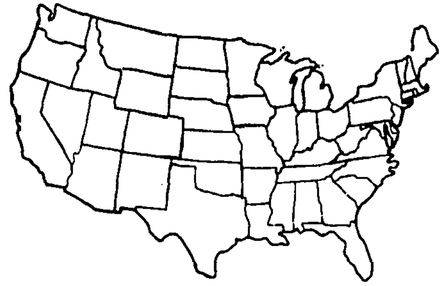
COOLING ZONE I

EQUIVALENT FULL-LOAD HOURS: 285 (51-9 mos.)

DESIGN CONDITIONS: $\Delta t = 10°F$

INSIDE: 78°F OUTSIDE: 88°F

SUNLIGHT PROBABILITY: 0.60



COOLING EQUIPMENT COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

	OPAQUE WALLS (U = 0.10)				SINGLE SHEET GLASS			DOUBLE GLASS	
	LIGHT WEIGHT		HEAVY WEIGHT						
Facing	*Dark*	*Light*	*Dark*	*Light*	*No Shade*	*Interior Shade*	*Exterior Shade*	*No Shade*	*Exterior Shade*
N	$ 6.70	$ 3.60	$ 1.50	$ 0.01	$ 260.00	$196.00	$148.00	$ 186.00	$ 92.50
NE	8.80	4.80	6.80	2.10	260.00	196.00	148.00	186.00	92.50
E	11.40	6.30	10.60	3.90	260.00	196.00	148.00	186.00	92.50
SE	12.20	6.40	9.10	3.00	264.00	198.00	149.00	189.00	93.80
S	13.50	7.10	4.50	0.75	723.00	473.00	286.00	570.00	208.00
SW	18.50	9.70	4.60	1.00	1345.00	847.00	473.00	1086.00	364.00
W	17.80	9.30	4.90	1.10	1241.00	784.00	442.00	1000.00	338.00
NW	11.60	6.10	3.10	0.40	524.00	354.00	227.00	471.00	159.00

(Based on an equipment cost of $750.00 per cooling ton).

ANNUAL COOLING FUEL COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

12 MONTHS ANNUAL OPERATION

N	$ 0.11	$ 0.08	$ 0.07	$ 0.05	$ 4.70	$3.00	$1.80	$ 3.60	$1.20
NE	0.15	0.09	0.13	0.07	7.60	4.80	2.40	6.10	1.70
E	0.24	0.11	0.17	0.09	12.30	7.60	3.30	9.90	2.50
SE	0.21	0.11	0.16	0.08	14.30	8.80	3.70	11.60	2.80
S	0.18	0.11	0.13	0.07	13.60	8.40	3.60	11.00	2.70
SW	0.24	0.14	0.14	0.07	14.30	8.80	3.70	11.60	2.80
W	0.27	0.16	0.14	0.07	12.30	7.60	3.30	9.90	2.50
NW	0.20	0.12	0.07	0.06	7.60	4.80	2.40	6.10	1.70

9 MONTHS ANNUAL OPERATION

N	$ 0.02	$ 0.01	$ 0.01	$ 0.01	$ 2.50	$1.50	$0.90	$ 2.00	$0.70
NE	0.03	0.02	0.02	0.01	4.20	2.50	1.40	3.40	1.10
E	0.04	0.02	0.03	0.02	8.10	4.90	2.60	6.70	2.10
SE	0.04	0.02	0.03	0.01	11.20	6.80	2.90	9.30	2.30
S	0.03	0.02	0.02	0.01	12.90	7.80	2.90	10.70	2.50
SW	0.04	0.03	0.02	0.01	11.20	6.80	2.90	9.30	2.30
W	0.05	0.03	0.02	0.01	8.10	4.90	2.60	6.70	2.10
NW	0.04	0.02	0.02	0.01	4.20	2.50	1.40	3.40	1.10

(Based on electricity at $0.025 per Kwh).

COOLING EQUIPMENT AND FUEL COSTS

PER 100 SQUARE FEET OF ROOF ELEMENT

	LIGHT CONSTRUCTION		HEAVY CONSTRUCTION	
(U = 0.10)	*Dark Color*	*Light Color*	*Dark Color*	*Light Color*
Cooling Equipment Cost (@ $750/ton)	$47.20	$23.80	$27.80	$11.20
Annual Fuel Cost (Electricity)				
9 Months Annual Operation	$ 0.05	$ 0.01	$ 0.01	$ 0.01
12 Months Annual Operation	0.67	0.12	0.39	0.01

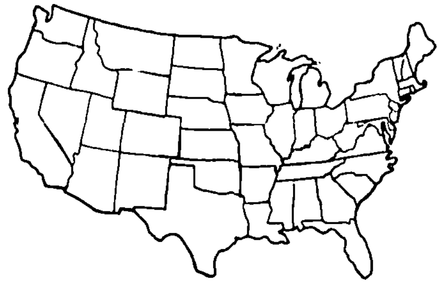
COOLING ZONE II

EQUIVALENT FULL-LOAD HOURS: 479 (119-9 mos.)

DESIGN CONDITIONS: Δt = 15 F

INSIDE: 78 F OUTSIDE: 93 F

SUNLIGHT PROBABILITY: 0.70



COOLING EQUIPMENT COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

	OPAQUE WALLS (U = 0.10)				SINGLE SHEET GLASS			DOUBLE GLASS	
	LIGHT WEIGHT		HEAVY WEIGHT						
Facing	*Dark*	*Light*	*Dark*	*Light*	*No Shade*	*Interior Shade*	*Exterior Shade*	*No Shade*	*Exterior Shade*
N	$ 9.80	$ 6.70	$ 4.60	$ 2.90	$ 306.00	$236.00	$184.00	$ 214.00	$122.00
NE	11.90	8.00	9.90	5.30	303.00	235.00	184.00	212.00	121.00
E	14.50	9.40	13.70	7.00	303.00	235.00	184.00	212.00	121.00
SE	15.40	9.60	12.30	6.10	380.00	238.00	185.00	215.00	123.00
S	16.60	10.20	7.60	3.90	622.00	426.00	279.00	476.00	217.00
SW	21.60	12.80	7.70	4.10	1306.00	836.00	484.00	1044.00	422.00
W	20.90	12.40	8.00	4.30	1303.00	835.00	483.00	1042.00	421.00
NW	14.70	9.30	6.30	3.50	64[illegible].00	443.00	288.00	499.00	225.00

(Based on an equipment cost of $750.00 per cooling ton).

ANNUAL COOLING FUEL COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

12 MONTHS ANNUAL OPERATION

N	$ 0.24	$ 0.18	$ 0.18	$ 0.07	$ 7.40	$ 4.80	$ 3.40	$ 5.50	$ 2.20
NE	0.32	0.20	0.27	0.10	11.80	7.50	4.20	9.10	2.90
E	0.43	0.25	0.34	0.12	17.70	11.00	5.40	14.10	3.90
ES	0.41	0.25	0.33	0.11	19.10	11.80	5.70	15.20	4.10
S	0.36	0.24	0.27	0.10	16.80	10.50	5.30	13.30	3.70
SW	0.47	0.30	0.29	0.10	19.10	11.80	5.70	15.20	4.10
W	0.51	0.32	0.29	0.10	17.70	11.00	5.40	14.10	3.90
NW	0.40	0.27	0.23	0.09	11.80	7.50	4.20	9.10	2.90

9 MONTHS ANNUAL OPERATION

N	$ 0.06	$ 0.05	$ 0.04	$ 0.03	$ 3.40	$ 2.10	$ 1.40	$ 2.70	$ 1.00
NE	0.08	0.05	0.07	0.04	5.70	3.50	2.10	4.60	1.60
E	0.11	0.06	0.09	0.05	10.40	6.30	3.50	8.40	2.80
SE	0.10	0.06	0.08	0.05	13.10	8.00	4.40	10.70	3.40
S	0.09	0.06	0.07	0.04	13.30	8.10	4.30	10.90	3.50
SW	0.12	0.07	0.07	0.05	13.10	8.00	4.40	10.70	3.40
W	0.12	0.08	0.07	0.05	10.40	6.30	3.50	8.40	2.80
NW	0.10	0.07	0.06	0.04	5.70	3.50	2.10	4.60	1.60

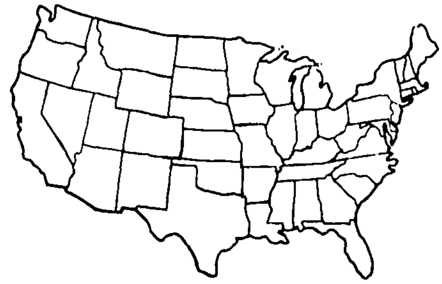
(Based on electricity at $0.025 per Kwh).

COOLING EQUIPMENT AND FUEL COSTS

PER 100 SQUARE FEET OF ROOF ELEMENT

	LIGHT CONSTRUCTION		HEAVY CONSTRUCTION	
(U = 0.10)	*Dark Color*	*Light Color*	*Dark Color*	*Light Color*
Cooling Equipment Cost (@ $750/ton)	$50.30	$26.90	$30.90	$14.30
Annual Fuel Cost (Electricity)				
9 Months Annual Operation	$ 0.34	$ 0.06	$ 0.18	$ 0.02
12 Months Annual Operation	1.30	0.64	0.95	0.43

COOLING ZONE III



EQUIVALENT FULL-LOAD HOURS: 633 (195-9 mos.)

DESIGN CONDITIONS: $\Delta t = 20°F$

INSIDE: 78°F OUTSIDE: 98°F

SUNLIGHT PROBABILITY: 0.75

COOLING EQUIPMENT COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

	OPAQUE WALLS (U = 0.10)				SINGLE SHEET GLASS			DOUBLE GLASS	
	LIGHT WEIGHT		HEAVY WEIGHT						
Facing	*Dark*	*Light*	*Dark*	*Light*	*No Shade*	*Interior Shade*	*Exterior Shade*	*No Shade*	*Exterior Shade*
N	$12.90	$ 9.80	$ 7.70	$ 6.00	$ 349.00	$276.00	$221.00	$ 239.00	$143.00
NE	15.00	11.10	13.00	8.40	343.00	272.00	219.00	234.00	141.00
E	17.70	12.50	16.90	10.10	343.00	272.00	219.00	234.00	141.00
SE	18.50	12.70	15.40	9.30	344.00	273.00	219.00	234.00	141.00
S	19.80	13.30	10.70	7.00	520.00	378.00	272.00	382.00	194.00
SW	24.80	15.90	10.90	7.30	1243.00	812.00	489.00	981.00	411.00
W	24.00	15.60	11.10	7.40	1355.00	879.00	523.00	1074.00	444.00
NW	17.90	12.40	9.40	6.60	791.00	541.00	353.00	606.00	275.00

(Based on an equipment cost of $750.00 per cooling ton).

ANNUAL COOLING FUEL COSTS

PER 100 SQUARE FEET OF VERTICAL WALL ELEMENT

12 MONTHS ANNUAL OPERATION

N	$ 0.39	$ 0.32	$ 0.31	$ 0.26	$10.10	$ 6.70	$5.10	$ 7.30	$ 3.20
NE	0.50	0.34	0.44	0.31	15.70	10.00	6.20	11.90	4.10
E	0.71	0.41	0.53	0.35	21.80	13.70	7.50	17.00	5.10
SE	0.61	0.41	0.51	0.33	21.40	13.50	7.40	16.70	5.10
S	0.56	0.40	0.43	0.31	17.40	11.10	6.60	13.40	4.40
SW	0.70	0.47	0.46	0.32	21.40	13.50	7.40	16.70	5.10
W	0.75	0.50	0.46	0.32	21.80	13.70	7.50	17.00	5.10
NW	0.60	0.43	0.38	0.28	15.70	10.00	6.20	11.90	4.10

9 MONTHS ANNUAL OPERATION

N	$ 0.12	$ 0.10	$ 0.10	$ 0.08	$ 4.60	$ 2.90	$2.20	$ 3.40	$ 1.50
NE	0.16	0.11	0.13	0.09	7.40	4.70	3.10	5.80	2.20
E	0.20	0.13	0.16	0.11	12.30	7.60	3.50	9.90	3.40
SE	0.19	0.13	0.16	0.10	14.00	8.60	5.00	11.20	3.80
S	0.17	0.12	0.13	0.10	13.10	8.00	4.80	10.50	3.60
SW	0.21	0.15	0.14	0.10	14.00	8.60	5.00	11.20	3.80
W	0.23	0.16	0.14	0.10	12.30	7.60	3.50	9.90	3.40
NW	0.19	0.13	0.12	0.09	7.40	4.70	3.10	5.80	2.20

(Based on electricity at $0.025 per Kwh).

COOLING EQUIPMENT AND FUEL COSTS

PER 100 SQUARE FEET OF ROOF ELEMENT

	LIGHT CONSTRUCTION		HEAVY CONSTRUCTION	
(U = 0.10)	*Dark Color*	*Light Color*	*Dark Color*	*Light Color*
Cooling Equipment Cost (@ $750/ton)	$53.40	$30.10	$34.00	$17.40
Annual Fuel Cost (Electricity)				
9 Months Annual Operation	$ 0.63	$ 0.17	$ 0.31	$ 0.07
12 Months Annual Operation	1.60	0.86	1.20	0.61

SOURCES OF FURTHER INFORMATION

Caudill, William W., Frank D. Lawyer and Thomas A. Bullock. *A Bucket of Oil*. Boston: Cahners Books, 1974.

Subtitled "A Humanistic Approach to Building Design for Energy Conservation," this book advocates a return to the fundamentals of design which will result in buildings which are both architecturally fulfilling and energy conservative.

Educational Facilities Laboratories, Inc. *The Economy of Energy Conservation in Educational Facilities*. New York: EFL, 1973. (Available from EFL, 477 Madison Ave., New York, N.Y. 10022; $2.00 postpaid.)

This publication provides a basic introduction to energy conservation in school plants by improvements in operations and maintenance and by physical changes. Techniques suggested are applicable to both new construction and existing buildings. An introduction to life-cycle cost analysis is provided with several examples.

Energy Conservation Design Guidelines for Office Buildings.
Washington: General Services Administration, January 1974. (Unpublished draft guidelines.)

Although not yet officially adopted and somewhat controversial, this set of guidelines contains a great deal of useful information which can be applied to school buildings as well as offices. The extensive energy conservation checklists contained in the summary section are invaluable.

Technical Options for Energy Conservation in Buildings.
U.S. Department of Commerce, National Bureau of Standards, NBS Technical Report 789. Washington: U.S. Government Printing Office, July 1973. (Available as SD Catalog No. C13.46:789 from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; $2.35 postpaid.)

This book provides a comprehensive introduction to technical means of saving energy in both existing and projected buildings. Considerable backup material is provided.

BUILDING SHELL LIFE-COST WORKSHEET

PROJECT ____________ HEATING ZONE ______ COOLING ZONE ______

CONSTRUCTION DATA WALLS: ____________ CONSTRUCTION ______ COLOR ______ U-FACTOR ______

ROOF: ____________ CONSTRUCTION ______ COLOR ______ U-FACTOR ______

GLASS: TYPE ____________ SHADING ______

	NORTH/NORTHEAST WALL	NORTH/NORTHEAST GLASS	EAST/SOUTHEAST WALL	EAST/SOUTHEAST GLASS	SOUTH/SOUTHWEST WALL	SOUTH/SOUTHWEST GLASS	WEST/NORTHWEST WALL	WEST/NORTHWEST GLASS	ROOF	TOTAL
1. ELEMENT AREA										
2. ELEMENT FIRST COST/SQ FT										
3. ELEMENT FIRST COST (Line 1 × Line 2)										A
4. HEATING EQUIPMENT COST/100 SQ FT										
5. COOLING EQUIPMENT COST/100 SQ FT										
6. Line 4 + Line 5										
7. $\frac{\text{U-FACTOR}}{0.10}$										
8. EQUIPMENT COST/100 SQ FT (Line 6 × Line 7)										
9. ELEMENT AREA ÷ 100 SQ FT										
10. EQUIPMENT FIRST COST (Line 8 × Line 9)										B
11. HEATING FUEL COST/100 SQ FT										
12. COOLING FUEL COST/100 SQ FT										
13. Line 11 + Line 12										
14. $\frac{\text{U-FACTOR}}{0.10}$										
15. ANNUAL FUEL COST/100 SQ FT (Line 13 × Line 14)										
16. ELEMENT AREA ÷ 100 SQ FT										
17. ANNUAL FUEL COST (Line 15 × Line 16)										

18. LIFE-CYCLE FUEL COST MULTIPLIER:
- ☐ New Construction, Life-Cycle = 40 years, Fuel Cost Multiplier = 40 — C
- ☐ Modernization, Life-Cycle = 20 years, Fuel Cost Multiplier = 20
- ☐ Escalating Fuel Costs, ______ years, ______% annual escalation; from Table II; Fuel Cost Multiplier = ______ → D

19. LIFE-CYCLE FUEL COST (Line 17 × Line 18) — E

20. ESTIMATED LIFE-CYCLE OWNING COSTS (BOX A + BOX B + BOX E) — F

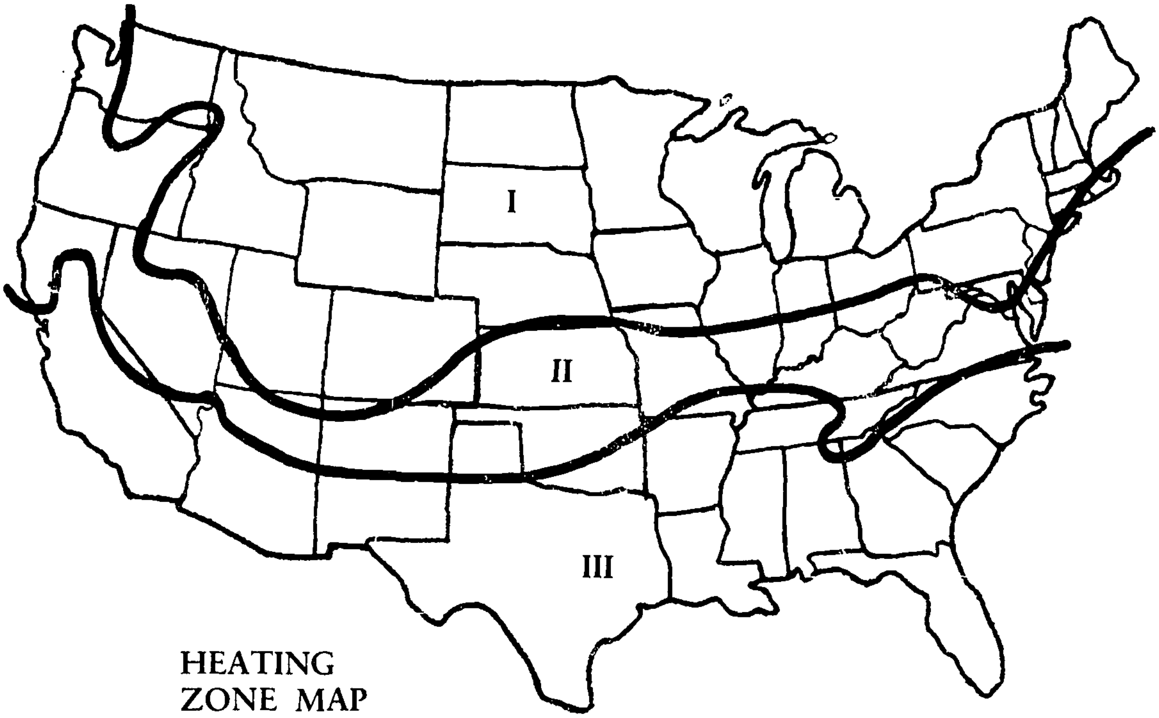
INSTRUCTIONS

Carefully examine the WORKSHEET and the HEATING and COOLING ZONE DATA SHEETS. Note that the WORKSHEET has separate columns for accounting the costs of the WALL and GLASS areas of each wall facing and the ROOF.

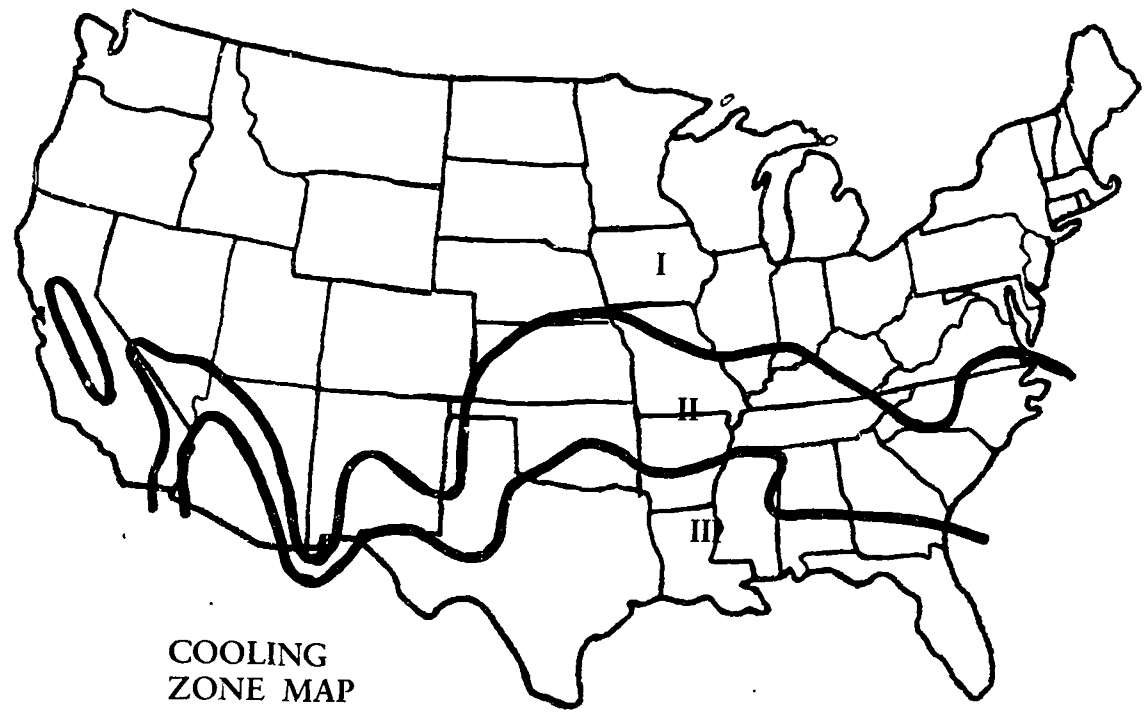
The first step in preparing a LIFE-CYCLE OWNING COST estimate is to complete the information required at the top of the WORKSHEET. This data will permit easier reference to the Tables of the ZONE DATA SHEETS.

Specific instructions for completing each item on the WORKSHEET are:

1. Enter the surface area of each element in the appropriate column of Line 1.
2. On Line 2, enter the cost per surface square foot of each element.
3. Multiply Line 1 by Line 2 and enter the result on Line 3. Sum all the figures in Line 3 and enter the result in Box A.
4. Using the HEATING ZONE DATA SHEET for your location, on Line 4, enter the HEATING EQUIPMENT COST PER 100 SQUARE FEET for each element.
5. If the building is not to be cooled, go to item 6. If the building is to be cooled, using the COOLING ZONE DATA SHEET for your location, on Line 5 enter the COOLING EQUIPMENT COST PER 100 SQUARE FEET for each element.
6. In the WALL and ROOF columns, add Lines 4 and 5 together and enter the result on Line 6.
7. Divide the U-FACTOR of WALL and ROOF elements by 0.10 and enter the result on Lines 7 and 14.
8. For WALL and ROOF columns, multiply Line 5 by Line 6 and enter the result on Line 7.
   For GLASS columns, add Lines 4 and 5 together and enter the result on Line 8.
9. Divide the ELEMENT AREA (Line 1) in each column by 100 and enter the result on Lines 9 and 16.
10. Multiply Line 8 by Line 9 and enter the result on Line 10. Sum all the figures on Line 10 and enter the result in BOX B.
11. On Line 11, enter the ANNUAL HEATING FUEL COST PER 100 SQUARE FEET from the HEATING ZONE DATA SHEET. If necessary, perform conversions to other fuel types and/or other fuel unit costs as indicated on the DATA SHEET before entering the costs on the WORKSHEET.
12. If building is not to be cooled, go to item 13. If building is to be cooled, on Line 12 enter the ANNUAL COOLING FUEL COST PER 100 SQUARE FEET from the COOLING ZONE DATA SHEET. If necessary, perform fuel unit cost conversion before entering the costs on the WORKSHEET.
13. In the WALL and ROOF columns, add Lines 11 and 12 together and enter the result on Line 13.
14. See Line 7.
15. For WALL and ROOF columns, multiply Line 13 by Line 14 and enter the result on Line 15.
    For GLASS columns, add Lines 11 and 12 together and enter the result on Line 15.
16. See Line 9.
17. Multiply Line 15 by Line 16 and enter the result on Line 17. Sum all the figures on Line 17 and enter the result in BOX C.
18. Select the FUEL COST MULTIPLIER by checking the appropriate box, completing any additional information required, and entering the m. ıtiplier in BOX D
19. Multiply BOX C by BOX D and enter the result in BOX E.
20. Add the figures in BOXES A, B and E together and enter the result in Box F.



HEATING
ZONE MAP



COOLING
ZONE MAP